Nestle Kabirwala Factory

PROJECT REPORT

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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 Kabirwala Factory (6.5km Kabirwala Khanewal Road), South Pakistan

HESC

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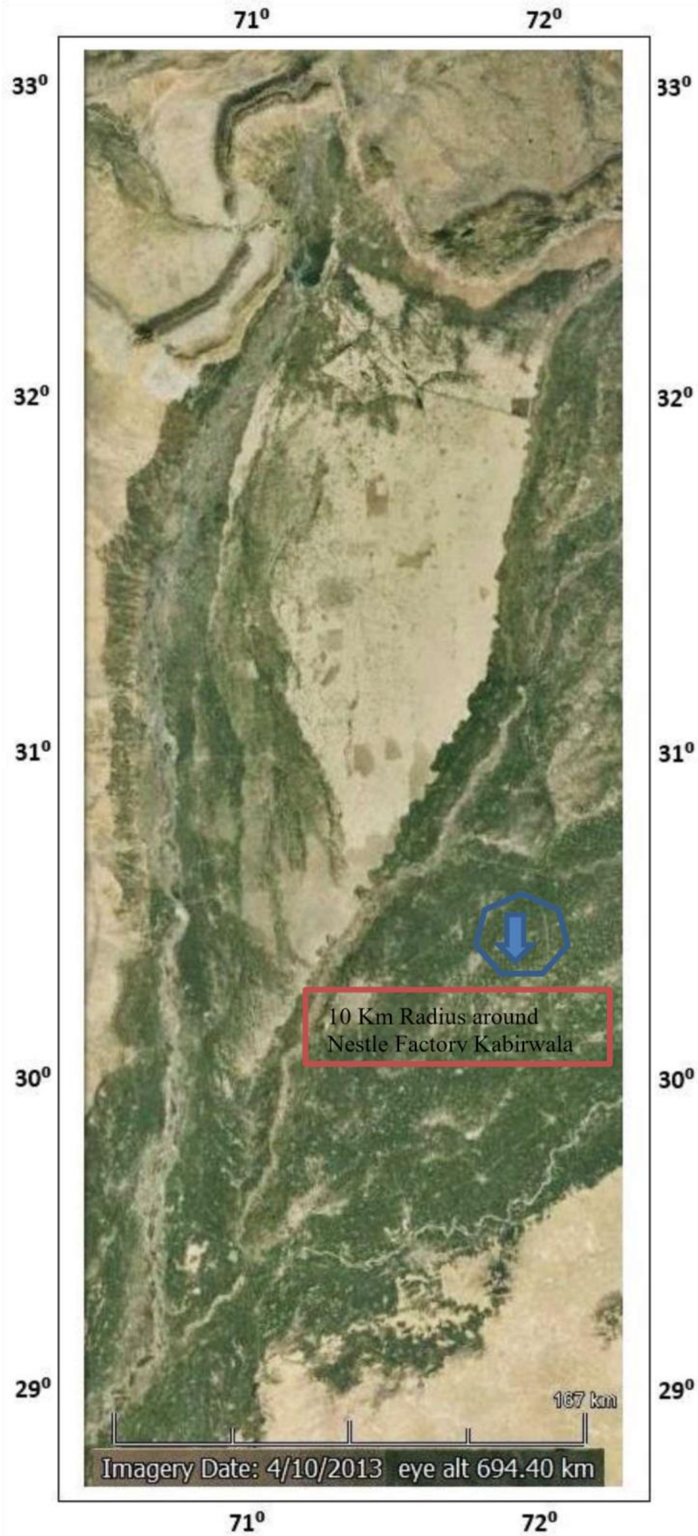
Contents



Satellite Imagery of the Bari Doab (Source: Google Earth, 2015)

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 Kabirwala Factory (6.5km Kabirwala Khanewal Road), South

Pakistan

1. Executive Summary

The present study entitled “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 Kabirwala Factory (6.5km Kabirwala Khanewal Road), South Pakistan”, covers a wide range of studies including hydrology and hydrogeology, temperature, rainfall, relative humidity, and spatial distribution of rainfall and temperature in Multan, Khanewal, TobaTek Singh, Jhang, Faisalabad, onsite data collection about fifty three (53) sites for water table, hydraulic heads, construction methodology, year of installation of wells, tentative well discharges and drawdown. Based on these information, contour maps of the water tables, hydraulic heads with vector lines (groundwater elevation map), and direction of groundwater flows 2015 are constructed by a best contouring routine SURFER Version 11. Numerical groundwater modeling study on a regional scale has also been carried out using 3-D Numerical groundwater flow and transport model (Visual ModFlow Software 2013) to develop steady-state and transient (non-steady state) flow models of the historic past in 1962 and most recent version in 2015. Directions of flows are in the southwest and southeast directions on the regional trend. Particle tracking (Contaminants) are also added as a point source and their direction of dispersion have been simulated with MODPath transport utility of the Visual Modflow, which tend to move towards the Ravi River, and in the middle of the area southwest of the Nestle Kabirwala Factory. Different Scenarios of dispersion paths are simulated shown in figures 33, 34, and 35.

Electrical Resistivity Sounding Survey (ERSS) is carried out within the Nestle Factory Kabirwala over seventeen (17) different locations to study the subsurface lithology and potential of underlying groundwater aquifer regimes. Mostly the aquifers are unconfined in nature and they represent large quantity of groundwater with negligible drawdown of about 2~4 meters in response to pumping of 0.5 to 0.75 cusecs. Suitable probes recommended for future drilling for tube-wells (if needed) are provided in Table 6. The locations of ERSS sites are provided in the accompanied figure 36.

Table 6. Recommendations of ERSS Points for future drilling

Nestle Factory Kabirwala	RECOMMENDATION DEPTH
ERSS-1, ERSS-8	Water Well of 390 feet depth
ERS-2, ERSS-4, ERSS-10, ERSS-15	Water Well of 370 feet depth
ERSS-5	Water Well of 380 feet depth
ERSS-13	Water Well of 365 feet depth

At present KBF has two tube wells fully functional for providing raw water for processing in the factory located about 7 Km northwest of Khanewal & 3 km south of Kabirwala in the canal command area.

To study the distribution of chemical concentrations in and around the Nestle Kabirwala Factory, five (5) samples each of different quantities were collected to determine the trace elements, Volatile organic compounds (VOCs), THMs, Pesticides, and radioactivity. The samples are taken from the existing water wells that are located in the Google Map (Figure 52) and also listed in Table 7 with reference to their latitude and longitude.

Table 7. Locations of water sample collection sites for Chemical Analyses

Locations of Water Samples Collection Sites		
Latitude (degree-min-sec)	Longitude(degree-min-sec)	Remarks
1) 30-18-12 N	71-55-26 E	TMA Khanewal Well 1, 350 feet deep, year of installation 1987
2) 30-22-22 N	71-52-99 E	Nestle Well 2 (in actual well 1) 350 feet deep, year of installation 1989
3) 30-22-24 N	71-52-56 E	Nestle Well 3 (in actual well 2) 350 feet deep
4) 30-24-29 N	71-52-06 E	TMA Kabirwala Well 4, 450 feet deep, year of installation 1998
5) 30-23-07 N	71-52-16 E	Kabirwala Agricultural Well 5 200 feet deep

The results of the trace elements, Volatile organic compounds (VOCs), THMs, Pesticides, and radioactivity fall within the permissible limits for the Nestle Water Wells 1 and 2, but for the TMA Khanewal well results of total dissolved solids (TDS), total hardness, Nitrate are relatively high.

2. Scope of Water Resources Study (WRS)

1. Scope of Water Resources Study (WRS) refers to the evaluation and the exploitation of levels of the local water bodies within a radius of 10 km (315 square kilometers area) in and around Nestle Kabirwala Factory (6.5km Kabirwala Khanewal Road). This study will base on both the qualitative and quantitative evaluation of figures of industries, municipalities, domestic and agriculture users of water in the context of surface water and ground water. Data acquisition with seasonal variations may be

collected at places when and where it seems feasible. Water wells inventory tapping alluvial aquifers of Nestlé facilities' production wells, monitoring wells, other wells that do not belong to Nestlé and are 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. Recharging to study area with respect to the overall water sustainability analysis should be evaluated based on recharge and discharge. Study should be extended to the entire recharge basin of the aquifer system (generally are of same origin and types) in the study area. Source of recharge and its potential contribution by each source should be examined in the study area.

3. A conceptual groundwater flow model should be developed with the support of existing and recently collected data. Water balance components should also be identified that means input and output discrepancies.

4. Amount of abstraction as per official legislation, from the surface and groundwater shall be part of the key information.

5. Precipitation, Maximum / Minimum temperature/flood level and runoff/drought evolution over the last 10 years (monthly data for 10km radius)

6. Topographic map 1:25,000 of the study area be included
7. Geological information should be included as:
   a. Type of each aquifer layer (Electrical Resistivity Data may be used),
   b. Shallow lithology,
   c. Intrinsic and hydrogeological properties (porosity, permeability, and hydraulic conductivity).
   d. A geological map of 1:50,000 should be included.

8. Existing groundwater system should be discussed with respect to the following:

a. Lithology: literature review, information from drillings, geophysical investigation,
b. Aquifer's types: unconfined, confined, Leaky, semi unconfined…
c. Hydrologic characteristics: porosity, transmissivity, storativity, and hydraulic conductivity from in-situ techniques by pumping test analysis
d. delineation of the recharge area with graphical representations containing equipotential maps,
e. direction of groundwater inflow,
f. natural environmental protection level of the aquifers,
g. quantitative aspects: a water balance between the input and output components ,withdrawal per year per aquifer, total recharge volume per year per aquifer,

9. Water levels data should be collected and constructed 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. Five samplings 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. Utilization of water by each stakeholder from shallow or deep wells might have a serious impact to downstream (river/stream/pound/wet zones) that is recharged by these groundwater sources. Any impact by Nestlé's abstraction. Such impacts/risks (if any) should be assessed with reference to natural ecosystems, biodiversity, other water uses.
b. Examination and validating upstream / downstream analysis with respect to the abstraction by Nestle in order to assess what real impact might derive from the water use by the manufacturing facility and also from other local stakeholders.

11. Long-term components evaluation of surface water, ground water and hydrogeology in the study area and surrounding areas. (national and regional levels)

12. References as quoted in this report should also be given as annexure of in the list of references

13. Conclusions should comprise of

   a. a brief summary on the surface and groundwater characteristics of area
   b. description of the sustainability level of water resources used by the Nestle and recommendations on how to address potential risks (including reduction in water supply for water conservation, and avoiding potential threats to the existing source
   c. The study must be written in English and should be available in soft and hard copies.

3. INTRODUCTION

Reliable data collection, procurement from industries and its proper utilization is the backbone of producing accurate and valid hydrogeological information, groundwater elevation maps and profiles, hydraulic characteristics (Transmissivity T and Storativity S), and hydraulic conductivity K to be used for locating a new source site for water supply, annual replenishment of aquifers, and depletion in levels. Such information will lead towards identifying successful hydrological priorities for Nestle Kabirwala Factory as that it can be operated with more environmentally safe yield limits. While searching through the literature, books, reports and periodicals, only old data relating to water-table, elevation, latitude and longitude, groundwater quality, and aquifer type (confined or unconfined) and their thickness, fresh-brackish interface could be found (which in some cases is more than 2 decades old), but still valid with the addition of some new information for studying the hydrological changes in the study area i.e. within 10 Km radius around Nestle Factory Kabirwala.

4. HYDROGEOLOGICAL DATA BASE

Hydrogeological database has been established over 50 sites within 10 Km radius of the Nestle Factory Kabirwala to study the variations in water table depths, hydraulic heads, and direction of groundwater flow. To maintain safety check of the following parameters for the successful operation of water supply in and around the Nestle Kabirwala Factory, database has been formed.

i) Existing water level position in September 2015
ii) Fresh-brackish interface, if any iii) Hydraulic heads in September 2015 iv) Effects of pumping on hydraulic heads
v) Numerical Groundwater modeling in regional area around Nestle Factory using

Visual Groundwater Flow Model vi) Water Balance Study as a part of modeling output scenario

vii) Water quality & quantity viii) Direction of Groundwater flow

IX) Trace elements, VOCs, THMs, pesticides, radioactivity

X) Electrical Resistivity Sounding Survey (ERSS) within the Nestle Factory Kabirwala

Most of the database is provided in the Excel spreadsheet in different columns for achieving information and some of it in the Appendix. Most of the data is collected in the field within 10 km radius around Nestle Factory Kabirwala as a part of the hydrogeological investigation. The database is comprised of recent information about the hydraulic parameters that is to be used for hydrogeological assessment with the simple manipulation of existing data. It is planned to retrieve sites by their latitudes and longitudes in future to view their parameters and make further changes, if any, and assessment for other sites that may exist in the nearby vicinity.

4.1 Existing wells and their appropriate utilization for water table observations

i) Existing shallow wells and private wells were used as ready-made sites for water table observations. Before such wells are included in the list of observation points, information on their depth, diameter, construction, penetrated layers and frequency of use is collected to ensure that the water levels measured in the wells indeed represent the water table. About 53 water wells have been studied that were constructed from 1967 to 2011 but most of them had been constructed from 1995 to 2011. Details of these wells are provided in Table 1.

ii) Finite diameter wells (15 to 20 feet dia) are usually large and the well has a large storage capacity. Such wells take considerable time for the water level in the well to adjust to changes in the water table (seasonal or artificial recharge), or to recover when a slug of large quantity of water is removed from storage. Clogging of the well screen and a low permeability of the water transmission layers are causes of erroneous data collection from such wells.

iii) The location of existing wells may not always fit satisfactorily into an appropriate network. The wells may be sited on topographical highs and their water levels may be deeper.

Such wells may fall dry in the dry season and readings of the levels cannot be taken during a full hydrological year. Therefore, the depth of observation wells should be based on the expected lowest groundwater level Well Elevations (EMSL)

To correlate the water table levels with the land surface level and to compile water table contour maps, a leveling survey needs to be carried out to determine the elevation of the observations wells and piezometers. However, Global Positioning system is used to cater for the ground level with respect to the mean sea level. Water levels in the wells are measured from a fixed measured point which, for cased wells, was the rim of the casing. For uncased wells, a measuring point was used a piece of steel, wood or pointed stone. The survey is made to determine the elevation of both the measuring point and the ground surface at the location of each well or piezometer.

4.2 Global Positioning System (GPS 2000 X L)

With the advent of recent advanced technology, latitude, longitude and approximate ground elevation of a specific point is determined by GPS 2000 XL. Global Positioning System (GPS) has the capability to orient its position after locating at least 2 satellites moving around the orbit of Earth. The Department of Defense (DOD) USA has launched about 24 satellites revolving around the orbit of earth 24 hours a day. To initialize the GPS, reference co-ordinates, time, date and rough elevation are to be entered as input data and then navigate punch key is pressed. It takes 3 to 5 minutes in searching for the satellites and once the satellites are sited, values of latitude and longitude will be locked up. At least 3 satellites need to be sited for acquiring information on the ground level elevations.

4.3 Electrical conductivity/TDS Measurement

Electrical conductivity (EC) measurement is the on-site test of water quality of the established source, which only provides the concentration of salt in water as a part per million (PPM) or milligram / liters. Representative water samples are also collected for laboratory analyses that include trace elements, VoCs, radioactivitiy, THMS, and Pesticides. Chemical analysis will not only help in finding potable water for consumption by either humans or livestock, but are helpful in preparing well and pump designs and specifications for permanent facilities where corrosive or encrusting waters are known to be or suspected of being present. From the EC values, total dissolved solids (TDS) can also be computed by the following relationship:

TDS = EC x A

A varies between 0.55 and 0.75 for most ground waters. An average value of 0.641 can be used. Analyses of five (5) water samples also include TDS as a part of trace element study.

5. HYDROGEOLOGICAL MAPS FOR NEW SITES

Hydrogeological maps are a true representation of the groundwater elevation in X and Y directions and are constructed by joining equal values of the groundwater elevation over the entire district. Initially, depth-to-water-table is measured below land surface in the preselected observation or open wells. Water table measurements can be taken in a number of ways:

i) Wetted tape method ii) Mechanical sounding device
iii) Electric water level indicator
iv) Floating level indicator

An electric water level indicator is used to measure the levels in 53 wells that are shown below in the snaps of different sites.

5.1 Processing of Groundwater Data

The raw groundwater data including water levels must be processed with known geological and hydrological information, canal periodic discharge rates, daily pumpage rates, and amount of recharge from canal seepage or from annual precipitation.

Processing of groundwater data comprises:

- Construction of water table maps
- Construction hydraulic head (elevation) maps
- Construction of hydraulic heads with vector lines showing direction of groundwater flow

6. Map Construction Procedure

The water level data from all the 53 wells or open wells for a certain date is converted to water levels below land surface (the reference point from which the readings were taken needs not necessarily to be the land surface). The transformed data is subtracted from the land surface elevation of all the wells which generally refers to elevation above mean sea level (EMSL). The resulting data will now represent the groundwater elevation and will have no significant influence of the surface topographic ups and downs. The data points thus evaluated are plotted on the digitized topographical base map at observation points and lines of equal elevations are drawn by joining the equal values. A suitable contour interval is selected on the basis of changes in groundwater elevation per kilometer.

Surfer 11 software and surface mapping system are used to construct the hydrogeological water table and groundwater elevation (hydraulic head) maps. Data points entered as inputs are simply he X and Y co-ordinates and groundwater elevations. From the data points provided, more data points are interpolated by the Surfer 11software using a recognized gridding method. This version comprises 7 gridding methods namely: i) inverse distance ii) krigging, iii) minimum curvature, iv) polynomial regression, v) radial basis functions, vi) Shepherd's method, vii) triangular with lines interpolation.

Any one of the methods can be used by the user. A grid file is created with an extension containing a large number of interpolated data points and the original data points. This grid file is then further utilized to construct the groundwater elevation maps with a suitable contour interval.

A hydrogeological map of Nestle Kabirwal Factory is shown below in Figure 1 indicating water table range of 9 to 19 meters. The water table decreases towards northeast and southeast. Some of the snaps taken of Sindhnai canal, Kabirwala minor, and TMA office and other related sites are shown in the Figures 2 through 7.

7. Table 1. New Main Data File Within 30 Km radius KBF Project

Sr No.	Owner Name	Year Installed	Coordinates		Elevation	DTW/GL	Drilled Well	Total Depth	Delivery Pipeline	Discharge	Use /Punp
			Latitude	Longitude	(meter)	(feet)	(feet)	(feet)	(in)	(cfs)	
1	Mr Hassan	2011	30 26 39	71 53 19	127	50	150	200	5	1	AGR/EM
2	Rana Farvat	1990	30 27 10	71 52 40	124	50	150	200	6	1.5	AGR/EM
3	Rana Zafar	2006	30 26 55	71 52 56	120	55	160	215	5	1	AGR/EM
4	Malik Ayaz	2011	30 25 39	71 25 39	125	50	120	170	5	1	AGR/TR
5	TMA Kabirwala	1998	30 24 29	71 52 06	125	0	450	450	2.5	0.5	Drinking/EM
6	TMA Khanewal-1	1987	30 18 12	71 55 26	130	0	350	350	6	0.5	Drinking/EM
7	TMA Khanewal-2	2012	30 18 12	71 55 24	126	0	305	305	8	2	Drinking/EM
8	Housing Society	2012	30 18 12	71 56 53	131	0	460	460	6	1	Drinking/EM
9	Asad Khan	1975	30 19 03	71 55 46	127	50	150	200	5	1	AGR/EM

10	Ch Aslim	2005	30 19 20	71 55 03	124	50	150	200	5	1	AGR/EM
11	Muhammad Seger	2005	30 23 07	71 52 16	137	50	120	170	5	1	AGR/EM
12	Ch Zafar	2009	30 22 45	71 52 08	133	50	120	170	5	1	AGR/EM
13	Amjad	2004	30 22 28	71 52 11	139	60	120	180	5	1	AGR/EM
14	Sabir Hussan	2015	30 22 27	71 51 53	132	50	120	170	5	1	AGR/EM
15	Ch Manzor	2014	30 22 18	71 51 45	130	50	120	170	5	1	AGR/EM
16	Muhammad Yousaf	2013	30 21 53	71 51 28	130	40	175	215	5	1	AGR/TR
17	Hyat	2011	30 21 30	71 51 35	131	60	120	180	5	1	AGR/EM
18	Alfat Khan	2007	30 24 51	71 53 29	131	50	130	180	5	1	AGR/TR
19	Rana Zafar Iqbal	2002	30 24 57	71 53 27	127	50	130	180	5	1	AGR/TR
20	Ch M. Iqbal	2000	30 24 53	71 53 39	134	55	130	185	5	1	AGR/EM
21	Haji Khalid	2005	30 25 09	71 53 47	127	50	130	180	5	1	AGR/TR
22	Ch Ameen	1999	30 25 07	71 54 06	131	50	130	180	5	1	AGR/TR
23	Zahoor Ahmed	2003	30 25 08	71 54 18	130	45	130	175	5	1	AGR/EM
24	Ch Sayyad	2002	30 24 56	71 54 03	131	50	130	180	5	1	AGR/EM
25	Haji Asharf	2002	30 25 28	71 54 15	134	40	135	175	5	1	AGR/EM
26	Ch Anwer	1998	30 26 08	71 54 22	131	40	135	175	5	1	AGR/TR
27	Zahid	2005	30 26 19	71 54 21	132	45	200	245	6	1.2	AGR/EM
28	Ch Asharf	2011	30 26 24	71 54 21	134	0	300	300	5	1	AGR/EM
29	Haji Mustaq	2011	30 25 57	71 53 19	129	45	130	175	5	1	AGR/EM
30	Mohsin	2012	30 26 34	71 53 38	134	45	130	175	5	1	AGR/TR
31	Ismaiel	1967	30 27 37	71 54 25	131	35	150	185	5	1	AGR/TR
32	Ch Ashfaq	2004	30 27 47	71 55 15	129	45	150	195	5	1	AGR/EM
33	Rana Dilshad	2000	30 27 44	71 55 53	128	45	150	195	6	1.2	AGR/TR
34	Rana Sadaqat	1982	30 26 42	71 56 48	126	45	150	195	5	1	AGR/EM
35	Nestle-1	1989	30 22 22	71 52 59	131	0	350	350			Commercial/EM
36	Nestle-2		30 22 24	71 52 56	131	0	350	350			Commercial/EM
37	Rana Mansha	2010	30 22 04	71 53 45	121	50	180	230	6	1	AGR/EM
38	Bao Irshad	2000	30 22 03	71 53 57	126	40	150	190	6	1	AGR/EM
39	Usman	1995	30 21 58	71 53 57	126	25	150	175	6	1	AGR/EM
40	Irshad	2000	30 21 54	71 54 10	126	50	150	200	6	1.1	AGR/EM
41	Arslan	2005	30 22 24	71 53 57	123	50	150	200	5	1	AGR/EM
42	Falk Shar	1995	30 22 24	71 54 10	123	55	150	205	6	1.2	AGR/EM
43	Pathan Khan	1995	30 22 37	71 54 10	123	50	150	200	6	1.2	AGR/EM
44	Falk Shar	1990	30 22 32	71 54 29	120	40	120	160	5	0.75	AGR/TR
45	Ch Zaheer	2002	30 22 30	71 55 08	126	35	150	185	5	1	AGR/TR
46	Naveed	2000	30 22 25	71 55 50	127	45	150	195	6	1.2	AGR/EM
47	Mukhtar	2010	30 22 24	71 56 53	128	45	150	195	5	1	AGR/EM

48	Dr. Abdul Haq	1970	30 22 18	71 56 40	127	55	150	205	6	1.2	AGR/EM
49	Abbasi Raza	2002	30 21 05	71 54 46	128	55	140	195	5	1	AGR/TR
50	Iqbal Khan	2000	30 19 57	71 54 30	123	60	140	200	6	1.1	AGR/TR
51	Sahid	2001	30 19 43	71 54 33	128	55	150	205	5	1	AGR/EM
52	Adeel	2011	30 19 33	71 54 34	127	65	150	215	5	1	AGR/EM
53	Shabiz Ali	2005	30 19 11	71 54 10	124	42	120	162	6	1.1	AGR/EM

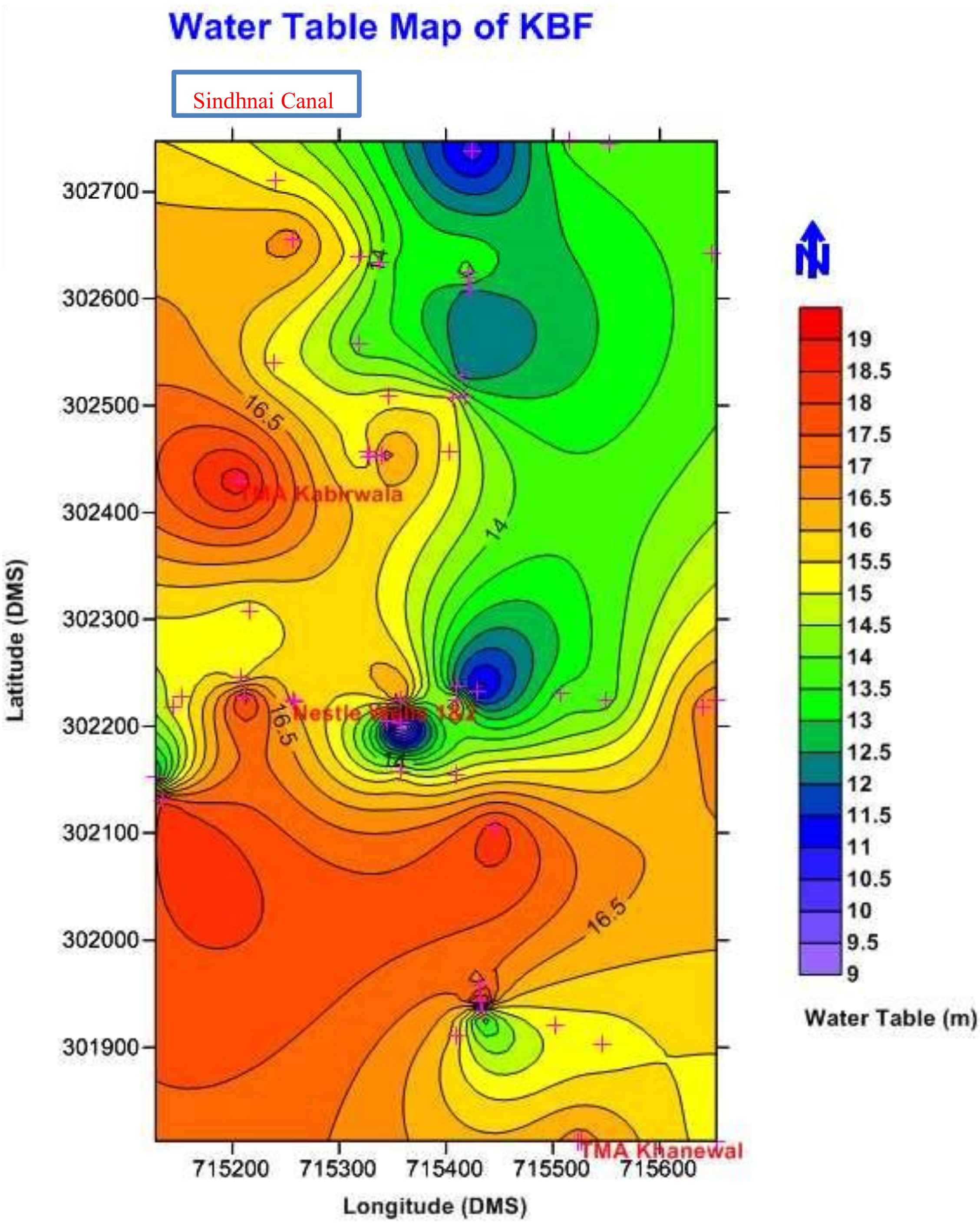


Figure 1. Water Table Contour Map of the Nestle Kabirwala Factory and surroundings (within 10 Km radius); Contour map constructed by Surfer 11.0

