WATER RESOURCES STUDY – WATER BALANCE STUDY
NESTLE, SHEIKHUPURA

DRAFT COMPLETION REPORT

TABLE OF CONTENTS

ANNEXURES

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Water is an essential element for human survival, unfortunately, while Pakistan is blessed with adequate surface and groundwater resources, rapid population growth, urbanization and un-judicious water consumption practices have placed immense stress on the quality as well as the quantity of water resources in the country. Deterioration of water quality caused by contamination of lakes, rivers and groundwater aquifers has resulted in increased waterborne diseases and other health impacts. Per capita water availability in Pakistan has decreased from 5,000 cubic meters per annum in 1951 to about 1,000 at present. So here the point lies that every stakeholder in the region has to be careful in using this precious resource as well as conserving it for the present and future generations to come. This is the theme behind carrying out the water resource study of the Nestle Plant at Sheikhupura, Punjab, Pakistan. The current report is perhaps the first in its kind in Pakistan amongst the groundwater users in the private sector.

The principal source of drinking water for the majority of the people in Pakistan is groundwater, so is also the situation for majority of the industries, due to readily and cheap availability. The Nestle Plant wholly depends upon groundwater, for its process requirements and other plant uses. An area of 10 km radius with Nestle factory at center (315 square kilometers), was selected for detailed regarding groundwater sustainability issues in the area. The Nestle plant at Sheikhupura lay once away from the city in sparsely populated area, but now the industries is occupying the surrounding land at an increasing pace, as well as the nearby city of Sheikhupura is also expanding.

Surface and groundwater availability in the region was assessed in general, from the available literature. Hydrogeologic investigations carried out in the past for the area were highlighted, after further data processing. The aquifer is unconfined, formed by alluvial deposits, with intermittent clay layers which are discontinuous. In Upper Rechna Doab (study area), comparison of shallow and deep water quality indicates that at places, water quality at shallow depths is inferior to the quality of deep waters. This has been confirmed by vertical groundwater salinity profiles drawn from 1960s groundwater investigations. The 1960s data of groundwater samples for the study area, also contains a number of Cations/Anions, the Nitrate (NO_3) concentration was found as varying from just trace to 0.01meq/l.

Average static water level in the study area is 3 to 7 meters below ground surface. Groundwater elevation contours and hydrographs were drawn using the current groundwater data. Detailed survey was carried out in the area regarding groundwater pumping and quality of the pumped water. Groundwater balance for the study area was prepared: agriculture, industry and domestic sectors pump about 52, 62, 68 MCM per year respectively, thus the total annual pumping from the study area is about 182 MCM. Nestle Plant used about 1.9

MCM of groundwater in 2013. With this groundwater extraction (182 MCM), there is a net loss of 6.26 MCM / year from the aquifer, which is equivalent to an annual depletion rate of 0.052 m/year. Based on the data of 12 observation wells, since 2003, the actual groundwater depletion rate is 0.0356 m/year. Length and consistency of Nestle's well is not enough to draw any conclusion. As continuous static water table data of Nestle wells is not available.

The underlying study identified several issues:

- The increasing population using groundwater mainly for domestic, industrial and agricultural uses is putting little more pressure on the water resources than the earlier times.

- Particularly of concern is the municipal and industrial waste disposal – almost all of it without treatment, particularly the industrial effluent which is highly toxic and major threat for shallow groundwater sources presently in use. Particularly, the Deg Nullah has an average electrical conductivity (EC) of 4000 μS/cm. Thereby, shallow sources pumping from the aquifer, along both sides of the Deg Nala, have high EC values. Therefore, untreated effluent disposal is likely to be a major issue/vulnerability for the underlying fresh groundwater and downstream surface water users.

- The increasing pressure on groundwater use is also leading to an increasing depth to watertable in areas, although the average depletion rate, based on last ten years data being only 0.0356 m/year, is not an alarming one. The two major reasons behind this groundwater depletion trend are: increasing stress on groundwater due to increasing population; and the decreasing river storages which are causing reduction in Rabi canal supplies, due to sedimentation of Mangla and Tarbela reservoirs; and development by India in the upper catchments. All these are causing reduction in Rabi canal supplies, inducing extra pumpage by the farmers to fulfill crop water requirement and reduced recharge to groundwater as well. Therefore, it is likely that at Nestle Plant site, depth to groundwater will increase by not more than one meter in a period of 10 to 20 years; but there is no vulnerability expected that may hamper plant production due to groundwater depletion.

- In Upper Rechna Doab (study area), comparison of shallow and deep water quality indicates that at places, water quality at shallow depths is inferior to the quality of deep waters. This has been confirmed by vertical groundwater salinity profiles drawn from 1960s groundwater investigations). The 1960s samples for the study area were also analyzed for a number of Cations and Anions, the Nitrate (NO_3) concentration was found as varying from just trace to 0.01meq/l.

- The Nestle plant can work for protection of the aquifer by joining hands with local stakeholders (particularly with the other industry) as well as the government departments by sharing/demonstrating Nestle existing effluent treatment to the permissible standards set by EPA. Thus quality protection campaigns could be the ultimate outcome of this study, to achieve the waste disposal within the limits of set standards by EPA, before discharging to the surface drainage system in the area, by all the stakeholders in the area, especially the industry, being the largest polluter.

1. INTRODUCTION

Nestle is the top multinational food company with its Head office in Switzerland. It provides numerous number of food products to its customers worldwide. Nestle Pakistan is operating since 1988 under joint venture with Milk Pak Ltd and took over management in 1992. As potable water is requirement for every inhabitant. Nestle Pakistan Limited started its water wing in 1996 and since then continuously providing best quality potable water to its customers nationwide. With passage of time and increasing demand of potable water, Nestle Pakistan Limited intends to estimate aquifer strength, behavior and quality of groundwater in the premises of Nestle factory, Sheikhupura district, Punjab, Pakistan. Salient features of the study area are given in Table 1.1. In order to assess the underlying aquifer, Nestle proposed a Water Resources Study comprising the area of 10 Kilometers radius (315 Sq. Km) around Nestle Factory, Sheikhupura. The Nestle plant location is shown on the map of Pakistan in **Figure 1.1**. National Engineering Services Pakistan (Pvt), Limited (NESPAK) was engaged as consultant for the study. The study mainly emphasizes a conceptual groundwater model and water balance of the project area, along with other water related sustainability issues.

Table 1.1: Salient Features of the Water Resources Study (WRS)

Date:	January 20, 2014
Project Name:	Water Resource Study of Nestle
Location:	Sheikhupura District, near Lahore Punjab, Pakistan
Client Name:	Nestle Pakistan Ltd
Consultant	NESPAK

1.1 BACKGROUND

Nestle continue to make water resources management at top priority and to work with governments, UN bodies, International Organizations, Non Governments Organizations (NGO's) and other stakeholders to address the global water challenge. Being one of the committed and responsible members of international organizations, Nestle in their report 'Creating Shared Value and meeting our commitments 2013' renewed the scope of vision for water as Nestle's commitments on Water Stewardship. Nestle acknowledges the responsibilities as a major water user and outline the actions needed to implement (both individual and collaborative) for the sustainable management of shared water resources. Nestle seeks to use water sustainably and aim to achieve the continuous improvements of water management processes. Therefore, Nestle regularly reviews water stress and efficiency data to improve our practices. In this regard, Nestle has reduced the direct withdrawals in every product category achieving an overall reduction per ton of product of 33% since 2005.

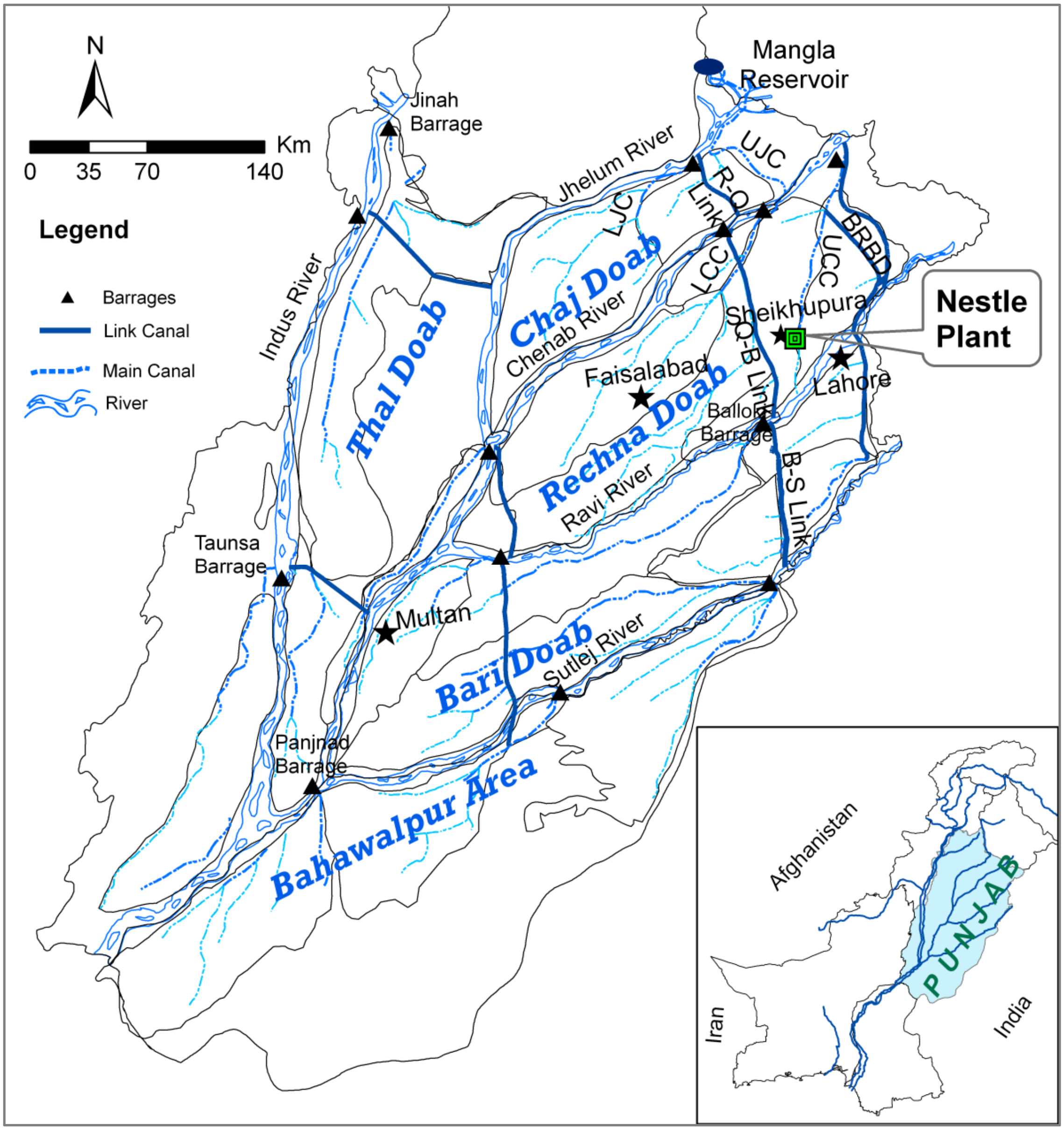

Figure 1.1: ***Rivers and irrigation system, location of Nestle plant, near Sheikhupura, falling in Rechna Doab, Punjab, Pakistan***

Keeping in view of the sustainable management of the water resources of the Pakistan, Nestle initiated the steps to determine qualitative and quantitative analysis of water wells being used under the administration of Nestle. This water balance study of Nestle factory Sheikhupura is a part of Nestle vision of sustainable management of water resources.

1.2 AIM OF THE STUDY

Water access is a business survival issue for every company using water as raw material and when it is directly related to human consumption, its importance further increases in the wake of increasing population. In order to address the issue of water access sustainability, The Nestle has embarked upon a water resources study that includes a source water evaluation and risk mitigation measure to help ensure adequate supplies of high quality source water throughout its plants.

National Engineering Services Pakistan (Pvt) Limited (NESPAK) carried out the Water Resources evaluation study in the study area (10 km radius) of the plant at Sheikhupura, near Lahore, Punjab Pakistan, in order to be able to ensure that adequate supply of high quality source water is available to manufacture Nestle products.

NESPAK has carried out numerous groundwater studies around the Project Area. The aim of this Water Resources study is to ascertain groundwater potential in the area and to investigate the effects and changes in groundwater quantity and quality in the surroundings of Nestle factory and specially to the downstream surface water bodies due to Nestle's abstraction.

1.3 SCOPE OF WORK

The services to be performed by the Consultant are as follows;

1. Assessment of the exploitation level of local water bodies by all water consumers in a radius of 10 km (315 square kilometers area) around Nestle Sheikhupura Factory (29km Lahore-Sheikhupura Road). Assessment of qualitative and quantitative figures of all industries, municipalities, domestic and agriculture users of water with respect to different sources like surface water and groundwater. Data required would be with seasonal variations wherever possible. An appropriate inventory of the wells tapping each aquifer (e.g.: Nestlé facilities' production wells, monitoring wells, other wells not owned/operated by the Nestlé and used for agriculture or industrial or municipal purpose) shall be provided as available:
   a. positioning on a map, (Google maps through GPS coordinates).
   b. well construction details (including casing diameter, screens position (if any), measurement of the elevation above sea level of the well head flange, at centimetrical precision),
   c. evaluation of the contamination risks due to bad well design (isolation /mixing of aquifer, bad cementing…),
   d. depth to bed rock and tapped aquifer,,
   e. flow rate if exploited,
   f. water bearing zone,
   g. evaluation of inter influence with the nearest exploited wells,
   h. results of any pumping test (raw data + interpretation)

i. available static/dynamic water level monitoring
j. available water quality data.

2. Total recharge to the study area and overall water sustainability analysis based on recharge and discharge, including the entire recharge basin of the targeted aquifer system in the study area. Information of recharge sources and potential contribution by each source in the study area.

3. Development of conceptual model of the groundwater flow system in the study area. This model shall characterize and describe the occurrence of water in the aquifer and describe the water balance (inlet/outlet) of each aquifer layer, including the occurrence of natural springs, as appropriate.

4. Official legislation related to surface and groundwater abstraction/use shall be part of the key information. The official text should be possibly available in English. An official translation may be requested. (Legislation information should include Provincial as well as Federal areas).

5. Rainfall, temperature/flood level/drought evolution over the last 10 years (monthly data for 10km radius)

6. Topographic map of the study area (1 : 25,000 is recommended)

7. Geology: Geological description includes but not be limited to:
   a. information related to the geometry of each layer (data from geophysical investigation if available),
   b. surficial materials,
   c. lithology and intrinsic properties (porosity, permeability).
   d. A clear geological map (scale: 1/50000) should be included.

8. Each groundwater system should be described with respect to:
   a. Lithology: evaluated from scientific literature, exploratory drillings, perhaps geophysical investigation,
   b. Type of aquifer: unconfined, confined, porous, fissured, karstic…
   c. hydrodynamic properties: porosity, transmissivity and hydraulic conductivity evaluated from *in-situ* techniques such as pumping tests
   d. description of the recharge area: graphical representations, including maps, are recommended,
   e. direction of groundwater inflow should be assessed,

   f. natural protection level of the targeted aquifer should be estimated
   g. quantitative aspects: a water balance including estimated total withdrawal per year per aquifer, total recharge volume per year per aquifer,

9. Information on water levels should be collected and consolidated for:
   a. piezometric and potentiometric maps for the aquifer materials as applicable,
   b. water level trend over previous 5 years (national, regional and study area)
   c. Quality data should be consolidated with major elements at least. Data should be evaluated in comparison to regional and local official legislation and/or regulations (compliance, non-compliance, issue-specific, etc.).
   d. Some sampling should be organized to support additional analyses (trace elements, VOCs, THMs, pesticides, radioactivity…).
   e. The list of potential pollution sources and/or risk analysis (farming, industries, roads, increasing of cities…) should be identified and discussed. A hazards map should be included.

10. Impact to downstream surface water bodies
    a. The use of water at internally operated water resources (e.g.: shallow water wells, natural springs) might potentially have a detrimental impact to downstream water bodies (river/stream/pound/wet zones) which are recharged by these groundwater sources, insofar their natural flows might be reduced by Nestlé's abstraction. These impacts/risks (if any) should be assessed (impact on natural ecosystems, biodiversity, other water uses) and reported in the WRS.
    b. Evaluation and updating of an upstream / downstream analysis vis-à-vis Nestle's water abstraction points is critical element in order to check what real impact might derive from the water use by the manufacturing facility and what from other local stakeholders.

11. Historical evolution of surface water, ground water and hydrogeology in the study area and surrounding areas.(national and regional levels)

12. Any reliable reference quoted in the report shall be fully produced as annexure (the complete reference report). International rules of referencing should be used wherever applicable.

13. Conclusions should include
    a. a brief summary on surface and groundwater characteristics of the study area
    b. a clear description of the sustainability level of water resources used by the manufacturing facility and recommendations on how to address potential risks

(including roll out of possible collective action towards water conservation, aimed at transforming any potential threats into win-win opportunities).

The study must be written in English and should be available in hard and soft copies.

1.4 LOCATION OF THE STUDY AREA

Lahore is the capital city of the Punjab province situated adjacent to international border with India (about 25 Km) as shown in **Figure 1.1**. The Nestle plant is located at about 9 km from Sheikhupura, on Sheikhupura-Lahore road. In terms of latitude/longitude coordinates, the location of the plant is 31º 41' 10.61" N and 74º 04' 16.85" E and about 206 m above mean sea level.

On the east side of the plant, Main Line Lower of Upper Chenab Canal (UCC) is flowing **(Figure 1.2)**, with a design discharge of 231 cumecs and bed width of 68 meter. The canal carries a usual discharge of 62.345 cumecs and occasionally used as a link canal, thus utilizing its full capacity. The surrounding area is perennially irrigated under the command of UCC, with a water allowance of 0.63 cumecs per 405 hectare, which is equivalent to 1649.8 $m^3/day/km^2$.

The area under study lies in Rechna Doab (land between Chenab and Ravi rivers) of Punjab Plains, and further under the command of Upper Chenab Canal (UCC). An area of 10 km radius (315 Square Kilometers), around Nestle Factory, was selected for detailed field survey and an area of 20 km square, covering the same 10 km circle, was analyzed for groundwater balance analysis of the area. The Land use statistics of the study area is shown in **Figure 1.3**. The major Land use in the area is agriculture, covering 82 Percent (258.22 Square Kilometers) of the total Area. The Municipal and Industrial area is 15 Percent (48.65 Square Kilometers), while the Nullah Deg, Upper Chenab Canal and its distribution system covers about 1.8 Percent (5.62 Square Kilometers) of the study area. The roads in the area cover about 0.8 Percent (2.58 square Kilometers) of the area.

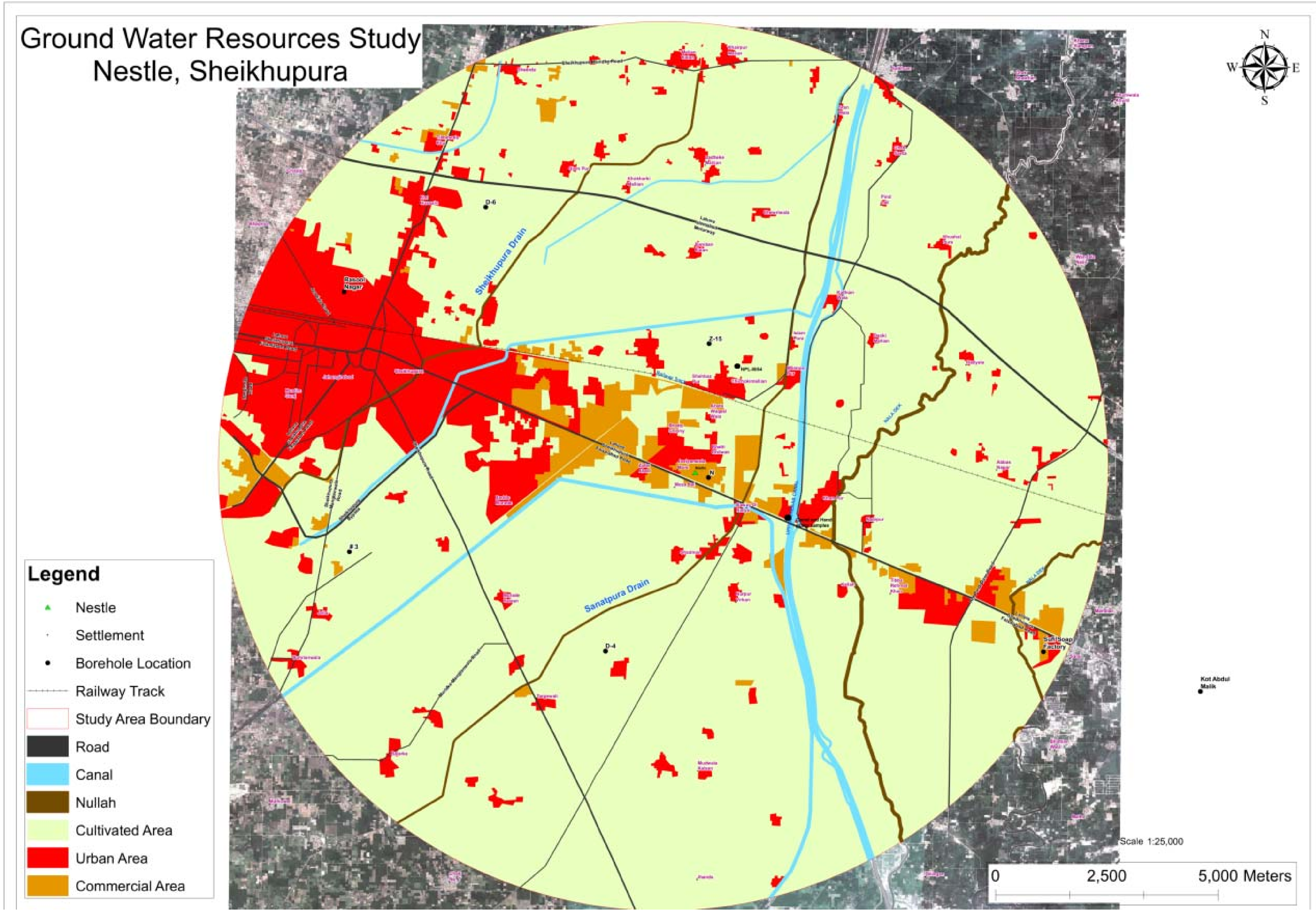

Figure 1.2: Topographic Map of Study Area, Land Use and Location of the Nestle Plant and other Features

1.5 LIMITATIONS OF THE STUDY

Any water source sustainability study is based on readily available information. Most of information used in this report regarding plant pumping sources and installations was obtained from the Nestle plant office at Sheikhupura. The field data was collected during the site visits, conducted from February 15 to March 20, 2014. Information was gathered through written documents and verbal discussion with local groundwater users (industry, Municipal Corporation and farmers) and sample measurements e.g. tubewell discharges, electrical conductivity.

Information about land use pattern particularly industrial establishments etc. in the study area was gathered from maps and through observations made during site survey. Other geo-data used for geographical analysis are used from different government data collection agencies e.g. SCARPs Monitoring Organization (SMO) of WAPDA, Directorate of Land Reclamation (DLR), Irrigation Department and other departments, available published literature.

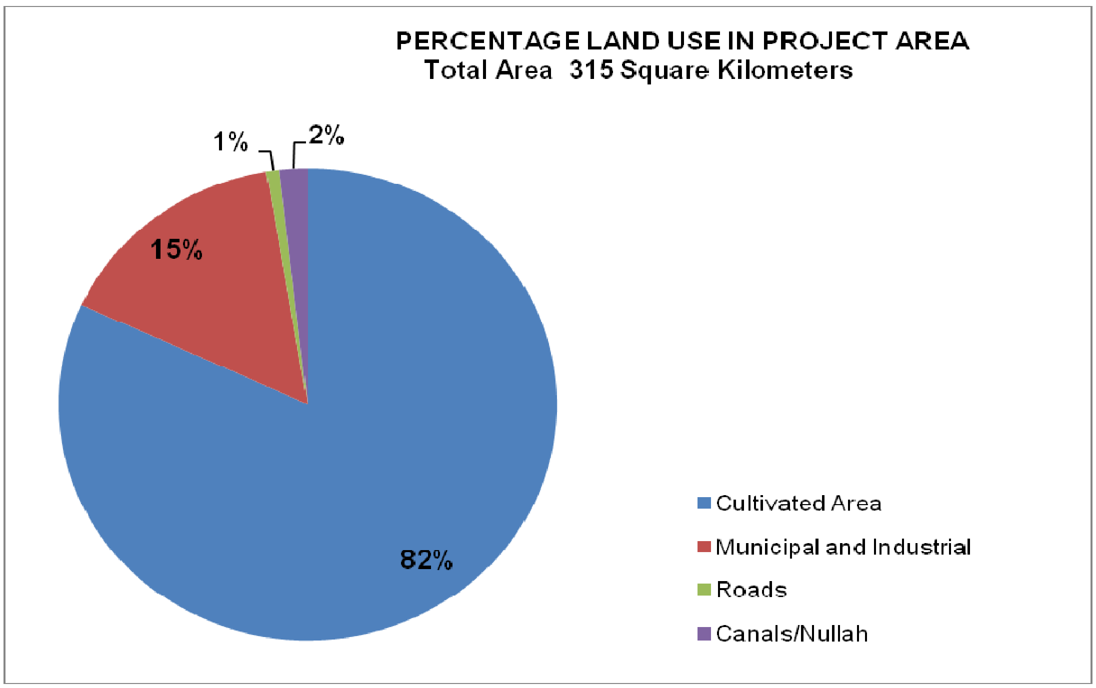

***Figure 1.3*: Land use distribution in the study area.**

2. PERSPECTIVE OF WATER RESOURCES OF PAKISTAN

2.1 GENERAL

Pakistan has the largest contiguous irrigation system in the world, with three major dams, several barrages, numerous weirs, and a comprehensive system of main canals, distributary canals and water channels. Irrigation and agriculture consume 97 percent of Pakistan’s allocated surface water resources of 144,320 MCM. This irrigation system and the rainfall (decreasing in North-south direction) are major source of groundwater recharge throughout the country. Pakistan is fortunate in that the soils, topography and climate are generally suitable for agriculture. The major agriculture areas lie within the basin formed by the Indus River and its tributaries, namely the Jhelum, Chenab, Ravi and Sutlej, which run in a general north-east/south-west direction (**Figure 1.1**). The system is like a funnel with numerous sources of water at the top converging into a single stream which flows into the Arabian Sea, east of Karachi.

2.2 SURFACE WATER RESOURCES OF PAKISTAN

The main source of water in Pakistan is the Indus River system. The system resembles a funnel, with a number of water sources at the top that converge into a single river that flows into the Arabian Sea, east of Karachi. The average annual inflow of the western and eastern rivers and their tributaries at the rim stations is 180 BCM (146.01 million acre-feet, MAF). The Indus River and its five major tributaries form one of the world’s largest contiguous irrigation systems. The Indus basin irrigation network in Pakistan stretches over an area of 22.14 Mha. Based on the Indus Water Treaty (IWT) of 1960 with India, Pakistan was allocated the flow of three western rivers (Indus, Jhelum and Chenab), with occasional spills from the Sutlej and Ravi rivers. The network has three major reservoirs: the Tarbela, Mangla, and Chashma. It also includes 19 barrages/headworks, 12 link canals, 43 canal commands, and over 107,000 watercourses. Irrigation developments over the past 150 years have resulted in very large diversions of water. The three reservoirs are losing their storage capacity due to sedimentation.

After Independence of Pakistan in 1947, problems between India and Pakistan arose over the distribution of water as rivers in Punjab Province flow into the Pakistan territory from across India. To solve this water distribution problem, a treaty known as Indus Water Treaty, brokered by the World Bank, was signed by the two countries in 1960. As per this treaty, Pakistan has exclusive rights for the three western rivers, namely Indus, Jhelum and Chenab whereas India retains rights to the three eastern rivers, namely Ravi, Beas and Sutlej. The new river water distribution seriously affected the urban centers’ aquifers which were previously being recharged by these eastern rivers and their associated irrigation canal systems. But after the Indus Basin Treaty of 1960, India stopped the flows of eastern rivers (Sutlej, Beas and Ravi). In order to relieve this shortage, link canals were constructed (**Figure 1.1**) to transfer the surplus water available in western rivers (Chenab, Jhelum and Indus) to the eastern river.

The flows of the Indus and its tributaries vary widely from year to year and within the year, as given in **Table 2.1**, for different periods. Post Tarbela (1976-77 to 2008-09) annual average inflows at Rim Stations for eastern and western rivers, and combined flows are also given in **Tables 2.2, 2.3 and 2.4**, respectively (source: H&WM). The construction of two mega storages (Mangla and Tarbela) and inter river link canals compensated the allocation of three eastern rivers to India, as result of IWT of 1960. It also helped the operation of the IBIS in an integrated and improved manner, with greater control and enhanced river water utilization. Consequently, the canal head withdrawals in the Indus increased to 124.6 BCM just after the Tarbela Dam and reached the peak of 133.2 BCM in 1979. Thereafter, canal withdrawals then stagnated at this level up to 1989-90 and have now declined to around 125.8 BCM due to reduction in reservoir capacities caused by progressive sedimentation of Tarbela, Mangla and Chashma reservoirs, total depletion of 5.39 BCM (4.37 MAF, 28%) by the year 2012. The process of sedimentation will continue and it is estimated that the gross storage loss would reach to 7.18 BCM (5.82 MAF 37%) by 2025 (Ahmad, 2012). In the current scenario (post Tarbela), annual average (1976-77 to 2008-09) inflow to IBIS at Rim Stations is about 181 BCM (147.0 MAF). Annual average canal withdrawals from 1976-77 to 2006-07 are 124.6 BCM (101.5 MAF). The major part of this difference goes to Arabia Sea, without any management, and minor part can be attributed to river losses, which too are variable along different reaches due to difference in river water surface and surrounding groundwater elevations.

Table 2.1: Annual average flows (BCM) to Indus River and its tributaries (Ahmad et al., 2012)

River	Annual average flows (BCM)		
	1922-61	**1985-95**	**2000-09**
Kabul	32.1	28.9	23.3
Indus	114.7	77.3	100.3
Jhelum	28.4	32.8	22.8
Chenab	32.1	33.9	27.8
Ravi[1]	8.6	6.2	1.4
Sutlej[1]	17.3	4.4	0.5
Annual total	233.1	183.5	176.0

[1] Under the IWT of 1960, India was entitled to the exclusive use of three eastern rivers (Ravi, Beas and Sutlej), while the western rivers (Chenab, Jhelum and Indus) were earmarked for use by Pakistan. A system consisting of 2 storage dams, 8 inter-river link canals and 6 barrages was constructed as replacement works under the Treaty to transfer water from western rivers to canal systems, which were dependent on the eastern rivers.

Table 2.2: Western River Inflows (BCM) at Rim Station (1976-77 to 2008-09)

Scale	Indus at Kalabagh			Jhelum at Mangla			Chenab at Marala			Total		
	Kharif	Rabi	Total	Kharif	Rabi	Total	Kharif	Rabi	Total	Kharif	Rabi	Total
Average	92.10	18.85	110.94	21.55	6.39	27.95	26.59	5.87	32.48	140.25	31.12	171.36
Maximum	114.89	25.77	138.38	31.06	9.49	39.47	33.87	8.09	40.32	174.58	43.35	212.29
Minimum	68.37	13.15	81.88	10.11	2.81	14.62	18.38	3.37	23.31	98.50	20.43	119.81

Table 2.3 Eastern Rivers Inflows (BCM) at Rim Station (1976-77 to 2008-09)

Scale	Ravi at Balloki			Sutlej at Sulemanki			Total		
	Kharif	Rabi	Total	Kharif	Rabi	Total	Kharif	Rabi	Total
Average	4.13	1.21	5.34	2.60	0.63	3.24	6.75	1.84	8.59
Maximum	12.15	3.42	13.63	11.83	4.42	13.10	20.74	7.80	24.63
Minimum	0.48	0.11	0.83	0.00	0.01	0.02	0.48	0.20	1.02

Table 2.4: Annual Inflows (BCM) to IBIS at Rim Stations (1976-77 to 2008-09)

Scale	Kharif	Rabi	Total
Average	147.00	32.96	179.95
Maximum	195.32	51.14	236.92
Minimum	98.98	20.62	120.84

During previous many decades (1960s – 1990s) surplus water was available in the Indus River System, but exceptionally low quantity was available during the last decade as shown in **Figure 2.1**. Although, extreme floods were observed during 2010, but major chunk of the flows drained to Arabian Sea due to lack of storages in the river systems. The preceding many decades, therefore presented a condition where canal water was available in excess to the crop water requirements due to low cropping intensities. This generated a situation where recharge component from seepage surpassed the abstraction from groundwater and as a result groundwater levels rose to near to ground surface. This resulted in maximum rise in groundwater level till 1960. As the cropping intensities increased constantly and drought conditions prevailed, crop water requirements were met through pumping of groundwater. This steadily induced declining trends in depth to watertable (DTW) as is currently being observed since many years, resulting not only in the elimination of water logging but now groundwater depletion is a fact in many of the canal commands and big urban centers and

[1]Kharif (summer) season: April to September.
[2] Rabi (winter) season: October to November

un-commanded areas. The danger in current scenario is over pumping causing groundwater mining and secondary salinity caused due to poor quality of groundwater.

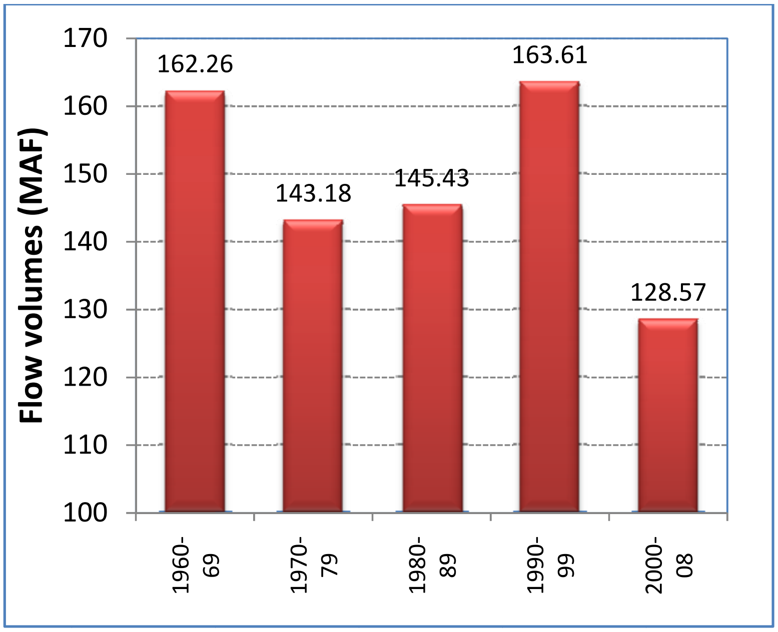

Figure 2.1: Ten yearly average annual flows in Indus Basin Irrigation system (Basharat and Hashmi, 2010)

2.3 GROUNDWATER RESOURCES OF PAKISTAN

Presently in Pakistan, groundwater is an open access common property natural resource and any one can bore a well and pump water till his satisfaction without any limit. In many of the irrigated areas of Punjab, and non-irrigated (barani) areas of Punjab and Baluchistan, groundwater extraction has exceeded annual natural recharge and groundwater levels are going down and down. On the other hand, there are also areas which are waterlogged (Basharat et al., 2014, see Annexure IX (iii)).

Essentially the whole of the Indus Plain is underlain by deep, mostly, over 300 m (1000 feet) deposits of unconsolidated and highly permeable alluvium, deposited by river Indus and its tributaries in a subsiding tectonic depression lying between the Himalayas and contiguous mountain ranges and Plateau. The bulk of the alluvium consists primarily of fine to medium sand, silt and clay. Coarse sand and gravel, however, are not uncommon, particularly near to the mountainous borders of the plain. Fine grained deposits of low permeability (silts and clays) generally are discontinuous so that sands, making up 65 to 75 percent of the alluvium in most areas serve as a unified and highly transmissive aquifer. Irregularly shaped Kankar occur in certain zones of the fine sand and silt beds formed by the cementation of the alluvial particles with secondary calcium carbonate.

During the hydrogeologic investigations carried out in 1950s and 1960s, in the Indus Plain 3322 test holes were drilled, 1587 tubewells were installed and 856 pumping test were carried out (United States Department of the Interior, 1967; WAPDA, 1980a; WAPDA, 1980b). The results of these investigations show that the characteristics of the Indus Plain aquifers vary substantially from place to place. However, overall averages can provide a general impression of aquifer management potential. Average specific yield is about 19 percent for Punjab aquifers and 13 percent for Sindh aquifers. Lateral hydraulic conductivity averages about 84 m/day (0.0032 ft/second) in Punjab and 29 m/day (0.0011 ft/second) in Sindh. Anisotropy ratios average about 55:1 in the Punjab and 30:1 in Sindh (Ahmad, 1995). Before inception of irrigation systems in the basin, the depth to groundwater table varied between 20-30 m. Recharge from earthen canals and irrigated fields resulted in a significant rising of the watertable in certain locations. Acute shortage of irrigation water, due to increasing population and cropping intensities, urged the farmers to exploit groundwater reservoirs. Number of tube wells in Punjab increased exponentially from 334,099 in 1992-93 to 1,009,097 in 2009-10 (Agricultural Statistics of Pakistan, 2011) resulting in lowering of the watertable in areas with less canal supplies.

The exploitation of groundwater, mostly by private farmers, has brought numerous environmental and economic benefits to the agriculture sector in Pakistan. Share of groundwater is now almost half of all crop water requirements in the irrigated environment, especially in Punjab. Consequently, some of the areas in Punjab, started showing excessive depletion at the onset of drought period (1998-2002). Actually, in Punjab province, canal supplies are far less than actual crop water requirement. In areas where, this gap between water demand and canal supplies along with rainfall is higher, groundwater pumping is more than the recharge. Therefore, mining of the resource is taking place continuously, in addition to its ill impact on the economic conditions of the farmers. On the other hand, water logging conditions prevailed in some of the other areas in Punjab and Sindh-Balochistan irrigated areas (Figure 2.3).

Basharat et al. (2014) analyzed depth to watertable data and proposed groundwater management options for different irrigated areas of the IBIS. The comparison of areas under different DTW classes amongst the regions in Punjab is shown in **Figure 2.3**, for June 2012. In Bari Doab, 65.4% area is highly depleted (DTW > 12m), whereas in Bahawalpur and Rechna Doabs, 10.9 and 7.8%, respectively, falls in depleted class. According to the DTW map, depth to groundwater successively increases towards downstream of the irrigation system. According to the new classification, highly depleted area (DTW > 13m), falls in lower

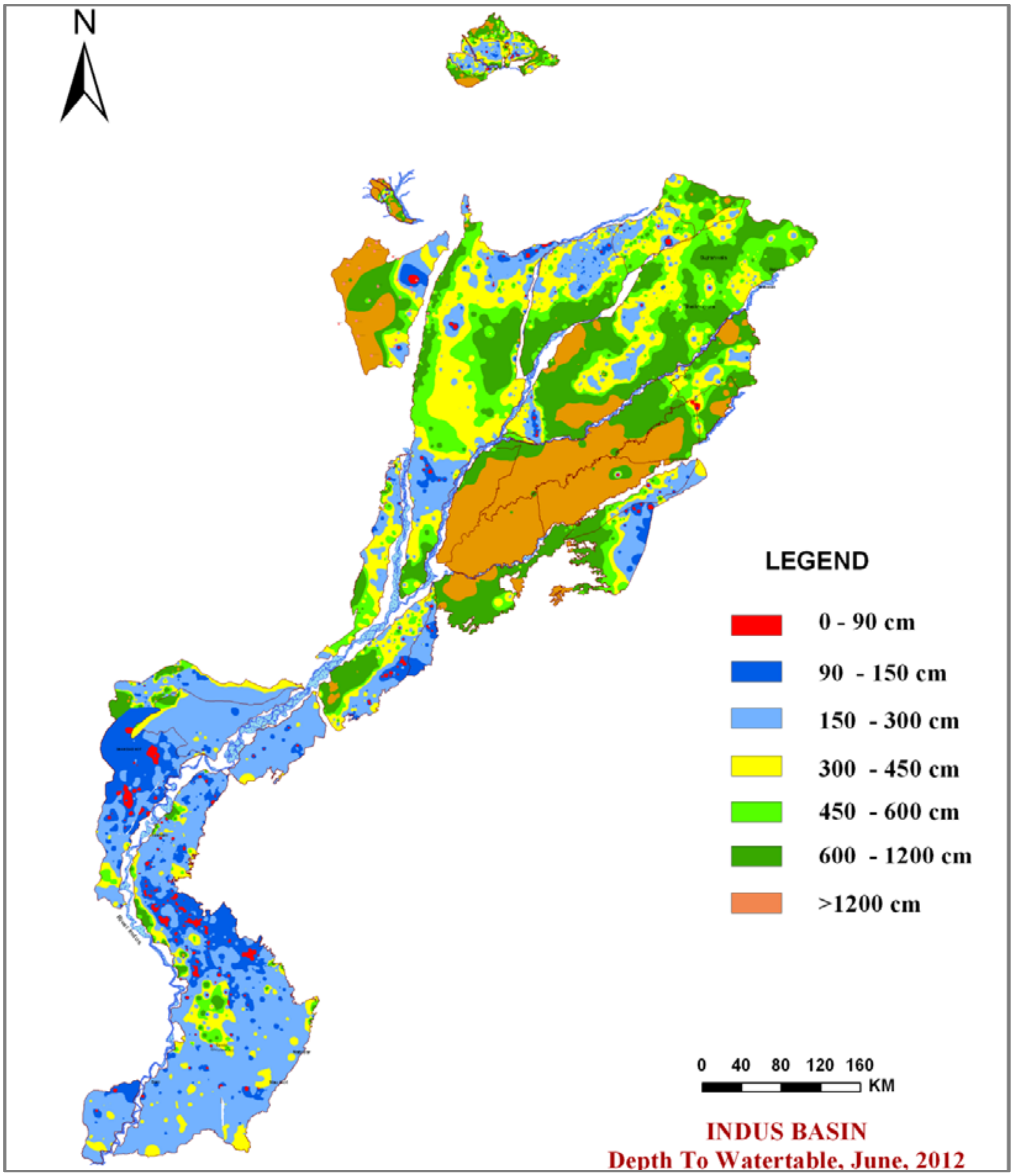

Figure 2.2: Depth to watertable in IBIS, during June 2012 (Basharat et al., 2014a).

part of the Doab, its further distribution is towards Sutlej River and towards the center of the Doab. In reality, groundwater is deeper in central part of the Doab, i.e. along the course of old Sukh-Beas River, which is now disconnected from its head waters (in Indian part) and completely dry. Similarly, in Rechna Doab, depleted area (DTW > 12 m) fall in south-western part of the Doab.

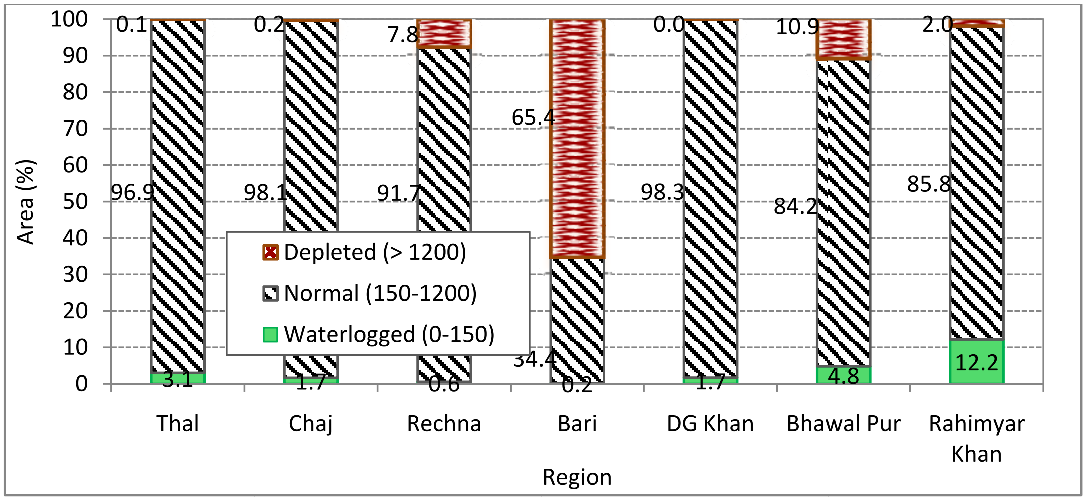

Figure 2.3: Comparison of DTW amongst regions of Punjab for June, 2012 (Basharat et al., 2014)

2.3.1 Changing Groundwater Regime in Pakistan

Currently, surface water in Pakistan is managed at federal and provincial scales, leaving groundwater at sole discretion of end users. Keeping in view the increasing water demands, especially the groundwater, sustainable management of groundwater resources is imperative to the agricultural, industrial, urban, rural and environmental viability of the country. Such management requires not only a robust scientific basis but also on-going monitoring and re-assessment of surface water allocations to different irrigation systems, water levels, and groundwater quality. This re-assessment can point out any flaws in current water management approaches, which are based on more than century old status and knowledge of the irrigation system (Basharat et al., 2014).

The cropping intensity was 102.8, 110.5 and 121.7% during 1960, 1972 and 1980, respectively (Ahmad, 1995), and now operating at about 172% (Mirza and Latif, 2012) and even higher in certain areas. As a result, groundwater mining due to higher abstraction rates as compared to the corresponding recharge is well reported in the literature (NESPAK/SGI, 1991; Steenbergen and Olienmans, 1997; Basharat and Tariq, 2013; Basharat et al., 2014; Cheema et al., 2013). It means the underground reservoir that was recharged by the newly built irrigation system with low cropping intensities is now being overexploited due to increased cropping intensity, more stress from the population, in the form increased domestic and industrial use of groundwater. Depth to watertable map of Rechna for June 2002, developed by WAPDA is shown in **Figure 2.3**, according to the results only 0.59% area of the Doab had DTW more than 12 m from the NSL. Due to increasing groundwater extractions, DTW is increasing in the area as groundwater levels are falling. The observation well no. NPL-III/54 location shown in figure 1.2, falling near the Nestle Plant, shows an average groundwater depletion rate of 13.85 cm/year, for the period from 1980 to 2012.