Figure 2. Flow in Sindhnai Canal

Figure 3. Diversion of Kabirwala Minor from Sindhnai Canal

Figure 4. Flow in Sindhnai Canal

Figure 5. Newly constructed Tube-well in Khanewal TMA

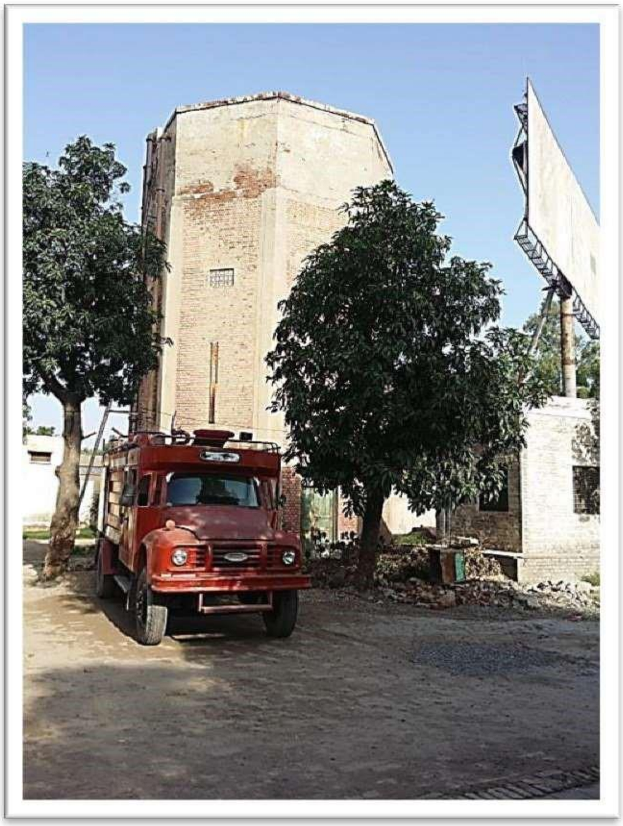


Figure 6. TMAOffice, Khanewal

Figure 7. Kabirwala Minor Canal

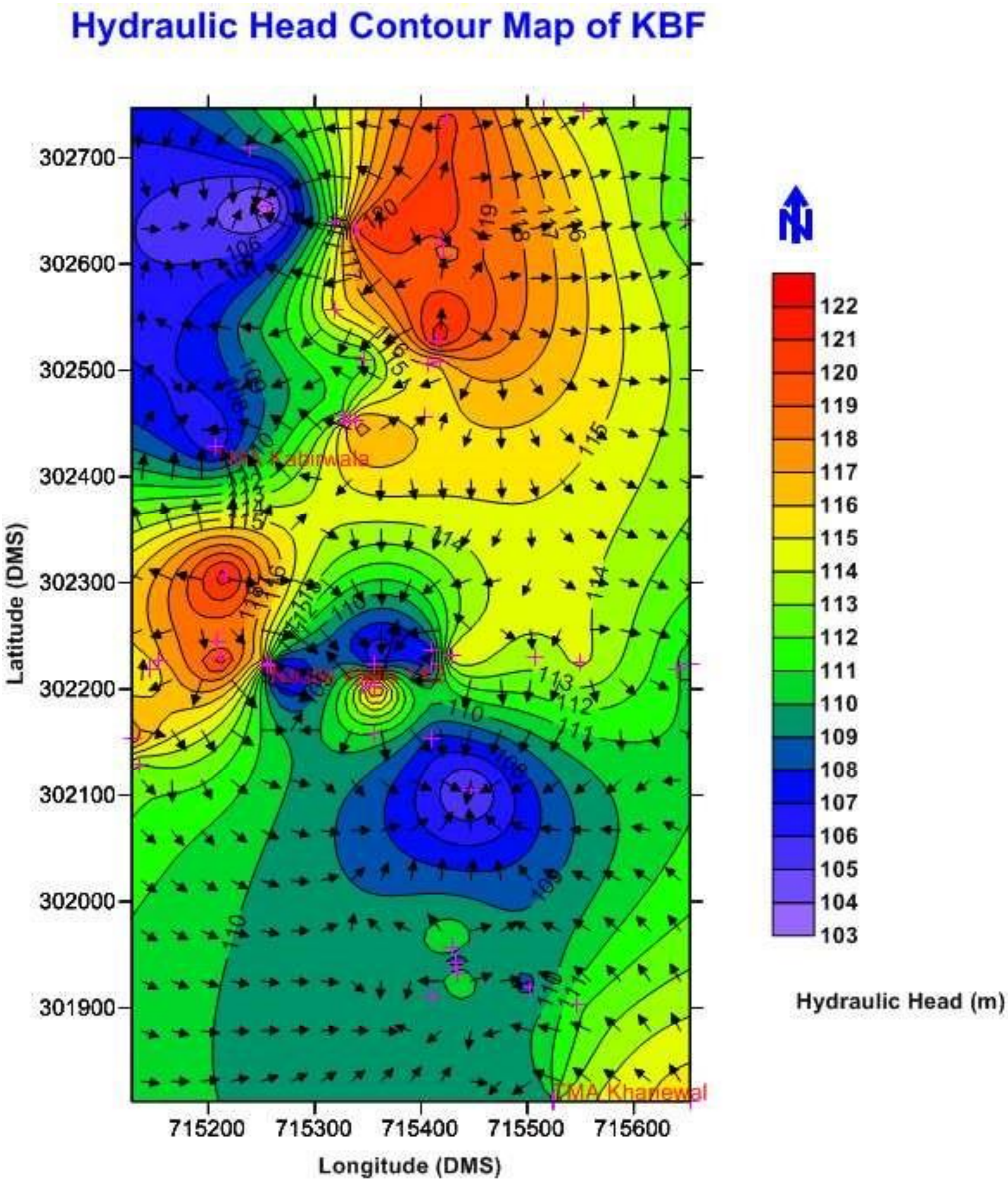


Figure 8. Localized Groundwater Flow components Contour Map of the Nestle Kabirwala Factory and surroundings (within 10 Km radius)
Contour map constructed by Surfer 11.0

8. Hydraulic heads and Local Components of Flow Map

Hydraulic heads (groundwater elevation) are constructed for the entire area under investigation that fall between 103 to 122 meters and have indicated a total head drop of 19 meters (Figure 8). Localized flow patterns are also shown as a vector lines indicating pattern of flows in different directions. In general the heads are dropping towards TMA Khanewal office in the south. In the vicinity of Nestle wells pumping the direction of flow tends to move towards the declining water table within the cone of depression. Groundwater in these areas has shown a good potential having enriched unconfined aquifers with negligible amount of drawdown.

8.1 Accessibility

The accessibility of the study area is through main highways in the country (Figure 9). The main access is from Multan highway leading to Karachi and a bypass to Kabirwala that would lead to Nestle Factory. Many other factories are located in this area and a great hustle and bustle due to trucks including local transports can be seen. Figures 10 through 13 provide information on the location of the area.

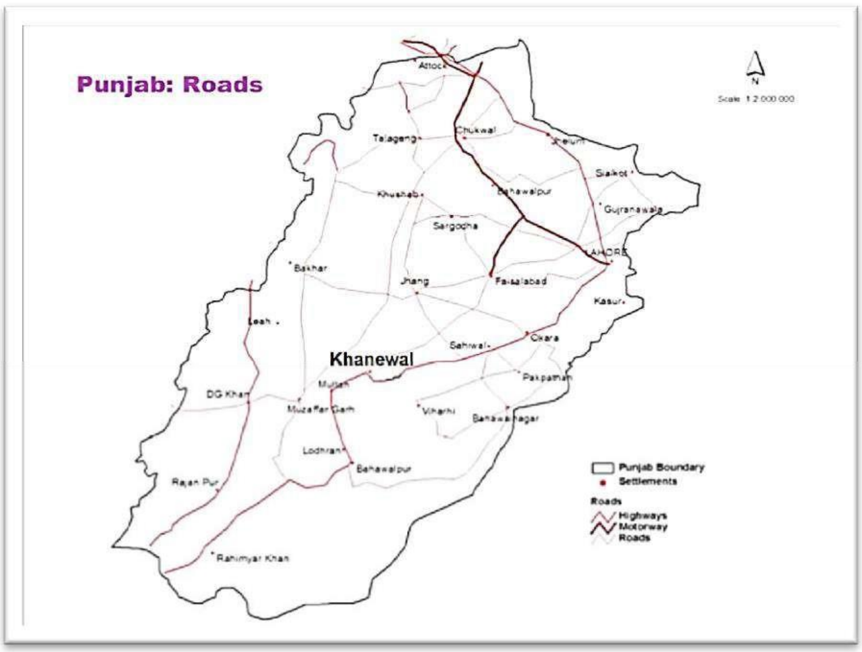


Figure 9. Location map of the study area

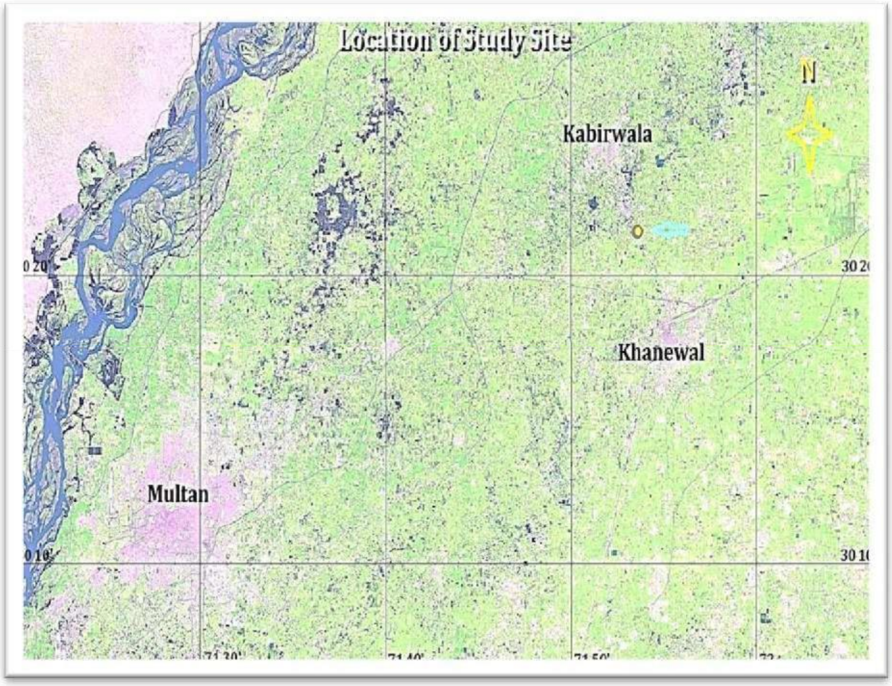


Figure 10. Location of the study area in the Landsat 8 image of 2013 period

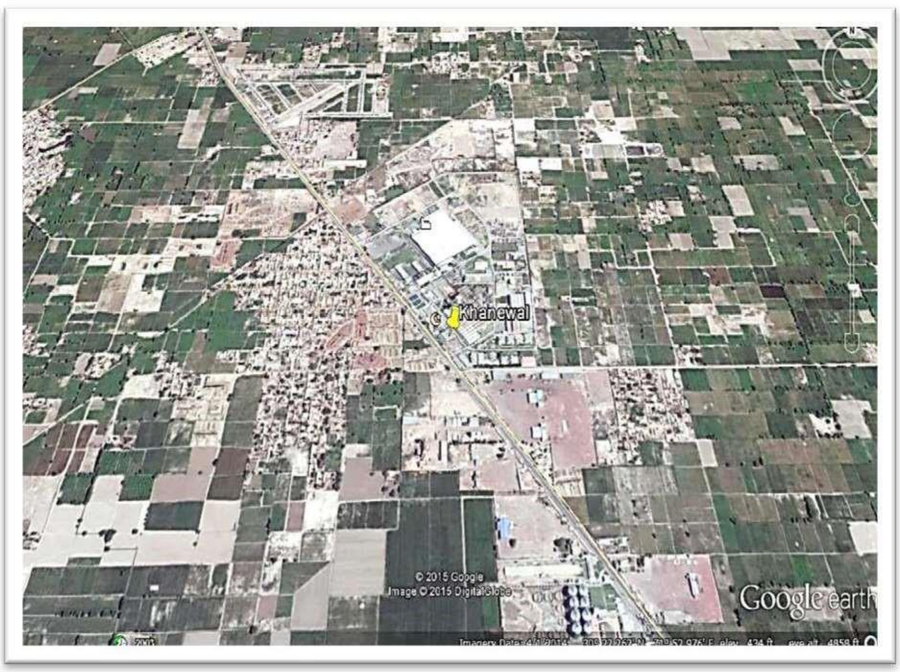


Figure 11. Location of the study area over Google Earth image

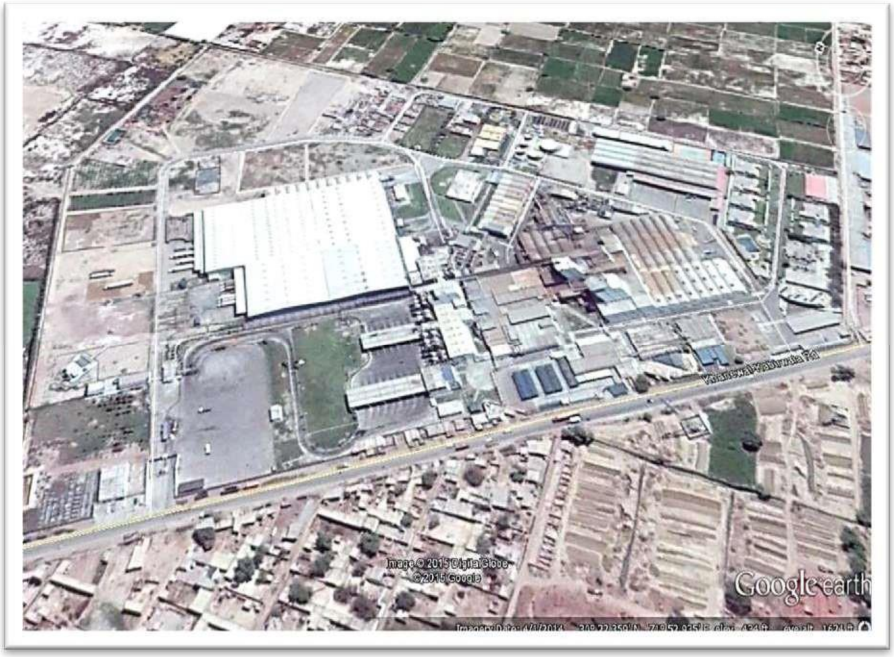


Figure 12. Location of the study area over Google Earth image in different orientation

Figure 13. Location of the study area over Google Earth image in different orientation

Figure 14. Location of the study area over Google Earth image in different orientation

9. Stratigraphy and Lithology

In Punjab, the Indus plain is underlain by thick alluvial complex deposited by the ancestral Indus River and its tributaries in a subsiding tectonic depression lying between the Himalayas contiguous mountain ranges and plateaus. Alluvium of the Indus basin has been deposited on the basement of Tertiary shales and limestones. The stratigraphy map is shown in Figure 15. The unconsolidated valley-fill deposits of Quaternary age cover the valley floor.

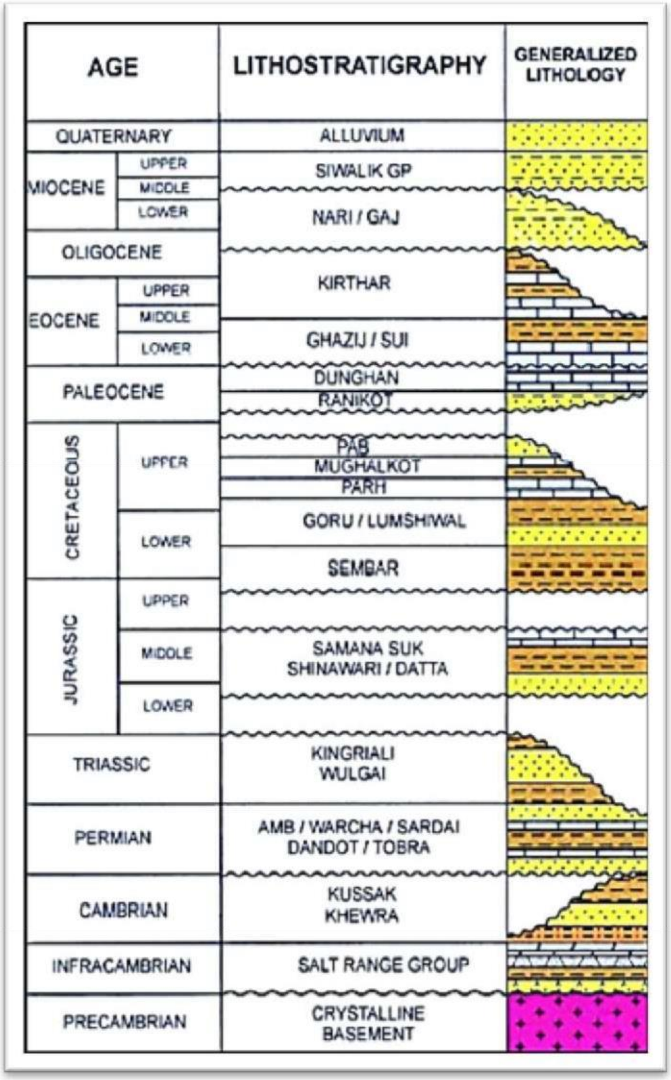


Figure 15. Generalized stratigraphy of Punjab platform

The bulk of the alluvium consists chiefly of fine to medium sand, silt and clay. Coarse sand and gravel however are not uncommon, particularly near the mountainous borders of the plain. Concretions of silt and sand are commonly found in the silt and clay deposits. The alluvial complex contains a vast regional porous aquifer system which extends to a depth of few hundred meters or more virtually throughout the Indus plain. The alluvial deposits occur chiefly in irregularly shaped tabular bodies of sand, interbedded with lenticular layers of silt and clay (WAPDA and MHW 1989).

10. Hydrogeological characteristics

Groundwater investigations in Pakistan began in the mid-fifties as a component of the eradication of the serious problems which developed in the irrigation areas of Indus plain as a result of water logging and soil salinization. The investigation program was concurrently supported through studies carried out by international consulting firms such as M/s Tipton and Kalmbach (1967) and Harza international (1968) for regional development and planning in Punjab. In Sindh, the Government of Pakistan through Water and Power Development Authority (WAPDA) utilized the services of a British firm of consultants for investigation and planning of the land and water resources in the region.

The porous type aquifer is found in the unconsolidated sediments in the vast alluvial deposits of the Indus plain. Groundwater occurs in the interstices or pore spaces between the granular sedimentary particles of unconsolidated deposits constituting the groundwater reservoirs. The porous aquifer on the basis of grain size could be distinguished in sandy and gravelly type aquifers. The sandy aquifer covers almost the entire Indus plain where the aquifer is encountered at shallow depth having large vertical and lateral extent. It is not uncommon to strike over thick saturated 300 meters sand formation in the large parts plain. The sand formation constituting the aquifer generally grade from fine to medium size well assorted having porosity up to 30 percent. The average value of specific yield of these aquifers is 17 percent. The sand formation in the Indus plain is found to have high transmissivity. The tube-wells installed with screen section of 10 to 15 meters in length facing the aquifer yield of one cusec (102 m^3/hr) with a drawdown of 1 to 1.5m of water level (WAPDA and MHW 1989).

11. Water table Depth and Potential

Ground water potential is shown in the accompanying maps (Figures 16, 17, 18). The depth of ground water table in the Indus Basin canal commands exhibits an annual cycle of rise and fall. The water table is measured twice a year during pre-monsoon (April/June) and post - monsoon (October) period. It is at its lowest point in the period prior to the monsoon (April/June). Recharged through Kharif season (summer) irrigation and rains, it rises to its highest point in October, when it is closest to the land surface before declining again. High water table conditions after the monsoon, although transitory, interfere with the cultivation of Rabi (winter) crops. The water table position in April/June is, particularly, critical as it persists throughout the year and is used as an index of waterlogged area. Zone-wise point data of depth to water table below national standard limit (NSL) for the periods June and October 2002, for all the irrigation canal commands were digitized, analyzed and the contour maps were generated through interpolation technique (LUAP, 2009). The criteria for classification of water table depth categories adopted for this study are according to Soil Survey Manual Agricultural Handbook No.18 and are shown in Figures 16 & 17 and given in the Table 2.

Table 2. Classification of Water table Depth by Drainage

Drainage Class	Water table Depth (cm below NSL)
Very poorly drained (Waterlogged)	< 100
Poorly drained (Waterlogged)	100-150
Moderately drained	150-300
Well drained	>300

NSL indicates National Standard Limit

The zone-wise depths to water table results for June and October 2002 are shown in Figures 16 and 17 (LUAP, 2009).

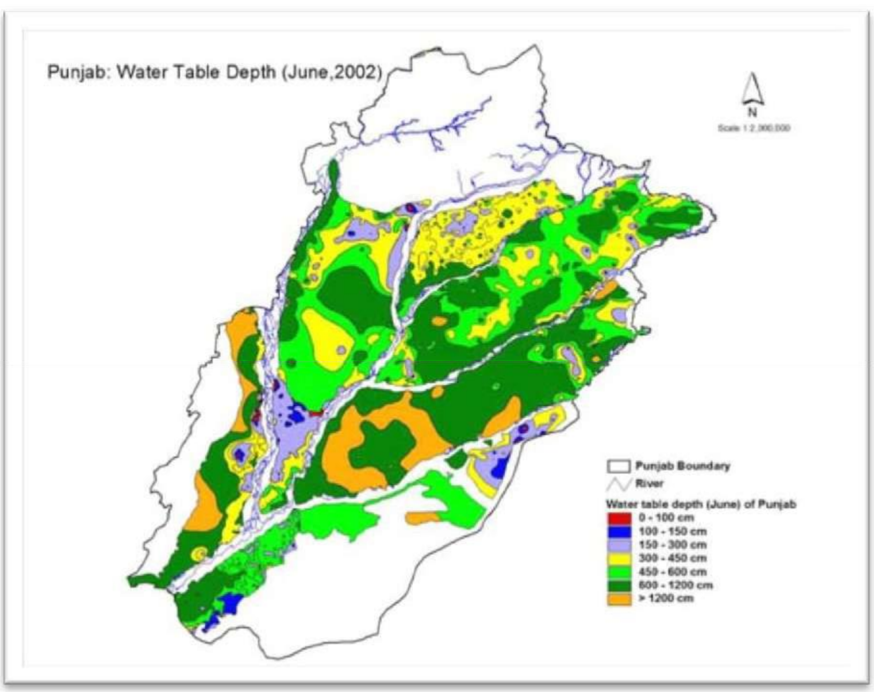


Figure 16: Water Table depth during June 2002 in Punjab (LUAP, 2009)

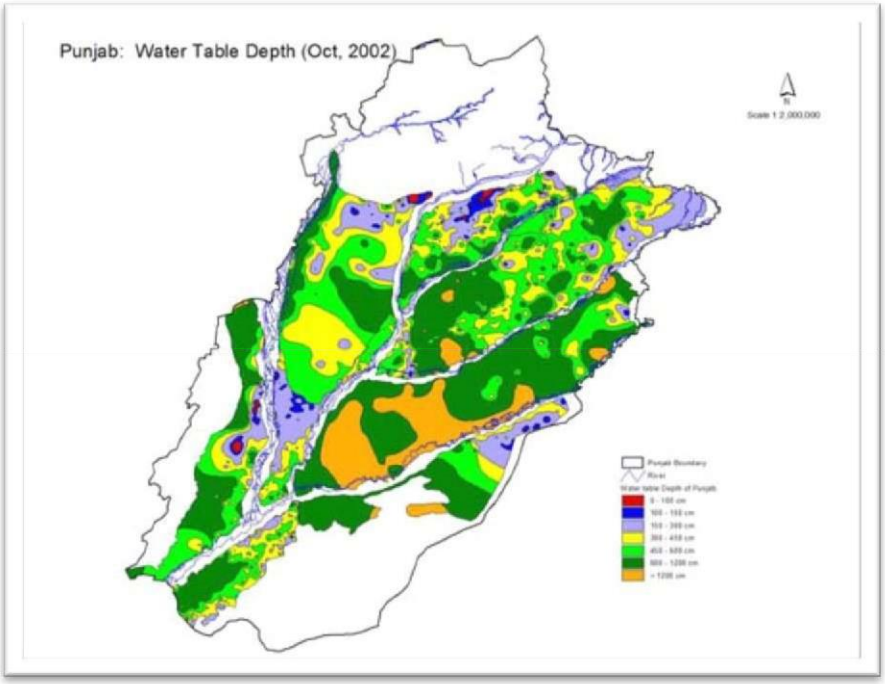


Figure 17: Water Table depth during October 2002 in Punjab (LUAP, 2009) The zone _wise water quality based on TDS results for the survey during 2001_2003 are shown in Figure 18 and Table 3. The study area lies in Bari doab where about 65% area possesses usable groundwater quality.

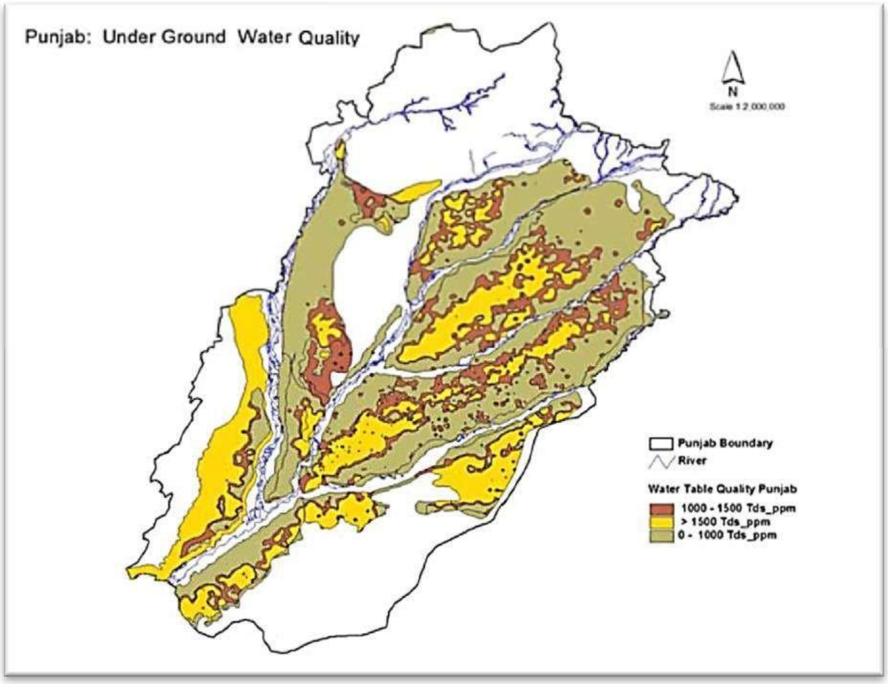


Figure 18: Groundwater quality in Punjab area (LUAP, 2009)

Table 3. Shallow water quality based on TDS in Punjab area

Zone Name	Area Surveyed	Shallow Water Quality Based on of TDS(ppm)					
		Usable (<1000)		Marginal (1000-1500)		Hazardous (>1500)	
		Area	%	Area	%	Area	%
PUNJAB							
Thal Doab	3.977	2.627	66.05	0.567	14.26	0.783	19.69
Chaj Doab	2.474	1.624	65.64	0.49	19.81	0.36	14.55
Rechna Doab	5.729	3.245	56.64	1.095	19.11	1.389	24.25
Bari Doab	4.288	2.77	64.60	0.76	17.72	0.758	17.68
Fordwah Zone	2.534	0.718	28.33	0.336	13.26	1.48	58.41
Punjnad Zone	1.644	0.986	59.98	0.161	9.79	0.497	30.23
D.G.Khan Zone	0.957	0.37	38.66	0.214	22.36	0.373	38.98
Total	**21.603**	**12.34**	**57.12**	**3.623**	**16.77**	**5.64**	**26.11**

12. Groundwater potential

The hydrolgeological maps prepared by WAPDA at scales of 1:500,000 and 1:250,000 were used to extract information related to surface and groundwater resource of the Punjab area. There are five potential zones of groundwater defined for Rod-kohi region i.e. High, Medium, Low, Poor and N.A (No potential aquifer) as modified from WAPDA (1989 & 2001). The zones are based on the following characteristics of groundwater aquifer:

- **High** — Yield 100 to 300 m^3/hr or more, down to 150m, Fairly thick and extensive aquifer.
- **Medium** — Yield between 50 to 100 m^3/hr down to 150m. Moderately thick and extensive aquifer.
- **Low** — Yield between 10 to 50 m^3/hr down to 150m. Aquifer of limited thickness and extension.
- **Poor** — Yield less than 10 m^3/hr down to 150m. poor and patchy, hard rock, discontinuous aquifer
- **N.A** — No potential Aquifer

The extent of these zones in central Punjab is shown in Figure 19 including the Kabirwala and Khanewal areas around Nestle Factory Kabirwala.