2.3.2 Overview of Groundwater Issues in Punjab, Pakistan

The population of Pakistan is increasing at the rate of 2.03 percent per annum (World Population Day, 2011), which is putting a great pressure on the agriculture and water sectors. About 65 percent of the population lives in the rural areas with agriculture as the main source of livelihood. The total area of the Punjab is about 51 Million acres (MA) of which 24.6 MA is under the irrigation system, commanded by 24 major canals. The use of groundwater has played a key role in meeting the increasing cropping intensity and poverty alleviation in rural areas of the Punjab. More than 90 percent of the total groundwater abstraction is being used for agriculture. Ever increasing demographic pressure and the increasing demands of water for drinking, irrigation, industry and environmental needs is such that groundwater use will be of continuing importance in the years to come. Uneven groundwater development and uncontrolled pumping through private tubewells has started showing stressful effects on the aquifer in form of excessive draw down and deterioration of groundwater quality in some parts of the Province. Pollution of the aquifer through unchecked discharge of untreated industrial and sewage effluents, and application of agro-chemicals is posing another major threat to groundwater reservoir. The unsystematic/unevenly distributed large scale groundwater abstraction has given birth to a number of problems of intricate and interactive nature such as:

- Abnormal lowering of the watertable in some areas making the pumping more expensive, depriving the poor from using groundwater;
- Saline groundwater intrusion in the fresh areas adjacent to the saline groundwater (SGW) zones as a consequence of differential hydraulic head (caused by excessive pumping in fresh groundwater areas),
- Deterioration of groundwater quality in the areas with shallow lenses of fresh groundwater (FGW) overlying saline groundwater (SGW) due to upcoming of saline-fresh groundwater interface.

A national water quality study was carried out by the Pakistan Council of Research in Water Resources (PCRWR) in 2001. In the first phase of the program, covering 21 cities, all samples from four cities and half the samples from seventeen cities indicated bacteriological contamination. In addition, arsenic above the WHO limit of 10 parts per billion (ppb) was found in some samples collected from eight cities. A second PCRWR study was launched in 2004, and preliminary results indicate no appreciable improvement, while a separate study reported that in Sind almost 95% of shallow groundwater supplies are bacteriologically contaminated. There is very little separation of municipal wastewater from industrial effluent in Pakistan. Both flow directly into open drains, which then flow into nearby natural water bodies i.e. rivers.

2.4 GROUNDWATER QUALITY

The quality of groundwater in the Indus Plains varies widely, both spatially and with depth and is related to the pattern of groundwater movement in the aquifer. Areas subject to heavier rainfall and consequently greater recharge, in KP and the upper parts of Punjab, are underlain with waters of low mineralization. Similarly recharge occurring from the main rivers and canals has resulted in the development of wide and deep belts of relatively fresh groundwater along them. In Punjab 23% of the area has hazardous groundwater quality, while it is 78% in Sindh (Haider, 2000). The groundwater quality varies from 0.3 dS/m to 4.6 dS/m in the Punjab province. The water quality is fit to marginally fit, for agriculture in upper and central Punjab (except at few locations, mostly in the centers of Doabs) but in lower Punjab deep groundwater quality is unfit for agriculture purposes, at majority of the places. Here irrigation is possible only by mixing groundwater with the canal water.

Rechna Doab

Fresh water occurs in a 25 to 30 km width, along the flood plains of Chenab and Ravi rivers in the northern part up to a depth of 300 m. In the lower part of the Doab, this width is considerably reduced. Upper Rechna is the largest fresh groundwater reservoir which extends from Sheikhupura, Khangah Dogran to the border of Jammu and Kashmir (**Figure 2.3**). In most of this area the salinity is less than 500 ppm. Saline groundwater is found in the central and lower parts of the Doab. Highly saline zone is restricted to central Doab and contains water of 10,000 to 18,000 ppm, near Shorkot Road. In this area the degree of mineralization is remarkably uniform from about 30 m to 330 m.

In Upper Rechna comparison of shallow and deep water quality indicates that at places, water quality at shallow depths is inferior to the quality of deep waters. This has been confirmed by vertical groundwater salinity profiles drawn from 1960s groundwater investigations (**Figure 2.4**). The samples were analyzed for a number of Cations and Anions, the Nitrate (NO_3) concentration was found as: trace to 0.01 Milliequivalents/litre, for D-3; just trace for D-3; trace, 0.01, trace and 0.17 meq/l for D-6; and Z-13 was not analyzed for Nitrate. However, in Lower Rechna, shallow water quality is better than deep groundwater quality due to seepage from irrigation system.

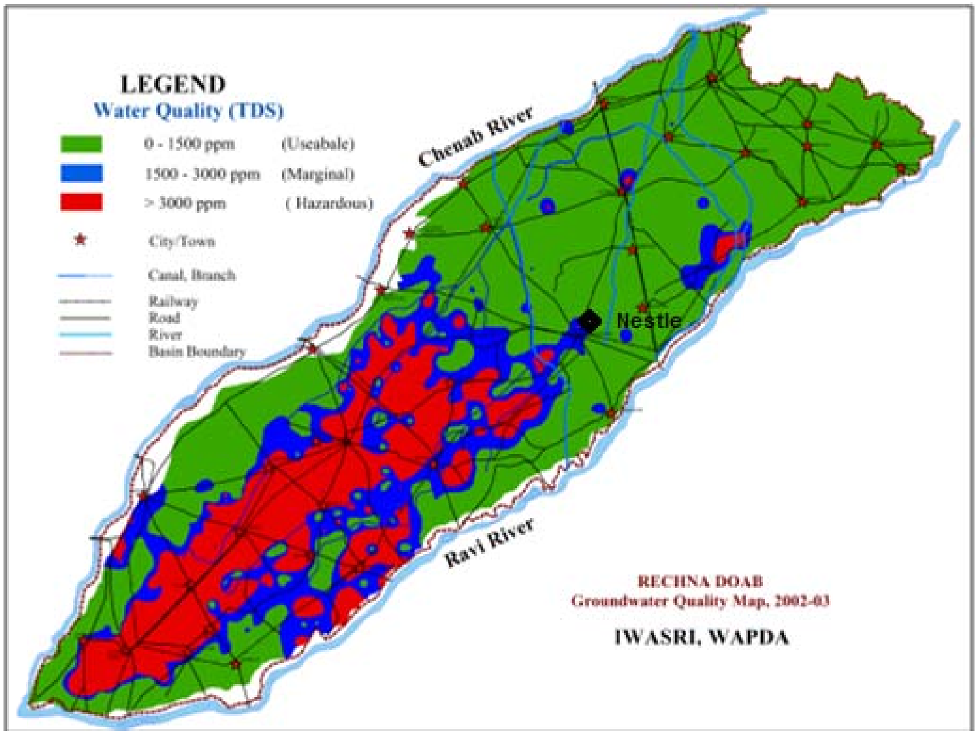

Figure 2.4: Groundwater Quality in Rechna Doab, during 2002-03 (Basharat et al., 2014).

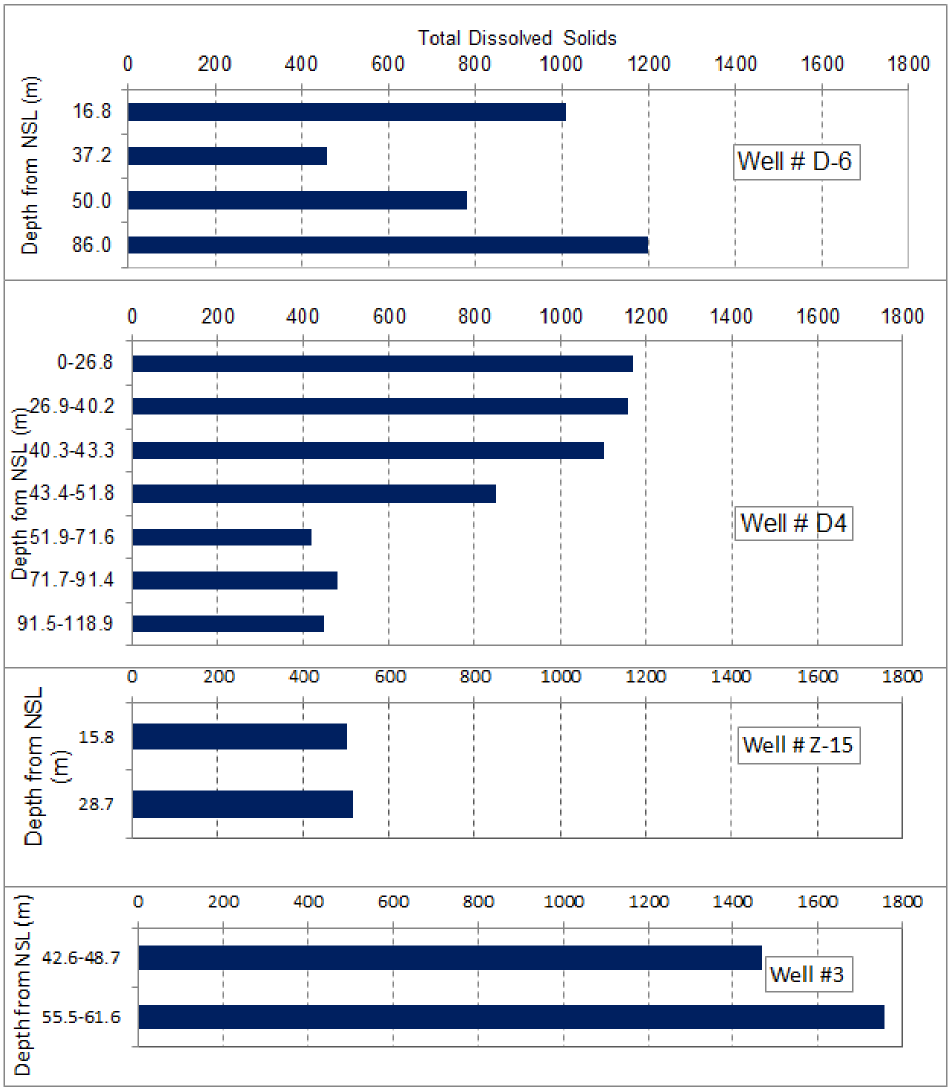

Figure 2.5: Groundwater salinity (vertical profile) at selected wells in the study area (data sourcse: 1960s groundwater investigations, WAPDA (1978)

WAPDA periodically collected samples from different pumping sources from shallow depth. The extent of fresh groundwater is demonstrated by the area underlain by different quality groundwater under the three canal commands of Upper Rechna Doab in Tables 2.5 to 2.7. According to the results, during 1959-62 survey, almost 100 percent of the commanded area of these three canals was showing groundwater having total dissolved solids ranging less than 1000 ppm. Similarly, WAPDA conducted groundwater survey during 2001-2002, some deterioration of the shallow groundwater quality was found during the elapsed period. The reduction of the area having less than 1000 ppm, was 7, 15 and 5 percent, for Marala Ravi Link Canal, Rayya Branch and Upper Chenab Canal commands, respectively. However, still most of the commanded area of these canals is underlain by fresh groundwater. The study area also lies within this fresh groundwater zone.

Table 2.5: Number of tubewells falling under different ranges of TDS during 2001-2002

Canal Command	Number of Tubewells	TDS < 1000 PPM		TDS 1000-1500 PPM		TDS >1500 PPM	
		Number	%	Number	%	Number	%
Marala Ravi Link Canal	23	21	91.3	2	8.7	0	0.0
Rayya Branch	66	53	80.3	8	12.1	5	7.6
Upper Chenab Canal	166	155	93.4	7	4.2	4	2.4

Table 2.6: **Area & percentages falling under different ranges of TDS during 2001-2002**

Canal Command	Area	Area under Different Ranges of TDS (PPM)					
		TDS < 1000 PPM		TDS 1000-1500 PPM		TDS >1500 PPM	
	M. ha	M. ha	%	M. ha	%	M. ha	%
Marala Ravi Link Canal	0.068	0.063	93.4	0.003	4.8	0.001	1.8
Rayya Branch	0.179	0.152	84.6	0.022	12.2	0.006	3.2
Upper Chenab Canal	0.452	0.428	94.9	0.021	4.7	0.002	0.4

Table 2.7: Change in area and percentages falling under different ranges of TDS during 1959-1962 and 2001-2002.

Canal Command	Total area	Area under Different Ranges of TDS (PPM)					
		TDS < 1000 PPM		TDS 1000-1500 PPM		TDS >1500 PPM	
	M. ha	M. ha	%	M. ha	%	M. ha	%
Marala Ravi Link Canal	0.068	-0.0045	-6.6	0.0032	4.8	0.0012	1.8
Rayya Branch	0.179	-0.0276	-15.4	0.0219	12.2	0.0057	3.2
Upper Chenab Canal	0.452	-0.0231	-5.1	0.0211	4.7	0.0020	0.4

2.5 RAINFALL

Mean annual precipitation ranges from about 100 mm in parts of Lower Indus Plain to over 1000 mm near the foothills in the Upper Indus Plain (**Figure 2.6**). On the other hand, lake evaporation increases in north-south direction from 1270 mm at Peshawar to 2800 mm at Thatta (Ahmad, 1982). The mean annual rainfall in Rechan Doab varies from 1000 mm, at Sialkot, to about 290 mm, at Shorkot, the lower end of Rechna Doab, whereas, for Faisalabad, lying almost in the middle of the Rechna Doab, the mean annual rainfall is 375 mm (**Figure 2.6**). For the Lahore city, nearest to the Nestle plant site, falling in Bari Doab, the mean annual rainfall is 712 mm.

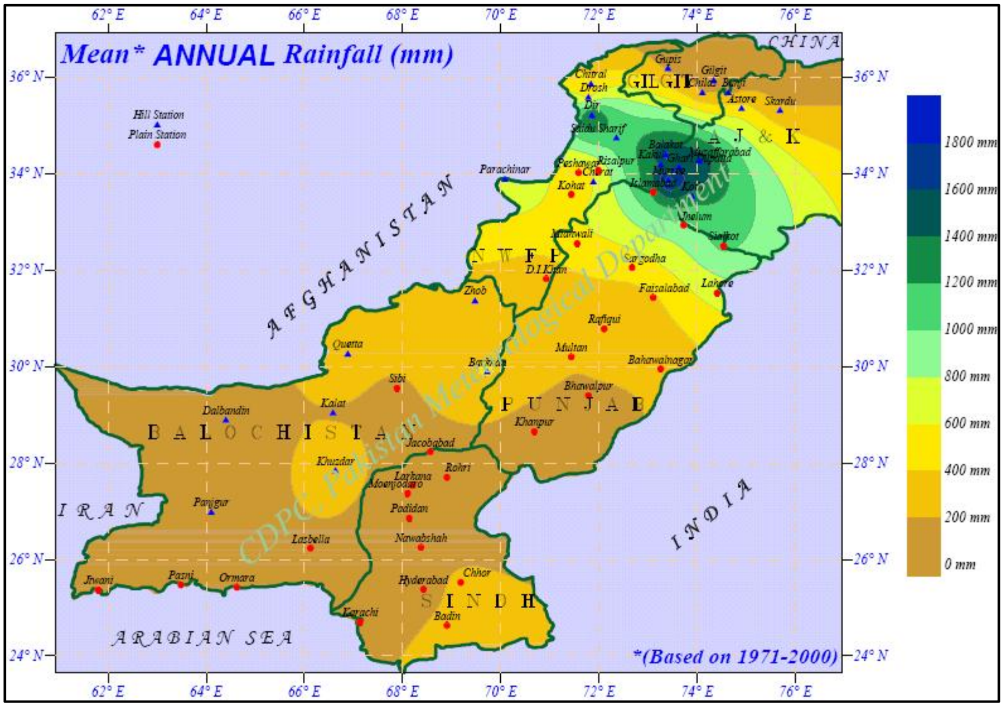

Figure 2.6: Variation of annual normal rainfall in Pakistan (PMD, 2010).

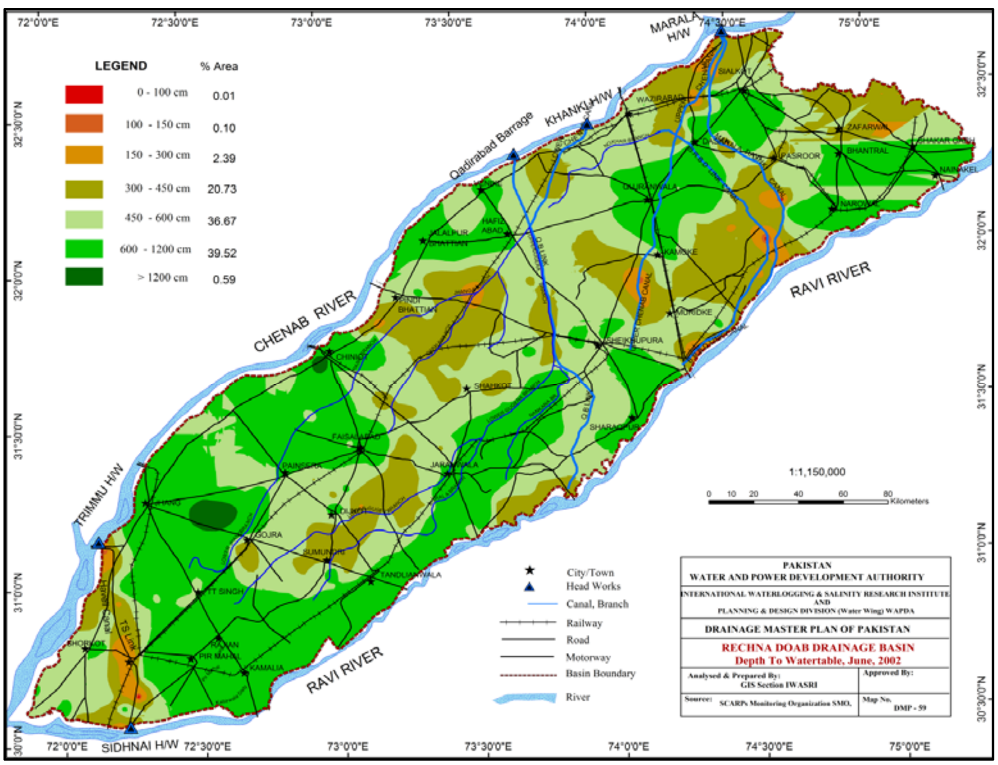

Figure 2.7: Depth to Watertable in Rechna Doab, as on June 2002 (WAPDA, 2004)

2.6 PREVIOUS HYDROGEOLOGICAL STUDIES

Various studies with varying objectives have been conducted in the study area, the major and authentic studies include:

i) Salinity Control And Reclamation Project SCARP-IV;
ii) Honda Atlas Power Plant;
iii) Nestle Pump out Test;
iv) Hydrogeological Studies Carried Out by WAPDA; and
v) A Study of Drinking Water of Industrial Area of Sheikhupura with Special Concern to Arsenic, Manganese and Chromium

2.6.1 Salinity control and reclamation project

The problem of water logging and salinity assumed such a proportion in the last fifties that it started to be termed as number one problem in irrigated agriculture. Food shortage made it imperative to tackle the problem on war footings. To alleviate the problem of waterlogging and salinity, Salinity Control and Reclamation Program was conceived, under the program various Salinity Control and Reclamation Projects called SCARPS were undertaken in IBIS. Under this program SCARP-IV project was executed for eradication of waterlogging and salinity in areas of Gujranwala, Sheikhupura and Sialkot districts. The project covered a gross areas of 0.558 M.A. and CCA is 0.544 M.A. A total of 935 tubewells with collective design capacity 3714 cusec at utilization of 46 percent were installed. Maximum pumpage during 1975-76 was 1176 MCM (0.953 MAF) with utilization factor 38 percent. The pumpage and utilization during 1987-88 were 1071 MCM (0.868 MAF) and 35 percent respectively. The reduction was due to the lowering of watertable and deterioration of tubewells. Disaster area was very small i.e. 0.2 percent during June 1969 which reduced to zero percent during June 1988. Cropping intensity was 65 percent 1968-69 (base year) which reached maximum of 114 percent during 1986-87 against 150 percent designed. It was 107 percent in 1987-88. The project was completed in 1973 (Qamar and Hafeez, 2004).

2.6.2 Hydrogeological Studies carried out by WAPDA

During the 1960's, US Geological Survey initiated hydrogeological investigations in Punjab in cooperation with Water and Power Development Authority (WAPDA) under the auspices of the US Agency for International Development (USAID). The investigations included the drilling of test bores, construction of test tubewells, carrying out pumping tests, data analysis and preparation of the following reports:

- Geological Survey Water Supply Paper 1608-G
- Geological Survey Water Supply Paper 1608-H
- Geological Survey Water Supply Paper 1608-I
- Geological Survey Water Supply Paper 1608-Q

Pumping test data for 8 test wells, located around the project area, are given in Table 2.8.

Table 2.8: Results of selected pumping test, near the study area (Bennett et al., 1967).

Test site #	Location	Screen length (m)	T/w depth (m)	DTW (m)	Q (m^3/hr)	Max. DD (m)	Sp. Capacity (m^3/h/m)	Permeability (m/day)	Sp. yield (S)
R-6	Chichki Malian Drain	43.89	87.78	0.76	254.8	6.71	38.01	82	0.01
R-8	UC Branch	60.05	71.32	1.22	185.54	3.96	46.83	42	0.22
R-20	Qila Didarsingh	30.48	76.20	3.66	152.92	3.05	50.17	105	0.15
R-22	Lahore-Sargodha Rd (M St-40)	43.89	91.44	2.44	254.86	3.17	80.27	105	0.06
R-29	Mangatanwala Rest House	39.62	84.13	2.44	254.86	5.20	49.17	100	0.09
R-31	Ludianwala Rest House	40.5	90.22	1.52	258.94	3.98	80.94	108	
R-47	Kala-Shah Kaku	42.67	91.44	3.05	305.83	3.78	80.94	84	0.07
R-50	Qila Sattar Shah	42.67	92.36	4.36	356.81	5.62	63.55	108	0.13

The test bore data shows that the strata underlying the Project Area comprise alternate layers of clay, silt and sand up to a depth of about 396 meters (1312 ft), which is the depth of the deepest borehole (Annexure VII: borehole 9, section RD-RD’). Parts of two geological cross-sections of Rechna Doab, falling near the study area are shown in Figure 2.8, whereas Figure 2.9 shows logs of individual bores holes from the same data. Figure 2.10 shows the lithologic logs of the wells installed by various industries in the vicinity of Nestle plant. Geological map of the study area is attached in Annexure-VI.