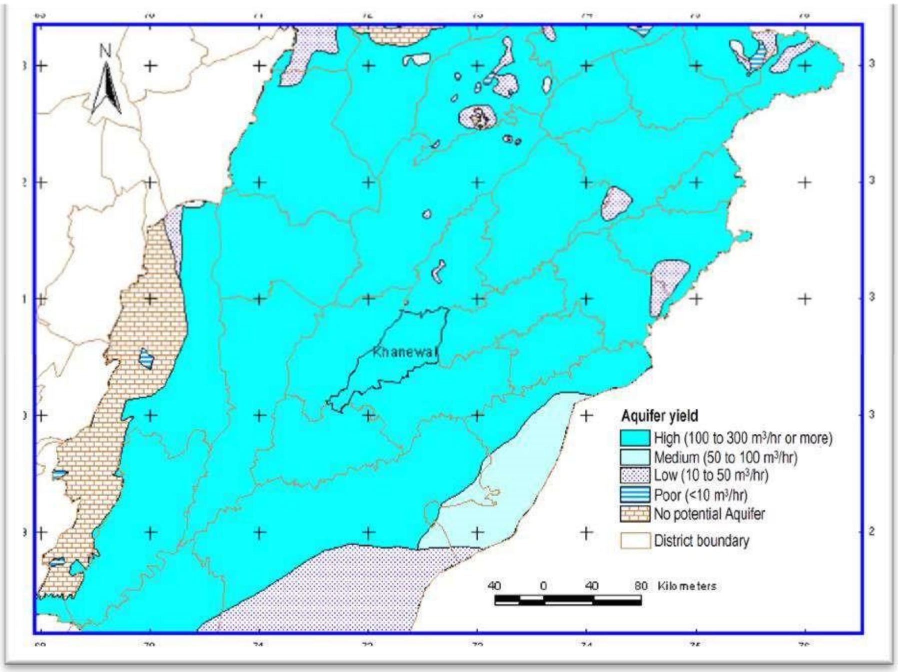


Figure 19. Groundwater potential in the central Punjab area (Wapda, 2001)

13. Three-dimensional Groundwater flow and Contaminant transport Modeling of the Nestle Kabirwala Factory and surroundings in the Indus basin Aquifer, Multan District, Pakistan

13.1 Overview

A three dimensional numerical groundwater flow model is developed using Visual MODFLOW to characterize the groundwater regimes of Multan District in Pakistan including the Nestle Factory Kabirwala. The multi-layered model was calibrated to stimulate the groundwater flow from 1962 to 2010 period. The model was rerun to predict future changes in groundwater regimes from 2010 to 2015 period. In addition arsenic contamination risk for the local communities was evaluated. The findings of the study reveal that Chenab River in the west is acting as a significant source of groundwater recharge in this part of the Indus basin. The results of transport modeling depicted arsenic movement towards the rivers during the steady-state condition of the groundwater flow model. The water quality data analysis indicated that shallow groundwater is most unsafe for the population of Multan city as only 7 percent of the water samples were found to have arsenic contamination level below the EPA's permissible limits. The groundwater needs to be managed properly and over exploitation should be controlled for effective development of groundwater resource in the area. Proper purifying/filtering techniques need to be adopted to ensure safe use of groundwater for domestic purpose.

13.2 Introduction

To understand the behavior and transport of contamination in the groundwater of the regional area around Nestle Factory Kabirwala, numerical flow and transport modeling of the area is considered to be the best option and it is therefore carried out.

The hydrogeological monitoring studies were started in the area in 1962 by WAPDA. Water and Power Development Authority (WAPDA) had executed substantial work on groundwater exploration in pursuit of improvements in agrarian economy of the country. In the period of 1961 to 1963 extensive work was done in Bari Doab, and basic data on the subsurface lithology, and quality of groundwater was collected. Data on aquifer tests and their analysis was also collected. This data was published in 1980 and 1982. Some of the important work on different aspects of hydrogeological investigations in this area were carried out by Kidwai and Swarzenski (1964), Bhatti et al. (1967), WAPDA (1980, 1982), Shahid (1990) and, Akhter and Ahmad (2005), Ahmad et al. (1997a, 1997b, 1999, 2001, 2009, 2011), Asharf et al. (2008), Arora et al. (2003) .

In the present study, a numerical flow model of the groundwater has been developed for the Multan area using Visual MODFLOW Pro 4.0 model using groundwater data of 1962. Multan lies in Bari doab. Doab is the local term for the area which is surrounded by the river from two sides. The Multan is located in southern Punjab at almost the exact centre of Pakistan and it is a bend created by five rivers of the Punjab province (World Bank 2006). Model is calibrated using the hydraulic head data of 1962 as at that time groundwater was in steady state condition (WAPDA 1980 and 1982). The calibrated heads with specific yield values were used for calibrating the transient state. In transient state the model was run for 183 days for the summer season, and simulate the heads from 1962 to 2010 and then to predict future changes in heads from year 2010 to 2015. Three dimensional flow modeling was necessary for transport modeling of arsenic and the flow path evaluation. Furthermore, this calibrated model data was used for the particle tracking and flow path determination by the program MODPATH. MODPATH has been used for both forward and backward tracking. Forward tracking of the particles is used for determining the possible path and rate of flow of the particles. On the other hand, backward tracking is useful for determining the possible route of the particles or source of the contamination in the groundwater regime.

13.3 Description of the study area

The study area of Multan lies within longitudes 71º 12´ to 72º E and latitudes 29° 24´ to 30° 48´ N covering an area of about 3,721 sq km in the Bari Doab of Pakistan (Fig. 20). It comprises of four Tehsils namely Multan Cantonment, Multan Sadar, Shujabad and Jalalpur Pirwala. It is well connected via rail, road and air links with other parts of the country.

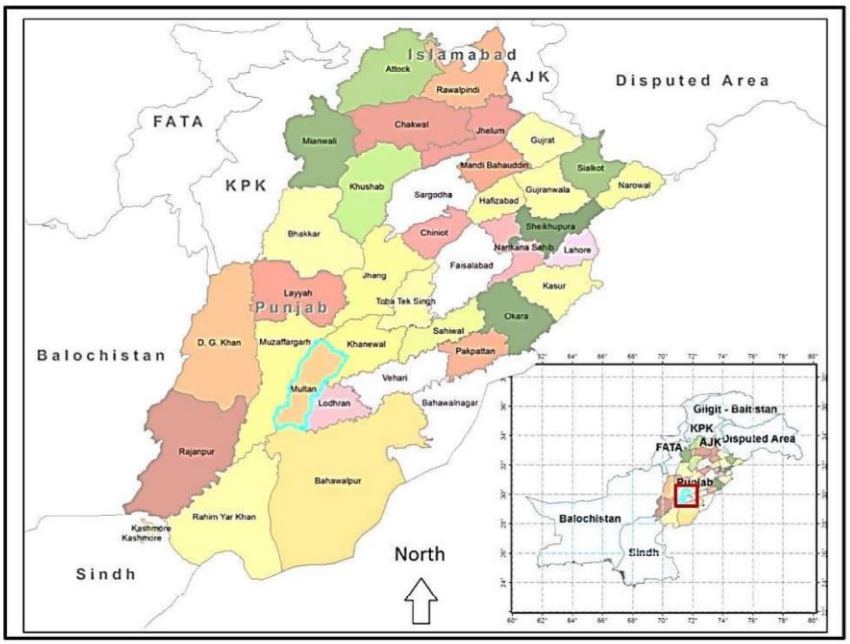


Fig. 20 Location map of the study area

14. Hydrology and Hydrogeology

River Chenab is the main stream of the area, which flows from northeast to southwest direction and lies west of the city. This is the main source of surface water and recharge of the ground water. Unconsolidated deposits spread over a large part of the alluvial plain deposited by the Chenab River prevail. The alluvium chiefly consists of fine to medium sand, silt and clay (WAPDA 1982).

The map shows that an unconfined, transmissive, fairly thick and extensive aquifer is present. Tube wells of 100-300 m³/hr capacity and 150 meters deep can be installed here except in the walled city area. Depth to water is around 1 to 6 meters. The water quality is fresh (not saline) and within the limits approved by WHO. There appears to be no regular monitoring of drawdown, or cones of depression, but the water table is thought to be dropping at some 0.3 m per year (World Bank 2006). The access to the shallow aquifer is at 9-10 m depth. The shallow water is polluted with surface water and sewerage. There is an extensive canal network is present in the area; some important canals of the area are Sindhnai canal, Faizpur distributry, Jahania canal, Sikandarabad branch, Gajjuhatta branch, Pakpatan canal, Chitdain branch and Jalalpurpirwala branch (Fig. 21). These canals are the source of irrigation for this agricultural area as well as they act as a source of groundwater discharge. Because according to a study conducted in the area 18 percent of canal discharge is lost as seepages and 80 percent of this seepage is infiltered in the ground and recharges the groundwater (Akhter and Ahmad 2005).

Figure. 21 Important canals around the Nestle Factory Kabirwala (ADB)

The Asian Development Bank (ADB) Consultants for the Southern Punjab Basic Urban

Service (SPBUS) Project apparently tested water at the taps in various parts of Multan and found contamination due to leaking pipes and sewerage infiltration in 15 areas. Major sources of contamination of the piped water supply include: Inadequate sanitation and drainage facilities leading to wastewater pounding and infiltration of virus and bacteria into groundwater; Improper disposal of industrial wastes from fertilizer plants and tanneries. Since there is no regular monitoring of water at the tap, evidence of pollution remains anecdotal. Contamination of supply has become a critical issue in Multan, since the majority of households use their own wells with motor pumps. In addition to the abovementioned causes of contamination, contamination of aquifer by naturally occurring arsenic in shallow sub-soils affects the shallow wells that households use (World Bank 2006).

15. Conceptual model of groundwater flow

A model is a tool designed to represent a simplified version of reality. Groundwater models are the representation of reality and, if properly constructed, can be valuable predictive tool for management of groundwater resources (Wang and Anderson 1982). The study area is lying in the floodplain; therefore, main geological material underlying the area is the sand and gravel, while at some places boulders are also found. At many places thin lenses of silt and clay are also found. Silt and clay are not the aquifer materials therefore only the logarithmic mean of aquifer material is calculated. Data of 1962 is used for construction of the conceptual model of the area (Fig. 22). The aquifer in the study area is divided into three layers depending on the sub surface geology obtained from the well data. Lithological logs of the study area are drawn to understand the subsurface lithology of the area. The model layers contain the following specifications:

- Sand from ground surface to 30 meter depth (thickness 30m)
- Gravel and sand with some clay lenses from 30m to 48m depth from ground surface(thickness 18m)
- Mainly Gravel with sand and silt from 48m to 90m from ground surface(thickness 42m)

This layering was developed from the lithological logs of the study area and taking the logarithmic means of different aquifer materials. For this purpose the lithological data of 1962 (WAPDA) was used.

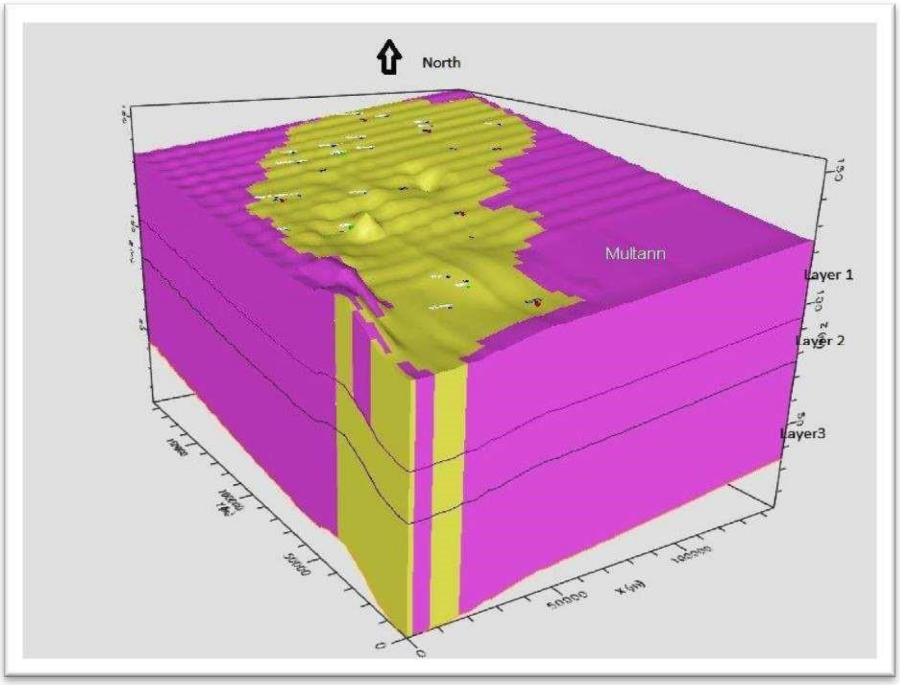


Figure 22. Conceptual models of the Nestle Factory & Surroundings (pink color depicting inactive zone)

16. Model design

In the model River Chenab is treated as the western constant head boundary and the Sutlej River as the southern constant head boundary. Different hydraulic parameters are calculated by using the hydrogeological data of WAPDA (1980). The area is divided into 11 zones for conductivity, specific yield and storage using thiessen polygon method. The model covers an area of 3,721 square kilometers (Figure. 23). The spatial domain represented in the model consists of three layers (0-30m, 30-48m and 48-90m), 60 rows and 20 columns (total of 1200 cells in each layer) with a variable spacing of 1000m to 2000m in both x and y directions respectively. This layer system was chosen to represent recharge, groundwater pumping and water quality aspects at different depths within the study area.

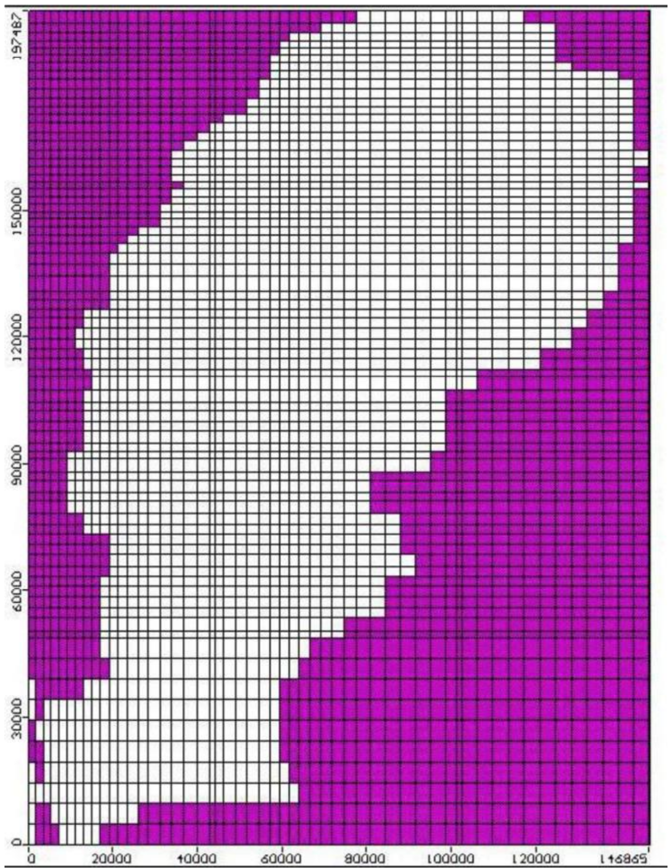


Figure. 23 Finite difference variable grids overlain on the study domain

The elevation values of the ground surface were taken for different points. These data points were then used for making the surface elevation map of the area. This map shows the slope of the study area which is from northeast to southwest direction, and all the layers were made on the basis of these elevations and these elevations were used in the Visual Modflow input section too.

The area lying out of the study domain is treated as inactive zone, only those cells are active which are lying inside the district Multan and calculation are made on these cells only. Figure 23 is representing the active and inactive flow zones of the model.

17. Numerical modeling of groundwater flow

17.1 Steady state modeling

The groundwater regime of the study area according to WAPDA was in the steady state in 1962, therefore the observed heads of the June 1962 were used for the calibration of the model. The groundwater data had been acquired from Water and Power Development Authority (WAPDA, 1980 and 1982). Model is calibrated by the automated parameter estimation-PEST program, which is embedded in Visual MoDFlow.

Model was calibrated both in steady state and transient state successfully. Because calibration is the most important and essential step in groundwater modeling, PEST is a unique package that can be used with any pre-existing model for data interpretation or model calibration. The groundwater heads of June 1962 (pre monsoon) were used as initial condition for steady state simulation. Recharge and discharged components were also bringing into consideration when executing the steady state simulation. Recharge from rainfall, and canals were considered in the initial data input.

The initial parameters were adjusted in the automated calibration by PEST. The calibration graph of the area is given in the Figure 24.

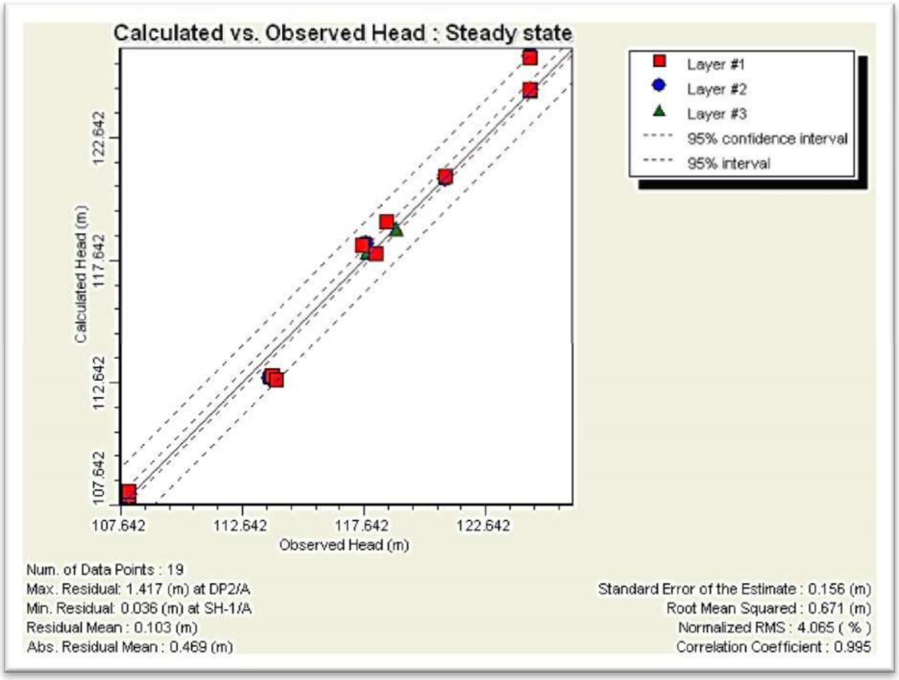


Figure 24 Steady state calibrations (1962)

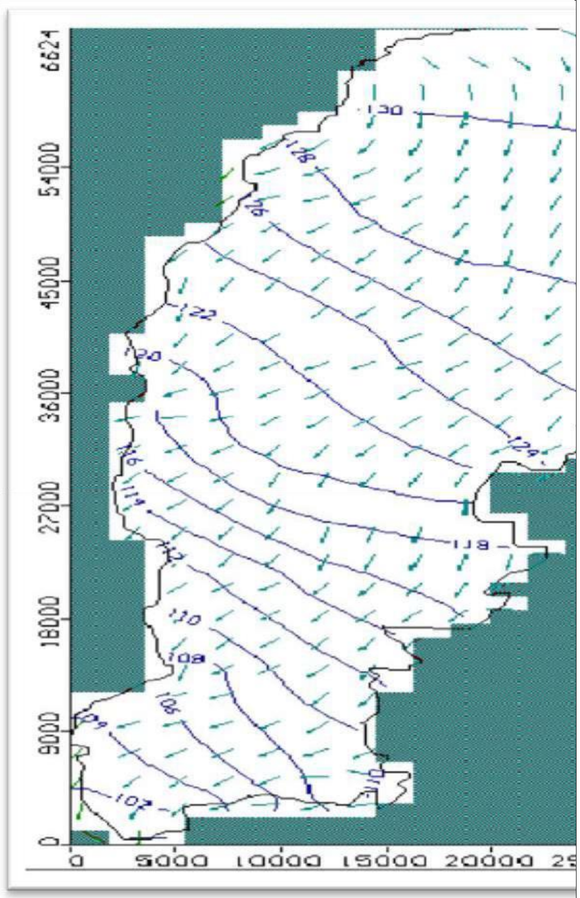
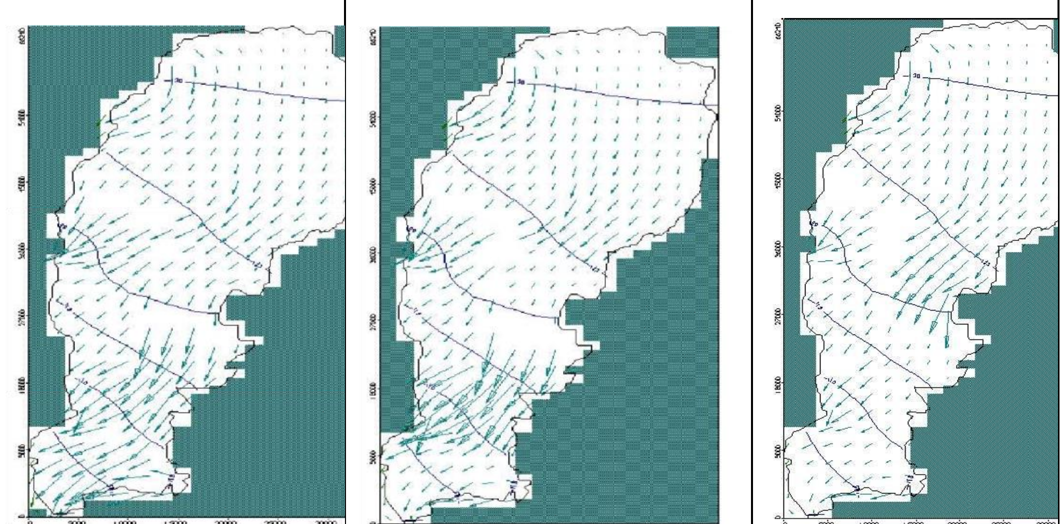


Fig. 25 Steady state calibrated equipotential map of 1962 (layer 1)



a

b

c

Figure 26. Steady state map of velocity magnitude of 1962 in a. layer 1, b. layer 2 and c. layer 3

The groundwater flow follows the topographic relief of the area. The equipotential map of the steady state simulation shows groundwater flow towards southwest direction. Hydraulic heads are decreasing from northeast to southwest direction (Figure 25), the heads fall in the range of 130.9 to 90 meter above mean sea level.

The velocity vectors drawn shows that flow is towards the constant heads boundaries in the west and south of the model domain. A 3-dimensional view of the water table in transient condition [Nestle Factory & Surroundings] is shown in the Figure 32.

The velocity magnitude analysis shows the greater magnitude in the lower part of the model area while lowest velocity magnitude is in the northeast of the area in Figure 25.

In the 2nd layer velocity magnitude is highest in the area below the center of the study area while lowest velocity is evident in the north of the study area represented in Figure 26 b. In the 3rd layer highest velocity is evident in the center of the study domain while lowest in the north and some of the eastern parts represented in Figure 26 c.

17.2 Transient state simulation

In transient problems, heads changes with time. Therefore transient problems are also called time dependent, non-steady or non-equilibrium. For the transient simulation the initial conditions were the calibrated heads of the steady state simulation.

In the transient state simulation the yield and storage properties of the aquifer regime are considered.

Then this unsteady state model was calibrated against the pumping test data of 1962, in calibration the model successfully produced the heads of the 1962 data. Draw down was equal to the drawdown of the 7 days pumping test data. The calibration graph of 1st 7 days of the simulation is shown in the Figure 27. The drawdown map is shown in the Figure 28 that indicates only a negligible average drawdown of 2 meters in and around the vicinity of Nestle Factory & Surroundings. Figure 10 to Figure 12 represents the simulated equipotential maps of the year 1962, 2010 and 2015 for all three layers in each simulation period. The area in the vicinity of the Nestle Factory is quite enriched having good potential in the sand aquifer of various sand particles.

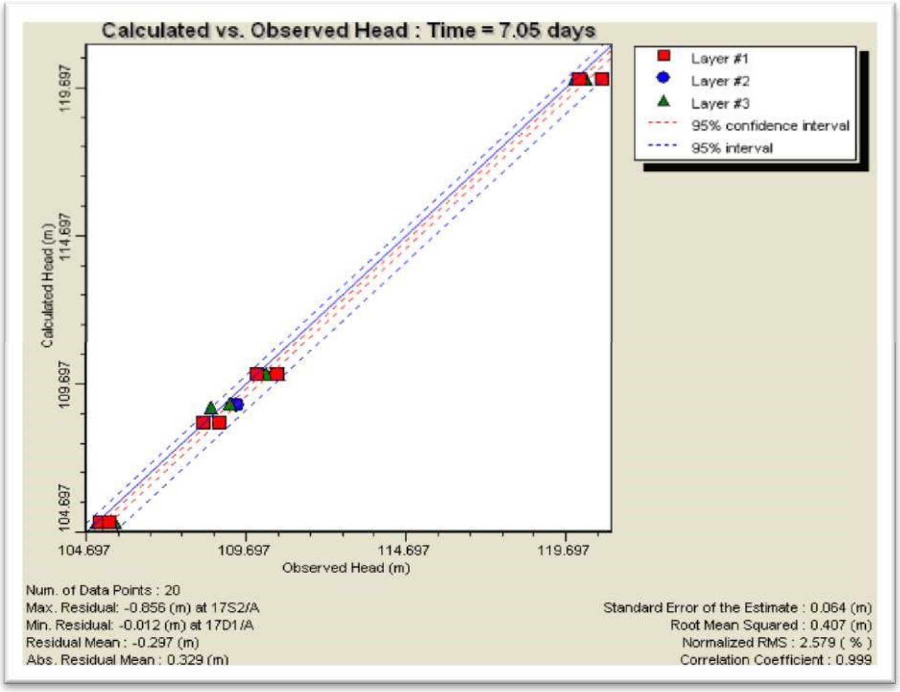


Figure 27. Non steady state calibrations of 1962 with the pumping wells [Nestle Factory & Surroundings]

17.3 Hydraulic Budget /Water Balance Model for the Bari Doab

Water balance budget totals the release of water from storage is known as inflow and uptake is counted as outflow. Inflow into the aquifer must balance with the outflow with a minor error of 0.1 that is considered to be ideal (Konikow, 1978). An error of around 1 % is usually considered acceptable. A large error in the water balance could also mean that the numerical solution is inaccurate or that the solution did not converge within the set maximum number of iteration. The results of water balance study of 2015 for the Bari Doab is shown below with discrepancy of zero (0%), which is the output of Visual Modflow.

Flow Term	IN (m^3/year)	OUT (m^3/year)	IN-OUT (m^3/year)
Constant Head	2.2741093×10^{2}	1.7136906×10^{3}	-1.4862797×10^{3}
Recharge	1.4867842×10^{3}	5.6516045×10^{-1}	1.4862190×10^{3}
Sum	1.7141951×10^{3}	1.7142557×10^{3}	$-6.0668945 \times 10^{-2}$

Discrepancy [%] 0.00

Constant head contains the recharge from the Ravi and Sutlej Rivers and other recharges are comprised of canal seepages and rainfall. Annual volume of water moves through the aquifer is expressed as m^3/year both in and out of the aquifer.

The major sources of groundwater recharge in Bari Doab are rainfall and the irrigation system. Rivers and drains can behave either recharge and discharge sources. Pumping from public and private TWs and Evaporation from open water body / groundwater are the main sources of discharge. Studies carried out by WAPDA for estimating groundwater recharge from the irrigation system indicate that the total recharge is of the order of 34747 Million m^3 of which 29036 Million m^3 is not useable due to quality related issues. Water Budget of the Bari Doab including both the subsurface and surface parameters for different canal commands is evaluated by the available data from Wapda as shown below:

Groundwater Balance of Bari Doab (2015)

Adopted from Wapda report & with modeling simulation	MAF
Recharge Components Parameters MAF Rainfall recharge (11 % of average 15 .8 inches/year)	6.97
Recharge from irrigation system(38 % of 57.4 MAF)	21.81
Return flow from GW abstraction(18 % of 35 MAF)	6.3
Total	35.08
Discharge Components Groundwater abstraction (Public & Private TWs)	34.0
Evapotranspiration losses	1.545
Total	35.54

Area of Bari Doab = 4,364 square kilometers (1,685 sq mile)

Balance is generally valid over one decade with ± change of 1% (10 year period)

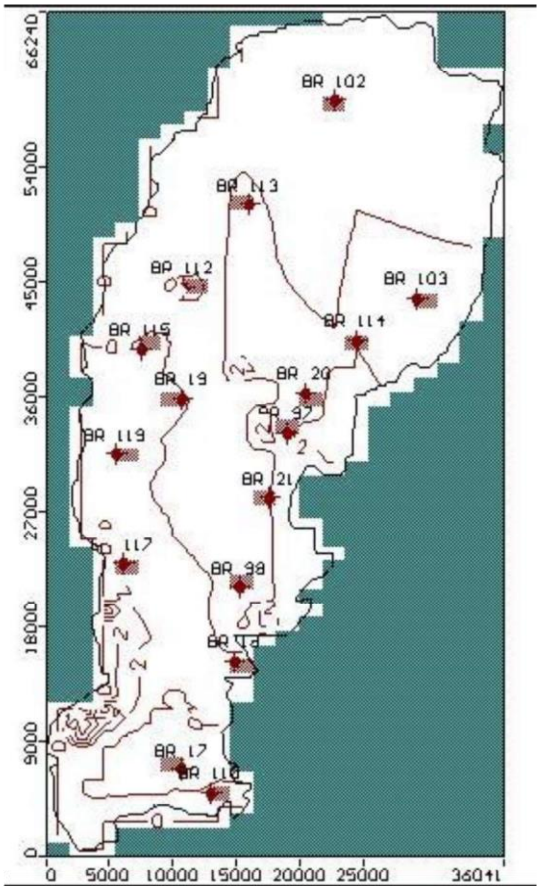
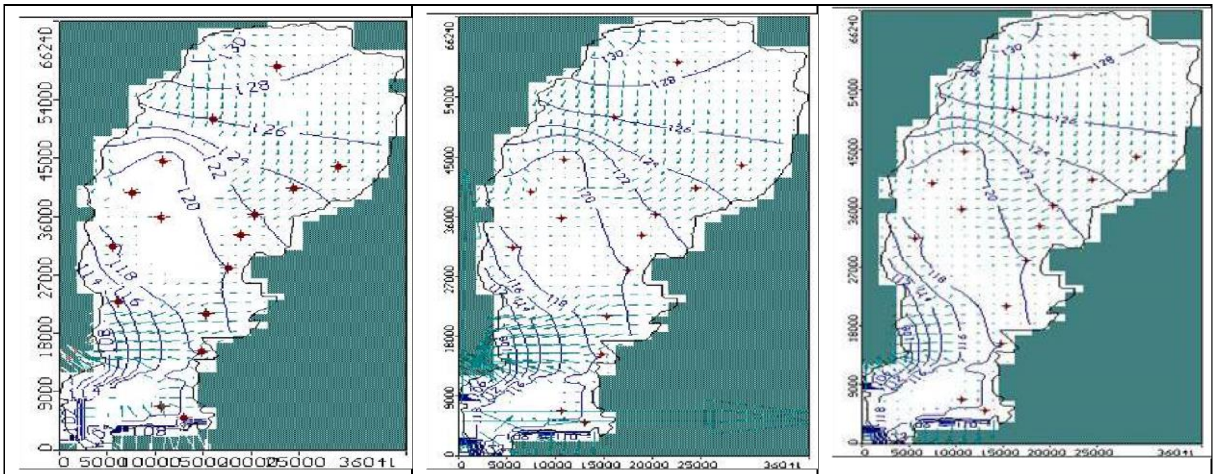


Figure. 28 Drawdown map of the area [Nestle Factory & Surroundings]

The layer 1 representing the upper unconfined aquifer which has thickness of 30 m. velocity is faster in the upper layer because of recharge and local components of the groundwater flow (Figure. 29). It represents the 1st layer simulation after 1st time step of the transient simulation which is for 7.05 days. The heads ranges from 130 to 85m AMSL.



a b

Figure. 29 Non-steady state simulated equipotential map of 1962 (15 wells are operating with variable discharge rate in a. layer 1, b. layer 2 and c. layer 3 [Nestle Factory & Surroundings]

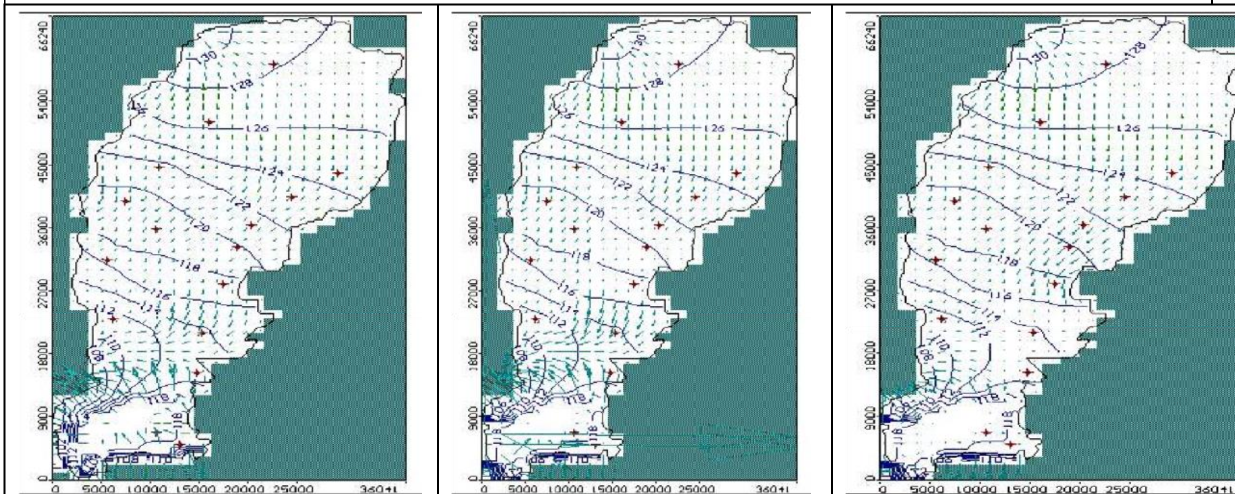


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Figure. 30 Non-steady state simulated equipotential map of 2010 (15 wells are operating with variable discharge rate in a. layer 1, b. layer 2 and c. layer 3[Nestle Factory & Surroundings]

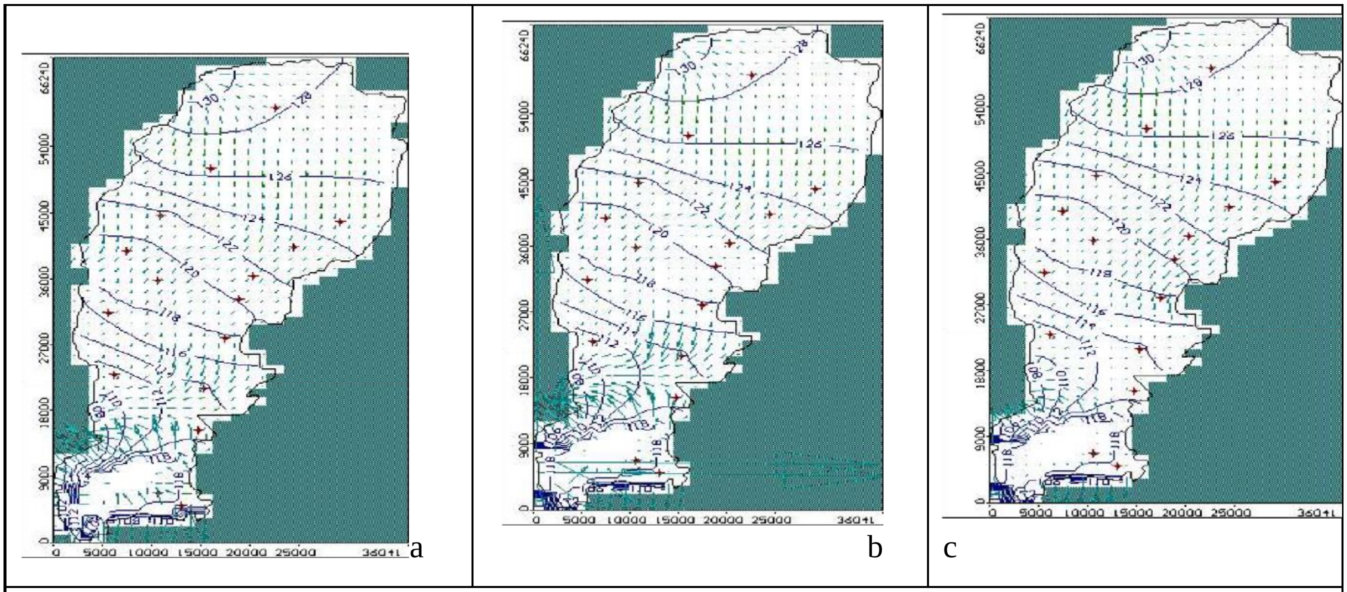


Figure 31. Non-steady state simulated equipotential map of 2015 (15 wells are operating with variable discharge rate in a. layer 1, b. layer 2 and c. layer 3 [Nestle Factory & Surroundings]

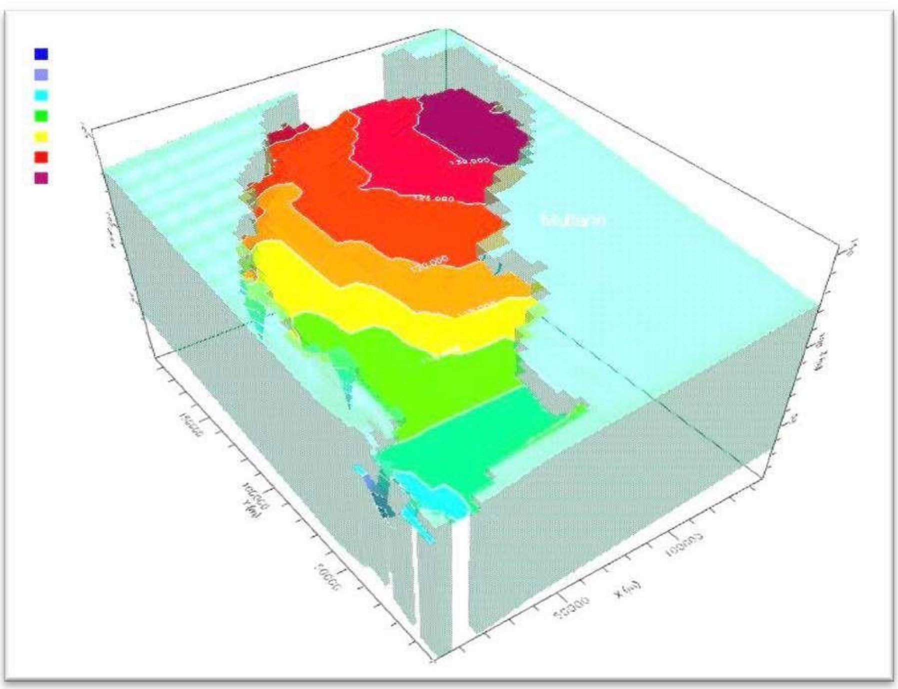


Figure. 32 Transient state heads 3-dimensional representation, Nestle Factory, 2015

18. Particle streamlines

In addition to the numerical finite difference solution 3-dimensional particles tracking is also used to compute the streamlines and the position of the particle at a specified point in time. Both the forward and backward tracking is executed. The purpose of the forward tracking is to evaluate the flow paths of the groundwater in the Nestle Kabirwala Factory & Surroundings.

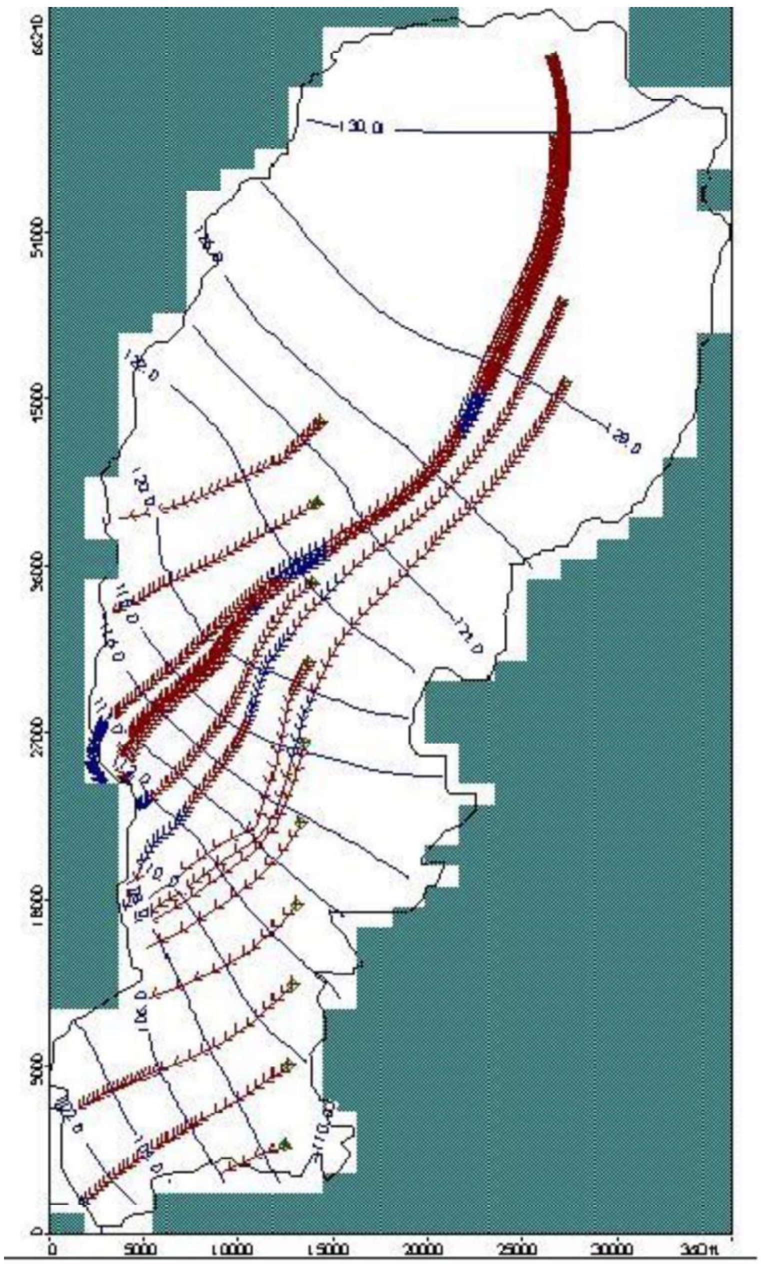


Figure. 33 Flow path representation of steady state
(forward tracking)

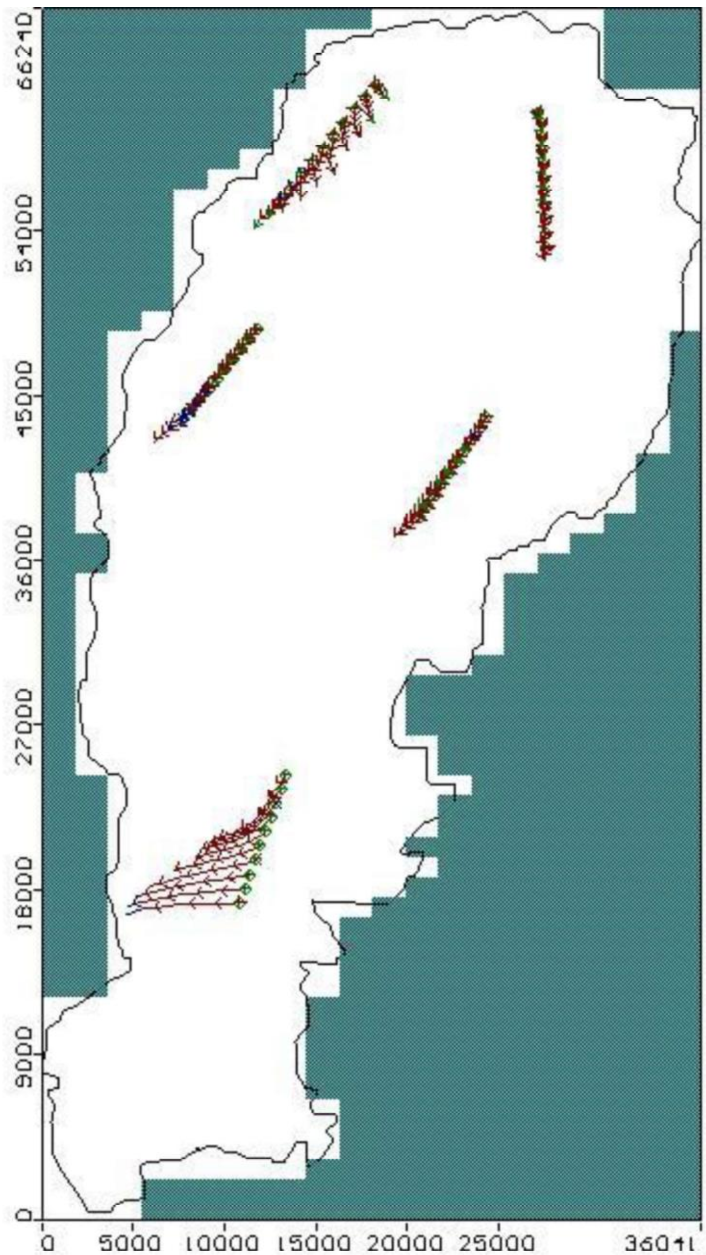


Figure. 34 Flow path representation transient state
(forward tracking)

The concept of particle tracking is adapted here for the evaluation of flow paths of the groundwater in the aquifer regime of the Nestle Factory & Surroundings. The particle streamlines show that the flow of the water is towards southwest directions (constant heads). Figure 33 is representing the flow paths of the particle in the steady state conditions. While

Figure 34 represents the forward particle tracking in transient state it depicts that rate of flow of particles decreases in the transient state.

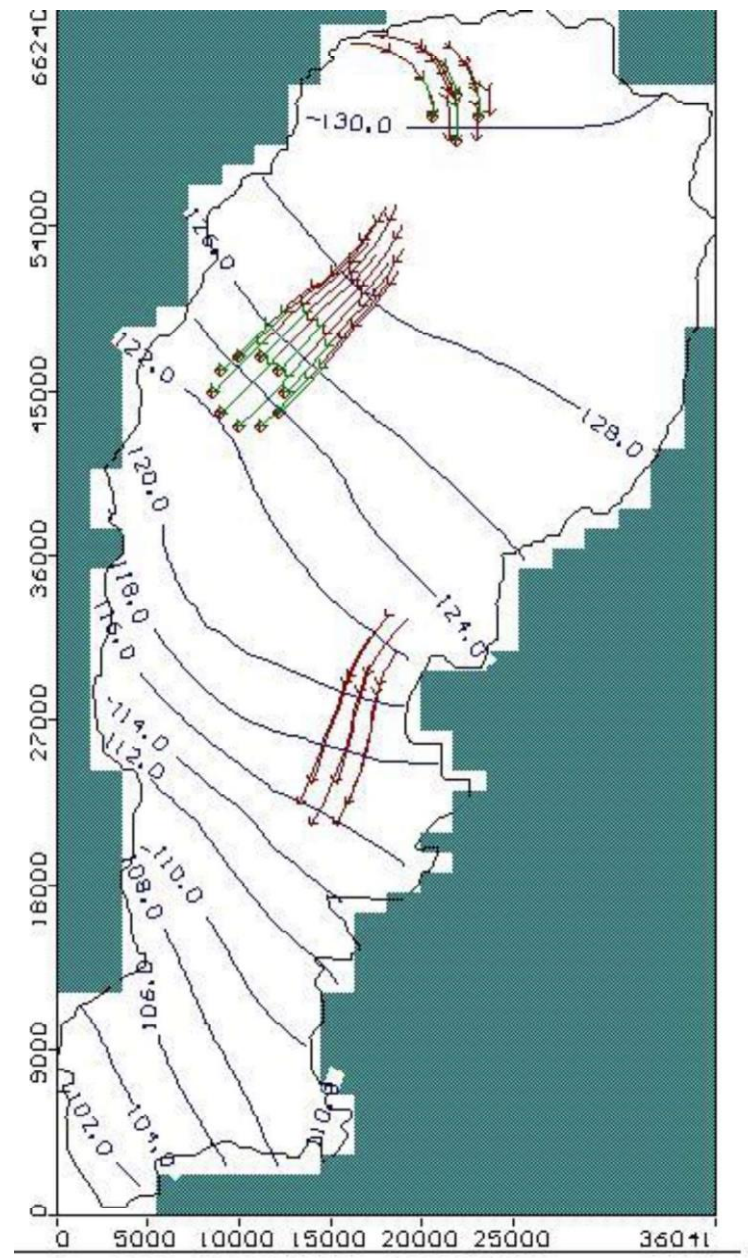


Figure. 35 Flow path representation to evaluate the source of arsenic (backward tracking)

In addition to forward tracking of the particles, backward tracking is also executed. If the backward tracking is executed on the concentration wells with contamination, we can determine the source of the contaminants on that point. Figure 35 represents the backward tracking of the particles from the concentration wells. This means if any concentration of contamination is found in a well it is going to adopt a south-southwest (SSW) direction.

19. Inferences

Results of the groundwater flow and transport of concentration using Visual MODFLOW has shown that direction of groundwater and contaminant concentration both move in the southwest (SW) and south-southwest (SSW) directions.

The model proved to be very useful in studying different scenarios of groundwater flow and monitoring contaminant transport in the Nestle Factory & Surroundings. The model calibration indicated a close relationship between the simulated and observed heads. In the steady-state calibration, residual mean was 0.103 m and correlation coefficient was 0.99. The groundwater heads vary between 110 m and 130.2 m range. The velocity magnitude is dominant in the lower part of the model while lowest velocity magnitude is found in the northeast.

Forward tracking in the steady-state depicted contaminant movement will be towards the rivers while in transient state flow paths tend to move in the southwest down the hydraulic gradient.

20. Location of ERSS in Nestle Factory Kabirwala

A base map provided in Figure 36 shows the distribution of electrical resistivity sounding (ERS) within the Nestle Factory Kabirwala. ERS data is used to effectively interpret the subsurface layers of water bearing formations (aquifers) using 1X1D-3V software. Geoelectrical units mainly various sizes of sands (FMC) acquired from the two (2) water well logs are used to standardize with the ERS interpreted data.

A map depicting background reference information such as landforms, roads, landmarks and political boundaries onto which other thematic information is placed. A base map is used for location reference and often includes a geodetic control network as part of its structure. (GIS Dictionary)

Electrical resistivity data were measured over 17 different locations within the Nestle Factory using Schlumberger electrode configurations.

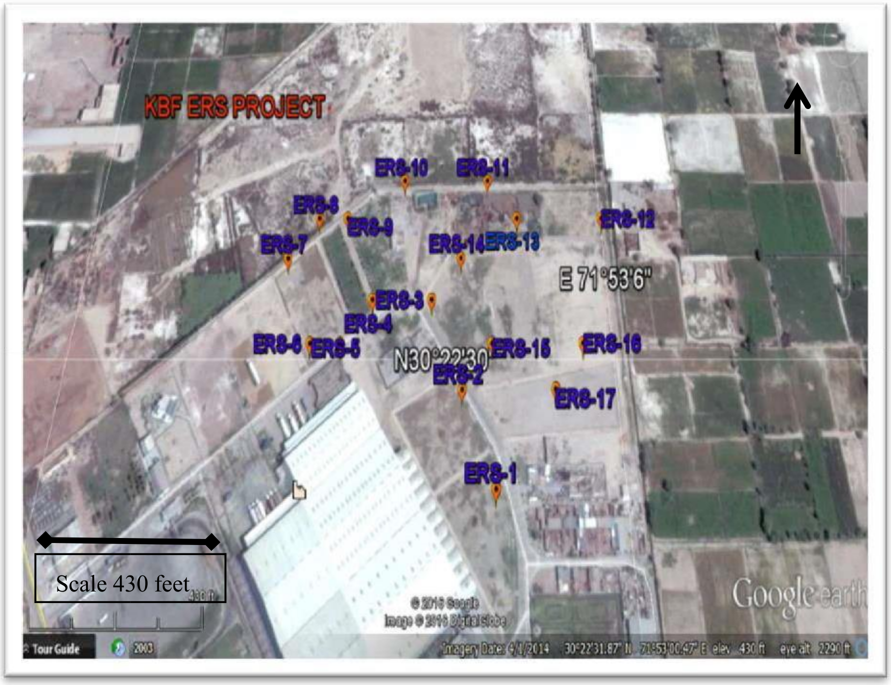


Figure 36. Location Map of Electrical Resistivity Sounding Survey (ERSS) over 17 different points, Nestle Factory Kabirwala

21. Climate in the Vicinity of Nestle Factory

The climate of the Nestle Factory Kabirwala is hot and dry. Nearest observatory managed by the Pakistan Meteorological Department is Multan.

- The summer season starts in April and continues until October. May, June and July are the hottest months. The mean maximum and minimum temperatures for these months are about 47°C and 28°C. Dry, hot and dusty winds are common during summer.
- The winter season lasts from November to March. December, January and February are the coldest months. The mean maximum and minimum temperatures for this period are about 22°C and 4°C. Fog is very common during winter.

Most of the area's rainfalls during the monsoon season from July to September. During winter season, there is very little rain; however, floods can occur often.

22. Rainfall and Temperature Affects the Underlying Aquifers

Changes in future climate will change the regional hydrologic cycles and subsequently impact the quantity and quality of regional water resources (Gleick, 1989). While climate change affects surface water resources directly through changes in the major long-term climate variables e.g. air temperature, precipitation, and evapotranspiration, the relationship between the changing climate variables and groundwater is more complex and difficult to enumerate.

Groundwater resources are related to climate change through the direct interaction with surface water resources, e.g. lakes and rivers, and indirectly through the recharge process. Therefore, quantifying the impact of climate change on groundwater resources requires not only consistent forecasting of changes in the major climatic variables, but also accurate assessment of groundwater recharge.

Groundwater recharge is part of the vadose zone soil water budget, which is driven by precipitation.

Recharge rates can be extensively impacted by human activities such as urbanization, which influence the rates through increased impervious cover; leakage from water distribution systems, sewers, and septic tanks; and over-irrigation of parks and lawns (Lerner, 2002).

Groundwater recharge is affected by many complex parameters and processes, which themselves are influenced by many factors. Precipitation is affected by climatic factors such as wind and temperature, resulting in a very complex and dynamic distribution. Vegetation influences recharge through the processes of interception and transpiration, and other less commonly characterized, yet potentially significant processes such as stem flow and through fall (Le Maitre et al., 1999 and Taniguchi et al., 1996).

Arguably, these processes are very difficult to quantify since they are dependent on a multitude of climatic parameters, such as intensity and duration of rainfall, temperature, and wind speed, as well as the physical characteristics of the individual plants (Larcher, 1983).

Plant roots also play an important role in the recharge process not only by enabling plants to draw water from deep in the vadose zone (and even from the saturated zone) thereby reducing the amount of percolating water that reaches the water table, but also be creating preferential flow paths and channels that aid water flow through the soil profile (Le Maitre et al., 1999).

The results of the study indicate that the overall rate of groundwater recharge is predicted to increase as a result of climate change. The higher intensity and frequency of precipitation will also contribute significantly to surface runoff, while global warming may result in increased evapotranspiration rates.

Warmer winter temperatures will reduce the extent of ground frost and shift the spring melt from spring toward winter, allowing more water to infiltrate into the ground. While many previous climate change impact studies have focused on the temporal changes in groundwater recharge, our results suggest that the impacts can also have high spatial variability.

23. Temperature

Temperature is divided into Rabi (Oct April) and Kharif (May-Sep) because of the study area has significant values in agriculture. Temperature is further distributed in minimum and maximum classes which are shown in Figures from 37 to 39 for Multan city as it is the closest observatory to Nestle Factory Kabirwala. Figure 39 represents the mean temperature of the Multan observatory. Spatial distribution of minimum and maximum temperature is shown in Figures 40 and 41.