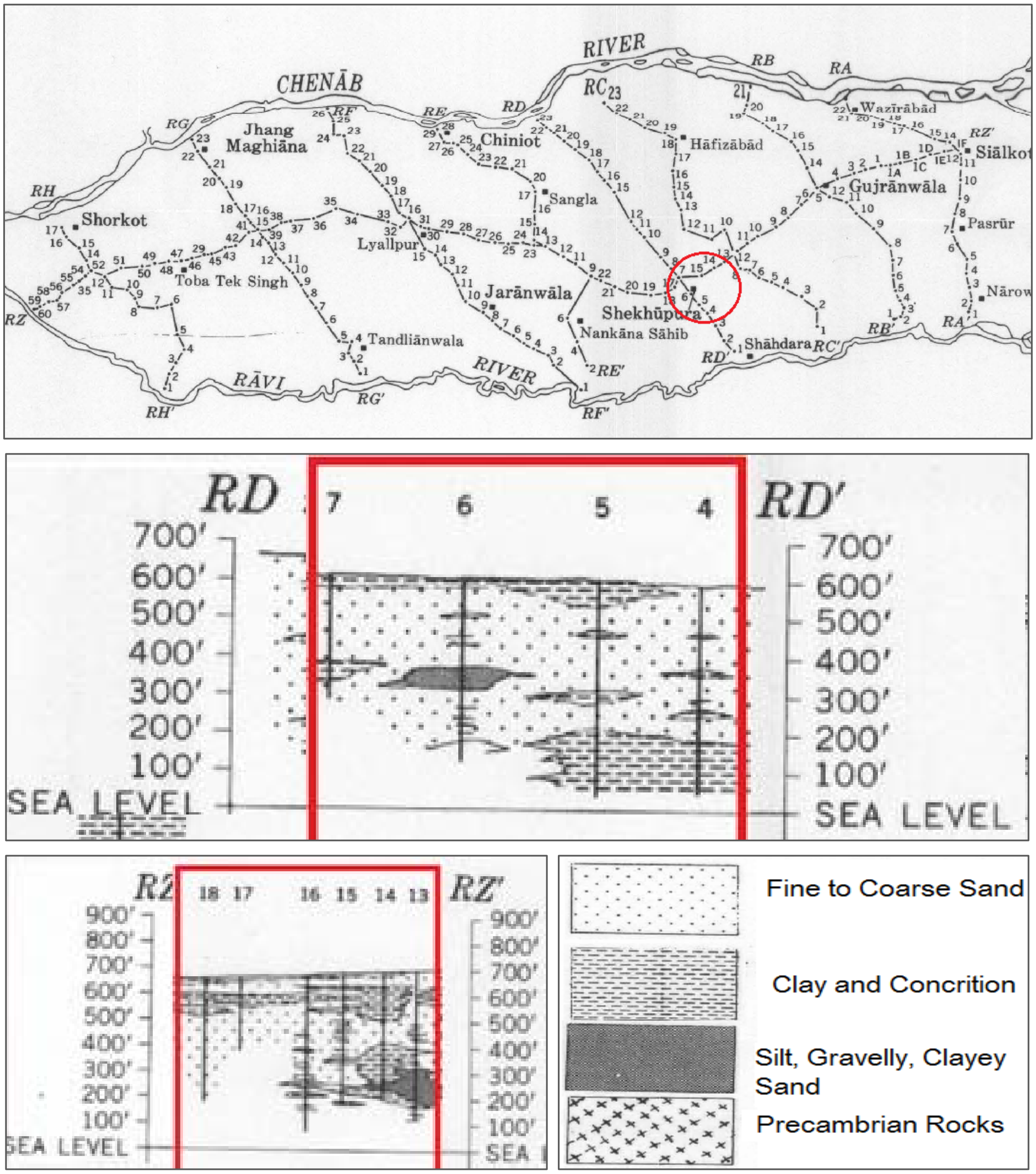

Figure 2.8: Test/borehole sites in Rechna Doab and geologic X-sections falling in the study area

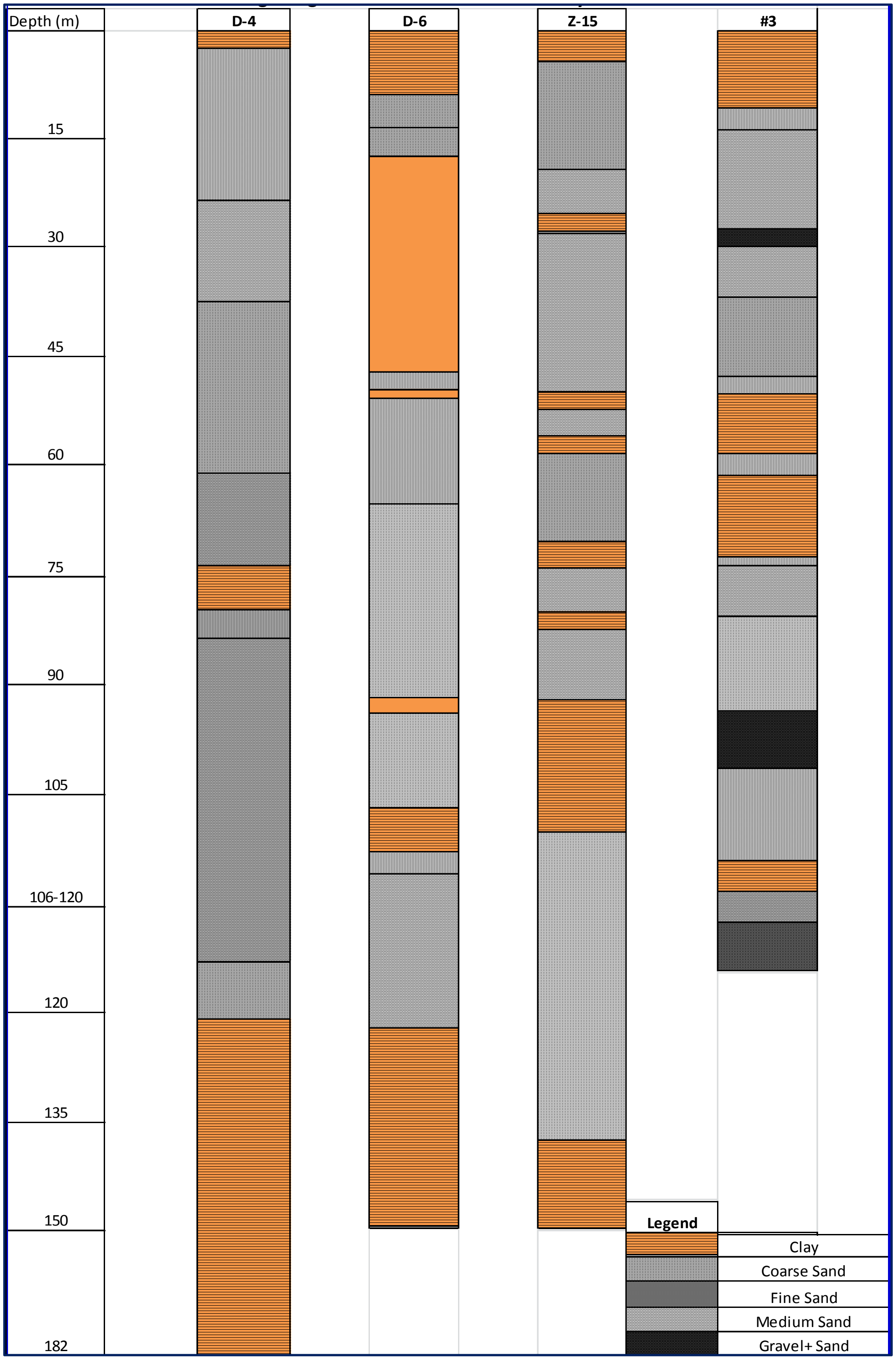

Figure 2.9: Lithologic logs of boreholes carried out in 1960 near the study area (data source: WAPDA, 1978)

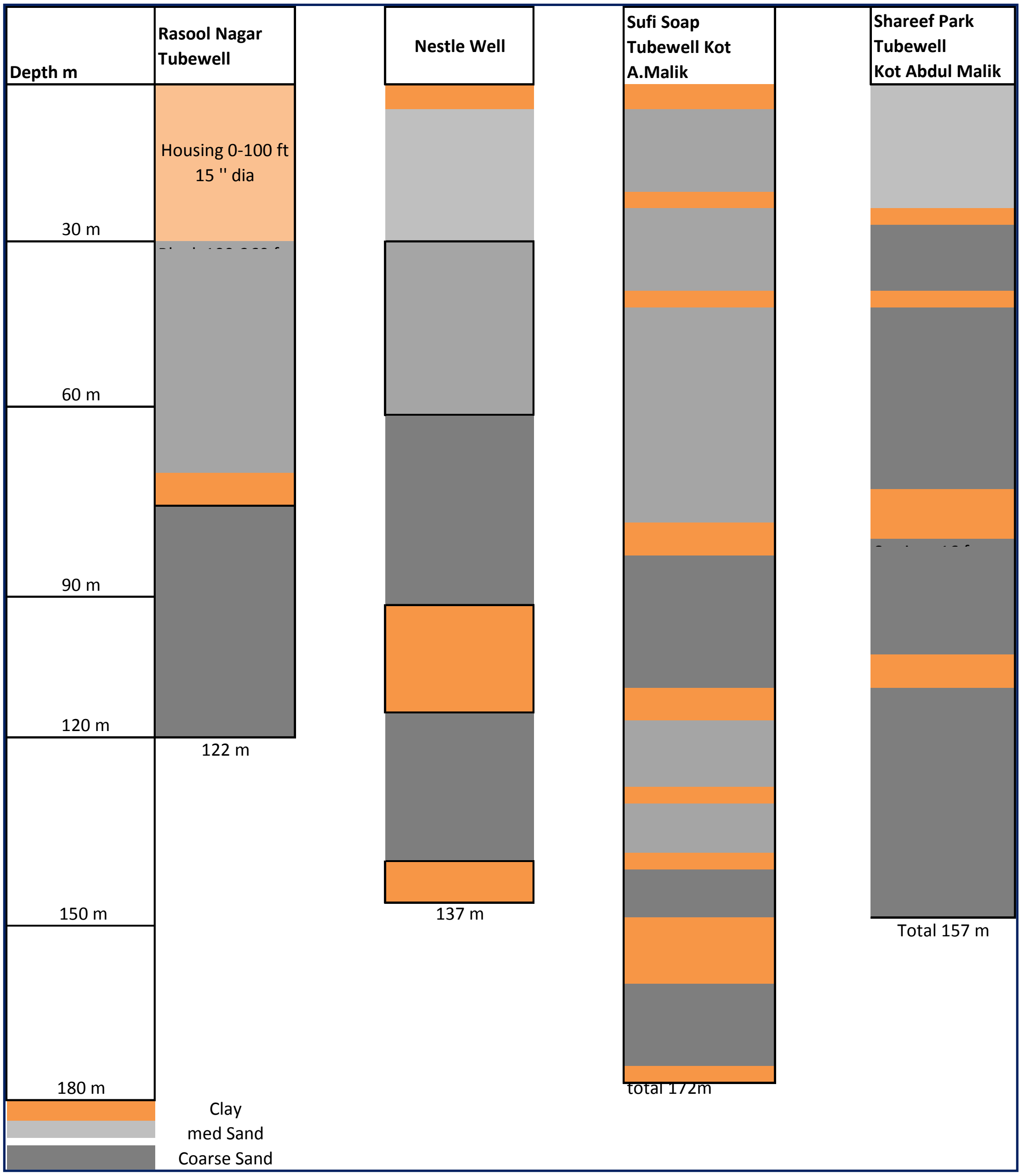

Figure 2.10: Logs of boreholes showing lithology in and around the vicinity of Nestle Plant (source: TMA Sheikhupura)

2.6.3 Study of Drinking Water of Industrial Area of Sheikhupura

Gilani et al., (2013) carried out the study titled "A Study of Drinking Water of Industrial Area of Sheikhupura with Special Concern to Arsenic, Manganese and Chromium" in the same areas that is of interest in this water resource study. The particular attention of the study was to analyze the drinking water of industrial area of Sheikhupura that is swarming with small and large industries. Samples were collected from the twelve different sites in the mentioned area, for six months, at frequency of once per fifteen days. Four sites showed bacterial contamination, five sites indicated high level of TDS and conductivity. Only one site indicated elevated chromium level (0.6 mg/L), two depicted increased level of arsenic but five sites gave idea about the high level of manganese(highest average value 1.2 mg/L) in the study area. All the sites showed carbonates & bicarbonates within the limits. Average value of its hardness was found to be 505 ppm. Sulfate was found in elevated amount, at three of the samples i.e. above the WHO limit of 250 ppm, this might be due to sulfate fertilizers. All the samples depicted the chloride within the limit. Average value of sodium of 9 sites were above 200ppm, the permissible level of WHO.

2.6.4 Pump Test Carried out at Nestle Factory Sheikhupura

Nestle Factory Sheikhupura carried out a pump test, during April 2005. Salient features of the test are given in **Table 2.9**.

Table 2.9: Pumping test results of tubewell installed at Nestle Plant (April 23-27, 2005).

Static water level below measuring point (m) =				10.01			
Measuring point above ground surface (m) =				1.32			
Static water level below ground surface (m) =				8.69			
Duration of test (hours) =				96			
Description	**Discharge**	**PWL**	**Drawdown**	**Sp. Cap**	**Drawdown**	**Sp. Cap**	**Sp. DD**
	m^3/hr	**m**	**M**	**m^3/hr.m**	**(m)**	**(gpm/m)**	**(m)**
After 24 hours	40	11.61	1.60	25.0	1.6	112	4
B. STEP TEST RESULTS OF NESTLE TUBEWLL							
Duration of each step			=	2	hours		
Description	**Discharge**	**PWL**	**Drawdown**	**Sp. Cap**	**Drawdown**	**Sp. Cap**	**Sp. DD**
	m^3/hr	**(m)**	**(m)**	**m^3/hr.m**	**(m)**	**(gpm/m)**	**(m)**
First step	35	11.76	1.75	20.0	1.74	89.8	5
Second step	45	11.99	1.98	22.7	1.98	102	5
Third step	50	12.09	2.08	24.0	2.07	108	4.1
Fourth step	55	12.12	2.11	26.1	2.10	117	3.8
C. AVERAGE VALUES FOR NESTLE FACTORY							
Adopted value of specific capacity =			25.0	m^3/hr.m			
			34.2	gpm/ft			
Length of screen			18.3	M			
Specific capacity/m			1.367	m^3/hr.m^2			

3. DESCRIPTION OF STUDY AREA

3.1 GENERAL

The study area lies in Rechna Doab, a land of 2.98 million hectares (Mha). *Doab* means the land between two rivers (**Figure 1.1**). It is a part of the alluvium-filled Indo-Gangetic plain. Out of 2.98 million hectares of gross area, about 2.3 million hectares is cultivated and classified as the irrigated croplands (IWMI, 2002).

3.2 RECHNA DOAB

Rechna Doab is a part of land between rivers Chenab and Ravi. The gravity flow of surface water through canal supplies in the Rechna Doab area constitutes a major portion of the total water available for weir-controlled irrigated agriculture. The supplies are conveyed to almost every part of the Rechna Doab through a contiguous network of elevated main and branch canals, distributaries, minors and watercourses. The area is mainly commanded by Upper Chenab Canal (UCC) and Lower Chenab Canal (LCC) systems, off-taking at Marala and Khanki Headworks, respectively, on Chenab River. Also, there are four major link canals, which supply and transmit surface water through the Rechna Doab area to the eastern rivers (Ravi and Sutlej) of the Punjab province. The river water has good quality water with TDS contents of 200 to 300 ppm, depending upon the discharge. The Chenab River water quality data, at Akhnoor city (map with Nestle SKP factory attached in Appendix-II), Jammu and Kashmir, with a number of parameters, measured during monsoon and non-monsoon season seasons is given in **Table 3.1**.

3.3 IRRIGATION NETWORK AROUND STUDY AREA

Upper Chenab Canal (UCC) and Lower Chenab Canal (LCC) are the two main canals passing through the study area. The two main canals fulfill most of the irrigation needs and sustain irrigated agriculture in the Rechna Doab area. The Upper Chenab Canal (UCC) commands the majority of the area between the Marala Ravi and Qadirabad-Balloki Link Canals and a small area below the Qadirabad-Balloki Link Canal along the Ravi River. The area is popularly termed as the Upper Rechna Doab and is administratively within the Upper Chenab Canal Circle of the Lahore Irrigation Zone in districts of Sheikhupura, Gujranwala, Narowal and Sialkot. As a part of the field under the study, two samples are taken from Main UCC Canal and three were taken from hand pumps installed near canal (locations marked in Figure 1.2) to check nitrates concentration in Canal water. These samples were tested by Nestle. The results of these tests are given in **Table 3.1**.

The UCC (**Figure 3.1**) runs almost diagonal in this area before conveying some of its water to the Ravi River upstream of the fall of QB Link Canal at the Balloki headworks on the river.

Table 3.1: Water Quality Data for River Chenab at Akhnoor City, Jammu and Kashmir

STATEWISE/BASINWISE INFORMATION ON WATER QUALITY

1 **Basin: Indus Basin (J&K)**
2 **River :Chenab**
3 **Site : Akhnoor**
4 **Name & Location of Laboratory : LLevel II Laboratory ,Chenab Division, CWC, Jammu**
5 **Type of Staion, Parameter and frequency of monitoring : Trend Station , 24 parameters, monthly**

Water Quality Data

Parameter	Unit	Analysis of Data From 1999-2000 to 2008-0910 Years						Last Year Average		Remarks
		Maximum Observed		Average		Minimum Observed		Nov08 to Oct09		
		Monsoon	Non-Monsc	Monsoon	Non-Monsc	Monsoon	Non-Monsc	Monsoon	Non-Monsoon	
Q-	(Cumec)	1790	964	1160	411.4	527	131	1020	317.5	
PHYSICAL										
pH		8.10	8.70	7.90	7.90	7.60	7.40	7.90	7.70	
electrical Conductivity	(umho/cm.)	232.00	265.00	164.45	180.22	110.00	106.00	132.00	136.00	
Temp.	°C.	23.50	20.90	17.53	13.13	12.00	8.80	16.80	13.75	
CHEMICAL										
BORON	mg/l	0.42	0.29	0.22	0.07	0.01	0.02		0.06	
CALCIUM	mg/l	43.00	58.00	30.40	32.00	20.00	21.00		26.50	
MAGNESIUM	mg/l	10.80	14.20	8.68	8.13	7.20	2.70		7.00	
CHLORIDE	mg/l	17.20	15.90	7.87	8.55	2.00	2.50	5.70	4.95	
CARBONATE	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
BICARBONATE	mg/l	118.00	157.00	85.40	88.13	57.00	48.00		82.00	
SODIUM	mg/l	3.10	8.10	2.55	3.68	2.00	1.60		3.10	
POTASSIUM mg/l	mg/l	2.70	3.00	2.45	1.49	2.20	0.30		0.30	
FLUORIDE	mg/l	0.22	0.31	0.22	0.11	0.22	0.00		0.06	
IRON	mg/l	1.10	0.40	0.77	0.14	0.40	0.00		0.10	
NO2+NO3	(mg N/l)	0.21	0.22	0.07	0.08	0.02	0.02	0.02	0.06	
Ammonia-	N (mg N/l)	0.53	0.18	0.11	0.04	0.00	0.00	0.04	0.03	
Total-P	mg/l	0.05	0.24	0.04	0.06	0.02	0.02	0.02	0.04	
NITRITE-	N (mg N/l)	0.01	0.01	0.01	0.01	0.01	0.00			
NITRATE-	N (mg N/l)	0.77	0.86	0.27	0.36	0.01	0.05			
Phosphate	mg/l	0.09	0.08	0.08	0.04	0.04	0.01			
SILICATE	mg/l	61.30	46.60	32.20	18.03	3.10	0.60		0.70	
SULPHATE	mg/l	36.70	37.70	28.50	26.15	19.10	19.60		20.05	
Turbidity	NTU	5.60	4.30	2.08	1.37	0.40	0.30	0.40	0.55	
MANGANESE	mg/l	0.44	0.06	0.22	0.01	0.00	0.00			
COD	mg/l	21.80	34.20	12.03	13.13	7.80	5.90	9.90	9.35	
BOD	mg/l	2.50	2.50	1.00	1.16	0.50	0.60	0.50	0.60	
D.O.	mg/l	10.60	11.30	8.98	9.79	5.00	8.40	9.20	8.65	
Biological/Bacteriological										
TOTAL COLIFORM	MPN/100 ml.	3.00		3.00		3.00	0.00	3.00		
FECAL COLIFORM MP	MPN/100 ml	0.00				0.00	0.00	<2		
PESTICIDES										
DDT	ppb		143.03		143.03	0.00	143.03			
Endosulfan	ppb		0.00			0.00	0.00			
TOC		2.24	1.70	2.24	1.49	2.24	1.38			

Figure 3.1: Main Line Lower of UCC canal passing through the middle of study area.

3.4 DRAINAGE NETWORK IN THE STUDY AREA

Raw sewage in all the cities is either used for irrigation purposes or discharged into fresh water bodies through a network of drains, which ultimately fall into the rivers. Water from these water bodies and rivers is again used for irrigation purposes. The river waters contaminated by untreated municipal and industrial discharges are also used for drinking and recreational purposes. All this has serious environmental concerns and impacts on the ecosystem and human health significantly. In Punjab none of the cities has a proper waste water treatment (WWT) system, except in Faisalabad that has a limited capacity of treating only 20 percent of the total wastewater generated in the city (GoP, 2007). There are some individual wastewater treatment plants in some of the industries (mostly the exporting industries e.g. the one installed by The Coca Cola Bottles Pakistan Limited (CCBPL), Lahore. These plants are installed under the international environmental governance by the buyer's.

3.5 CONTAMINATION HAZARDS IN THE STUDY AREA

Nullah Deg is a major hill torrent originated from Indian occupied Kashmir, which falls in to river Ravi, after passing through the study area. It is occasionally flooded with severe floods in monsoon season. These channels usually contain industrial and sewage wastes (**Figures 3.2 and 3.3**) except the months of July and August in which peak rainfall discharges were observed. The Nullah Deg carries industrial and municipal wastes in the study area.

Although the deep aquifer storage underlying the study area has not shown any major impact in the form of pumped groundwater quality deterioration so far, but the shallow aquifer quality is deteriorating day by day. The electrical conductivity values of water samples collected from shallow depth (less than 20 meters) nearer to these effluent carrier drains is higher than the rest of the area. Besides these drainage networks, most of which carry industrial effluent, another pollution hazard was observed in the form of sewerage waste ponds in surrounding almost all the villages. This is due to the fact that villages in the study area have no sewage system. The domestic effluent/wastes flow in open channels along streets and fall into ponds (locally called Chappar) at the boundary of the villages. The size of these wastage ponds vary from 500 to 1000 square meters depending upon the covered area and population of the village. Due to unconfined nature of the aquifer, this factor for contamination to the underlying groundwater cannot be negated altogether.

There are three main drains in the study as given below:

i) Nullah Deg
ii) Chichuki Drain
iii) Sheikhupura Drain

i) Nullah Deg

Two tributaries of Nullah Deg run in the study area. The average depth to the bed is 6.0 to 7.0 meters, whereas the depth of water is 0.6 to 0.9 meters. The width of the main Deg Nullah is 15 meters. For carrying industrial effluent to the Deg Nullah, lined channels are constructed along both sides of Lahore-Sheikhupura road which collected the toxic wastes from factories and discharge into Deg Nullah tributaries. Also, during monsoon season, some flow of flood water is normally observed every year. EC of the flowing water in the drains was measured, the Deg Nullah has an average electrical conductivity (EC) of 4000 µS/cm. The shallow sources pumping from the aquifer, along both sides of the Deg Nullah, have high EC values. The EC Deg Nullah and respective coordinates of water points are given in **Table 3.2**.