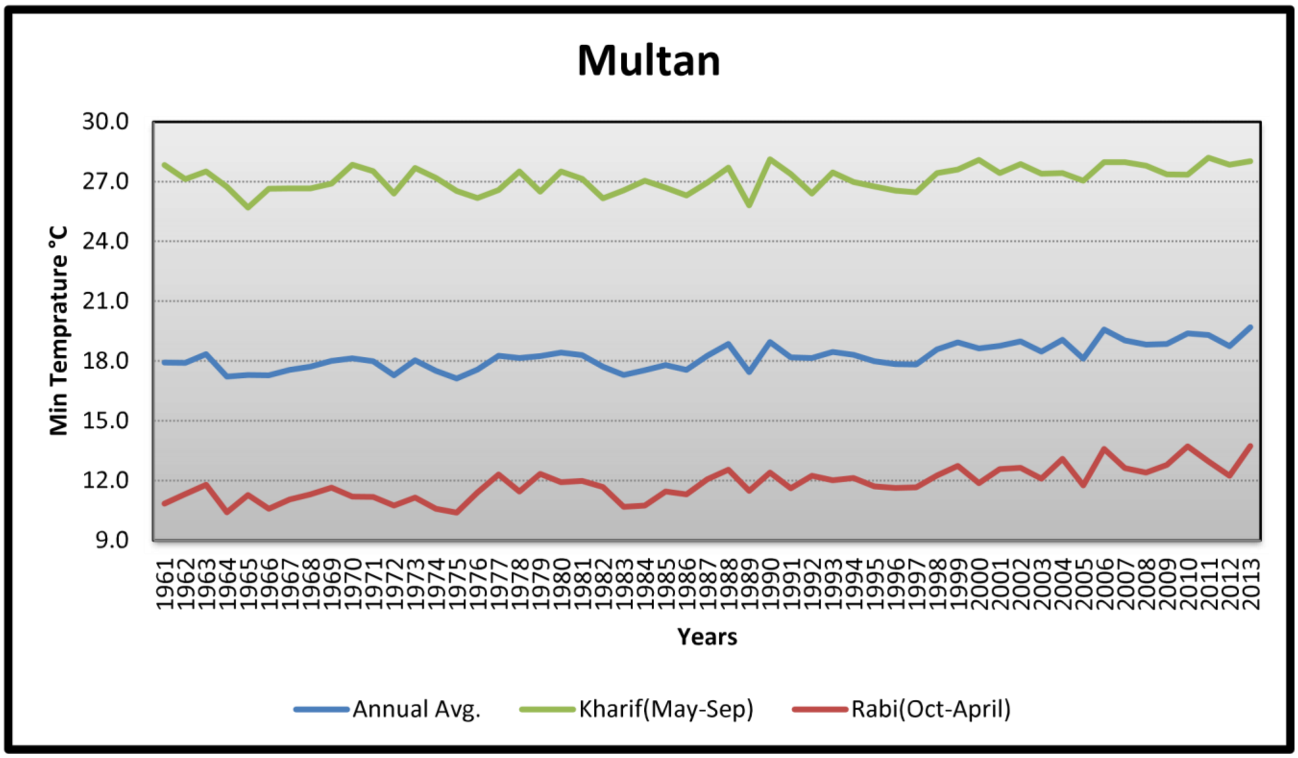


Figure 37. Minimum Temperature of Multan Observatory

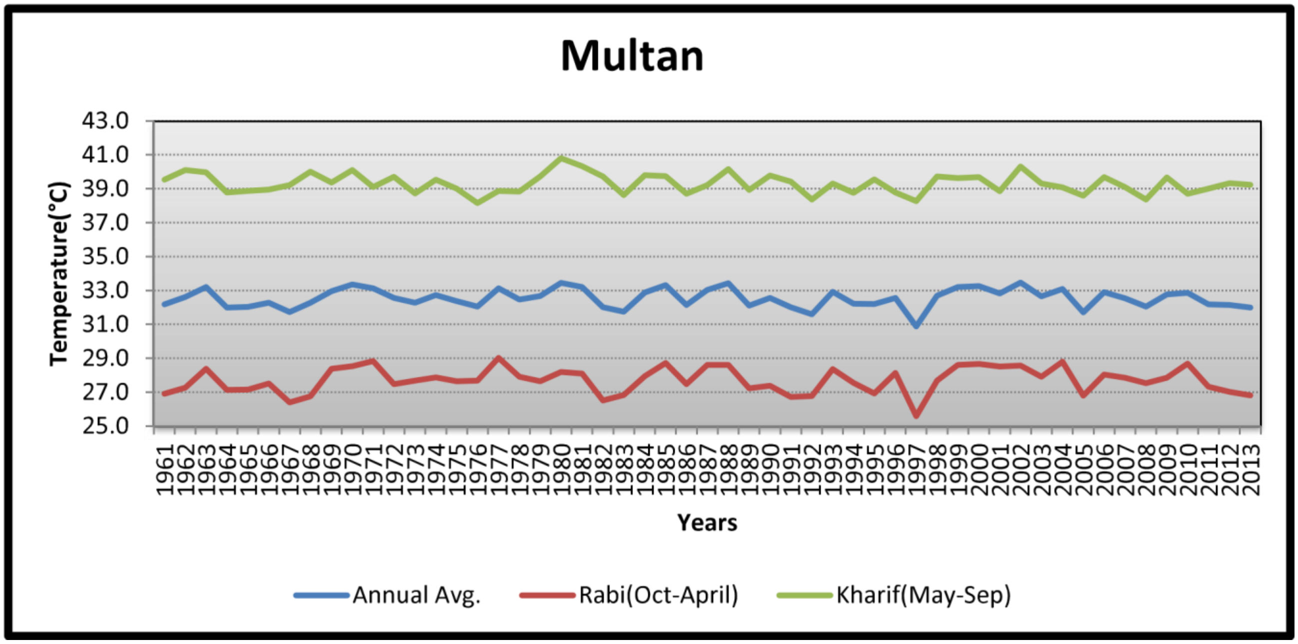


Figure 38. Maximum Temperature of Multan Observatory

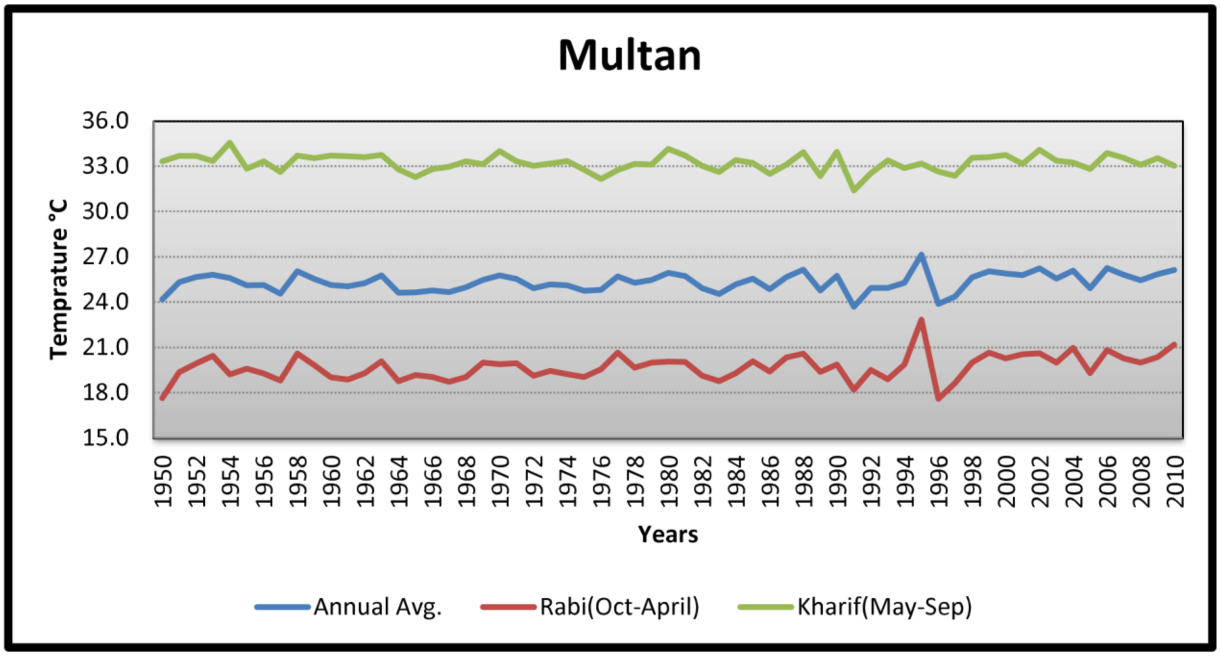


Figure 39. Mean Temperature of Multan Observatory

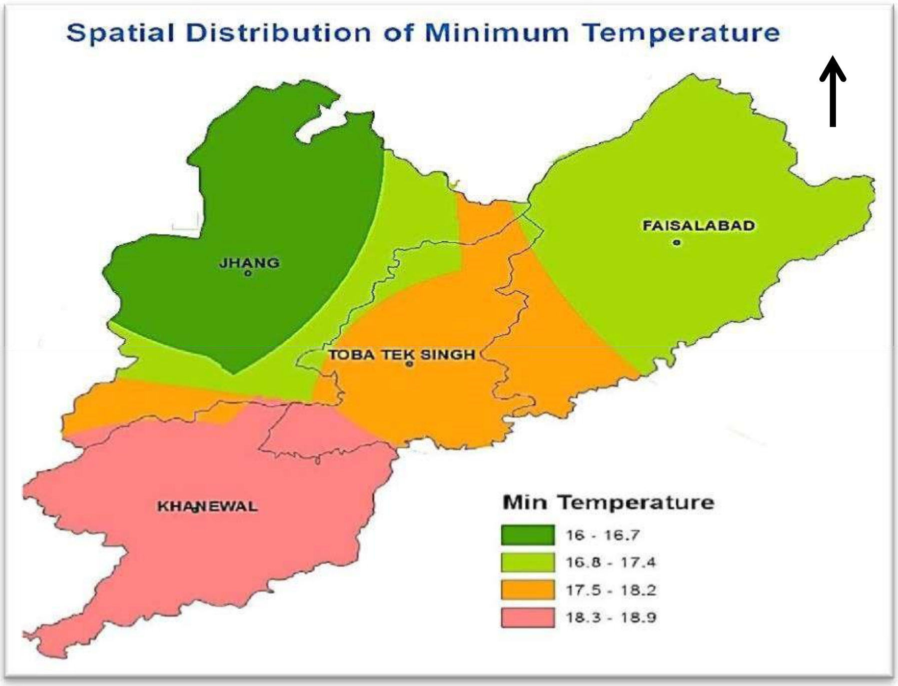


Figure 40. Spatial Distribution of Minimum Temperature

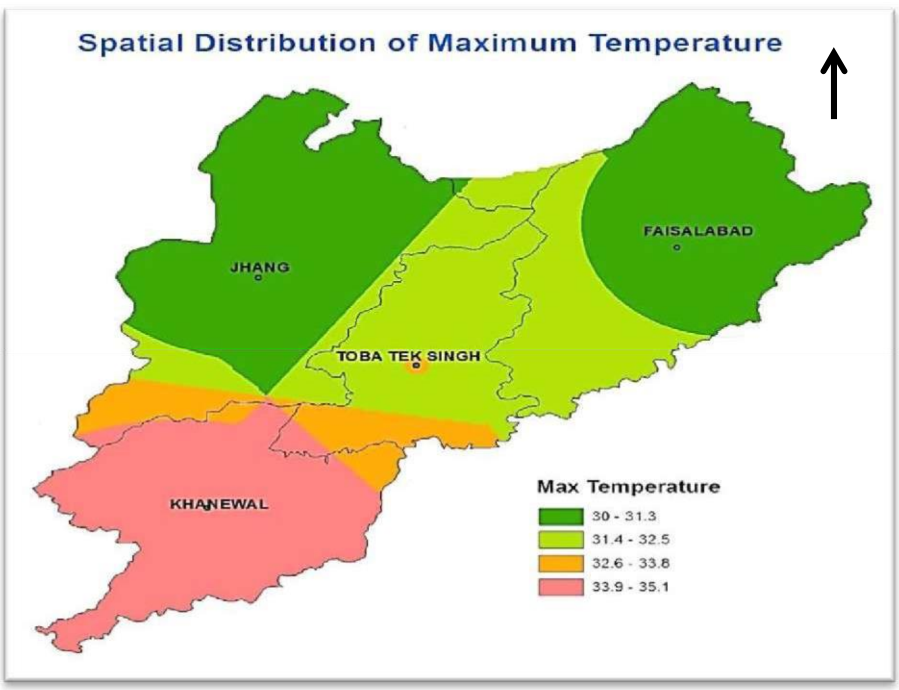


Figure 41. Spatial Distribution of Maximum Temperature

23.1 Rainfall

Rainwater is vital source for agriculture, human beings and animals that falls on the surface of earth. Agriculture production in Pakistan is highly dependent upon precipitation, which either fall in the form of rain or snow. Also under lying aquifers affect from the rainfall.
Not all that is useful somewhat a part of it is effective. This study deals with “effective rainfall”, i.e. useful rainfall. Agriculturists consider the portion of rainfall effective that directly satisfies crop water requirements. The effective rainfall have been projected for two crop growing seasons, i.e. Rabi (October to April) and Kharif (May to September) (Adnan and Azmat, 2009).

The arid areas of Pakistan where the evapotranspiration rate is very high and water table is shallow, an increase in air temperature may cause loss of water rapidly and consequently the aridity would increase. If the evapotranspiration rate continues to increase then the water reservoirs in the form of small dams, ponds and streams etc. would dry more rapidly and water shortage may entrap humans along with plants. Almost two third areas of the country lie in arid zone. Pakistan fulfills its water requirement from winter and summer rainfall along with the melting of snow fall from the glaciers (Chaudhry and Rasul, 2004). Due to global warming, variability of summer rainfall has considerably increased and glaciers have started melting at a much faster rate than observed before (Rasul, 2008). The annual rainfall of Multan observatory along with its spatial distribution is shown in Figures 42 and 43, which tells us the trend and quantity of rainfall in these areas.

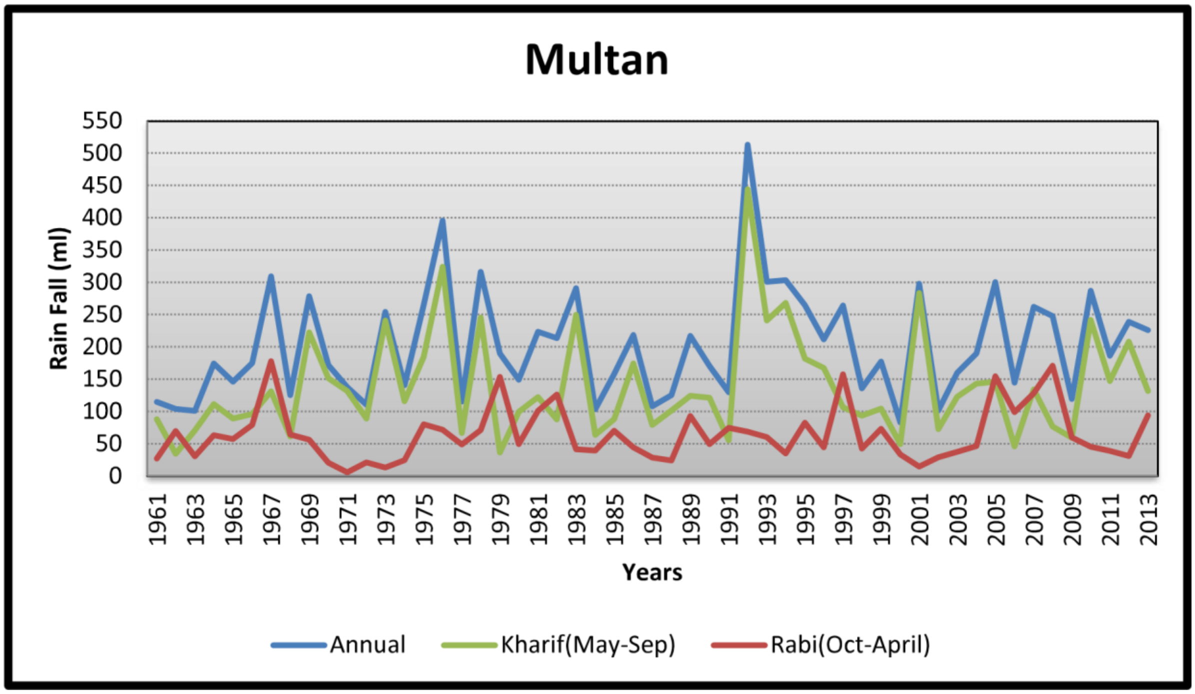


Figure 42. History rainfall in the Multan Observatory closest to Nestle Factory

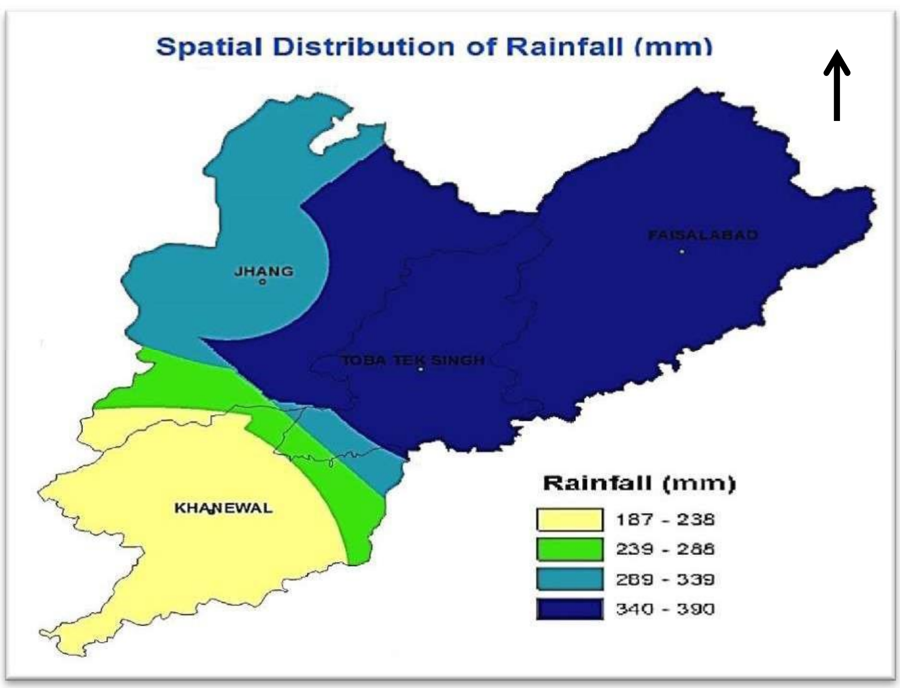


Figure 43. Spatial Distribution of Rainfall. Khanewal being the closest to Nestle Factory

24.0 Agriculture and River, Canal Command System

The district consists of plain area with fertile land. It is a part of Indus plain. It has the best cultivated land which is suitable for cotton, wheat and other agricultural crops. Its land is irrigated with the fertile water of the Chenab and the Ravi rivers along different diverted canals.

24.1 Nullahs and Climatic Variations

The Chenab River is known as the main river and the Ravi River is the tributary. Sindhnai Canal is main canal that leads to some minor canals like Kabirwala minor. These canals are the source of recharge in the underlying aquifers mainly composed of sand formation.

Standardization of resistivity values are made with the known information of lithology acquired from 2 existing water wells in Nestle Factory Kabirwala. Behavior of climatological variations is made using Temperature and Rainfall data from Multan observatory.

25 Hydrogeology of the Area

25.1 Nestle Factory between Kabirwala and Khanewal (Lower Bari Doab) Bari Doab, shown in Figure 44, is surrounded by the Ravi and the Chenab Rivers on the northwest and west, and by the Sutlej River in the south east. It is located between latitude 29°30′ to 31°45′ N and longitude 71°to 74°45′ E. It has an area of 12, 150 square miles. Even though the North Eastern boundary of the Doab lies near the foot hills of the Himalayan Ranges but politically this boundary almost coincides with that of Lahore District. It is composed of a central, slightly raised and relatively flat tableland bounded by the flood plains of the Ravi, the Sutlej and some of the Chenab River.

Most of the area of Lower Bari Doab is a flat and tedious plain. The area is bounded by the flood plains of the Ravi River, the Sutlej River and some parts of the Chenab River. The alluvial plain slopes from about 220 meters in the northeast to about 98 meters in the southwest above sea level. The only prominent relief features the steep bluffs, 20 to 30 feet high, which face the flood plains of the Ravi and the Sutlej Rivers in the upper part of the Doab (Kidwai and Alam, 1964).

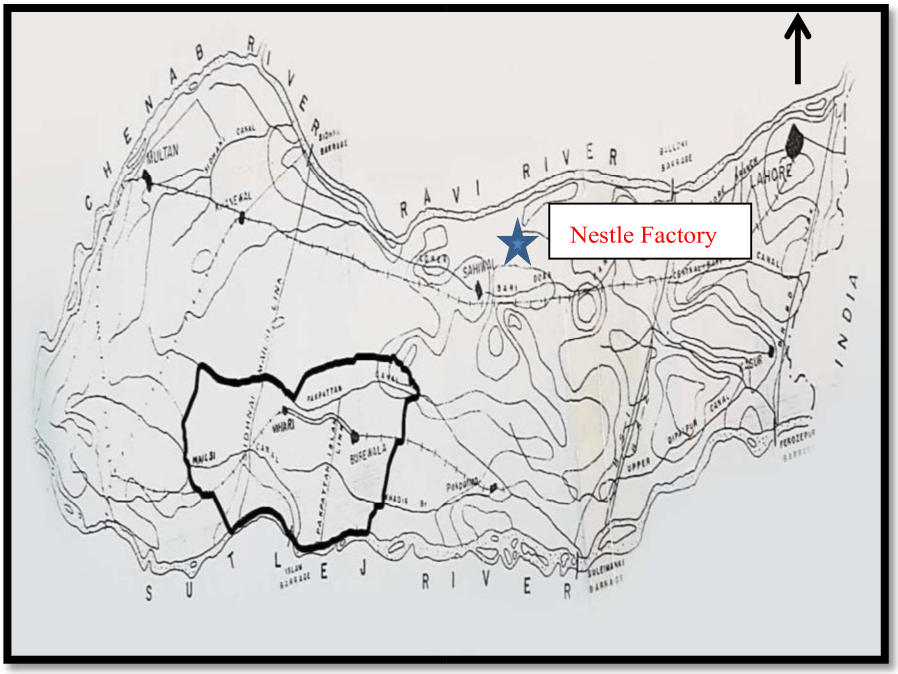


Figure 44. Nestle Factory is bounded by the Ravi, the Chenab, the Sutlej

25.2. Climate of in and around Nestle Factory Kabirwala

The climate of the area is arid to semi-arid. The mean annual precipitation in Bari Doab ranges from 4 inches in the South to 28 inches in the North. Two third of this precipitation occurs in the four summer months, the remaining being spread over the rest of the year.

25.3. Agriculture in and around Nestle Factory Kabirwala

The agriculture in Bari Doab is the major occupation. The Southern part of the Bari Doab falls in the rice and wheat zone. Kharif crops include primarily cotton, rice, fodder and also maize. In the Rabi season, the most important crops are wheat and fodder. The recurrent crops are sugar-cane and fruits.

25.4. Physiography of Upper Bari Doab near Nestle Factory and Surroundings The Doab is composed of three physiographic units which are as follows:

1. Present Flood Plains
2. Abandoned Flood Plains
3. Bar Uplands

25.5 Present Flood Plains

This area is locally known as Sailaba. During the active season of the present rivers, a narrow strip of 2 to 8 miles in width because of the floods and meandering making thereby characteristics topographic features like natural levees, swales and sand bars. The flood plains of the Chenab and the Sutlej are wider than the Ravi and are scarcely inhabited and cultivated (Nazir, 1974).

25.6 Abandoned Flood Plains

It covers about two thirds of the Doab area. It has general low relief shaped by meandering courses of former streams. The area around Ox-bow lakes, segments of stream channels and natural levees which show to the presence of streams, nullahs up to comparatively recent time. The area was occupied by old channels of the Ravi, the Sutlej and the Chenab Rivers and also by the Beas River whose former channel can be traced throughout most of the Doab. This area is generally 5 to 15 feet above the present flood plains. However, the low lying portions may be flooded during high flood seasons.

A brief discussion about the different abandoned flood plains of the Sutlej, the Ravi and the Chenab rivers is given below:

25.7 Abandoned Flood Plains of Sutlej and Beas

This is a remarkably wide zone of about 30 miles between the Sutlej and former the Beas Rivers in the Doab. Photo mosaics of the area show the combined activity of these rivers in the upper part of the Doab from Kasur to Pakpattan. The area is covered with remnants of previous courses of the major rivers and their tributaries.

Evidence exists in photo mosaics that the Sutlej oscillated over an area 10 to 30 miles wide in the Doab, forming confluence with the Beas at different places. Two of these are the most distinct, one is near Jandwala and Maulpur near Chunian; and the other is near Kamir. Channels can be traced without break for long distances in this portion. The soil is sandy with high water table which is alarmingly tells us this area with water logging and salinity. Towards the southwest, it seems that the two streams (the Sutlej and the Beas) have maintained relatively stable courses, because the area from Arifwala to Dunyapur is interfluvial with few or two ontrenched channels. These depressed areas are cultivated and are never under water in any part of the year.

From Dunyapur southward upto Punjad Headworks, the area is similar to that of Northern part described above except that at some places it is covered with sand dunes.

25.8 Abandoned Flood Plains of Ravi River

The highly steep banks that parallel to the Ravi River from Lahore to Balloki form the boundary of the present flood plain. The scarp of an older terrace 5 to 6 feet higher than the present flood plain, takes a southerly turn from Balloki passing through Hala, Renala and Okara. It merges with bluffs of the lower level near Chichawatni. The area between these two scarps represents the abandoned flood plains of the Ravi. There is a broad and long levee parallel to the Ravi which divides the abandoned flood plain into two depressions. The Gujera branch of Lower Bari Doab canal passes over the highland formed by this levee. As there is broad depression between the levee and the bar upland, there is considerable water logging due to seepage from the Gujera distributary and its branches from the levee side and from Lower Bari Doab Canal and the branches from the bar side. As compared to abandoned flood plain of the Sutlej, South of Kasur to Pakpattan, there is less evidence of river action such as ox-bow lakes, natural levee and bars in the former flood plains of the Ravi. The only prominent channel in the area is Sukhrwala Nala, which appears to be the abandoned course of the Ravi River. This nala is prominent from the neighborhood of Mirak, some 15 miles northeast of Okara to Harappa where it ends. Sukhrwala nala at one time carried a large volume of water, but now it has been converted into a drainage channel.

Most of the land in this part of the Doab is under cultivation. High and low lands occur alternately. The depressions always contain more or less clayey deposits. In general the water table is high and the land from Hala to Okara is water logged and saline.

In Lower Bari Doab, a part of the abandoned flood plain can be attributed to two historical changes in the course of the Ravi River about 200 years ago.

1. The first course is from Talamba via Rashida and Tallipur to near Multan. This course is marked by slightly lower level of the land straight away south of Talamba and by some marked depressions near Rashida and Tallipur. This abandoned course is inundated during ovary flood seasons.

2. An abandoned channel extends from the Lower end of Sindhnai reach southwards, and joins the older bed near Rashida. This course is slightly higher than the older bed and lies almost in the center of the area now irrigated by Sindhnai Canal (northwest of Nestle Factory).

25.9 Abandoned Flood Plains of the Chenab

This part of the abandoned flood plains of the Bari Doab, although subject to the action of both the Chenab and the Ravi, is almost free from any distinct channel marks or signs of river action and is an almost uniformly level plain.

25.10 Bar Upland

An interfluvial strip of land, 10 to 20 miles wide, between the Ravi and former the Beas Rivers, run almost parallel to these rivers in the central part of the Doab and is known as Bar Upland.

It is separated from the adjacent flood plains in the north eastern end of the Doab by steep scarps about 30 feet high which decreases in highest downstream from Balloki and Chunian. Downstream from Sahiwal the bar upland is vague, its elevation being 5 feet or less above the adjacent abandoned flood plains (WAPDA, 1980).

The above description shows that the two rivers i.e. from Lahore to Balloki by the River and from Kasur to Chunian by the Beas River and lowered the base level. The two streams, in the process of adjusting their longitudinal projects, have cut steep banks along a reach of about 50 miles.