Table 3.2: EC of Deg Nullah, Measured at Select Points in the Field

S.No.	Longitude	Latitude	EC (µS/cm)
1	31.664577	74.105799	2370
2	31.658533	74.658531	2190
3	31.674228	74.680417	1920
4	31.665524	74.672114	2260

Figure 3.2: Nullah Deg crossing Lahore-Sheikhupura road and Industrial Waste Piled up along Nullah Deg

Figure 3.3: Industrial Waste Water being Discharged, Without Treatment into Deg Nullah through Lined Channels

ii) Chichuki Mallian Drainage System

The Chichuki Mallian Drainage system (**Figure 3.4**) comprise of three drains: Sanat Pura; Ghazi and Barrianwala drain. It has been designed to drain industrial and municipal wastes away from human settlements. The bed width of these drains is 1.5 to 6 meters. The electrical Conductivity of these drains vary from 3500 to 7000 μS/cm. the shallow water points along these drains contain marginal quality water and have EC values in the range from 1200 to 2500 μS/cm. However, the deep aquifer below 20m depth has not been yet polluted due to the aforementioned drainage effluent, as the EC values of lower aquifer ranges from 500 to 1200 μS/cm.

Figure 3.4: Industrial Waste of Factories being Disposed of in Chichoki Drain and Another Unlined Channel

3.5.3 Sheikhupura Drain

Sheikhupura Drain is constructed in 1970s in order to save the sheikhupura city from the flood water of Nullah Deg. The drain flows from northeast to southwest of sheikhupura city. The bed width of these drains is 4 to 6 meters. With the passage of time and increasing population and industry in the outskirts of the city, the drain started acting as sewage and industrial wastes drain. Some portion of the drain nearer to the human settlements of the city is lined.

3.5.4 Evaluation of Contamination risks due to bad well design

Well design of water supply wells and agriculture wells in the study area were reviewed. As per practice in sheikhupura city water supply wells and agriculture wells in the study area, shrouding material filled outside the casing up to surface level. Contamination risks increases mainly due to lack of sanitary seal and grouting around upper casing of the wells. The cement sand grouting of upper casing pack the tapping aquifer and cease the contaminations from upper aquifer to the deeper aquifer. Cement sand grouting is not being practiced in study area due to which the risks of contamination from upper aquifer increased in the study area.

3.6 CLIMATE

The Project Area falls in semi-arid to sub-humid subtropical continental region. The nearest Meteorological station for the study area is Lahore. The climate of the Lahore region is characterized by large seasonal variations in temperature and rainfall. The mean annual, summer and winter temperatures are 32°C and 14.2 °C, respectively. June is the hottest month with mean maximum temperature of 40.4 °C and January is the coldest month with mean minimum temperature of 5.9°C.

The rains are erratic and fall in two seasons that is Monsoon (major rainfall) and non-Monsoon (less rainfall). About 75 percent of the annual total falls between mid-July to mid-September (Monsoon season). Monsoon rains are usually accompanied by thunderstorms and occur as heavy downpours. The remaining one-third rains are received during the period January to March, which are brought by the western disturbances in the form of gentle showers of long duration. The total annual precipitation recorded at Lahore during 2013 was 738 mm, as given in **Table 3.3**.

The months of July and August during summer, whereas November, December and January during winter are relatively more humid having about 60 percent of the relative humidity. The month of May is the driest month showing 32 percent relative humidity, whereas, the month of August has the highest value of 68.8 percent relative humidity. The long-term average monthly values for some of these parameters recorded at PBO Lahore (the nearest meteorological station) are given in **Table 3.4**.

Table 3.3: Monthly rainfall data for 2013 and monthly normal rainfall at Lahore (Airport)

Month	Rainfall 2013 (mm)			Monthly normal rainfall (mm)
	Monthly total	Total Rainfall above 5 mm	Effective Rainfall (mm)	
January	13.3	10	7	22.4
February	71.1	58	40.6	39.3
March	19.2	10	7	37.8
April	7.4	0	0	23.9
May	0	0	0	20.8
June	0	0	0	47.7
July	242.2	238	166.6	217.9
August	353.7	347	242.9	182.9
September	0	0	0	74.6
October	17.4	10	7	18.5
November	7	0	0	5.2
December	7	7	4.9	10.8
Total	738.3	680	476	701.8
Source: Pakistan Meteorological Department				

Table 3.4: Mean Wind speed, Atmospheric Pressure recorded at Regional Meteorological Station Lahore from 1961-2010.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Rainfall (mm)	23.3	30.0	36.3	19.3	20.8	48.1	192.6	168.9	61.1	12.2	5.6	11.8
Wind Speed (m/sec)	0.5	0.9	1.2	1.3	1.3	1.4	0.8	1.0	0.8	0.5	0.2	0.3
Atmospheric Pressure (atm)	1.0	1.0	1.00	0.99	0.99	0.98	0.98	0.99	0.99	1.00	1.00	1.00
Wind Speed (KM/day)	41.6	78.0	101.1	114.3	110.2	118.5	65.5	83.9	66.9	40.8	18.3	21.6

3.7 LANDFORMS AND PHYSIOGRAPHY

The area is a part of a flat alluvial plain known as Indo-Gagnetic plain which extends to the north all along the foothills of outer Himalayas. In Pakistan, it is known as the Indus Plain, which extends from the foothills of outer Himalayas and the Western ranges to the Arabian Sea. In the east, it extends into India. The alluvial deposits of the Indus and its eastern tributaries namely Jhelum, Chenab, Ravi, Beas, and Sutlej built this flat alluvial Indus Plain. The soil profile comprises lean clay and silty clay. It extends generally from 4.5 to 11.5 meter below the natural surface level (NSL). Calcareous concentrations are found in the lower section of the lean clay.

The flat stretches of land between two rivers are usually called "doab", meaning land between two waters. These doabs are Bari (between rivers Beas and Ravi), Rechna (between rivers Ravi and Chenab), Chaj (between rivers Chenab and Jhelum) and Thal (between rivers Jhelum and Indus), as shown in **Figure 1.1**. The plains of these doabs have been formed by alluvial deposits brought by these rivers. Rechna Doab can be classified into four basic units based on the nature of the sediments, their topographic positions and the degree and direction of soil development, together with the available information on geomorphology and geology. The following landform units are present in Rechna Doab:

- Active floodplains; in the vicinity of rivers Ravi and Chenab,
- Kirana Hills – though minor when compared with the alluvial complex,
- Abandoned floodplains, and
- Bar upland – an elevated land beyond the reach of the flood water.

The study area falls in the 2nd last category i.e. abandoned floodplains. It is a flat land having elevation 203 - 213 m above mean sea level. Rechna Doab is about 403 Kilometers long in northeast-southwest direction and has a maximum width of 113 Kilometers. The area is interfluvial and southwesterly sloped. In the upper part of the Rechna Doab, the slope is about 380 cm/Km.

3.8 PLANT INFRASTRUCTURES

3.8.1 Water Sources

The Nestle Plant is 100% dependent on groundwater as its raw water source, municipal water supply has not been provided to the plant for any of the use, rather the plant has not to depend upon any of the such supplies in the presence of its own six installed tubewells (three for utilities and three for Nestle waters, however, one well of each type is on standby). Four tubewells: two tubewells for Nestle water (40 m^3/hr) and two tubewells for the plant utility (125 m^3/hr) in operation supplying raw water of reasonably good quality.

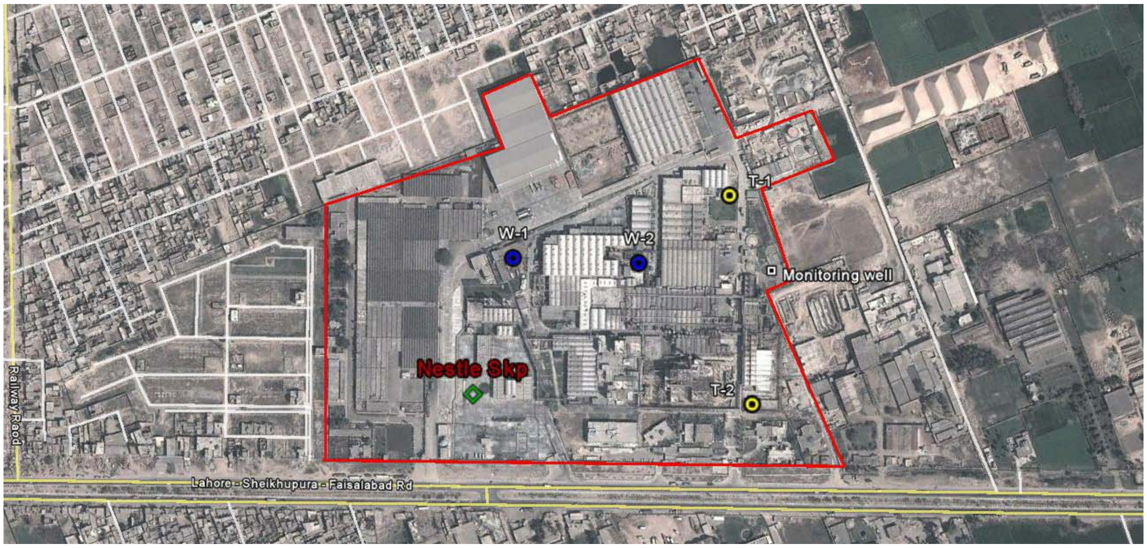

Figure 3.5_: Nestle factory Sheikhupura with operating wells locations

The figure 3.5 is a google map of Nestle factory Sheikhupura site with marked locations of utility (T-1 and T-2) and water wells (W1 and W-2). Presently two water wells of capacity 40 m^3/hr and two utility wells for plant requirements of capacity 125 m^3/hr are in operation. Besides, a separate monitoring well is installed within the factory for continuous water table monitoring. The distance of monitoring well from W-1, W-2, T-1 and T-2 are 316, 160, 103 and 162 meters respectively. The distance between W-1 and W-2 is 150 meters and the distance between T-1 and T-2 is 250 meters. The minimum distance between monitoring and operating well T-1 is 103 meters. As per scope regarding “evaluation of inter influence with the nearest exploited wells”, the required data was collected at site during simultaneous operation of W-1, T-1 and T-2. Depth to water table was monitored in the monitoring well, after a time lapse of five hours, since the start of pumping of the aforementioned wells.

3.8.2 Plant Water Consumption and Production Capacity

Nestle has installed six tubewells in Nestle Sheikhupura Plant, out of which three are used for utilities & plant operations (one stand by) while remaining three are used for Nestle Water (One stand by). Tubewell for utilities has a capacity of 125 m^3/hr while tubewells of Nestle water has 40 m^3/hr. Annual withdrawals of Nestle tubewells in 2013 are estimated as 1.9 MCM.

3.9 COMPETITORS & THEIR SUSTAINABILITY

Although no major competitor user exist in the sense of beverages/food industries but a lot of other stakeholders exist including steel, textile, knitting, chemicals and thread industries etc. These manufacturers are exploiting groundwater for their use. All these have developed their own water resources according to their needs. In spite of these, a number of housing units are under development phase in the area. Some of them have installed tubewells of 150 – 200 m^3/hr capacity in the same aquifer (average depth of about 145 m and the deepest bore at a depth of 170 m). Currently the facility area is not as dense populated as it will be in future. Hence the threat in the form of increasing depth to groundwater is expected after ten years or so from activities of the expansion of residential colonies and industrial units near the vicinity of the Nestle plant site.

3.10 HYDROGEOLOGY OF THE STUDY AREA

The alluvial plain of the Punjab is a part of the Indo-Gangetic Plain. The alluvium consists of sand and silt and minor amounts of gravel and clay, deposited by the Indus River and its present and ancestral tributaries. In accordance with their mode of deposition by large constantly shifting rivers, the alluvial deposits are heterogeneous, and individual strata have limited horizontal and vertical continuity.

The three physiographic subdivisions of the alluvial plain) are based on the present relationship of the surface features to the rivers. Active flood plain includes the belt consisting of present area which occasionally gets flooded nowadays. During low-water stage, the rivers flow in braided or meandering channels, as much as 8 Kilometers wide. Meander scars, sandbars, natural levees and backwater swamps are conspicuous features of the active plains.

Abandoned flood plains are those areas, paralleling the rivers in a belt as much as 32 kilometers wide, a few feet higher than the active flood plains. They represent flood that have been abandoned in comparative times by the major rivers. The flood plains are of hydrologic significance in that they provided the recharge by the rivers in recent past. The bar upland to the north and west Sheikhupura, in Rechna Doab, apparently has been breached by incursions of the Chenab and Ravi Rivers during floods. This low-lying area, mapped as part of the abandoned flood plains, contains ground water of excellent quality to depths of more than 425 meters (1,500 feet) probably largely as the result of infiltrating flood waters. (See Annexure VII: deepest borehole No. 9, in geologic section RD-RD')

The alluvial deposits consist mainly of grey to brownish grey fine to medium sand, silt and clay. And the aquifer is normally considered as an unconfined aquifer in the whole of Rechna Doab and the study area.

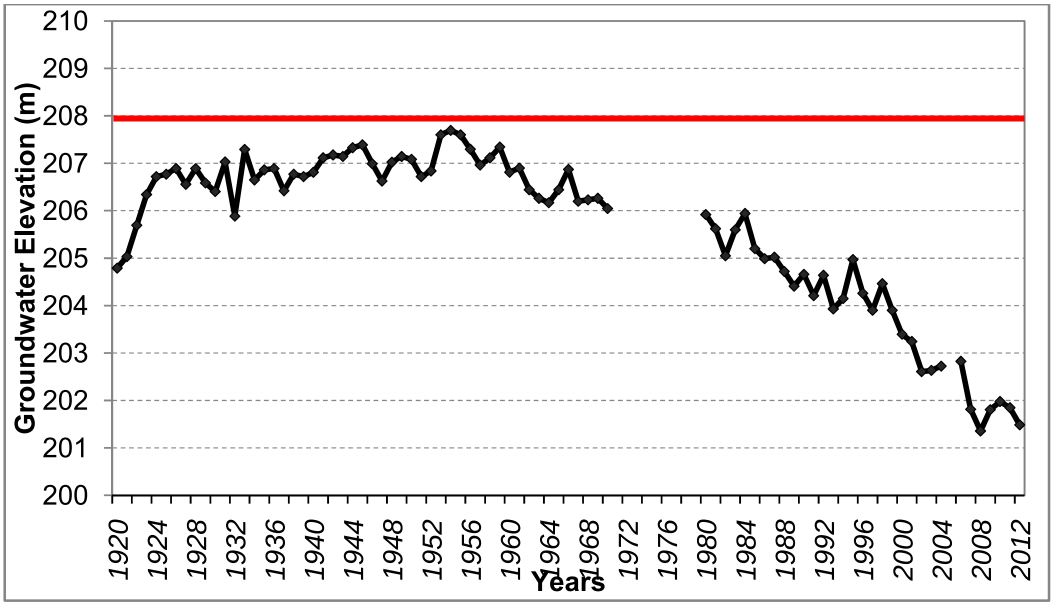

Figure 3.6: Historical behavior of groundwater elevation near Lahore - Sheikhupura road, between Chichoke distributary and Main Line Lower of UCC Canal

3.11 SOILS AND AGRICULTURE

The soils of the area composed of alluvial material which was carried from the Himalayan ranges by tributaries of the vast Indus River system. Frequent changes in the rate of flow of the streams, recurrent floods, and ponding of the sediment-laden water have created a varied and mixed soil pattern throughout the area. The soils are of recent origin and in many respects the soils show a high degree of similarity throughout the area. They are reddish-brown to greyish brown, mostly moderately coarse and medium-textured soils, containing high percentages of fine to very fine sand and silt. The clay part consists largely of non-swelling mineral, which is thought to be generally responsible for favorable permeability characteristics of the soils. In general, the area is fertile and has high productivity.

The overall area comprises medium textured soils, whereas some areas lying in depressions consist of moderately fine textured soils. The major land use of the study area is agriculture. The area lies in the command area of Upper Chenab Canal. Two major crops are rice and wheat, which are cultivated in Rabi (winter) and kharif (summer), respectively. Other crops cultivated in project area are fodder, oil seed and sugarcane. At present, annual cropping intensity in the Project Area is 190%. Irrigation system is designed to fulfill the crop water requirement for 60% annual cropping intensity, while the remaining crop water requirement is being fed by the rainfall and groundwater abstraction. The original design philosophy of the irrigation system was to have protective irrigation over a large area without consideration of crop water requirements. The present strategy of the UCC system is to grow more crops, the resulting gap between canal water supply and crop demands being met through groundwater abstraction.

3.12 GROUNDWATER QUALITY SAMPLING AND ANALYSIS

Nestle factory Sheikhupura has state of the art laboratory for continuous water quality monitoring. Water quality is monitored on daily, weekly, monthly and yearly basis, and analyzed for various parameters. Figure 3.7 to 3.11 indicating the values of Conductivity, sodium, iron, nitrates and arsenic for well # 1 from 1998 to 2013. No extraordinary change in water quality is observed in the results, since pumping started in 1998. The values of all quality parameters are within the permissible limits set by Pakistan Standards and Quality Control Authority (PSQCA).

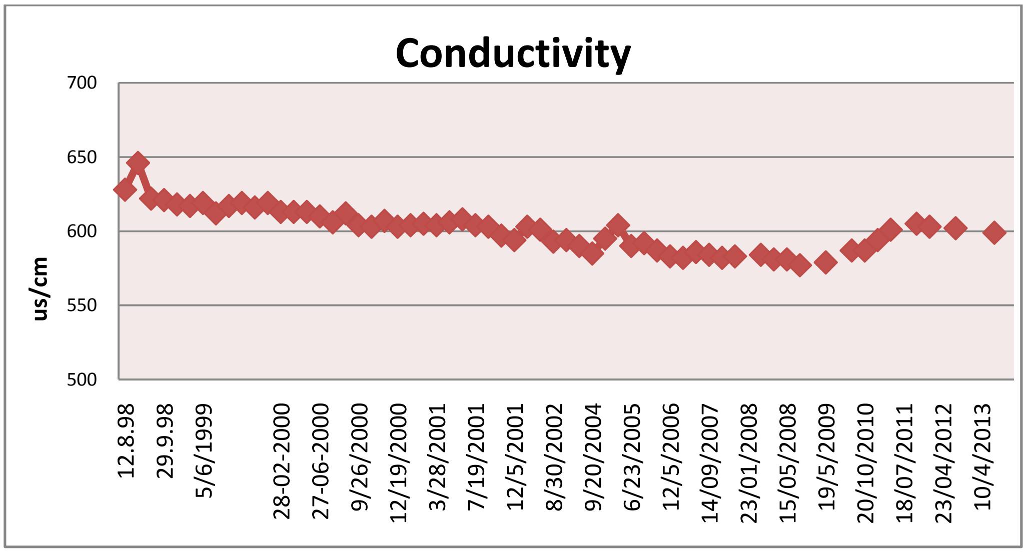

Figure 3.7: Electrical Conductivity of well # 1

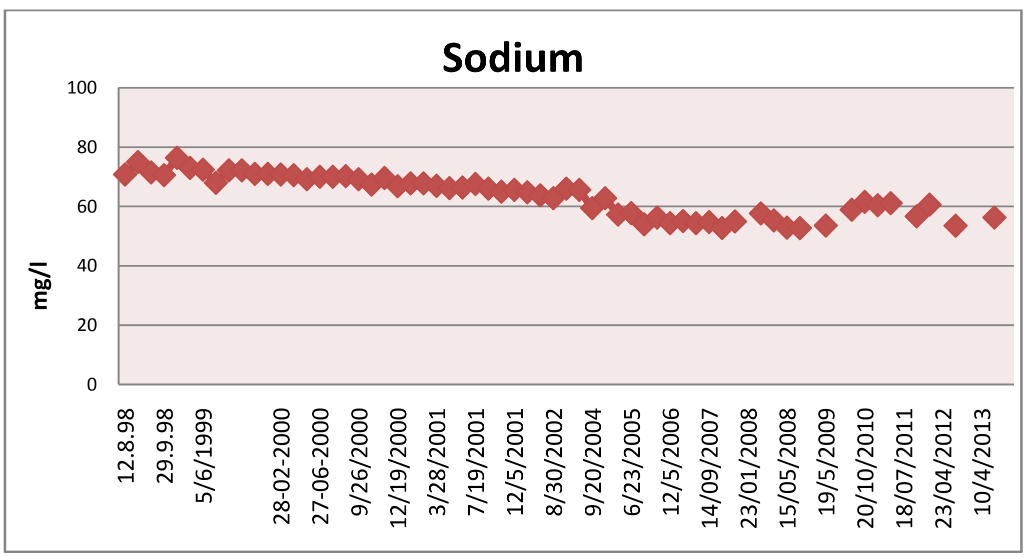

Figure 3.8: Sodium concentration in well # 1 (1998-2013)

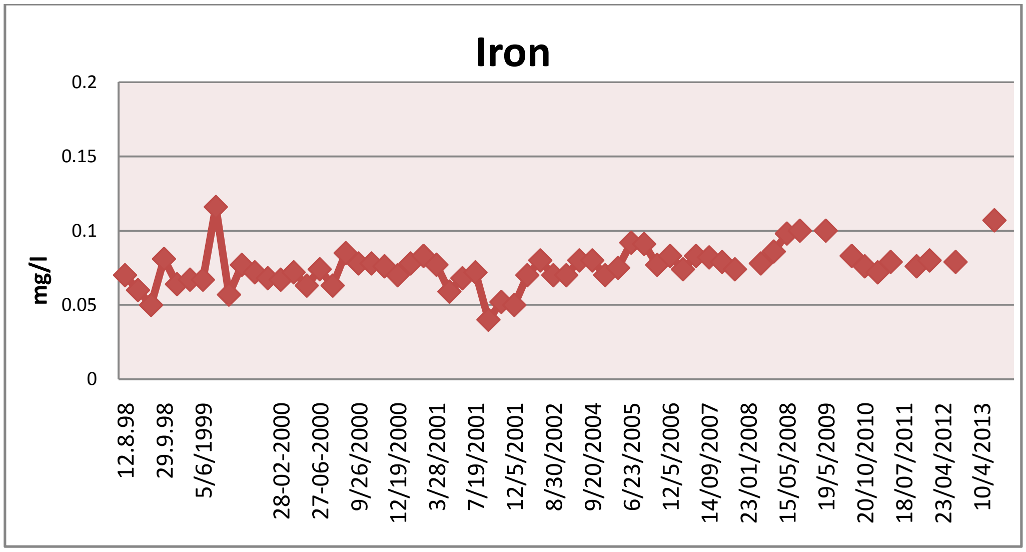

Figure 3.9: Iron concentration of well # 1 (1998-2013)

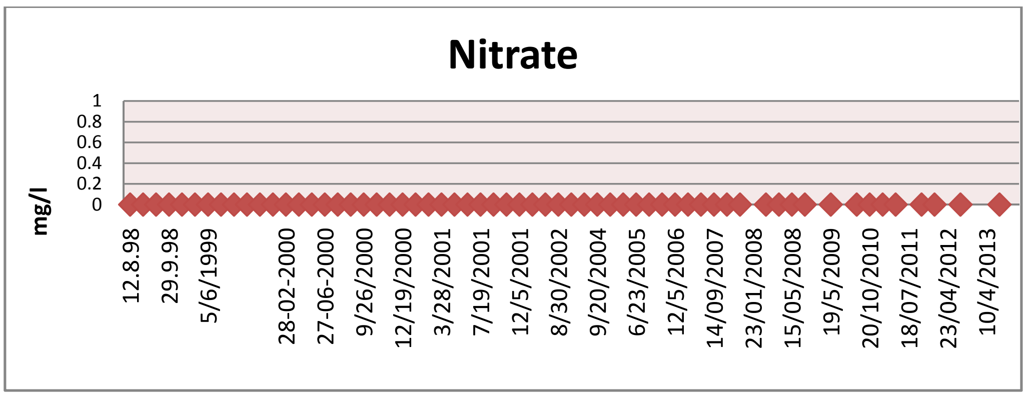

Figure 3.10: Nitrates concentration of well # 1 (1998-2013)

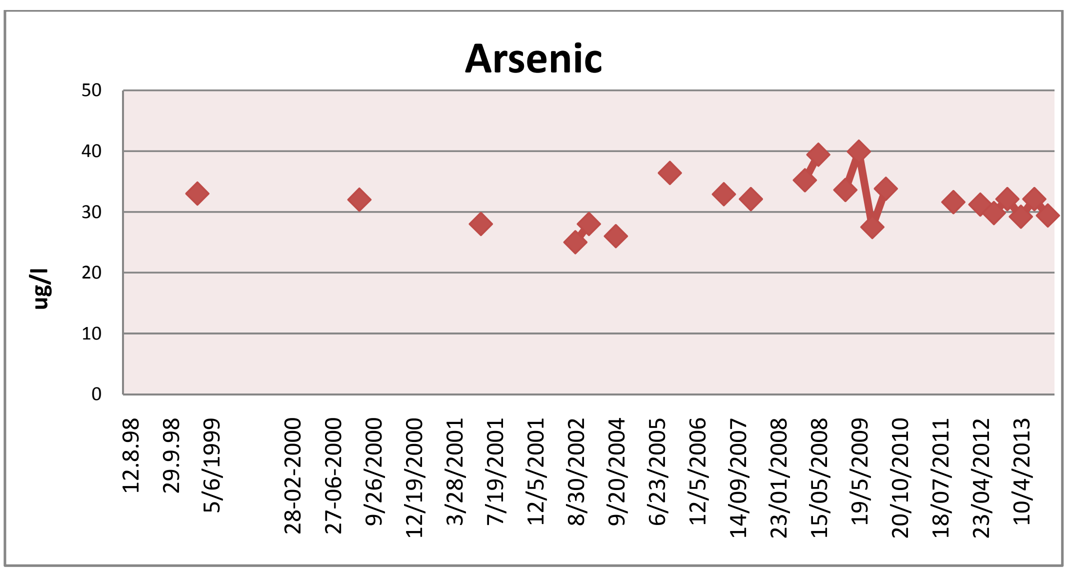

Figure 3.11: Arsenic concentration of well # 1 (1998-2013)

As part of the study, groundwater samples were collected during the field inventory of the study area. Ten samples from different locations in the study area were collected for detail chemical analysis. The chemical analysis of groundwater samples was carried out by the laboratory of Public Health Engineering Department, Punjab. Apart from these samples, Nestle collected and tested the canal water samples and hand pumps installed near the canal for Nitrates concentration and pesticides in canal water. The results are attached in Annexure-II. The summary of results of each sample is given in Table 3.5. Table 3.6 presents the nitrates contents in water collected from various sources around the project area. The detail of each results is attached as Annexure-II. The chemical analysis of the samples indicates that all the samples are within WHO permissible limits except sample number -25, which has higher Electrical Conductivity value.

The source aquifer is deep enough (more than 200m) and the wells are pumping from depths of about 90 to 125 m. Depth to watertable in the area is about 9 to 10 m. Thus, there is a buffer of about 80 m, above the tapped portion of the aquifer by the Nestle wells. Therefore, any pollutants joining the upper shallow layer of the aquifer do not reach the deeper portion of the aquifer contributing to the pumping wells. That is why pesticides and fertilizers being used by the farmers in the upper catchments and appearing in the river/canal water could not join the aquifer portion being tapped by the wells.

Table 3.5: Summary of Chemical Analysis of Water Samples

Sample No.	PH	odour	Color	Turbidity	TDS	Calcium	Mg	Hardness	Total Alkilinity	Sulphate	Chloride	Conductivity
				ppm silica units				mg/lit as CaCo3	mg/l as CaCo3			µS/cm
6	7.1	Odorless	Colorless	0.1 N.T.U	510	88	20	300	240	117	20	730
13	7	Odorless	Colorless	0.9 NTU	520	68	20	250	230	120	50	745
15	7.4	Odorless	Colorless	0.1 NTU	690	104	15	320	225	170	70	985
16	7.2	Odorless	Colorless	0.1 NTU	430	116	3	280	225	87	45	615
17 (ii)	7.2	Odorless	Colorless	0.9 NTU	670	72	10	220	290	155	45	955
17 (iv)	7.3	Odorless	Colorless	0.9 NTU	450	48	18	190	190	100	45	640
18	7	Odorless	Colorless	0.8 NTU	670	80	13	250	315	155	30	960
22	7.1	Odorless	Colorless	0.9 NTU	495	92	15	290	230	110	35	705
25	7.1	Odorless	Colorless	0.9NTU	1165	88	35	360	360	280	140	1665
25 (vi)	7.2	Odorless	Colorless	0.1 NTU	390	42	4	120	210	85	40	555
Nestle Well # 1	7.65	Odorless	Colorless	0.1 NTU	529	39	25.8			29	18.3	599

Table 3.6: Concentration of Nitrates in the canal water supplied in the area

Sample source	Quality Criteria	Method Reference	Result (mg/L)	Accreditation Status
Canal Water (UCC)	Nitrate	10.203-1	<0.10	N
Canal Water (UCC)	Nitrate	10.203-2	<0.10	N
Hand Pump # 1	Nitrate	10.203-3	<0.10	N
Hand Pump # 2	Nitrate	10.203-4	<0.10	N
Hand Pump # 3	Nitrate	10.203-5	<0.10	N

4. WATER SERVICES REGULATIONS

4.1 GENERAL

Surface water is available in throughout the Punjab plains in irrigation canals and the five major rivers. However, most people in Punjab use groundwater as a major source of domestic and industrial water consumption. In sweet water areas most households access shallow groundwater through shallow wells. Where village schemes exist, they obtain water from tubewells, which draw from deeper depths than individual household wells/hand pumps. In brackish groundwater areas, many villages located close to canals and rivers rely on seeped water taped by shallow tubewells installed purposely along the banks of these line sources of fresh water. Also the villages at far distance are provided this water by using transmission pipe lines e.g.in saline areas of Raiwind.

The Punjab's total population is 86 million out of which 27 million people are living in the cities. Groundwater is the main source of water supply which is rapidly depleting because of extensive water pumping in comparison to poor recharge. This is so because of lack of property rights over water usage and an absence of regulation to assign these rights. Prior to devolution by Musharf Regime, the Public Health Engineering Department (PHED) and the local government were responsible for implementing water supply and sanitation schemes. In 2001, the Punjab Local Government Ordinance (PLGO) assigned responsibility for water supply and sewerage services to Tehsil and Town Municpal Administrations (TMAs). PHED's role was initially restircted to monitoring and although more recently it has reclaimed most of its responsibilities for planning, design and implementation (Yusuf, 2010). Whereas in big cities like Rawalpindi, Lahore etc. the respective development authorities have Water and Saniation Agencies called WASA which has the reponsibility of providing clean drinking water and managing drainage of sewerage and rainfall runoff in the city. Most of the areas served by WASA have metered water supply charging for the services. But the mushrooming of private housing socities particulalry in periphry of the cities (supplying water at flat rates i.e. without metering) along with industrial activities has caused two fold stress on the underlying groundwater reservoir i.e.

- Increased groundwater pumping for domestic and industrial activities; and
- Decreased groundwater recharge due to ending canal irrigation of the fields one hand and rainfall recharge reduction particularly due to covering of the most of the area under buildings and roads on the other hand.

The tariff revenues of Water and Sanitation Agency (WASA) and Tehsil Municipal Authority (TMA) do not even cover current operating costs due to poor collection rates and low tariff levels. Service providers respond to financial shocks by reducing service quality (e.g. reducing hours of service to reduce electricity costs). Poor maintenance and poor operating efficiency leads to existing resources being poorly employed, thus contributing to the vicious circle of poor performance, poor service, poor collection rates, insufficient funding (GoP, 2007).

Although there does not exist any practice about the membership with agencies for the exploitation of groundwater that is why extraction of groundwater is increasing day by day, none of the government agencies operate in the area for regulation of groundwater exploitation. With existing setup of government departments, these kind of extra-ordinary efforts seem to be difficult to implement, unless the government, with the help of foreign assistance, takes some sound steps.

4.2 WATER LEGISLATION AND REGULATIONS

Groundwater in Pakistan is under increasing threat from over-exploitation, pollution and lack of proper management to match the demand and supply patterns of this natural resource base. Pakistan, still being a developing country and equipped with weakened water research, development and management institutions, is considerably lagging behind in converting the existing knowledge base into state of-the-art management policy. At present, no governance regime has been developed to control over-exploitation and ensure equitable use of the resources which is common property of all. Groundwater is now being over-exploited in many areas, and its quality is deteriorating due to lateral movement of brackish water to the sweet water aquifers with the threat of making existing sweet water aquifers unusable.

The particular single cause for increased use of groundwater is the increasing urban and rural population which is causing substantial pressure on surface and groundwater. The availability of surface water per capita is declining, and was projected to be less than 1,000 cubic meters (m^3) per capita per year by the year 2010 (Briscoe et al. 2005). Main features of the existing status regarding water use in Pakistan are as follows:

- No licensing system for water entitlements, other than the warabandi system, for the supply to agriculture irrigators is in place, whereby many irrigators have only recently discovered what their entitlements to canal water are following the transfer of irrigation management to Farmers Organizations and that too in a very few canal commands;
- Tails of distributaries and minors, in very few areas, have got permanently abandoned due to lack of interest in operation and maintenance of these channels.

As a result, farmers are totally dependent on groundwater for their livelihood in these areas.

- Farmers lying at the tail of the canal commands, are facing with depleting groundwater tables, forcing them to lower their pump sumps every four to five years or totally converting to turbine technology for long-term sustainability of the same as compared to centrifugal pumps.
- In the past, the cushion that groundwater provided during the drought (1999 to 2002) could not be replenished causing saline intrusion of the fresh groundwater resource due to unbalanced groundwater levels between saline and fresh areas.
- No groundwater management or regulation regime is in force.
- No provision exists for conjunctive use of water by Provincial Irrigation Departments for equitable water distribution to the farmers.
- No regulation of water consumed by cities or industries.

4.3 EXISTING LAWS AND POLICIES FOR MANAGEMENT OF POLLUTION:

There are Laws and Polices for management of pollution in Ordinance of Pakistan which are as follows:

- National Water Policy (Draft), National Environment Policy etc. frameworks for the provision of safe drinking water for all, along with hygienic sanitation for urban and rural populations.
- Pakistan Environmental Protection Act 1997. This Act mainly emphasizes, on Industrial and Municipal effluents disposal, which also specify National Environmental Quality Standards (NEQS) for such disposals.
- Canal and Drainage Act (1873) and the Punjab Minor Canals Act (1905), which prohibit the corrupting or fouling of canal water.
- Sindh Fisheries Ordinance (1980), which prohibits the discharge of untreated sewage and industrial waste into water.
- Under the ‘Lahore Water Supply Sewerage and Drainage Ordinance (1967)’, the government has launched a comprehensive nationwide clean drinking water program under two parallel phases, the ‘Clean Drinking Water Initiative’ (CDWI) and the ‘Clean Drinking Water for All (CDWA) which encompasses 6,579 water treatment plants throughout the country.
- The development of Meteorology, Standards Testing and Quality (MSTQ) infrastructure provides an essential component for industrial development in a country. Feeling this need, the Government of Pakistan established the Pakistan Standards and Quality Control Authority (PSQCA), through Act No. VI of 1996. The implementation of this Act has commenced on 1st December 2000.

- Punjab Local Government Ordinance, 2001 Provides environment control, sewage treatment plants, control over water resources and its regulation etc. but no enforcement by local government bodies so far.
- National Environment Policy 2005, whose one of the objectives is capacity building of government agencies and other stakeholders at all levels for better environmental management.
- The Mid-Term Development Framework (MTDF) (2005) has been prepared by the Federal Planning Commission with the long-term objective of attaining sustainable economic growth without environmental degradation.

The provisions of these laws to protect environment (in whatsoever manner) had been never implemented due to deficiencies in legalities, non-application of fines, lack of public and official ignorance of environmental issues, and also political influence etc. The sectoral legislations have totally failed to pay their even limited role in environmental protection.

5. CONCEPTUAL HYDROLOGIC MODEL AND GROUNDWATER BALANACE

A conceptual model of an aquifer system is a simplified, qualitative description of the physical system. A conceptual model normally includes a description of aquifers and any confining units that make up the aquifer system, boundary conditions, flow regimes, sources and sinks of water and general direction of groundwater flow. In the present report, The whole knowledge about the subsurface system gained from data interpretation has been coherently discussed into a perception about how the real system behaves. Many of the features relevant to the conceptual model regarding the study has been discussed earlier, therefore a brief description of each component is described below for complete understanding of geological characteristics, groundwater and surface water flow conditions in the area. Figure 5.1 shows the conceptual diagram of the groundwater water model.

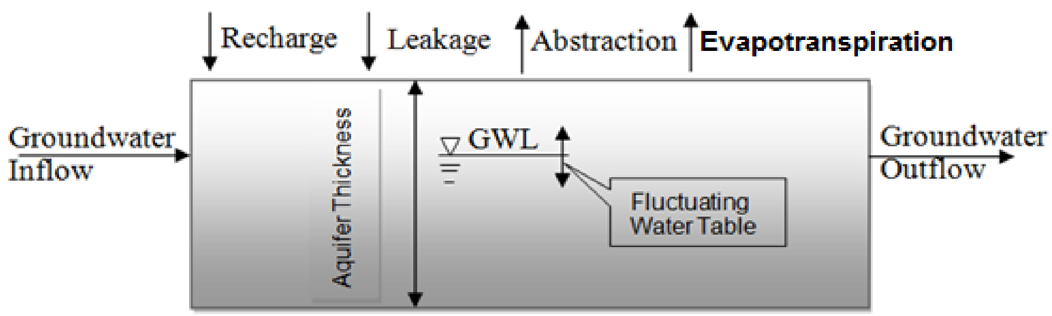

Figure 5.1: Conceptual diagram of the groundwater model

5.1 GROUNDWATER SOURCE FOR WATER SUPPLY

The Nestle Plant is 100% dependent on groundwater as its raw water source, municipal water supply has not been provided to the plant for any of the use, rather the plant has not to depend upon any of the such supplies in the presence of its own four number of tubewells supplying raw water of reasonably good quality. Further, all the other stakeholders are also using groundwater pumped from the underground reservoir which is being replenished by UCC canal (68 m wide canal) and its distribution system, and rainfall to varying extent at different places. Another major contribution to the aquifer is regional groundwater flow coming from north direction.

5.2 INCREASING GROUNDWATER DEMAND AND AQUIFER RESPONSE

Surface water allocation is only meant for agriculture from the UCC Canal, with a water allowance 2.73 /1000 acres (1649.81 $m^3/s/km^2$) for perennially irrigated areas and 2.93

cfs/1000 acres for non-perennial areas. There has been rapid increase in industry and population in the study area, particularly the population of the adjoining city of Sheikhupura has been rapidly increasing (@ 2.46 % per annum) due to industrial development in the surrounding area, particularly along the Sheikhupura-Lahore road. It is worthwhile to mention that industrial sector in Punjab has grown gradually from 6,223 industrial units in 1975 to 17,857 industrial undertakings in 2010. Out of this, Number of Industrial Units (Large Medium and Some Small) falling in Sheikhupura is 748 industry of different types, majority of which is large industry. According to the 'Three years rolling plan 2010-2013, District Sheikhupura'[2] total population of the district is 28,20,139 out of which 9,30,646 persons live with the urban area. And the annual growth rate of this population is about 2.46%. Estimations based on the field survey, indicate that about 800,000 inhabitants are residing both in urban and rural area, comprising the present study area.

The area of Sheikhupura District is 5600 square kilometers. 70.45 % of the total area is cultivated. The number of tubewells increased with every year passing. Number of tubewells estimated in Sheikhupura District by Pakistan Bereau of Statistics from 1994-2011 is given in **Figure 5.2**.

In the study area, 3910 agriculture tubewells are estimated. Tubewells in the area are of two types; Diesel and Electric. The electric motors capacity ranges from 5 HP to 10 HP. The discharges varied from 75 cubic meters per hour to 125 cubic meters per hour. Due to advancement in agriculture technology, the cropping intensity has increased to 180% in the project area, groundwater extraction is gradually increasing.

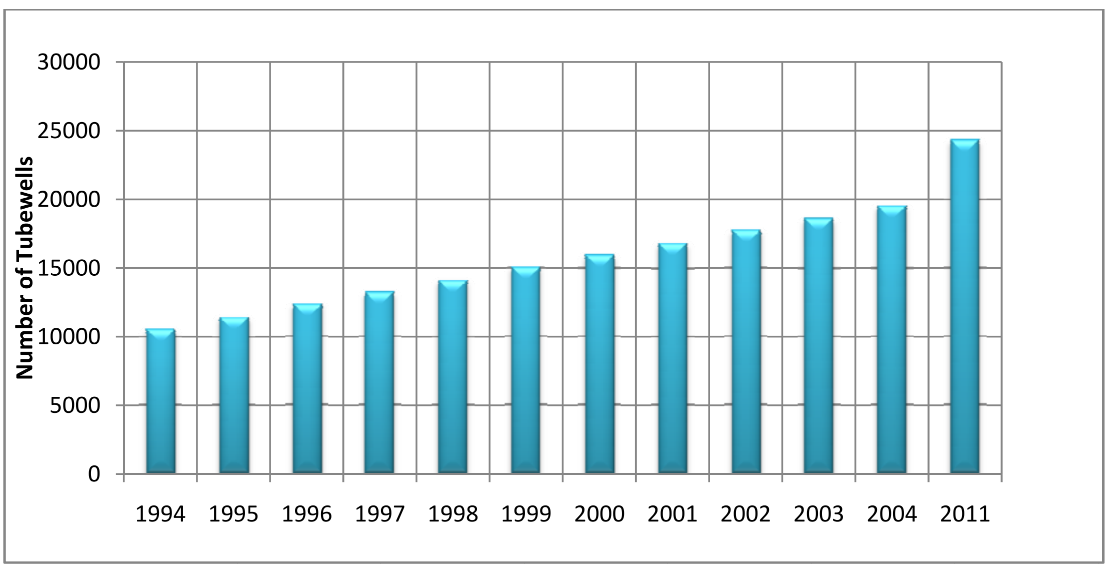

Figure 5.2: Growth of agricultural tubewells in District Sheikhupura 1994-2011

[2]https://www.google.com.pk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=5&cad=rja&uact=8&ved=0CD0QFjAE&url=http%3A%2F%2Fwww.phsrp.punjab.gov.pk%2Fdownloads%2F3yrp%2FSheikhupura.docx&ei=jA9tU4nABsaN0AW22IGgDQ&usg=AFQjCNGxgPKieT-vwDHaveuS3-h3eZe2mA&bvm=bv.66330100,d.d2k

Thus, due to both a general growth in population in Pakistan, and in addition the area having the status of industrial estate[3], due to the route link from Lahore to Western Punjab and KP province, there is little extra population growth rate. Thus, with this special pace of population and industrial growth, the demand on groundwater is increasing and thereby groundwater pumping is increasing with passage of time. Overall, there is groundwater depletion in the area with 0.035 m/year, the detailed depth to groundwater data, being observed by Directorate of Land Reclamation (DLR) of irrigation department is shown in Figure 5.3 and given in Table 5.1 Available depth to groundwater levels monitored in Nestle plant are also shown in Figure 5.3. In addition, latest available depth to groundwater data collected from Nestle observation well, for the period 2013-14, is also shown in Figure 5.4.

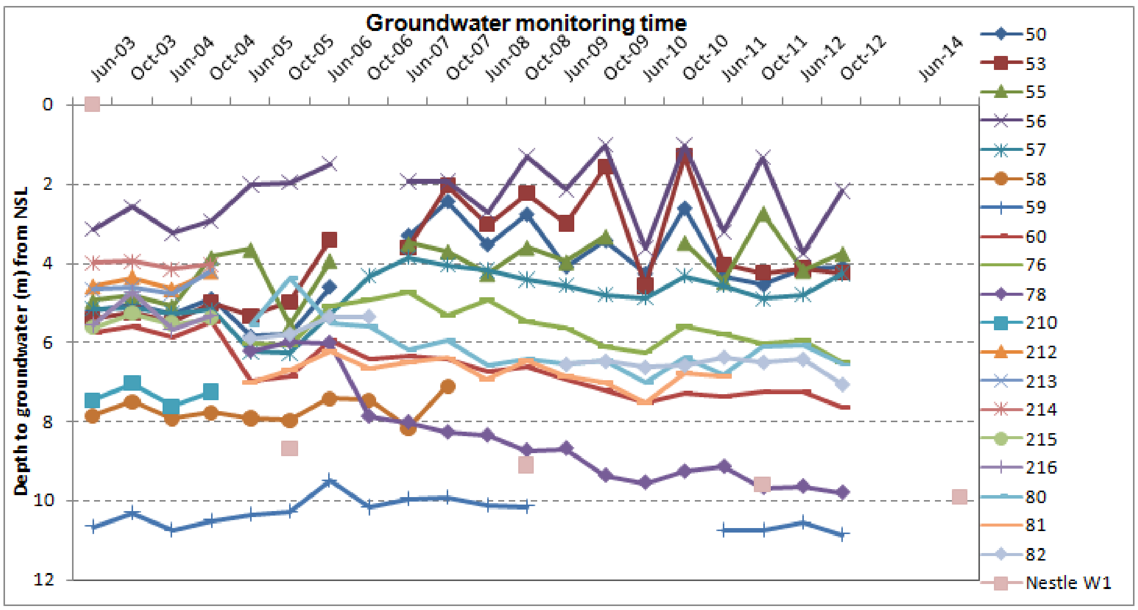

Figure 5.3: Depth to groundwater hydrographs for selected observation wells, within the study area and Nestle Well No. 1 (series Nos. represent the GIS reference for the wells as used by DLR and given in Table 5.1)

[3] Type of industries include: A.C/ Refrigerator/ Deep Freezers, Boiler, Carpets, Chemical, Chip / Straw Board, Cold Storage, Confectionery, Cutlery, Cycle Tyre /Tubes, Dairy Products, Drugs & Pharmaceutical, Embroidery, Essence, Fertilizer, Flour Mills, Fruit Juices, G.I./ M.S. Pipes, Glass & Glass Products, Hose Pipe, Iron & Steel Re-Rolling, Jute Textile, Knitted Textile, Leather Footwear, Leather Products, Match, Motor Cycle / Rickshaw, Paper & Paper Board, Pencil & Ball Point, Poly Propylene Bags, Polyester Yarn, Polythene Bags, Poultry Feed, Power Generation, Rice Mills, Soap & Detergents, Sodium Silicate, Solvent Oil Extraction, Sulphuric Acid, Surgical Instruments, Synthetic Resins, Tannery, Textile Processing, Textile Spinning, Textile Weaving, Tractor Parts, Tractors, Tyre & Tubes, Vegetable Ghee and Cooking Oil, Wire & Cables and Woollen Textile Spinning /Weaving.