The Bar upland is an almost uniformly level plain with very little relief, however, photo mosaics and topographic maps show traces of some channels that crossed it in the distant part. The most important channel, whose course is very prominent on the photo mosaics, is the Hudaira Rohi, which occupies a two to four miles wide depression of land some 13 miles South of Lahore. It parallels the Ravi from Hudaira village to Pattoki and drains a major part of the area north of upper Bari Doab Canal into the Ravi.

Another depression in the area between Sahiwal and Harappa suggests that a channel from the Ravi extended across the bar upland southward towards the flood plain of the Beas (Kidwai and Alam, 1964).

26. Geology of the Nestle Factory and Surroundings

Nestle Factory falls with the The Lower Bari Doab area is a part of the Indo-Gangetic Plain and has a geologic history similar to Reachna and Chaj Doabs (Kidwai, 1963). Bari Doab is covered by Quaternary alluvium which presumably over lies semi-consolidated Tertiary rocks or metamorphic and igneous rocks of Precambrian age (WAPDA,1980). Except for a small area in the northeastern part of the doab, where the basement rock was encountered by deep test holes, no information is available at present regarding the distribution of Tertiary and Precambrian rocks (bedrock) in the doab.

26.1. Precambrian Basement Rock

The oldest rocks, the well-known Kiranas of Precambrian age, have been mapped in Chaj and Rechna and are discussed in detail in WASID’s Bulletin 5 (Kidwai, 1963). They are completely hidden by Quaternary alluvial deposits that cover the Bari Doab. There are many comparatively deep test holes were drilled in Bari Doab to determine the thickness of the alluvium, the depth to bedrock and its nature, and the quality of water at deeper zones. Many tests holes were over 600 feet deep, and 33 were from 800 to over 1000 feet deep. Of the later 19 test holes were located in the northeastern part of the Doab to explore the probable extension of the Delhi-Shahpur buried ridge, a structure on the Precambrian basement. Of these, only 3 test holes namely BR-1A, BR- 6 and BR -7 reached Precambrian basement rock at 1252, 1021 and 928 feet respectively (WAPDA, 1980).

26.2. Unidentified Unit

In the northeastern part of the doab several deep test holes penetrated red clays and gravel of fluviatile origin which have noticeably difference from the overlying Quaternary alluvial complex and are described separately as an Unidentified Unit.

The alluvial material covering the Lower Bari Doab, forms part of the extensive heterogeneous and isotropic unconfined aquifer underlying the Indus plains and this material was founds at a depth of about 1,000 feet, and consisted of interbedded red clays and gravels that differ from Quaternary alluvium. The clays and silts are dark red; the gravels are quartzite, granite, chert and limestone, are devoid of kanker and are more compact. The general color of the Quaternary alluvium is earthy brown or grey and the gravels reported in the test holes logs are siltstone and mudstone of concretionary origin, and nodules of kankers (Bennet et al., 1967).

The unidentified unit of red clays and gravels should be considered separate from the alluvial complex, the material in test holes 9,17 and 142 apparently represents two distinct formations at these sites; the characteristics alluvium extends to depths of about 1000 feet. And this is underlain by the unidentified unit of red clays and gravel. It is believed that the unidentified unit was reached also in a few other deep test holes. However, in three test holes which reached the Precambrian basement rocks, this unit was absent. In test holes 6, 7 and 1A, the quaternary alluvium overlies the Precambrian basement rocks, separated by a zone of weathered bedrock. Lack of determination of the stratigraphic position of this unit, however, at Karampur, about 14 miles northwest of Islam Headworks, a deep exploratory well drilled by Pakistan Petroleum Ltd., has encountered a complete sequence of rocks below the alluvium ranging in age from Cambrian to middle Pleistocene (Kidwai and Alam, 1964).

26.3. Quaternary Alluvial Complex

Except in a small part of the northeastern corner, drilling in Bari Doab has not exposed a complete section of the alluvium overlying the basement. Even the deepest hole, drilled to 1350 feet, bottomed in the alluvium.

Study of the lithologic holes of 149 test holes and 28 tube wells by Wapda provides a fairly good idea about the texture and structure of the heterogeneous alluvium to a depth of 600 feet.

The Quaternary alluvial complex within the Doab consists of unconsolidated sand, silt and silty clay with variable amounts of kankers. The sands are mainly grey or grayish-brown, fine to medium grained and sub-angular to sub-round. Very fine sand is common. Finer grained deposits generally include sandy silt; silt and silty clay are rare in the area. This has been confirmed to some extent by the study of a small number of core samples (Kidwai and Alam, 1964).

Gravels of hard rock are not found within the alluvium and coarse or very coarse sands are uncommon. Gravels have been reported by the geologists in the drilling logs, but a closer examination of samples has shown that these are mudstones, siltstones and kankers of concretionary origin.

The lithology of the alluvial complex is inferred from the study of well samples and electric logs. The dominant material in the upper (northeastern) and central part of the Doab, from BR-1 to BR-28 is fine textured silt and silty clay, mixed with concretions of kankers, siltstone and mudstone; sand is found commonly in thin layers of limited extent (Wapda).

This area seems to be the extension of the belt of fine material along the buried ridge in Rechna Doab. Further southwest, in the Lower Bari Doab area are more extensive (Kidwai,1963).

27. Principle of Electrical Methods

In electrical method the current is introduced in the ground and detect surface effect (i.e. Potential drop) due to subsurface medium. The electrical methods that are used for geophysical prospecting are broadly divided into two types, natural sources and applied sources. In electrical methods we measure potential, electromagnetic field and current either produced by natural or artificial source. In addition these measurements are made by using different arrangements according to objective and field constraints. Electrical methods are quick and cheap relative to other prospecting methods (Telford et al., 1990).

A relationship between resistance (R), current (I), and the change in potential (V) is established by George Simon Ohm in 1827 which is the base of electrical methods and expressed as:

$$V = I \times R \text{ (Voltage = Current multiplied by Resistance)}$$

Where,

V = Voltage, or electromotive force (EMF) and measured in Volts

I = Current, or charge per unit time and measured in amp

R = Resistance measured in ohms

The resistivity is the intrinsic property of all types of material of earth which describe the resistance of the materials and we also know that the earth is not homogenous so the resistivity changes vertically and laterally as well. If there is medium then the resistivity is defined as

$$\rho = RA / L \text{ (Ohm-m)}$$

Where,

ρ = Resistivity (ohm-m)

R = Resistance offe red by material (Ohm's)

L = length of medium (meters) A

= cross sectional area (m^2)

27.1. Types of Electrical Methods

Electrical methods generally fall into two categories:

1. Those in which current is applied to the earth and
2. Those using natural energy sources

27.2. Applied Current Methods

In electrical resistivity (ER) methods, direct or low-frequency alternating current is applied at the ground surface and potential difference (voltage) is measured between two points. Induced polarization (IP) is a technique that uses the time-dependent decay of the potential difference to obtain information about the polarization properties of the earth materials. A third method, electromagnetic surveying (EM), uses a primary electromagnetic field produced by alternating current to induce a secondary field in subsurface conductive bodies. The difference between the primary and secondary fields provides information on subsurface characteristics (Burger, 1992).

27.3. Natural Current Methods

Natural current methods take benefit of naturally occurring currents in the earth. Tellurics is the method of measuring the potential differences at the earth's surface resulting from variations in the flow of natural (telluric) currents through earth mate- rials. Magnetotellurics is similar but measures the magnetic field as well as the electric field. Spontaneous potential (SP) is another method that detects potential differences arising from electrochemical effects in subsurface bodies, for example, ore bodies that lie partly above the water table.

27.4. Electrical Resistivity Methods

Electrical resistivity method is most useful and nondestructive technique in subsurface water exploration. The idea of electrical resistivity measurement to study the subsurface rocks is given by Schlumberger 1912. Resistivity has long been used to detect the subsurface hydro geological and geomorphological features and bedrock [(Stewart et al, 1983), (Courteaud et al. 1997), (Louis et al. 2002), (Zouhri et al. 2004), (Schrott & Sass, 2008), (Edmund A., 2009), (Hsu et al. 2009), (Alile et al. 2010), (Okoro et al. 2010) and (Riddell et al. 2010)]. Electrical resistivity is also strongly related to clay content in fresh water aquifer systems, with most clays acting as good electrical conductors and progressively coarser sediments behaving as poorer conductors (Yazicigal and Sendlein 1982). Resistivity data can thus be directly related to subsurface lithology, although the solution is generally non-unique and of low resolution in comparison to well logging. Several studies have demonstrated a strong correlation between resistivity and aquifer properties such as porosity, permeability, transmissivity and hydraulic conductivity [(Kelly 1977; Kelly and Frohlich

1985; Mazac et al. 1988 and Ahmed et al. 1988)] although in general this is a more difficult correlation to establish than to lithology.

(ER) can provide moderately detailed information about the subsurface in areas with reasonable resistivity contrasts (Burger, 1992), provides a list based on his personal experiences for commonly encountered conditions as shown in Table 4.

Table. 4 Resistivities of Common Shallow Subsurface Conditions

Material	Resistivity (ohm.m)
Wet to moist clayey soil and wet clay	1 to 10
Wet to moist silty soil and silty clay	Low 10
Wet to moist silty and sandy soils	10 to 100
Sand and gravel with layers of silt	Low 100
Coarse dry sand and gravel deposits	High 1000
Well-fractured to slightly fractured rock with moist-soil-filled cracks	100
Slightly fractured rock with dry, soil-filled cracks	Low 1000
Massively bedded rock	High 1000

Another useful list is found in (Ward, 1990), who presents resistivity ranges for common geological materials as shown in Figure 45. Note the variation in resistivity over six orders of magnitudes for these common materials. The main advantages of ER methods are their low cost and simple equipment requirements.

When current is injected into the ground in an ER process by using a pair of electrodes, the patterns of subsurface current flow reproduce the resistivities of the subsurface. These patterns can be incidental by measuring the variations in voltage at the surface using another pair of electrodes.

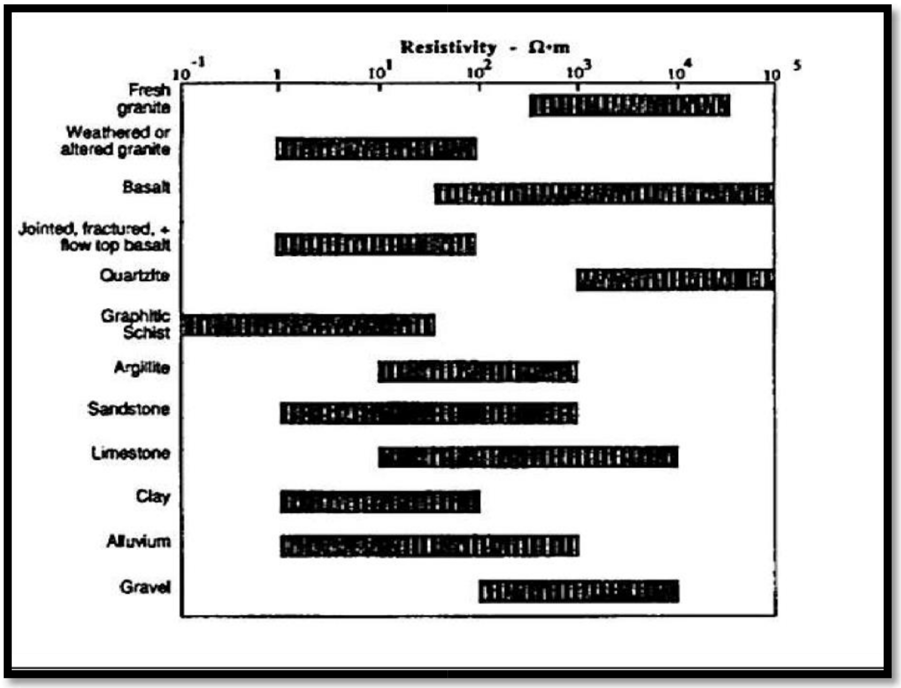


Figure 45. Range of Resistivities of Common Rocks and Soils (Ward, 1990)

27.5. Electrode Configuration

The electrode patterns used in resistivity surveying are called arrays. The usually used arrays are the Wenner, Schlumberger, and dipole-dipole. Other arrangements are used that are variations of these basic types but these have withstood the test of time. (www.subsurfacesurveys.com)

28. Electrical Resistivity Survey

The physical property which we measure in electrical resistivity survey is resistivity and expressed in ohm-m. The basic goal of electrical resistivity survey is to measure this physical property to understand the structure of the earth or to distinguish different rocks.

The basic principle of D.C resistivity measurement is shown in the Figure 46. In this method direct current use as a signal and measures the resulting potential. The amount of current passing through the formation is depending upon the potential difference. Four metallic electrodes are used A, B, M and N. A, B are current electrodes and M, N are potential electrodes. The current electrodes are connected to battery to create an electric circuit, an Ammeter also connected in this circuit. A voltmeter is connected between potential electrodes to measure the potential difference. For simplicity of our calculation all four electrodes are collinear (Robinson and Coruh, 1988).

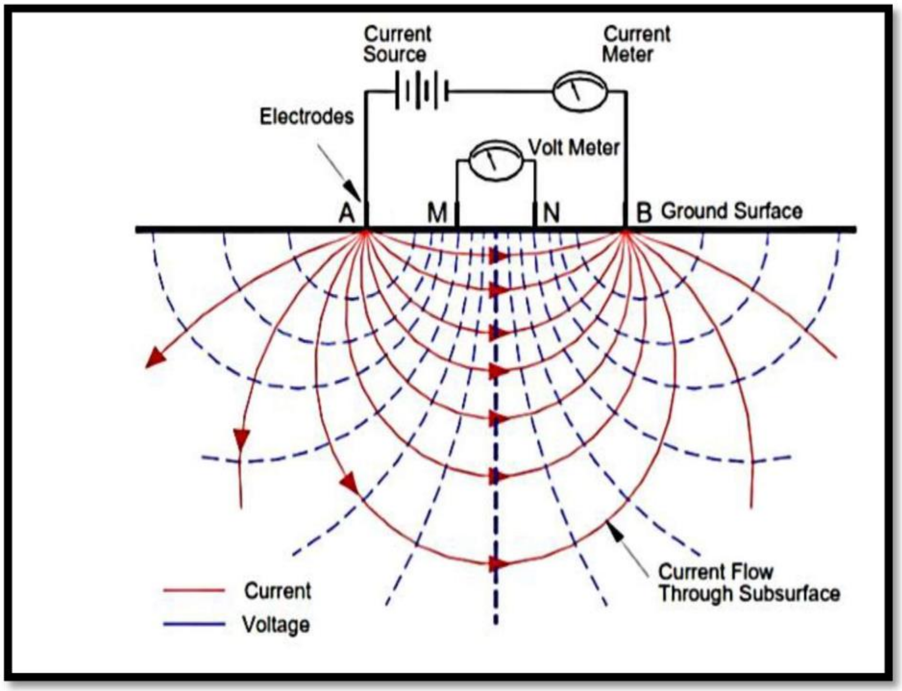


Figure 46. Basic concept of Electrical Resistivity Measurement (Todd, 1980)

From the value of potential difference (V), the current (I) and the distance between outer (AB) and inner (MN) electrodes the apparent resistivity is calculated. The current is already known which is introduced in the subsurface. The potential at electrodes M and N is measured to measure the potential difference. The electric potential at M and N is

$$V_M = \pi / 2 \text{ x } \pi \ (1/AM \quad 1/MB)$$

And

$$V_N = \pi / 2 \text{ x } \pi \ (1/AN \quad 1/NB)$$

Thus the total electric potential difference between these two points is

$$V_{MN} = V_M - V_N = \pi / 2 \text{ x } \pi \ [(1/AM \quad 1/MB) - (1/AN \quad 1/NB)]$$

It can also rearrange as

$$\rho = V_{MN} / I \times k$$

Where

$$K = 2 \text{ x } \pi \ [(1/AM \quad 1/MB) - (1/AN \quad 1/NB)]$$

‘K’ is geometric factor and depends upon the arrangement of electrodes. The resistivity which is measured by these surface electrodes is apparent resistivity and depends upon apparent resistance (V/I) and geometric factor (K). The value of K depends upon the position of electrodes on the ground and it represents the subsurface stratification in the equation (Robinson and Coruh 1988, Keary et al., 2002). Electrical resistivity surveying is carried out by using different electrode configurations that are used according to the requirement. These configurations are categorized according to the electrode arrangements. The most commonly used configurations are Wenner and Schlumberger. Different types of configurations are shown in Figure 47.

29. Surveying procedure

There are two modes of resistivity surveying are most commonly used in hydro geological investigation that are profiling and Sounding. In case of profiling electrodes have fixed spacing and measurements are made by moving the center point of array along the profile and if reading obtain along several profiles then contour map is generated. In profiling usually Wenner and Schlumberger configurations are used.

- Changes in depth to water table
- Map paleo-channels
- Map faults
- Delineate disposal areas

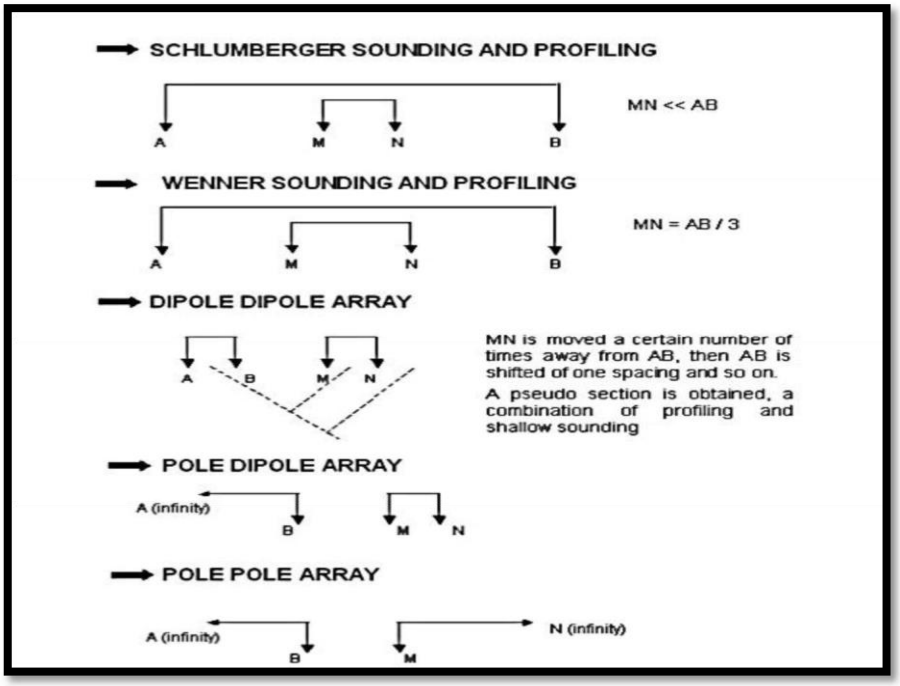


Figure 47. Commonly used Configurations

30. Apparent and True Resistivity

The instrument readings are reduced to resistivity by using an equation given below:

$$\text{Resistivity } (\rho) = \text{coefficient} \times \text{Voltage/ Intensity} = K\ \Delta_{V/I}$$

The resistivity which is calculated by the above relation is not a true resistivity because the earth is not homogeneous. The resistivity is apparent resistivity and changes with changing the arrangement of electrodes. On the other hand at greater depth there is a small effect on apparent resistivity as compared to shallow depths. So this method is not effective to establish the actual resistivity at greater depth (below few hundred meters).The resistivity values that are calculated in the field are not true resistivities but these are apparent resistivities that gives combine effect of all layers and materials. Apparent resistivity is defined as the bulk average resistivity of all soils and rock influencing the current. The true resistivity is calculated from the apparent resistivity. The relationship between apparent and true resistivity is complex and to calculate true subsurface resistivity the apparent resistivities are plotted against electrode spacing and curve drawn through these points.

These curves are interpreted according to the description of the area and deduce different information including true resistivities (Todd, 1980).

31. Resistivity Models

The first step in the interpretation of resistivity data is the theoretical interpretation of the observed resistivity values and second step is the deduction of hydro geological characteristics of the subsurface lithological layers from these interpreted resistivity values. In this study, the electrical resistivity survey data that consist of 17 probes were interpreted on computer by inverse iterative technique using 1X1D-3V software. The 1X1D-3V software is also employed for the ERSS data using automatic inversion method with least number of layers and least fitting error. The interpreted ERSS curves by computer modeling show the resistivity values and respective thickness of subsurface layers. Some of these curves are shown below and others are in the appendix. Most of them conform to Ktype curves and indicate the presence of large quantum of groundwater.

Table 5 summarizes the electrical resistivity survey data of selected ERSS probes collected within the vicinity of Nestle Kabirwala Factory and rests of them are in the appendix. ERSS measurement is shown in Figures 48 and 49 and data of probes (ERSS-1), (ERSS-5) and (ERSS-12) is given below (Table 5):

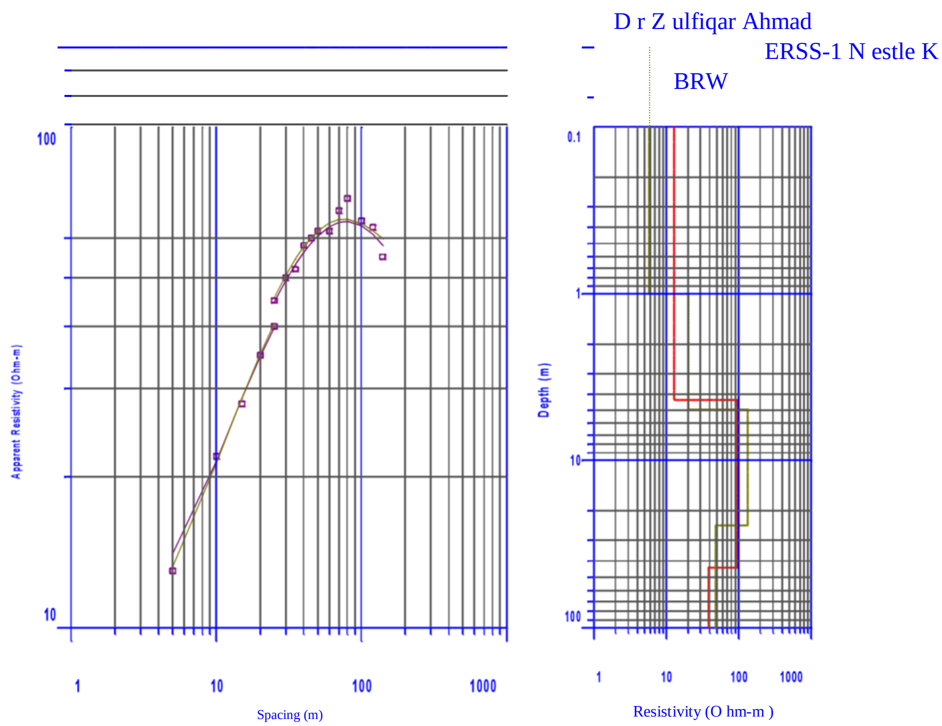
Table 5. Electrical Resistivity Survey data of probes (ERSS-1), (ERSS-5) and (ERSS-12)

AB/2 (m)	Apparent Resistivity(ERSS-1) (ohm.m)	Apparent Resistivity(ERSS-5) (ohm.m)	Apparent Resistivity(ERSS-12) (ohm.m)
2	48	28	12
4	58	28	21
8	68	40	36
10	74	45	44
15	91	59	65
20	106	74	90
25	116	85	97
30	108	93	100
35	107	101	112
40	112	108	124

45	104	116	136
50	102	122	142
60	101	118	140
70	90	109	140
80	79	100	140
90	64	92	139
100	53	83	135
120	43	62	119
140	26	52	91

Figure 48. Field data acquisition for ERSS

Figure 49. Field data acquisition Resistivity Meter by PASI (Italian Company) By using the apparent resistivity data of ERSS curves, Earth Resistivity Models of 17 resistivity probes and geoelectric parameters including Transverse resistance (T) and Longitudinal conductance (S) are evaluated with several modeling iterations (ERSS-1 through ERSS-17) as given below:

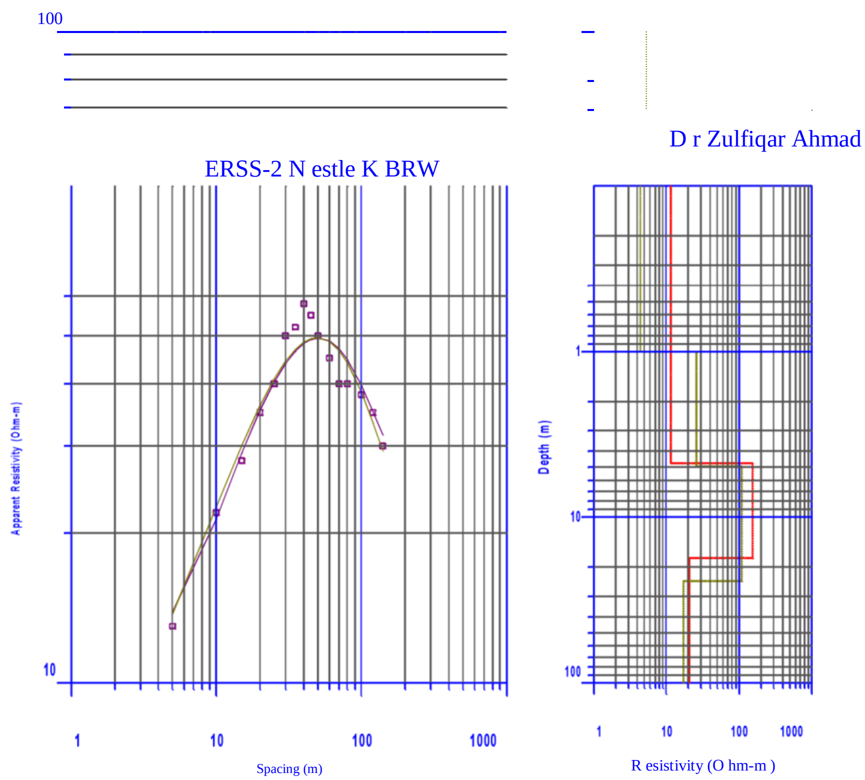


Earth Resistivity Model (ERSS-1)

Data set of (ERSS-1)

DATASET: ERSS-1 Nestle KBRW NORTH: 4398640.00 EAST: 703456.00 ELEVATION: 2673.00

LAYER	RESISTIVITY	THICKNESS	DEPTH	ELEVATION	LONG. COND.	T. RESIST.
1	5.8	1.0	1.0	2672.0	0.2	5.8
2	20.3	3.9	4.9	2668.1	0.2	79.9
3	131.8	19.4	24.3	2648.7	0.1	2555.7
4	48.0					



Earth Resistivity Model (ERSS-2)

Data set of (ERSS-2)

DATASET: ERSS-2 Nestle KBRW NORTH: 4398640.00 EAST: 703456.00 ELEVATION: 2673.00

LAYER	RESISTIVITY	THICKNESS	DEPTH	ELEVATION	LONG. COND.	T. RESIST.
1	4.4	1.0	1.0	2672.0	0.2	4.4
2	25.8	3.9	4.9	2668.1	0.2	101.4

100

0.

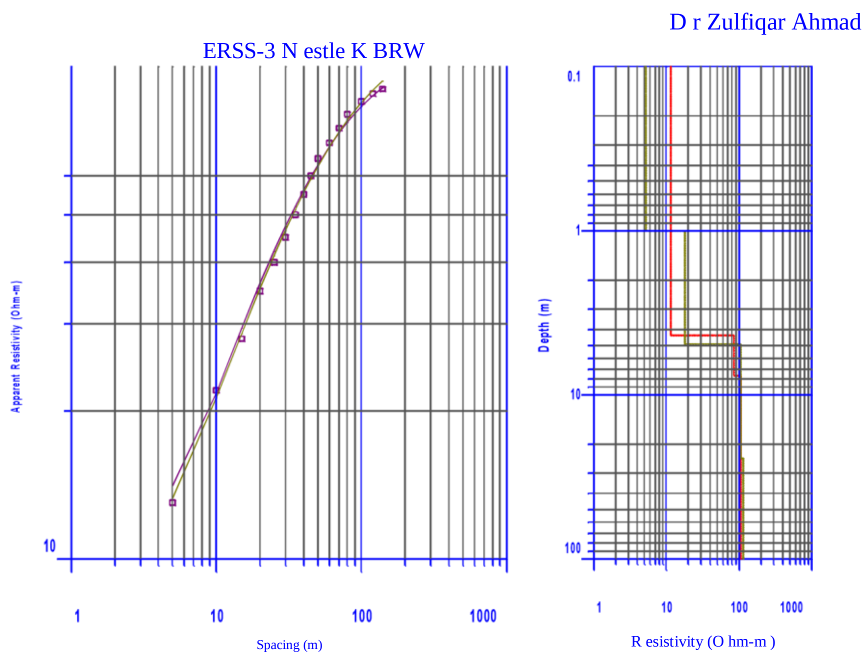
3 109.2

19.4 24.3

2648.7 0.2

2117.5

4 17.3



Earth Resistivity Model (ERSS-3)

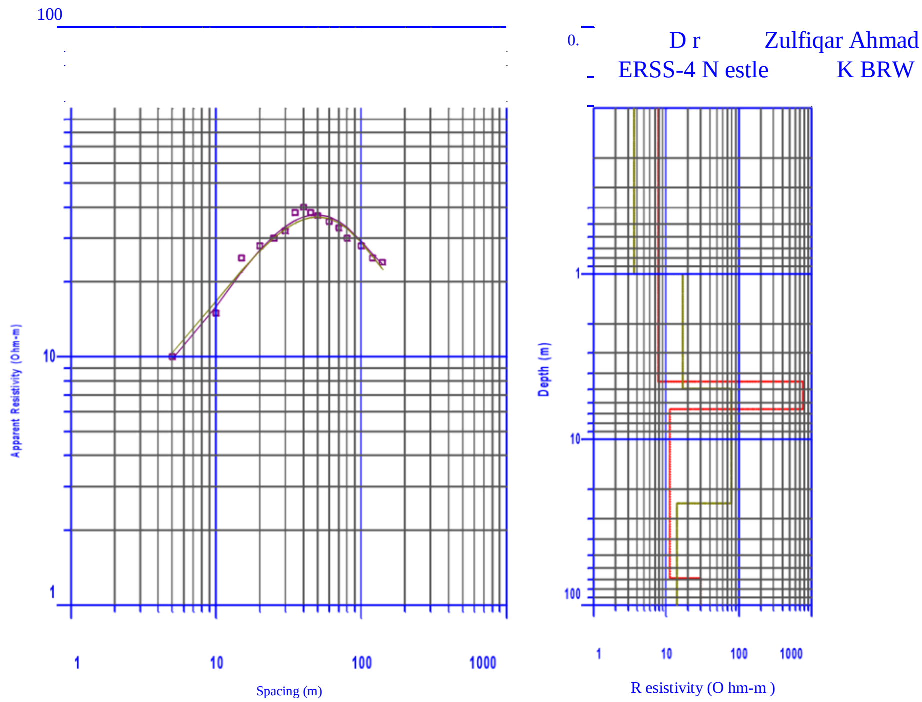
Data set of (ERSS-3)

DATASET: ERSS-3 Nestle KBRW NORTH: 4398640.00 EAST: 703456.00 ELEVATION: 2673.00

LAYER	RESISTIVITY	THICKNESS	DEPTH	ELEVATION	LONG. COND.	T. RESIST.
1	5.2	1.0	1.0	2672.0	0.2	5.2

100

2	18.0	3.9	4.9	2668.1	0.2	70.6
3	105.0	19.4	24.3	2648.7	0.2	2037.3
4	114.5					



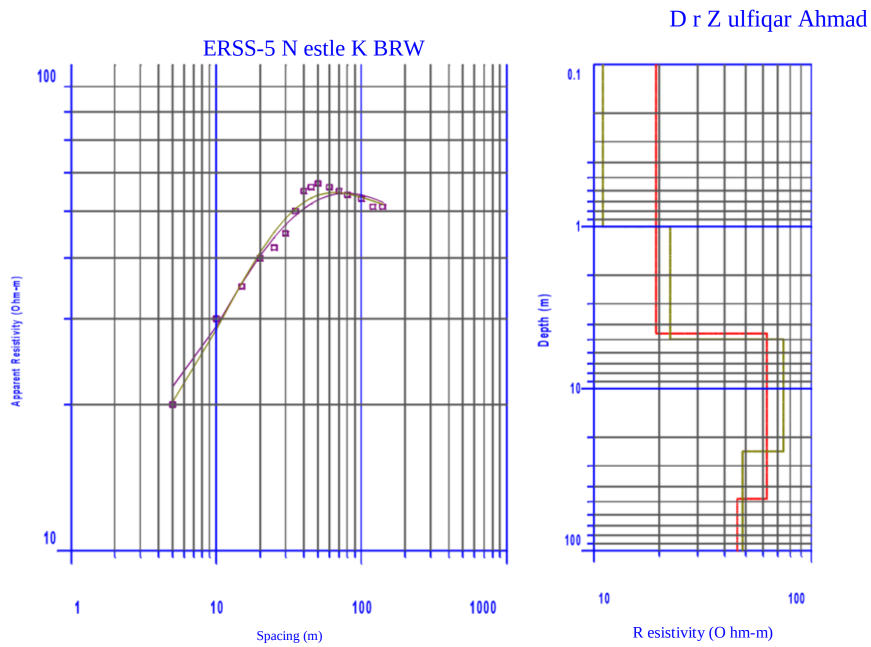
Earth Resistivity Model (ERSS-4)

Data set of (ERSS-4)

DATASET: ERSS-4 Nestle KBRW NORTH: 4398640.00 EAST: 703456.00 ELEVATION: 2673.00

LAYER	RESISTIVITY	THICKNESS	DEPTH	ELEVATION	LONG. COND.	T. RESIST.
1	3.6	1.0	1.0	2672.0	0.3	3.6

2	16.8	3.9	4.9	2668.1	0.2	66.0			
3	78.8						19.4	24.3	2648.7
	0.2					1527.9			
4	14.0								



Earth Resistivity Model (ERSS-5)

Data set of (ERSS-5)

DATASET: ERSS-5 Nestle KBRW NORTH: 4398640.00 EAST: 703456.00 ELEVATION: 2673.00

LAYER	RESISTIVITY	THICKNESS	DEPTH	ELEVATION	LONG. COND.	T. RESIST
1	11.0	1.0	1.0	2672.0	0.1	11.0
2	22.5	3.9	4.9	2668.1	0.2	88.4

3	74.3	19.4	24.3	2648.7	0.3	1441.0
4	48.3					

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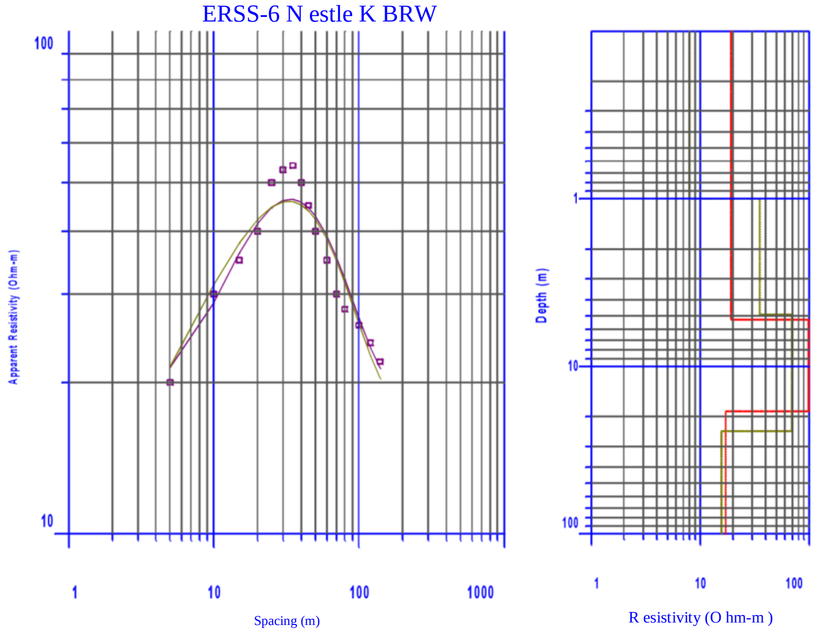


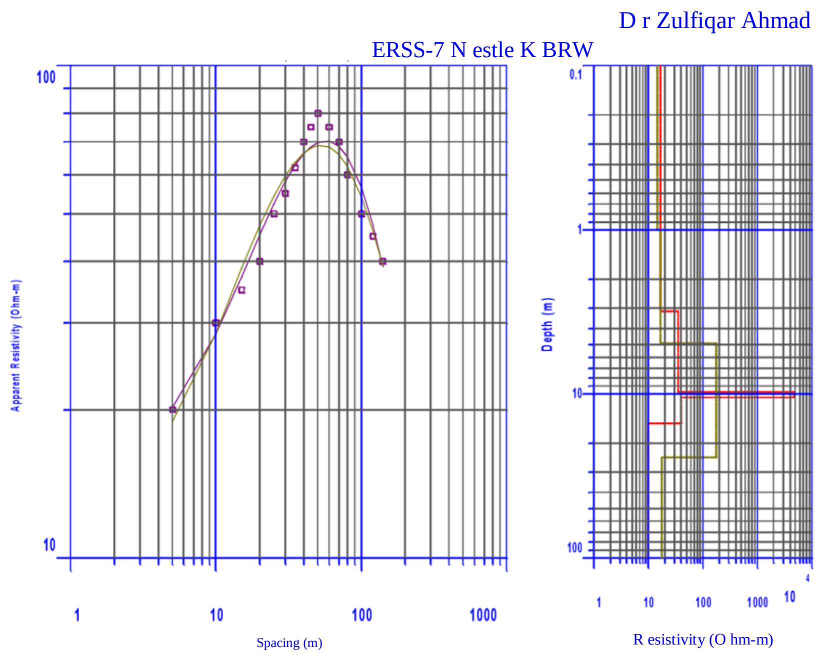
Earth Resistivity Model (ERSS-6)

Data set of (ERSS-6)

DATASET: ERSS-6 Nestle KBRW NORTH: 4398640.00 EAST: 703456.00 ELEVATION: 2673.00

LAYER RESISTIVITY THICKNESS DEPTH ELEVATION LONG. COND. T. RESIST.

1	7.9	1.0	1.0	2672.0	0.1	7.9
2	35.2	3.9	4.9	2668.1	0.1	138.6
3	69.7	19.4	24.3	2648.7	0.3	1351.4
4	15.7					



Earth Resistivity Model (ERSS-7)

Data set of (ERSS-7)

DATASET: ERSS-7 Nestle KBRW NORTH: 4398640.00 EAST: 703456.00 ELEVATION: 2673.00

LAYER	RESISTIVITY	THICKNESS	DEPTH	ELEVATION	LONG. COND.	T. RESIST.
1	14.7	1.0	1.0	2672.0	0.1	14.7
2	16.5	3.9	4.9	2668.1	0.2	64.9
3	179.1	19.4	24.3	2648.7	0.1	3474.8
4	17.7					

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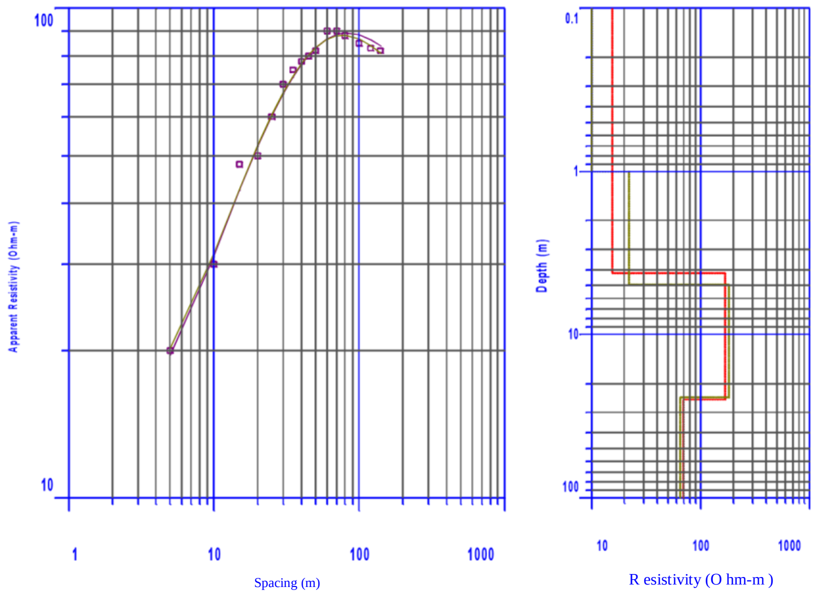
ERSS-8 N estle K BRW

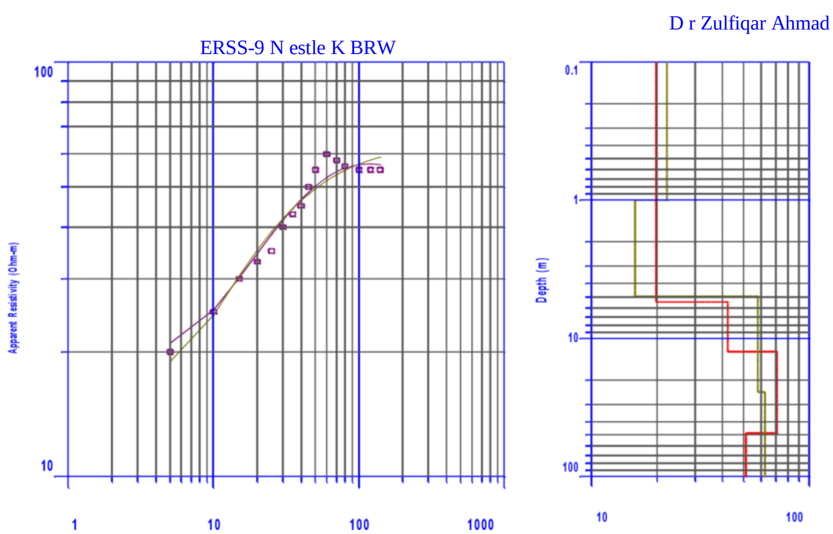


Earth Resistivity Model (ERSS-8)

Data set of (ERSS-8)

DATASET: ERSS-8 Nestle KBRW NORTH: 4398640.00 EAST: 703456.00 ELEVATION: 2673.00

LAYER	RESISTIVITY	THICKNESS	DEPTH	ELEVATION	LONG. COND.	T. RESIST.
1	10.0	1.0	1.0	2672.0	0.1	10.0
2	22.0	3.9	4.9	2668.1	0.2	86.6
3	181.6	19.4	24.3	2648.7	0.1	3523.2
4	64.7					



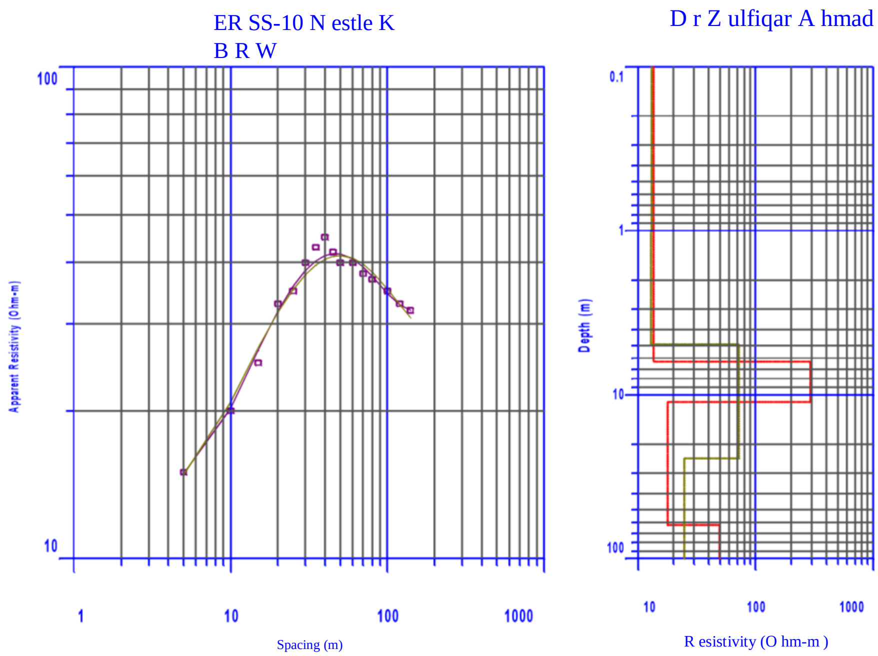
Spacing (m) Resistivity (Ohm-m)

Earth Resistivity Model (ERSS-9)

Data set of (ERSS-9)

DATASET: ERSS-9 Nestle KBRW NORTH: 4398640.00 EAST: 703456.00 ELEVATION: 2673.00

LAYER	RESISTIVITY	THICKNESS	DEPTH	ELEVATION	LONG. COND.	T. RESIST.
1	22.2	1.0	1.0	2672.0	0.0	22.2
2	15.9	3.9	4.9	2668.1	0.2	62.4
3	58.0	19.4	24.3	2648.7	0.3	1125.6
4	62.4					

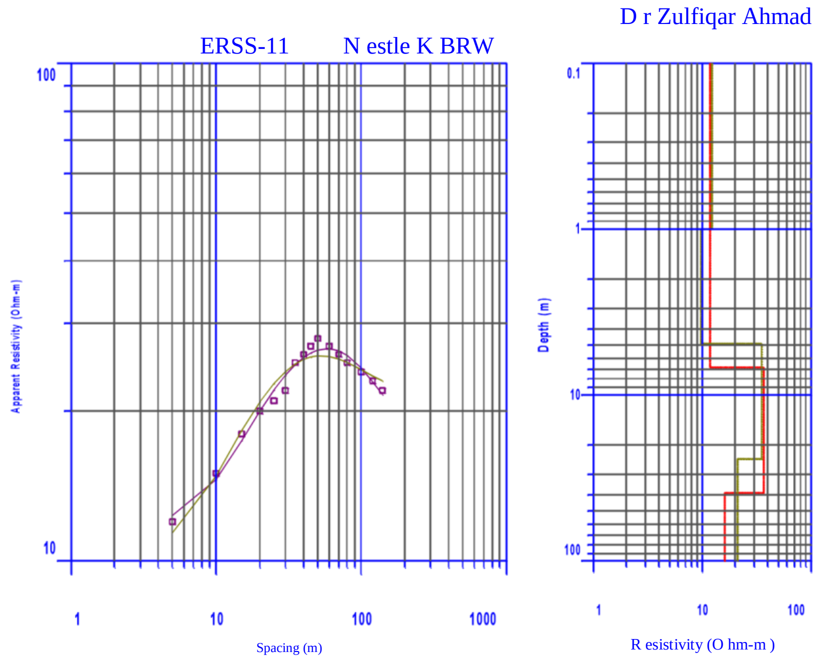


Earth Resistivity Model (ERSS-10)

Data set of (ERSS-10)

DATASET: ERSS-10 Nestle KBRW NORTH: 4398640.00 EAST:703456.00 ELEVATION: 2673.00

LAYER	RESISTIVITY	THICKNESS	DEPTH	ELEVATION	LONG. COND.	T. RESIST.
1	13.0	1.0	1.0	2672.0	0.1	13.0
2	12.9	3.9	4.9	2668.1	0.3	50.7
3	72.0	19.4	24.3	2648.7	0.3	1396.8
4	24.8					



Earth Resistivity Model (ERSS-11)

Data set of (ERSS-11)

DATASET: ERSS-11 Nestle KBRW NORTH: 4398640.00 EAST:703456.00 ELEVATION: 2673.00

LAYER	RESISTIVITY	THICKNESS	DEPTH	ELEVATION	LONG. COND.	T. RESIST.
1	12.3	1.0	1.0	2672.0	0.1	12.3
2	9.8	3.9	4.9	2668.1	0.4	38.3
3	35.3	19.4	24.3	2648.7	0.5	684.7
4	21.1					

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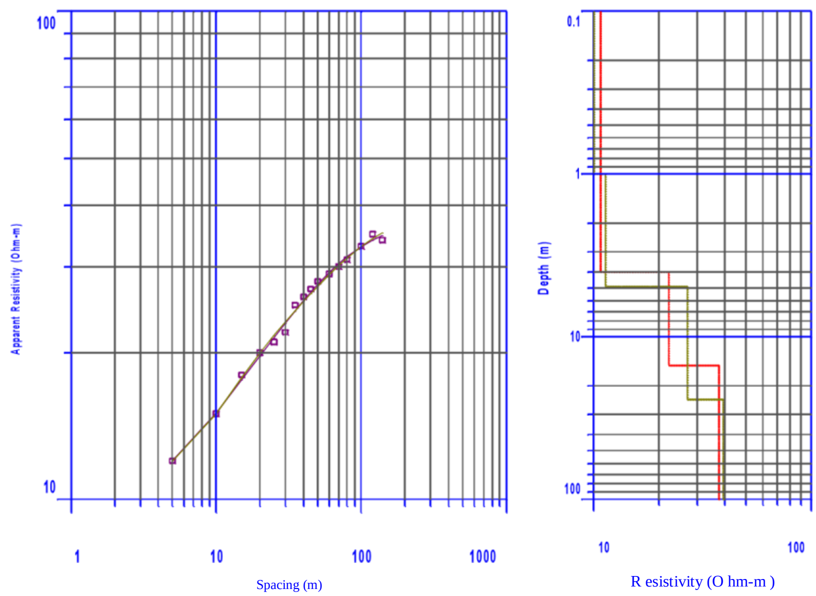
ERSS-12 N estle K BRW



Earth Resistivity Model (ERSS-12)

Data set of (ERSS-12)

DATASET: ERSS-12 Nestle KBRWNORTH: 4398640.00 EAST:703456.00 ELEVATION: 2673.00

LAYER	RESISTIVITY	THICKNESS	DEPTH	ELEVATION	LONG. COND.	T. RESIST.
1	10.1	1.0	1.0	2672.0	0.1	10.1
2	11.4	3.9	4.9	2668.1	0.3	44.8
3	27.1	19.4	24.3	2648.7	0.7	525.8
4	39.6					

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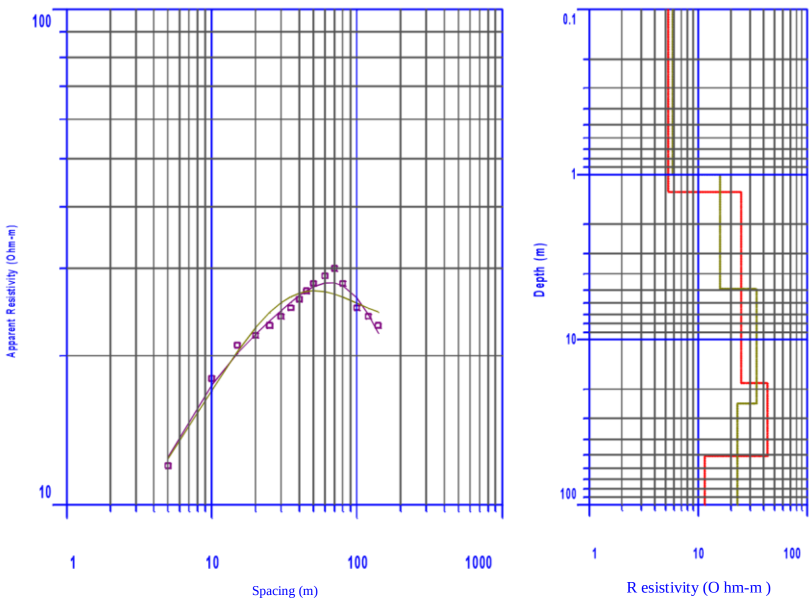
ERSS-13 N estle K BRW

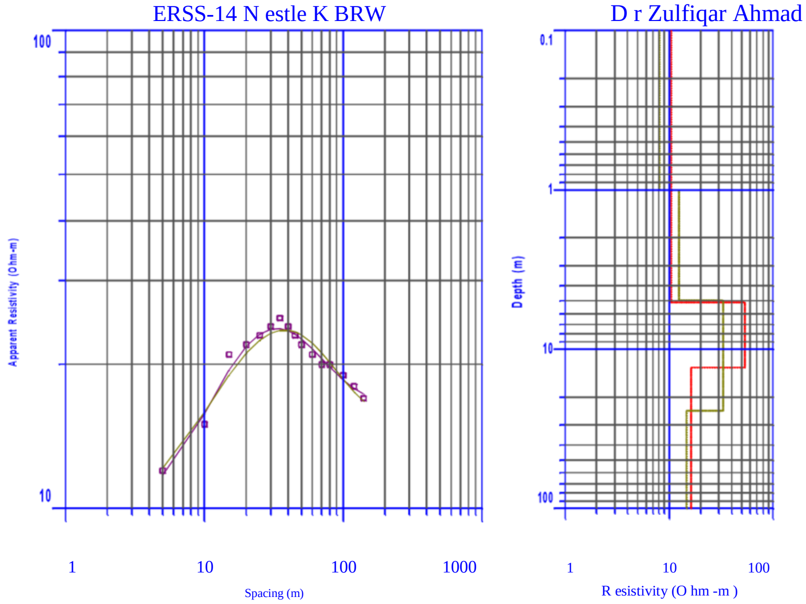


Earth Resistivity Model (ERSS-13)

Data set of (ERSS-13)

DATASET: ERSS-13 Nestle KBR NORTH: 4398640.00 EAST: 703456.00 ELEVATION: 2673.00

LAYER	RESISTIVITY	THICKNESS	DEPTH	ELEVATION	LONG. COND.	T. RESIST.
1	5.8	1.0	1.0	2672.0	0.2	5.8
2	15.8	3.9	4.9	2668.1	0.2	62.3
3	34.3	19.4	24.3	2648.7	0.6	664.9
4	23.0					



Earth Resistivity Model (ERSS-14)

Data set of (ERSS-14)

DATASET: ERSS-14 Nestle KBRW NORTH: 4398640.00 EAST: 703456.00 ELEVATION 2673.00

LAYER	RESISTIVITY	THICKNESS	DEPTH	ELEVATION	LONG. COND.	T. RESIST.
1	8.1	1.0	1.0	2672.0	0.1	8.1
2	12.5	3.9	4.9	2668.1	0.3	49.0
3	32.7	19.4	24.3	2648.7	0.6	634.7
4	14.7					

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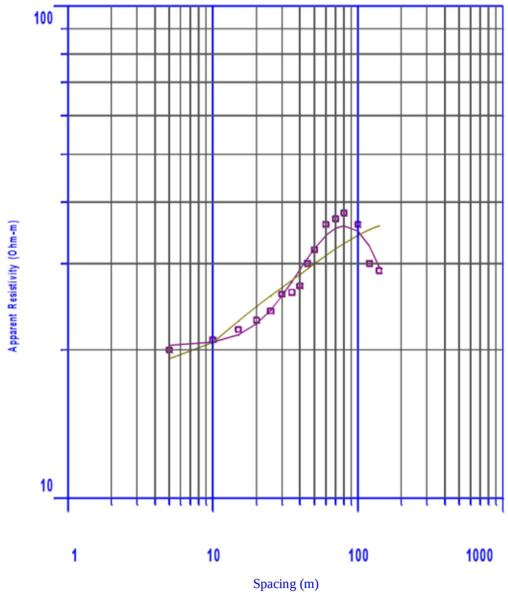
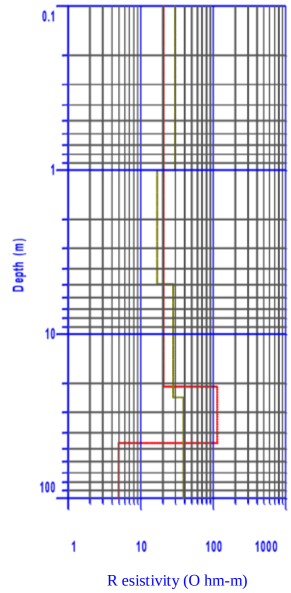
ERSS-15 N estle K BRW





Earth Resistivity Model (ERSS-15)