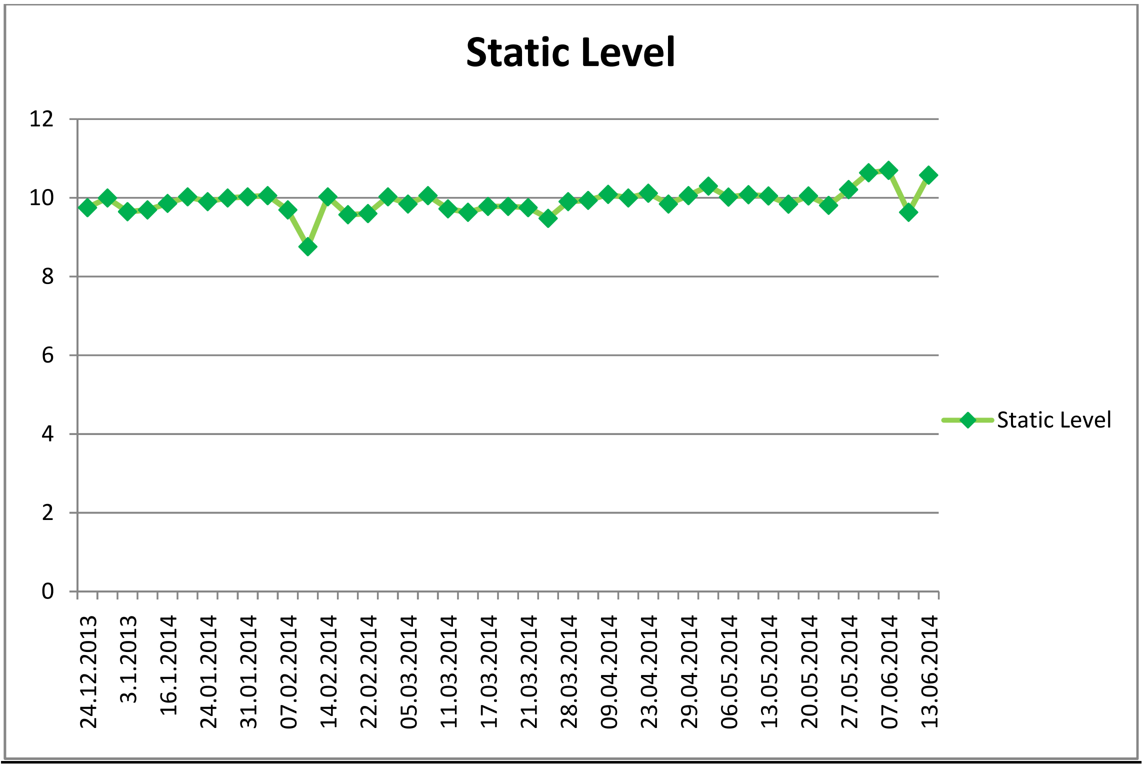

Figure 5.4: Static water table at Observation well, Nestle Sheikhupura

Table 5.1: Groundwater monitoring record of observation wells in and around the study area.

Channel	Location	GIS #	Jun 03	Oct 03	Jun 04	Oct 04	Jun 05	Oct 05	Jun 06	Oct 06	Jun 07	Oct 07	Jun 08	Oct 08	Jun 09	Oct 09	Jun 10	Oct 10	Jun 11	Oct 11	Jun 12	Oct 12
Sheikhupura Disty	Hardev, G.B.H. School Gujranwala road, Sheikhupura	50	5.19	5.05	5.28	4.90	5.84	5.82	4.60	2.62	3.30	2.44	3.53	2.77	4.09	3.43	4.27	2.62	4.34	4.55	4.14	4.09
Sheikhupura Disty	Qila Gian Singh, Gujranwala road, Sheikhupura.	53	5.41	5.26	5.49	5.00	5.34	4.98	3.40	1.78	3.61	2.03	3.02	2.23	3.00	1.57	4.57	1.30	4.04	4.24	4.14	4.24
Kala Shah Kaku Disty	Pindi Machhian Muridkey road, Sheikhupura	55	4.95	4.83	5.09	3.86	3.66	5.56	3.94	1.91	3.51	3.71	4.27	3.61	3.97	3.33	-	3.48	4.47	2.74	4.19	3.76
Murid ke Minor	Kotli Virk, Muridke Narowal road,Sheikhupura	56	3.15	2.59	3.25	2.95	2.03	1.98	1.50	0.79	1.96	1.96	2.72	1.32	2.16	1.04	3.63	1.04	3.22	1.35	3.76	2.18
Sheikhupura Disty	Kotla Panju Beg G.B.E. School, Faisalabad road, Sheikhupura.	57	5.16	5.13	5.28	5.19	6.25	6.28	5.31	4.32	3.86	4.04	4.19	4.42	4.57	4.80	4.88	4.32	4.57	4.90	4.80	4.27
Sheikhupura Disty	Ghang G.B.H. School, Farooqabad road, District Sheikhupura.	58	7.87	7.52	7.92	7.77	7.92	7.98	7.42	7.47	8.18	7.11	-	-	-	-	-	-	-	-	-	-
Sheikhupura Disty	Kharian wala, G.B.H School.Farooqabad road, District Sheikhupura.	59	10.67	10.31	10.77	10.52	10.36	10.29	9.50	10.18	9.95	9.93	10.13	10.16	-	-	-	-	10.77	10.74	10.56	10.87
Bahrian Wala Minor	Targay wali, Govt.Boys Middle School.Sharqpur road, Sheikhupura.	60	5.77	5.59	5.85	5.48	6.96	6.86	5.94	6.43	6.35	6.43	6.73	6.63	6.93	7.21	7.52	7.29	7.36	7.26	7.24	7.64
Jandiala Minor	Govt. Girls High School Waris Shah Road , Jandaila Sher Khan tehsil & District Sheikhupura.	76	-	-	-	-	6.04	6.07	5.11	4.93	4.75	5.33	4.93	5.49	5.66	6.12	6.25	5.61	5.79	6.04	5.97	6.50
Kala Shah Kaku Disty	Govt. Boys Primary School Bhattian wala, Mandiali Stop, Lahore Sheikhupura road	78	-	-	-	-	6.22	5.99	6.02	7.88	8.03	8.28	8.36	8.74	8.69	9.37	9.55	9.27	9.14	9.68	9.65	9.80
Marh Mr.	Marh - Mosque Well, Sharaq Pur, Sheikhpura Road, Distt. Sheikhpura.	210	7.47	7.06	7.62	7.26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sohal Dy.	RD 66 of Sohal Dy. MDK-377.	212	4.60	4.37	4.67	4.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Murid ke Dy.	RD-77 MDK Dy. Sheikuhpura.	213	4.67	4.62	4.78	4.19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Shahdara Dy.	RD-102 of old Shahdara Dy.MDK-446.Sheikuhpura.	214	4.01	3.96	4.17	4.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kalashahkaku Dy.	Ranipura - MDK-331, Ferozewala Sheikuhpura.	215	5.63	5.28	5.54	5.38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kalashahkaku Dy./Dargahi Mn.	RD-74 Dargahi Mn. MDK-294.Sheikuhpura.	216	5.56	4.72	5.69	5.33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chichoki Mallian Dy.	Boys High School, Sahoki Mallian, Sheikhupura.	80	-	-	-	-	5.54	4.37	5.51	5.59	6.20	5.94	6.58	6.40	6.53	6.45	7.01	6.38	6.81	6.10	6.05	6.55
Sikhanwala Minor	Govt. Boys High School, Sharakpur.	81	-	-	-	-	7.03	6.71	6.22	6.68	6.50	6.40	6.96	6.48	6.86	7.03	7.54	6.78	6.86	-	-	-
Murid ke Minor	Govt. Boys High School, Kot pindi Das, Sheikhupura.	82					5.89	5.79	5.35	5.35	-	-	-	-	6.55	6.48	6.63	6.58	6.38	6.50	6.43	7.06

5.3 INFLOW COMPONENTS

The main influencing components for groundwater conditions in the study area are the irrigation channels network and field application of available surface flows to the area. The second major factor is the rainfall contribution for both the crop water requirement and groundwater recharge.

5.3.1 Seepage from Irrigation Channels Network

Irrigation system in the area is present since the start of the last century, which had the major impact on groundwater profile of the region, resulting in maximum waterlogged condition till 1960s. First, with anti-water logging measures groundwater table was managed at optimum level below root zone and now, with increasing groundwater extraction, the groundwater table is about 3 to 9 m below the land surface.

The most prominent contribution to groundwater recharge is from the UCC canal having bed width of 68.3 m and total length of about 16 km in the area. The next contribution is from the canal water distribution system, having total length of about 118.4 km, up to the head of watercourse (called tertiary channels).

Various studies have been carried out for finding canal seepage and recharge to groundwater in IBIS, using inflow-outflow, ponding and other methods. But, there is no single answer or the reference which can be applicable to varying channel and groundwater conditions. After the analysis of the available canal seepage studies and data, PPSGDP (1998) adopted the canal seepage coefficients (cfs/msf) as given in Table 5.2, for the given range of discharges as initial estimates of recharge to groundwater for the purpose of groundwater modeling. It was specifically pointed out in the report that these seepage coefficients were revised downwards, keeping in view the accuracy problems of inflow-outflow methods. These canal seepage coefficients were used to find out the seepage rates contributing to the groundwater reservoir.

Table 5.2: Seepage Coefficients for Different Range of Canal Capacities

Discharge (cfs)		< 100	100 to 500	500 to 1000	> 1000
Seepage coefficient	cfs/msf	2.0	4.0	6.0	8.0
	m/day	0.053	0.105	0.158	0.211

Hydraulics and other features of irrigation network falling in the study area are given in Table 5.4. Using the seepage coefficients given in Table 8.1. and wetted perimeter calculated for each and every reach of these channels falling in the study area are also given in Table 5.2 and estimated seepage rates thereof in the study area. Total canal seepage rate of the irrigation channels in the area was calculated as 124.712 cusecs. With canal operation factor of 0.7176, adopted from Basharat (2013), for LBDC command (based on actual canal operations), the total seepage/recharge volume was calculated as 79.92 MCM/year.

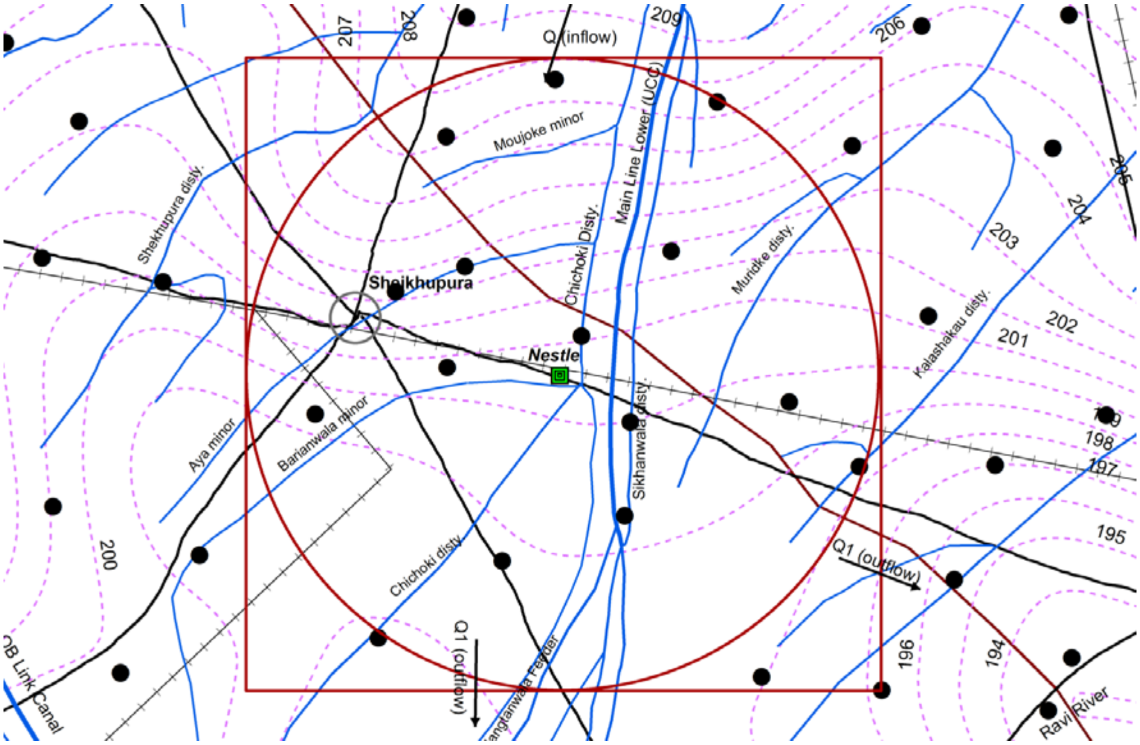

Figure 5.5: Irrigation Channel Network and Groundwater Elevation Contours (m) and monitoring points in and around the Study Area

Table 5.3: Depth to watertable (DTW) data (June 2012), used for preparation of groundwater elevation contour map in Figure 5.5.

WELL_No.	DTW (cm) (June 2012)	XXC (m)	YCC (m)	E (DMS)	N (DMS)	NSL (m)	Groundwater Elevation (m)
41/8	812	3299422	830625	735218	313619	207.547	199.427
41/9	1075	3302014	841891	735420	314220	211.100	200.350
41/11	653	3296206	849335	735055	314632	211.804	205.274
41/13	612	3296801	859103	735138	315148	214.300	208.180
42/6	283	3305097	824839	735541	313301	202.368	199.538
42/10	706	3300982	848643	735355	314601	210.029	202.969
43/4	513	3308579	824387	735752	313240	202.370	197.240
43/7	640	3312056	839926	740037	314058	205.661	199.261
44/5	695	3314491	835535	740200	313831	205.534	198.584
44/8	379	3312787	850290	740127	314633	211.550	207.760
44/10	482	3314695	860258	740301	315153	214.100	209.280
45/3	381	3320713	822608	740528	313120	201.850	198.040
45/4	454	3318563	827909	740418	313416	202.713	198.173
45/7	665	3317326	843152	740404	314233	207.870	201.220
45/8	483	3315970	849854	740327	314613	211.560	206.730

45/10	427	3320488	857815	740636	315023	215.100	210.830
46/9	419	3323887	860907	740852	315157	216.804	212.614
46/10	74	3321937	866464	740750	315501	217.466	216.726
47/4A	947	3326206	835342	740924	313803	207.100	197.630
47/6	577	3326611	849756	741011	314550	210.380	204.610
48/3	1016	3331287	839088	741245	313955	207.294	197.134
48/4	645	3333939	848242	741446	314447	211.000	204.550
48/5	607	3334037	853763	741502	314746	213.500	207.430
48/6	595	3330903	856045	741308	314906	213.073	207.123
48/7	676	3332853	861829	741435	315210	215.085	208.325
49/3	857	3332567	844248	741345	314240	211.300	202.730
49/4	617	3337223	847479	741649	314416	212.540	206.370
49/6	363	3336609	856996	741647	314926	214.369	210.739
50/1	946	3340451	839226	741833	313942	210.450	200.990
50/3	518	3341408	851949	741938	314633	213.594	208.414
50/5	508	3342457	863506	742044	315246	215.889	210.809
51/1	372	3346532	845074	742237	314240	213.262	209.542
51/2	480	3347300	848079	742313	314416	213.759	208.959
51/3	537	3345411	851047	742208	314556	214.792	209.422
51/4	556	3342563	855993	742031	314842	215.780	210.220
51/5	387	3346875	864818	742335	315320	218.429	214.559
51/6	211	3345393	868489	742247	315522	218.610	216.500
NP15	453	3324431	852403	740854	314720	213.000	208.470
NP16	409	3314631	853506	740244	314814	213.335	209.245
NP19	472	3312805	864834	740159	315425	214.983	210.263
NP46	594	3309350	852900	735922	314804	211.500	205.560
NP48	655	3307118	868765	735831	315643	217.618	211.068
NP49	795	3306767	858147	735755	315059	215.530	207.580
P3/10	681	3306704	852227	735740	314747	211.100	204.290
P3/21	716	3304329	866021	735639	315519	216.000	208.840
P3/24	503	3297516	836035	735117	313918	209.100	204.070

Table 5.4: Hydraulics and other Features of Irrigation Network and Estimated Seepage Rates thereof in the Study Area

Name	P / NP	From RD	To RD	Length (ft)	Discharge (cfs)	Bottom Width (ft)	FS depth (ft)	Wetted Perimeter (msf)	Seepage rate (cfs)
Upper Chenab Canal	P	230	283	53000	8145/2200	224	2.0	12.172	97.375
Chichoki Distributary	P	5.45	13	7550	251	34	3.5	0.331	1.326
		13	31	18000	228.5	32	3.4	0.749	2.996
		31	47	16000	178	28	3.1	0.588	2.353
		47	65	18000	51	14	2.2	0.364	0.728
		65	71	6000	38	12	2	0.106	0.212
		71	76	5000	31.5	10.5	1.9	0.079	0.159
		76	88	12000	25.5	9	1.8	0.169	0.338
Mahan Devi Minor	P	0	11	11000	30.25	10	2	0.172	0.344
		11	20	9000	24	9	2	0.132	0.264
		20	30	10000	21	8	1.9	0.134	0.267

Name	P / NP	From RD	To RD	Length (ft)	Discharge (cfs)	Bottom Width (ft)	FS depth (ft)	Wetted Perimeter (msf)	Seepage rate (cfs)
		30	36	6000	14.5	6.5	1.7	0.068	0.136
Barianwala minor	P	0	9	9000	74	15	2.7	0.204	0.407
		9	15	6000	68	15	2.6	0.134	0.268
		16	31	15000	62	15	2.5	0.331	0.662
		31	40	9000	55	14	2.45	0.188	0.377
Aya minor	P	0	14	14000	44	12	2.3	0.259	0.518
		14	23	9000	37	10	2.3	0.149	0.297
		23	33	10000	30	10	2.1	0.159	0.319
		33	42	9000	25	9	2	0.132	0.264
		43	50	7000	17	7	1.8	0.085	0.169
Maujoke minor	P	0	5	5000	18	8	1.8	0.065	0.131
		5	10	5000	14.5	7	1.7	0.059	0.236
		10	14	4000	11	5.5	1.6	0.040	0.160
		14	19	5000	8	5	1.4	0.045	0.179
		19	24	5000	4	3	1.2	0.032	0.128
Sheikhupura disty.	P	91	101	10000	98	20	2.8	0.279	1.117
		101	109	8000	87	19	2.7	0.213	0.852
Mangtanwala Feeder	P	0	19	19000	593	55	4.4	1.281	7.689
Sikhanwala Feeder	NP	10	20	10000	416	45	4.1	0.566	1.132
		20	32	12000	390	44	4	0.664	1.328
Sikhanwala Up Disty.	NP	0	8	8000	350	41	4	0.419	0.837
Joyanwala Disty	NP	13	19	6000	14	6.5	1.5	0.064	0.064
		19	22	3000	8	4.5	1.35	0.025	0.025
Qila Sattar shah Mr.	NP	0	2	2000	10	5	1.6	0.019	0.019
		2	5	3000	7	4	1.5	0.025	0.025
		5	6	1000	6	4	1.4	0.008	0.008
Muredke Disty	NP	181	190	9000	51	14	2.2	0.182	0.182
		190	203	13000	41	12	2.1	0.233	0.233
		203	215	12000	24	9	1.8	0.169	0.169
		215	224	9000	14	6.5	1.6	0.099	0.099
		224	227	3000	4	2	1.5	0.019	0.019
Kalashakaku Disty	NP	122	133	11000	23	6	1.7	0.119	0.119
		133	136	3000	23	6	1.6	0.032	0.032
		136	140	4000	9	4.5	1.6	0.036	0.036
Mandiali Mr	NP	0	3	3000	15.12	5	1.8	0.030	0.030
		3	5	2000	10.41	5	1.8	0.020	0.020
		5	12	7000	8.4	5	1.4	0.063	0.063

5.3.2 Seepage from Watercourses and Field Application Losses

Seepage losses from watercourses depend upon many factors, the most important of which include construction, maintenance and soil type. WAPDA (1980a) studied watercourse and field losses on selected watercourses. It was reported that 25 percent of irrigation water, which is supplied at watercourse head, is lost in seepage and 80 % of this reaches to groundwater. Actual volume of water delivered at watercourse head is never measured.

The recharge to groundwater from watercourses and filed irrigation application has been calculated based on water allowance in the area, which is 2.73 and 2.93 cfs/1000 acres (1649.8 and 1770.7 $m^3/sec/km^2$) for perennial and non-perennial areas, respectively (DLR, 2004). Based on the aforementioned water allowance and an adjustment with canal operation factor of 0.7176 (Basharat, 2012), volume diverted at watercourse head was calculated. For the water diverted to watercourse head, 25% were adopted as seepage losses within the watercourse (before entering farm gate) and 80% of this assumed as recharge to groundwater (WAPDA, 1980). Twenty five percent of the net canal water available at field level was as recharge to the groundwater (WMED, 1999).

5.3.3 Rainfall recharge

The quantity, temporal variability, and spatial distribution of precipitation recharge in the study area have not been defined in the past. Overall studies in the region indicate that the net effect of the precipitation is considerable both in meeting crop water requirement and groundwater recharge. The study area lies in a region of moderate rainfall. No rainfall recording station in the project area. The nearest recording station is Lahore. Average annual rainfall for nearest recording station is 630 mm (average taken from 1961-2010). Most of the monthly rainfall values are fraction of an inch and as such are inadequate to meet the evapo-transpiration needs of crops or contribute to the groundwater recharge. The component of recharge to the groundwater reservoir has been worked out on the basis of the mean monthly rainfall recorded at Lahore. The average rainfall of a given intensity has been worked out and the component of recharge has been estimated. It is assumed that for rainfall intensities of 5mm and less during a month, the recharge component will be practically negligible. Due to high temperature in June through August, which are the months of maximum rainfall there is considerable loss through evaporation. Kumar and Seethapthi (2002) calculated recharge from rain fall in Punjab plains 22% of the total effective rainfall, the same factor of 22% was adopted for calculation of rainfall recharge component to groundwater.

5.3.4 Regional inflow/outflow

Horizontal groundwater hydraulic gradients vary spatially across the study area (Figure 5.5) in response to local changes in hydraulic conductivity, aquifer thickness, and recharge. These watertable gradients/groundwater elevation contours were drawn in ArcMap using depth to watertable monitoring data of 52 observation wells (for 2012) in and near vicinity of the study area. At a regional scale, watertable gradients have remained relatively stable during the past about 50 years, except the changes brought about by local variation caused by disturbances/changes in groundwater pumping pattern and slight groundwater trend from the past about 20 years.

The distribution of groundwater fluxes within large deep hydro-geological basin is strongly influenced both by geology and topography and surface water flows. Groundwater elevation contours drawn for the study area (Figure 5.5) indicate regional groundwater flow entering aquifer cube under consideration from north and north-eastern direction. The most influential factor seems to be the UCC canal (having about 64 m bed width).

Lateral groundwater flow is going out of the area in two different directions. One is the usual downstream groundwater flow, owing to natural gradient in the north-east to south-west direction (Q1 outflow, Table 5.4) and the other is the flow towards a sink (Q 2 outflow), which has been created due to heavy groundwater pumping in Shahdara area, which actually is an immediate extension of Lahore on the right side of Ravi River.

Darcy's law: Q = KIA has been used to estimate regional groundwater entering and leaving the saturated aquifer volume under the study area as given in Table 5.5.

Where,

Q is discharge in cubic meters per second
A is area of segment in square meters
K is coefficient of Lateral Permeability in meter per day; and
i is groundwater hydraulic gradient;

A cubic volume, with dimensions of 20 km by 20 km on the land surface and 183 m equivalent saturated depth, representing the aquifer contributing face (see Figures 2.7, 2.8 and 2.9 for geologic sections) was taken as contributing to regional groundwater inflow and outflow.

Table 5.5: Regional groundwater flow calculations for the study area

In/out flow	Discharge (MCM/year) Q = KiA	Calculations / parameter values						
		K (m/day)	h1 (m)	h2 (m)	Δh	Distance, L (m)	Hydraulic gradient (i)	Area (m^2)
Q Inflow	54.599	81.6	209	207	2	2887	0.000693	2646180
Q 1 Outflow	26.718	81.6	199	197	2	8160	0.000245	3660000
Q 2 Out Flow	28.907	81.6	198	196	2	3771	0.000530	1830000

5.4 OUTFLOW COMPONENTS

The groundwater levels in the study area are well below the bed levels of natural and manmade drainage in the area. Therefore, groundwater outflow to the surface drainage system is not possible in the area. The most significant groundwater outflow component in and around the study area is pumped groundwater. The numbers of groundwater users are numerous. They can be categorised in to Industry, agriculture and domestic consumers. The agriculture and industrial users manage their pumping individually, whereas the domestic users are supplied from water supply wells run by the TMA. For agriculture use, three types of pumps are being used (Figure 5.6). The depth of these wells varies from 30 to 55 meters.

a) Peter Engine Operated tubewell
b) Electric Motor (5-10 HP)
c) Tractor Operated tubewells

The average agricultural discharges from each well is 100 m^3/hr. However, for Water Supply for Industries, 200 cubic meter per hour capacity were installed. The deep aquifer is tapped up to depth of 145 meters. The deepest running well in the study area is 172 meters at Sufi Soap Factory.

Figure 5.6: Agricultural Well (Centrifugal Pump) and Municipal Well (Turbine Pump)

Extensive field work was carried out in the study area. The field work was carried out in selected sample areas properly distributed within the 10 km radius from the Nestle Plant (315 km^2). The area was sub divided into 26 units called Inventory Points. The location and boundary of each Inventory Points is shown in Figure 5.7. The detailed inventory of each inventory point was carried out and information collected regarding groundwater extraction, quality of shallow and deep aquifer, coordinates, estimation of industrial, municipal and agricultural discharges and evaluation of potential contamination hazards was also carried out. The detail of each water point visited is attached in Annexure-IV.

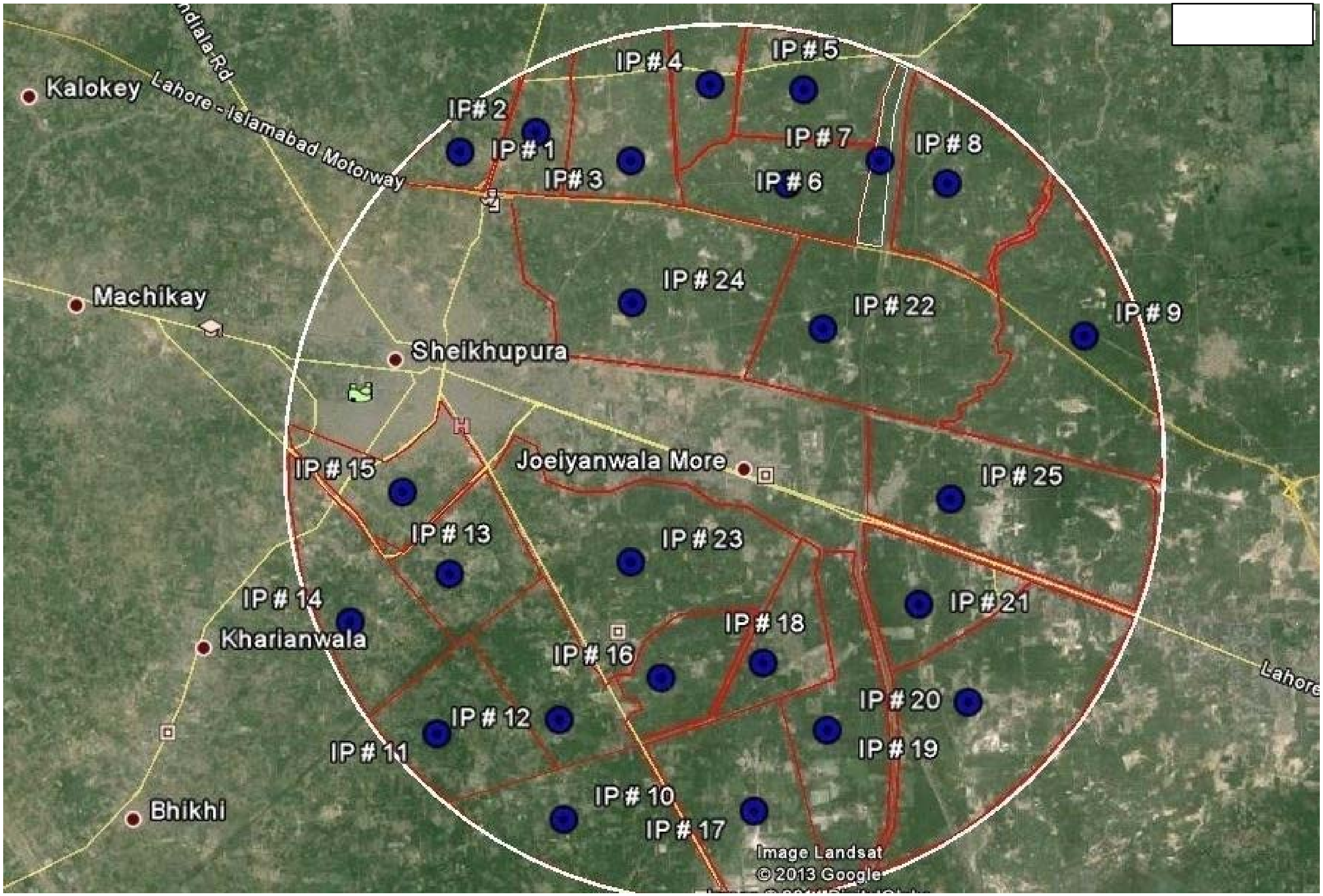

Figure 5.7: Inventory point used for detailed field survey in the study area.

5.4.1 Groundwater Pumping by Industry

Industrial Discharges are estimated separately for each industry in each inventory point by means of number and type of industry in a specific inventory point area. The access to the industrial water points was difficult, the information collected through indirect sources and previous estimations for the same type of industry. There are 107 number of factories in which 55 are major water users in the study area. The list of major water users of the study area is given in Annexure-V. The annual industrial discharges in the project area is 52 MCM/ year.

5.4.2 Groundwater pumping for agriculture

The number of agriculture tubewells in each inventory points was estimated and discharges were measured at wells which were available for the measurement. The running hours of agriculture tubewells was also enquired from the farmers. Three types of tubewells (peter pumps, electric motor and tractor operated) are installed in the agriculture area. The discharge of the tubewell was measured with an empirical formula developed by Dr. Ahmad, Nazir in “Groundwater Resources of Pakistan” , as given below

The relationship for discharge is:

$$Q = 1.015 * A * X$$

Where:

Q is discharge in US gallons per minute.

A is cross sectional area of discharge pipe in square inches.

X is the horizontal distance of trajectory in inches for a vertical drop “H” of 12 inches.

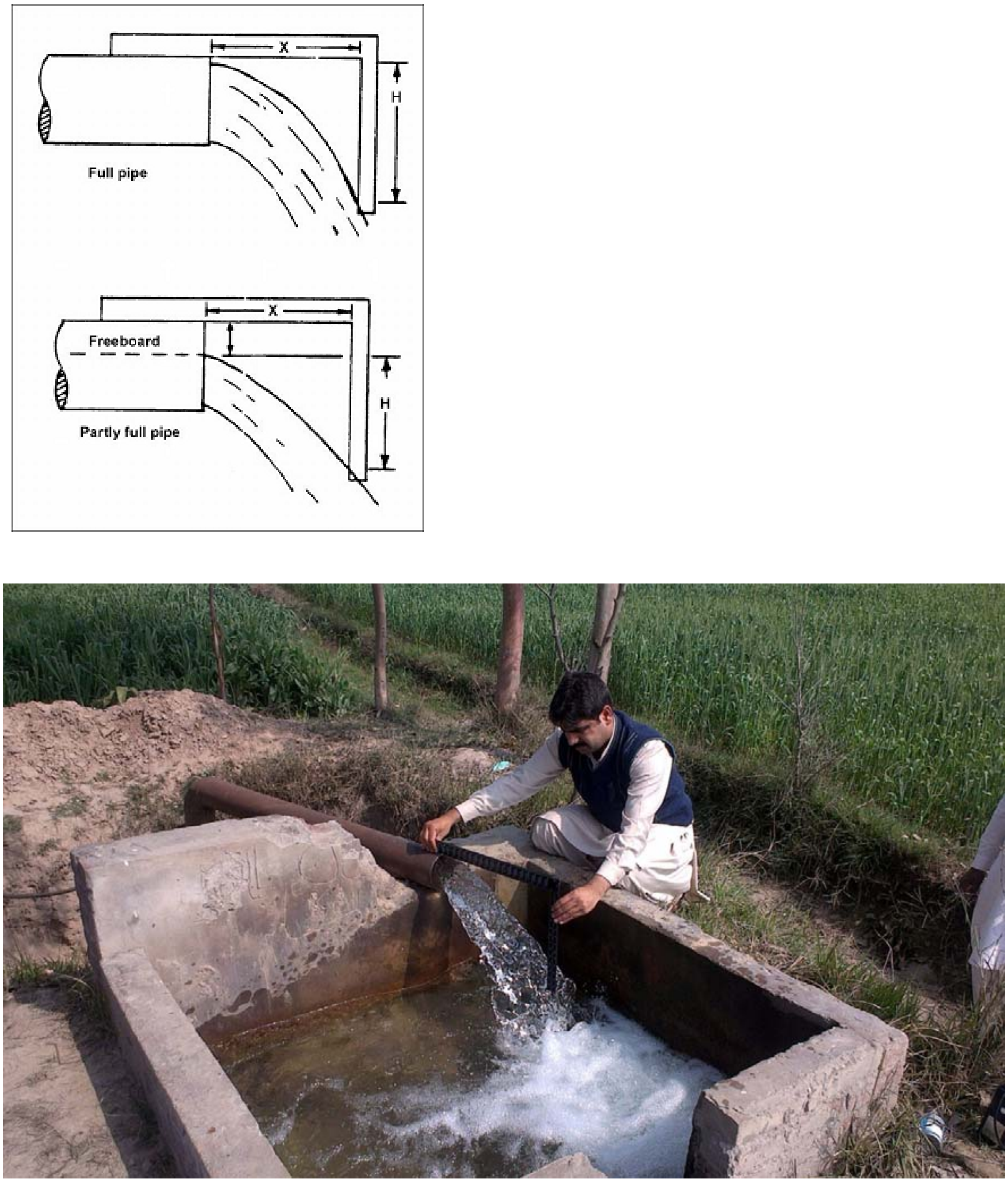

Figure 5.8: Measurement of Discharge by Coordinate method

The total number of tubewells in the project area was estimated about 3910. Which irrigate about 50% of the crop water requirement, as supplemental source for the canal irrigation system, which was designed for a cropping intensity of about 60% for the perennial area. The EC was checked by field Conductivity meter. The EC values vary from 600 to 2300 ΩS/cm, however, along the main UCC canal EC of all the samples was less than 1000 ΩS/cm. The discharges from tubewells vary from 75 to 125 cubic meter per hour.

Groundwater pumping estimation from filed survey for agriculture tubewells would not be prudent way for some dependable estimation, due to diverse land holdings under the command of each tubewell, cropping patterns and thus the pumping hours employed by the farmers for groundwater pumping could be a very crude estimation and so would be the discharge so estimated. Therefore, an alternate approach based on literature review was used as explained below.

Shakir et al. (2010) compared actual canal water supplies and crop water requirements for the UCC command area and indicated an annual shortage of more than 40%, which is met by groundwater pumping by the farmers. Basharat and Tariq (2012) carried out a detailed analysis for LBDC command regarding surface and groundwater balance in the command area of the canal. Accordingly, annual average deliveries of about 4,849 million cubic meters (MCM) were released to the LBDC command, against annual crop water requirement of 6,953 MCM. On an average, 48.75% of these canal releases were available for crop consumptive use, and 44.12% add to the groundwater via canal and watercourse seepage, and field application losses. Thus, net canal supply available to crops was 2,364 MCM (about 33.8% of crop consumptive use requirements). Against crop consumptive use requirement of 6,953 MCM, 2,364 MCM was provided from canal supply, 2,689 MCM from groundwater (68% as consumptive use, out of 3,954 MCM, groundwater pumping) and 1,406 MCM as effective rainfall. Thus, in LBDC command, share of canal and groundwater in meeting crop water requirement was 47 % and 53 % respectively. Due to more availability of annual rainfall in the study area, it is assumed that groundwater pumping is equivalent in meeting crop water requirements at field level. Therefore, groundwater pumping was estimated as 62 MCM per year, which is equivalent to the crop water requirement at filed level, being met by canal water supply.

5.4.3 Groundwater Pumping for Domestic Uses

Due to absence of any groundwater regulation in the area, groundwater abstractions from the aquifer are not measured at all by any authority. Municipal corporation and individual users pump groundwater according to their requirement. The major economic burden is in the form of electricity bills is the limiting factor to minimize pumping. The water supply is based on ground water and tubewells run by the TMA are 41 in number. The water supply network covers 33% of the town and serves 40% of the total population[4]. The remaining 60% population has own individual pumps.

An attempt was made to measure Municipal discharges, by estimation with number of houses in each Inventory Point in the project area. The average daily water consumption is

[1]http://www.urbanunit.gov.pk/PublicationDocs/Punjab%20city%20profiles/Sheikhupura%20City%20Profile.pdf

taken as 1557.5 liters per day per house. The whole study area has rural settlements except inventory point # 26 which comprise Sheikhupura city and Industrial area around Sheikhupura city. There was no water supply system developed in rural areas and villagers depend upon self employed groundwater extraction by means of hand pumps and injector pumps. However, in the Inventory point # 26, where water supply system is developed through 47 Government tubewells and 6 private tubewells. 34 number tubewells are operational out of 47 installed by Government. The discharge rate of each tubewell is 200 cubic meter per hour with 12 to 14 running hours per day. The detail of each water point visited and information collected is given in Annexure-IV.

However, for the Sheikhupura city, the groundwater discharge was estimated by using number of water supply tubewells (Government and private Housing societies) and their average running hours per day. The total Municipal Discharges was estimated as 45.183 MCM/ year. But this approach did not allow estimating the remaining 60% which do not have access to piped water supply. Therefore, an alternate approach based upon liters per capita per day (lpcd) based on the estimated population. Water consumption and total population was adopted. Upadhyay (2004) has quoted that the better-off residents of cities around the world typically consume around 200 liters per capita per day (lpcd). The total population (urban and rural) was estimated as about 800,000 in the study area (using 1998 census and normal growth rate). Using 220 lpcd (keeping an allowance for livestock consumption) as per capita consumption rate, the total annual pumping for domestic use was estimated as 67.89 MCM per year.

5.5 GROUNDWATER BALANCE OF THE STUDY AREA

Annual irrigation diversions to the area under study are 141.737 MCM. From these canal water supplies, the total annual recharge to groundwater is 54.923 MCM. Groundwater pumping for irrigation is 62.010 MCM (Table 5.6). Overall groundwater balance of the area is given in Table 5.7, accordingly there is shortfall of 6.259 MCM in the area on an annual basis. With an average specific yield of 0.3, it is equivalent to a decline of groundwater levels to the tune of 0.052 m. Also, six observation well have shown a rising trend in water level of the order of 0.093m/year, whereas other six observation wells have shown a groundwater declining trend of the of 0.164 m/year. The average overall decline in groundwater levels as observed in the field from these 12 observation wells for the period from June 2003 to October 2012 is 0.035 m/year.

Industrial and domestic wastewater return flows being discharged into the open surface drains could not be estimated, due to non-availability of design hydraulic data and normal flow depths in these drainage channels. If the seepage taking place through these channels is taken into account, the difference between groundwater decline with the groundwater balance (0.052m) and the actual observed groundwater decline rate (0.035 m/year) might fill the gap to certain extent.

Table 5.6: Recharge from canal water supply and groundwater pumping in the study area (MCM/year)

Annual irrigation diversion at W/C head	Recharge from W/C (@ 20% of delivered at head)	Recharge from field application (25% of the available at farm gate)	Total recharge from watercourse and field application	Available for CWR at fields	GW pumping (equivalent to CWR met by canal)
141.737	28.347	26.576	54.923	62.010	62.010

Table 5.7: Water balance of the study area (400 km^2)

Inflow Component	Inflows (MCM)	Outflow Component	Outflows (MCM)
Irrigation System Seepage	79.920	Groundwater pumping by Industry	52.0
Watercourse and Field application Losses	54.923	Groundwater pumping for agriculture	62.010
Rainfall recharge	41.888	Pumping for domestic uses	67.894
Regional inflow	54.599	Regional outflow	55.6253031
Total inflow	231.331	Total outflow	237.590

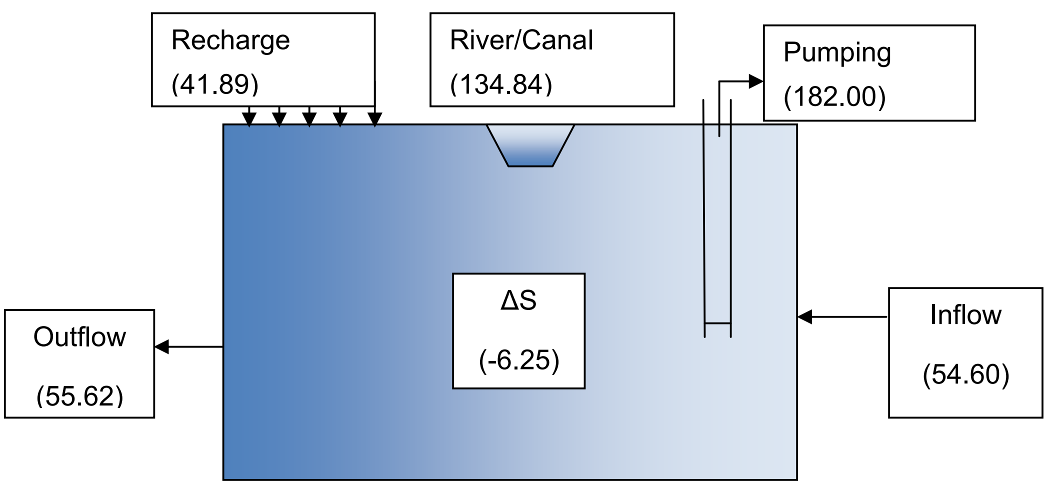

Figure 5.9: Conceptual Diagram of various Water Balance Components

6. CONCLUSIONS & RECOMMENDATIONS

Following are conclusions and recommendations as an outcome of the study:

- Both surface and groundwater are under increasing stress, both in terms of quantity and quality; However, the rate of groundwater depletion varies considerably across different areas;
- In the study area, groundwater is depleting at an average rate of 0.035 m/year, which does not depict any remarkable threat to groundwater sustainability in the area;
- This groundwater depletion can be attributed to reduction in canal supplies, caused by reduction in reservoir capacities, due to sedimentation of the reservoirs. However, the situation is expected to improve with the construction of new dams, e.g. Diamer-Bhasha dam is under initial stages of construction.
- Annual groundwater pumping by Nestle is about 1.04 % of the total groundwater being pumped in the area. And, the pumping by Nestle is 3.65 % of that being pumped by the industry as a whole;
- The Nestle plant is treating its waste water treatment plant, thus no major threat to the downstream community. However, there are several other industrial units, which dispose-off their effluent without any treatment, in to the nearby drains, are thus most probably, a potential threat to the shallow drinking water, being consumed by the residents, using hand pumps;
- The source aquifer is deep enough (more than 200m) and the wells are pumping from depths of about 90 to 125 m. There is a buffer of about 80 m, above the tapped portion of the aquifer by the Nestle wells. Therefore, any pollutants joining the upper shallow layer of the aquifer do not reach the deeper portion of the aquifer contributing to the pumping wells. That is why pesticides and fertilizers being used by the farmers in the upper catchments and appearing in the river/canal water could not join the aquifer portion being tapped by the wells.
- The major source of groundwater recharge is the irrigation system in the area. And amongst this irrigation system, the UCC canal, having the largest bed width is expected to be the major source of recharge to groundwater;
- Early warning analysis was carried out on upper Chenab canal water samples for pesticides and artificial sweeteners. The results attached in Annexure II, indicating the values are in nano gram/ liter. It is recommended to test the Nestle water for the

same on yearly basis. Also same analysis is recommended for the shallow groundwater points installed nearest to Nestle plant.

- The data of monitoring well installed at the Nestle Plant revealed that there is no influence of pumping wells on the groundwater level recorded at the monitoring well. The pumping well is at the minimum distance of 103 meters from the monitoring well, which did not show any response to the pumping well with respect to groundwater level fluctuation. This shows that the radius of influence of pumping well with discharge of 125 m^3/hr is less than 103 meters. There is no pumping well installed within a distance of 700 m from the boundary of the plant. Therefore, no question arises of inter influence of well of the plant with any of the wells within or outside of the plant.

- Regional groundwater flow is in general north-east to south-west direction, i.e. coinciding with the flows of river in the region. However, the local regional flow has been little distorted due to major sources and sinks in the area; i.e. inflow to the areas is mostly affected by the UCC canal. Also, the outflow is being influenced by a depression in south-east direction of the area. This depression has been created due to heavy groundwater pumping in Shahdara area, which is an immediate extension of Lahore on the right side of Ravi River.

- Upper Rechna is the largest fresh groundwater reservoir which extends from Sheikhupura, KhangahDogran to the border of Jammu and Kashmir;

- In Upper Rechna comparison of shallow and deep water quality indicates that at places, water quality at shallow depths is inferior to the quality of deep waters. This has been confirmed by vertical groundwater salinity profiles drawn from 1960s groundwater investigations. The samples were also analyzed for a number of Cations and Anions, the Nitrate (NO_3) concentration was found mostly as trace to 0.01 Meq/l and there was only one observation with NO_3 concentration as 0.17 Meq/l;

- In general, shallow groundwater quality has deteriorated with passage of time, due to pollution from the point and non-point sources at the surface. However, the groundwater lying deep in the aquifer is maintain its water quality; and

- Combined effect of these pollutants, which are directly affecting the groundwater reservoir must be checked with solute transport modeling technique. In depth analysis of these pollutants must be carried out to check the degradation of groundwater reservoir.

Natural streams or man-made surface drains are always considered as an easy way to dispose-off many kinds of waste water effluent. Sewage water from villages, urban area and industry is being discharged into these drains without any treatment. Waste water disposal ponds can also be observed surrounding almost every village. In this the waste water is causing swear hazardous problems to the nearby communities and also a major threat to the underground shallow aquifer storage. Community needs to be educated in this regard highlighting the possible impacts of the waste water disposal in the drains or evaporation ponds, so that the community can negotiate and convince the government for adopting measures to avoid such serious threats to the groundwater environment.

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