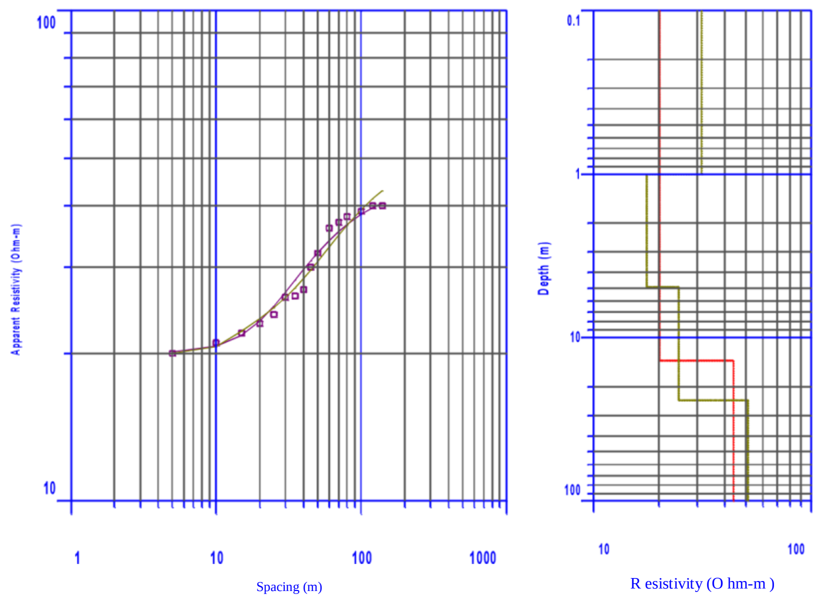
Data set of (ERSS-15)

DATASET: ERSS-15 Nestle KBRW NORTH: 4398640.00 EAST: 703456.00 ELEVATION: 2673.00

LAYER	RESISTIVITY	THICKNESS	DEPTH	ELEVATION	LONG.	COND.	T. RESIST.
1	29.6	1.0	1.0	2672.0		0.0	29.6
2	16.6	3.9	4.9	2668.1		0.2	65.4
3	27.9	19.4	24.3	2648.7		0.7	542.1
4	38.6						

D r Zulfiqar Ahmad

ERSS-16 N estle K BRW



Earth Resistivity Model (ERSS-16)

Data set of (ERSS-16)

DATASET: ERSS-16 Nestle KBRW NORTH: 4398640.00 EAST: 703456.00 ELEVATION: 2673.00

LAYER	RESISTIVITY	THICKNESS	DEPTH	ELEVATION	LONG.	COND.	T. RESIST.
1	31.4	1.0	1.0	2672.0		0.0	31.4
2	17.6	3.9	4.9	2668.1		0.2	69.3
3	24.7	19.4	24.3	2648.7		0.8	479.2
4	51.5						

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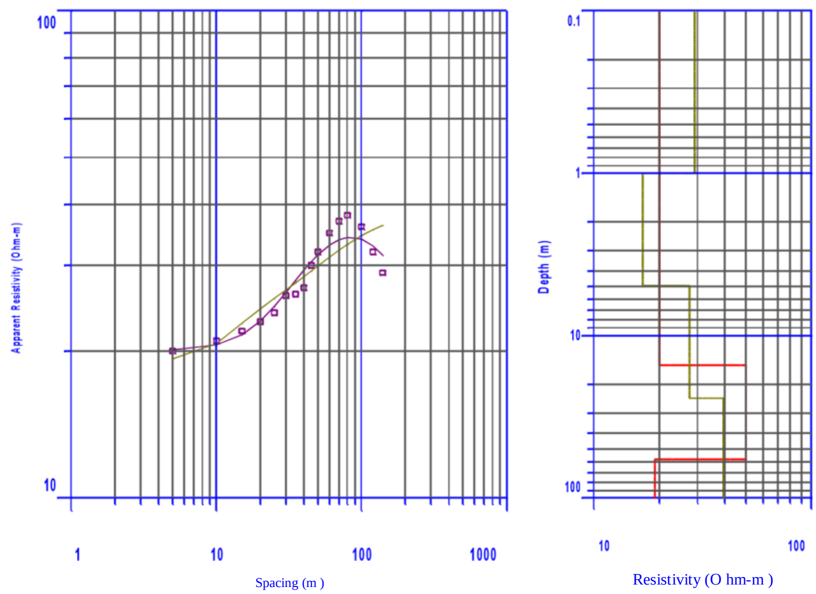
ERSS-17 N estle K BRW



Earth Resistivity Model (ERSS-17)

Data set of (ERSS-17)

DATASET: ERSS-17 Nestle KBRW NORTH: 4398640.00 EAST: 703456.00 ELEVATION: 2673.00

LAYER	RESISTIVITY	THICKNESS	DEPTH	ELEVATION	LONG. COND.	T. RESIST.
1	29.2	1.0	1.0	2672.0	0.0	29.2
2	16.8	3.9	4.9	2668.1	0.2	66.0
3	27.6	19.4	24.3	2648.7	0.7	534.7
4	39.4					

In these modeled curves purple colored squares represents the observed data and purple colored curved lines shows the modeled curves. The red colored line indicates the true resistivity and thickness of the layers.

The shape of curves depends upon the number of layers encounter and the thickness of layers, AB/2 in meter is the half distance between current electrodes (Alile et al. 2010). The tables below the modeled curves show the number of layers, thickness, depth, elevation and true resistivity of modeled curves.

32. Electrical Resistivities values Encountered in the Nestle Factory Kabirwala

The highest values of resistivity are related with fine very fine sand (F.V.F) deposits below the water table. The lowest values of resistivity are recognized to the dry strata above water table. Values of resistivity with a range of 40-150 are referred the presence of fresh water aquifer zone. Survey IDs, coordinates (Latitudes and Longitudes) and the values of resistivity are shown in the accompanied Table with each of the Earth Resistivity Model. Recommended ERSS sites are given in Table 6 for further drilling and conversion into tube-wells.

Table 6. Recommendations of ERSS Points for Drilling

Nestle Factory Kabirwala	RECOMMENDATION DEPTH
ERSS-1, ERSS-8	Water Well of 390 feet depth
ERS-2, ERSS-4, ERSS-10, ERSS-15	Water Well of 370 feet depth
ERSS-5	Water Well of 380 feet depth
ERSS-13	Water Well of 365 feet depth

33. Chemical Analysis of selected water samples collected from five (5) different locations and analyzed for trace elements, VOCs, THMs, pesticides, radioactivity

To study the distribution of chemical concentrations in and around the Nestle Kabirwala Factory, five (5) samples each of different quantities were collected to determine the trace elements, Volatile organic compounds (VOCs), THMs, Pesticides, and radioactivity. The samples are taken from the existing water wells that are located in the following Google Map (Figure 52) and also listed in Table 7 with reference to their latitude and longitude.

Table 7. Locations of water sample collection sites for Chemical Analyses

Locations of Water Samples Collection Sites		
Latitude (degree-min-sec)	Longitude(degree-min-sec)	Remarks
1) 30-18-12 N	71-55-26 E	TMA Khanewal Well 1, 350 feet deep, year of installation 1987

2) 30-22-22 N	71-52-99 E	Nestle Well 2 (in actual well 1) 350 feet deep, year of installation 1989
3) 30-22-24 N	71-52-56 E	Nestle Well 3 (in actual well 2) 350 et deep
4) 30-24-29 N	71-52-06 E	TMA Kabirwala Well 4, 450 feet deep, year of installation 1998
5) 30-23-07 N	71-52-16 E	Kabirwala Agricultural Well 529 feet deep

33.1 Trace Elements

Several of these trace elements are regulated by the Pak EPA and are on their list of primary drinking water standards. These include arsenic, copper, and lead, as well as cadmium, chromium, mercury, and selenium. Iron is not a regulated contaminant because it is not known to cause health problems, but there is a secondary drinking water standard based on its tendency to stain laundry and plumbing fixtures. Manganese, copper (again), silver, and zinc are also included in the secondary standards. The primary and secondary standards are available on the EPA Web page.

National Primary Drinking Water Regulations (NPDWRs or primary standards) are legally enforceable standards that apply to public water systems. Primary standards protect public health by limiting the levels of contaminants in drinking water.

Figures 50 and 51 show the main entrance and typical construction style of the Nestle Factory Kabirwala.

Figure 50. Main Entrance of Nestle Factory Kabirwala

Figure 51. Typical Construction Style of Nestle Factory Kabirwala

Analysis of trace element for 5 samples includes cadmium (Cd), copper (Cu), Lead (Pb), Iron (Fe), Magnesium (Mg) and chromium (Cr). Upper permissible limits for drinking water standard by Indian J. of occupation & Environmental Medicine (IJOEM) are given in Table 8 and results of the trace elements are listed below. Results fall within the permissible limits and are therefore considered to have no health hazard. However, lead concentrations are slightly higher.

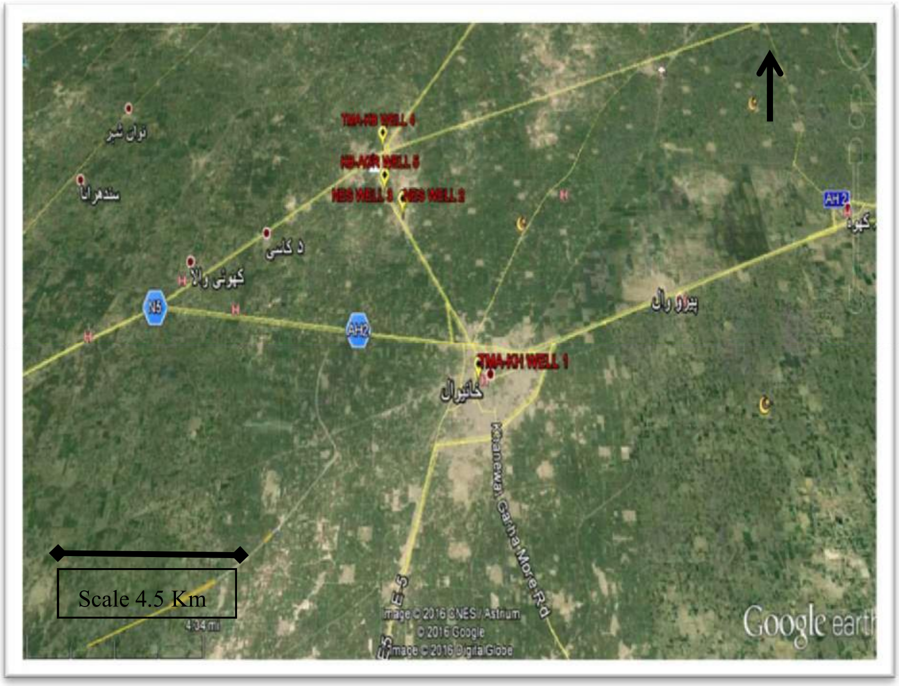


Figure 52. Locations of Water Sample Collection sites, Nestle Factory Kabirwala

Table 8. A review of permissible limits of drinking water

Parameters	USEPA	WHO	ISI	ICMR	CPCB
pH (mg/l)	6.5-8.5	6.5-8.5	6.5-8.5	6.5-9.2	6.5-8.5
Turbidity NTU	-	-	10	25	10
Conductivity (mg/l)	-	-	-	-	2000
Alkalinity (mg/l)	-	-	-	-	600
Total hardness (mg/l)	-	500	300	600	600
Iron *mg/l)	-	0.1	0.3	1.0	1.0
Chlorides (mg/l)	250	200	250	1000	1000
Nitrate (mg/l)	-	-	45	100	100
Sulfate (mg/l)	-	-	150	400	400
Residual (mg/l) free Chlorine	-	-	0.2	-	-
Calcium (mg/l)	-	75	75	200	200
Magnesium (mg/l)	-	50	30	-	100
Copper (mg/l)	1.3	1.0	0.05	1.5	1.5
Fluoride (mg/l)	4.0	1.5	0.6-1.2	1.5	1.5
Mercury (mg/l)	0.002	0.001	0.001	0.001	No relaxation
Cadmium (mg/l)	0.005	0.005	0.01	0.01	No relaxation
Selenium (mg/l)	0.05	0.01	-	-	No relaxation
Arsenic (mg/l)	0.05	0.05	0.05	0.05	No relaxation
Lead (mg/l)	-	0.05	0.10	0.05	No relaxation
Zinc (mg/l)	-	5.0	5.0	0.10	15.0
Chromium (mg/l)	0.1	-	0.05	-	No relaxation
E. coli (MPN/100 ml)	-	-	-	-	No relaxation

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Important Note:- Results of the Trace Elements should be examined in the chronological order where sample1: TMA Khanewal Well, sample 2: Nestle Well 1, Sample 3: Nestle Well 2, Sample 4: TMA Kabirwala well, Sample 5: Kabirwala agricultural well

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UNIVERSITY OF THE PUNJAB

Analysis of Trace Elements

Ref. No. 098

Batch No 044565 Sampling Date 08-09-15

Batch Size. Testing Date 09-09-15

Cadmium (Cd)

Sample no	Location	Results(mg/l)
1	TMA khanewal	0.002
2	Nestle 1	0.000
3	Nestle 2	0.004
4	TMA Kabirwala	0.001
5	Kabirwala agriculture	0.005

Permissible limit stated by ISI is 0.01mg/l

Copper (Cu)

Sample no	Location	Results(mg/l)
1	TMA khanewal	0.010
2	Nestle 1	0.019
3	Nestle 2	0.018
4	TMA Kabirwala	0.018
5	Kabirwala agriculture	0.018

Permissible limit stated by ISI is 0.6-1.2 mg/l

Lead (Pb)

Sample no	Location	Results(mg/l)
1	TMA khanewal	0.344
2	Nestle 1	0.346
3	Nestle 2	0.374
4	TMA Kabirwala	0.388
5	Kabirwala agriculture	0.414

Permissible limit stated by ISI is 0.10 mg/l

Iron (Fe)

Sample no	Location	Results(mg/l)
1	TMA khanewal	0.067
2	Nestle 1	0.059
3	Nestle 2	0.022
4	TMA Kabirwala	0.046
5	Kabirwala agriculture	0.051

Permissible limit stated by ISI is 0.3 mg/l

Magnesium (Mg)

Sample no	Location	Results(mg/l)
1	TMA khanewal	11.27
2	Nestle 1	8.40
3	Nestle 2	8.18
4	TMA Kabirwala	9.95
5	Kabirwala agriculture	10.14

Permissible limit stated by ISI is 30 mg/l Chromium (Cr)

Sample no	Location	Results(mg/l)

1	TMA khanewal	-0.797
2	Nestle 1	-0.784
3	Nestle 2	-0.743
4	TMA Kabirwala	-0.635
5	Kabirwala agriculture	-0.414

Permissible limit stated by ISI is 0.05 mg/l

Verified by________________________

Dated 09-09-15____

Quaid-i-Azam Campus, Lahore-54590 (Pakistan): Telephone: 92-42-35953102, Facsimile: 92-4235953100

34. What are THMs?

Trihalomethanes (THMs) are disinfection by-products that form when chlorine is added to water that contains elevated levels of natural organic matter such as decaying leaves and vegetation. High THM levels are common for surface-based public water supplies because many of them contain high levels of natural organic matter. Formation of disinfection byproducts continue to be an issue in the province and are being addressed through chlorine demand management and exploring various corrective measures. Disinfection is an essential component of public drinking water treatment. The health risks from disinfection by-products, including THMs, are much less than the risks from consuming water that has not been appropriately disinfected.

Both provincial and municipal governments have some level of responsibility in ensuring the safety of drinking water. The provincial government, in cooperation with municipal governments protects source water quality through the watershed protection program. Under a partnership program with municipal governments, the provincial government monitors drinking water quality on a regular basis in order to ensure compliance with the Guidelines for Pak EPA Drinking Water Quality and to deal with emerging issues on a proactive basis. The Department of Environment provides the drinking water quality data along with a brief interpretation to municipal governments on a regular basis.

34.1. What are chlorination disinfection by-products and how are they formed?

Chlorination disinfection by-products (CDBPs) are chemical compounds that form when water containing natural organic matter (the decay products of living things such as leaves, human and animal wastes, etc.) is chlorinated. Chlorine disinfection of water can lead to the formation of a number of chlorination by-products of which trihalomethanes (THMs) are only one subgroup. Among the many chlorination by-products, THMs are most often present and in the greatest concentration in drinking water and as such are used as indicators of total disinfection by-product formation

34.2. Why is drinking water chlorinated?

Chlorination is necessary for two reasons. First, almost all sources of surface water contain microbiological organisms, which have to be removed in order to prevent the outbreak of waterborne diseases such as typhoid fever and cholera. Second, once the treated water leaves the treatment plant, it may travel through water mains and pipes sometimes at significant distances, before it reach its destination. During this time, it is necessary to maintain a residual level of disinfectant in the water to ensure no possible regrowth of microorganisms.

Without adequate disinfection, the health risks from microorganisms far outweigh the risks from THMs.

34.3. Health effects associated with THMs?

The Federal-Provincial Subcommittee on Drinking Water established the current guideline for THMs in 1993. The guideline is based on the risk of cancer reported in animal studies of chloroform, the THM most often present and in greatest concentration in drinking water. Since then, new epidemiological (human) studies had been published which reported associations between THMs and bladder and colon cancer, and adverse pregnancy outcomes including miscarriage, birth defects and low birth weight.

34.4. How can I reduce exposure to THMs?

Consumers wishing to reduce their exposure to chlorination disinfection by-products can use a filter containing activated carbon certified to the NSF Standard 53 for THM removal. If a filter device is used it should be properly maintained because such devices can become sources of bacterial contamination in water. Although blending and boiling water will remove volatile (meaning easily evaporated) Chlorinated Disinfection By-Products (CDBPs) such as THMs, they do not eliminate or necessarily reduce the health risks of other CDBPs that may not evaporate easily. As such, blending and boiling of water are not recommended for reducing chlorination disinfection by-products.

Measurement of Trihalomethanes In Drinking Water With Gas Chromatography/Mass Spectrometry and Selected Ion Monitoring

ANALYTE:	CAS #
Chloroform	67-66-3
Bromodichloromethane	75-27-4
Chlorodibromomethane	124-48-1
Bromoform	75-25-2
Trihalomethanes	
THM	

With Method 501.3, method detection limits (MDLs) for trihalomethanes are:

chloroform, 0.06 ug/L;
bromodichloromethane, 0.07 ug/L; chlorodibromomethane, 0.05 ug/L; and
bromoform, 0.04 ug/L;

where MDL is the minimum amount that can be measured with 99% confidence that the reported value is greater than zero (3).

Results of THMs are listed for all five (5) samples.

Trihalomethanes, THM (ug/L)

TMA Khanewal Well 1	0.0346
Nestle Well 1	0.056
Nestle Well 2	0.077
TMA Kabirwala Well	0.503
Kabirwala Agricultural Well	0.033

It is to be noted that in TMA Kabirwala well, concentration of THMs is slightly high as per permissible limit.

35. Volatile Organic Compounds (VOCs)

Volatile organic compounds (VOCs) are organic chemicals that have a high vapor pressure at ordinary room temperature. Their high vapor pressure results from a low boiling point, which causes large numbers of molecules to evaporate or sublimate from the liquid or solid form of the compound and enter the surrounding air.

VOCs are ground-water contaminants of concern because of very large environmental releases, human toxicity, and a tendency for some compounds to persist in and migrate with ground-water to drinking-water supply well. In general, VOCs have high vapor pressures, low-to-medium water solubilities, and low molecular weights. Some VOCs may occur naturally in the environment, other compounds occur only as a result of manmade activities, and some compounds have both origins (Zogorski and others, 2006).

Hydrocarbon compounds that have low boiling points, usually less than 100ºC, and therefore evaporate readily. Some are gases at room temperature. Propane, benzene, and other components of gasoline are all volatile organic compounds.

Out of the 5 water samples, VOCs are extracted from only two samples while remaining did not show any VOCs concentrations (Table 9).

35.1. Analysis of the Volatile Organic Compounds (VOCs)

i) TMA Khanewal Well (sample 1)

ii) TMA Kabirwala Well (sample 2)

Table 9. Analysis for VOCs

NoS	Benzene	Bromodchloromethane	Chloroform	Ethybenzene	Methybenzene	Methyl tertbutyl ether	Tetra Chloro ethene	Tetra chloro ethene	Xylenes (total)	1,1,1-Trichloroethene
TMA Khanewal Well 1 (sample 1)	<0.06	0.20	2.1	<0.09	<0.05	<0.06	0.10	<0.16	<0.13	0.10
TMA Kabirwala Well (sample 2)	<0.06	0.29	11.0	<0.09	<0.05	0.33	0.90	0.21	<0.13	0.32

Guideline values of Benzene = 0.01 mg/l, Chloroform 0.3mg/l, Ethybenzene=0.3mg/l, Bromodchloromethane = 0.06 mg/l

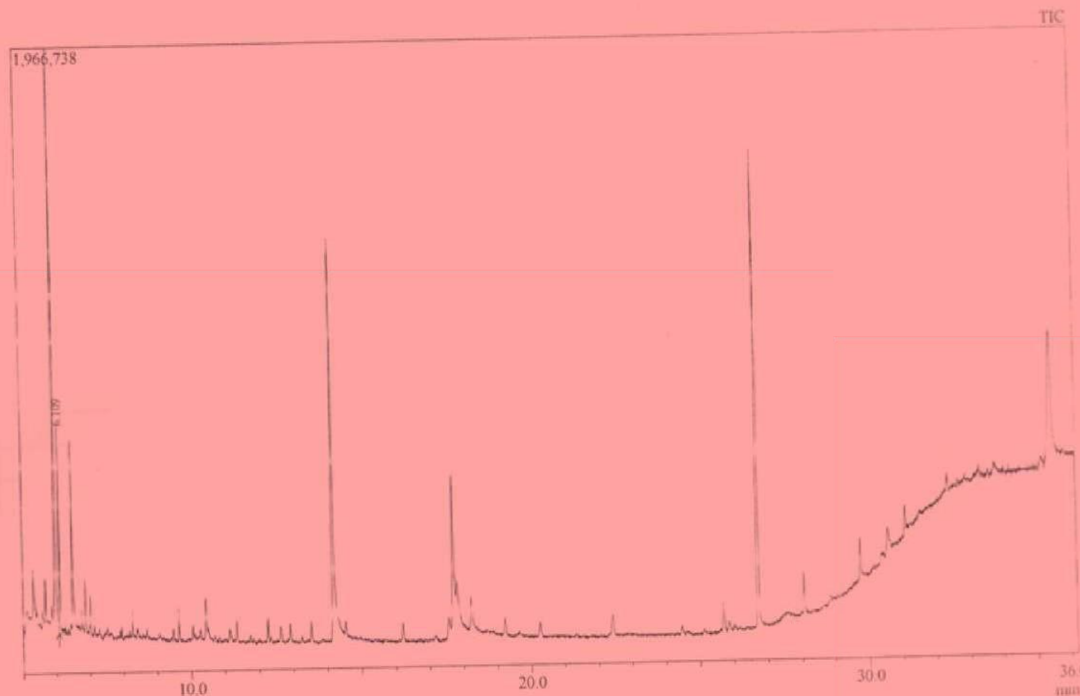
36. Pesticides

Pesticides are chemical or biological products which are used in direct form, in aqueous solutions or as mixtures for preventing, fighting and killing a variety of pests, such as weeds, insects, rodents, and fungi. The widespread occurrence of pesticides in natural waters is due to their widespread application in agriculture throughout the world. Human being is constantly exposed to a large number of pesticides present in the environment. Surface and ground water contamination due to extensive use of pesticide for agricultural purposes is a serious threat to the environment. Most important among them is pollution due to OCPs, because of their high toxic effect and persistence for a long time in the environment. Pollution by some common pesticides, such as organophosphorous pesticides (OPPs) due to mistreatment, direct run off, empty containers careless discarding, leaching, and utensils and apparatus washings, etc. is also important. Chlorinated pesticides have fatal toxic effects for aquatic life forms such as fish. These pesticides are counted hazardous for the environment and human beings as well, due to bioaccumulation and biomagnifying effects in the food chain and because they may produce reproductive and carcinogenic effects in animals and human beings. The Guideline values recommended by WHO for various pesticide residues in drinking water are 2 μg L-1 (Lindane), 0.03 μg L-1 for (Aldrin/dieldrin), 2 μg L 1 (DDT), 0.2 μg L 1 (Chlordane), 0.03μg L -1 (Heptachlor + epoxide) and 20 μg L -1 (Methoxychlor). Monocrotophos (C7H14NO5P) is an organophosphorus compound and used as a systemic insecticide and acaricide. It prevents pests on a variety of crops, such as sugarcane, cotton, rice and fruits and vegetables etc. Monocrotophos is commonly used for agriculture purposes in Pakistan to control boring, chewing and sucking insects (such as aphids, Helicoverpaspp, caterpillars, moths, mites, jassids, budworm, scale and stem borer, as well as locusts) for a large range of crops. Unfortunately, the extensive use and easy approach of monocrotophos has resulted in enhanced utilization for homicidal and suicidal poisoning cases.

Results of the 5 samples are analysed and plotted graphically to observe the concentration of pesticides. Samples have shown concentations that fall within the permissible limits in the following plots.

Sample Information

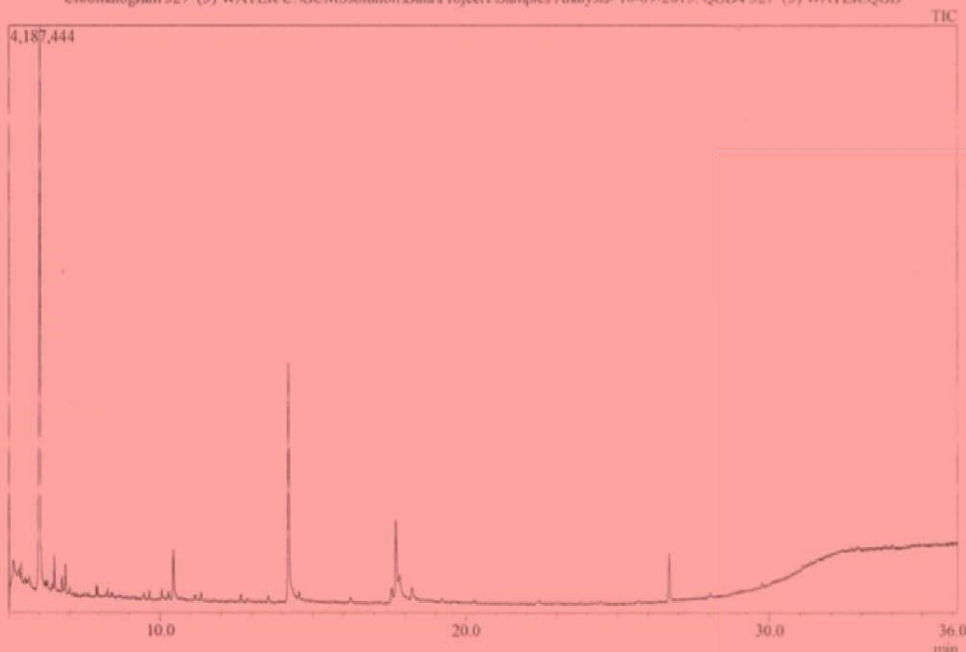
Analyzed by	: admin
Analyzed	: 9/10/2015 1:10:46 PM
Sample Type	: Unknown
Level #	: 1
Sample Name	: WATER TMA-KH WELL 1
Sample ID	: 325 (1) WATER
IS Amount	: [1]=1
Sample Amount	: 1
Dilution Factor	: 1
Vial #	: 4
Injection Volume	: 1.00
Data File	: C:\GCMSsolution\Data\Project1\Samples Analysis- 10-09-2015. QGD6 325 (1) WATER.QGD
Org Data File	: C:\GCMSsolution\Data\Project1\Samples Analysis- 10-09-2015. QGD6 325 (1) WATER.QGD
Method File	: C:\GCMSsolution\Data\Project1\SAMPLE ANALYSIS 03-6-15.qgm
Org Method File	: C:\GCMSsolution\Data\Project1\SAMPLE ANALYSIS 03-6-15.qgm
Report File	:
Tuning File	: C:\GCMSsolution\System\Tune1\tuning file 08-09-2014.qgt
Modified by	: Admin
Modified	: 1/1/2001 12:08:02 AM



Sample Information

Analyzed by	: ADMIN
Analyzed	: 9/10/2015 11:19:26 AM
Sample Type	: Unknown
Level #	: 1
Sample Name	: WATER NES-WELL 2
Sample ID	: 327 (3) WATER
IS Amount	: [1]=1
Sample Amount	: 1
Dilution Factor	: 1
Vial #	: 5
Injection Volume	: 1.00
Data File	: C:\GCMSsolution\Data\Project1\Samples Analysis- 10-09-2015. QGD4 327 (3) WATER.QGD
Org Data File	: C:\GCMSsolution\Data\Project1\Samples Analysis- 10-09-2015. QGD4 327 (3) WATER.QGD
Method File	: C:\GCMSsolution\Data\Project1\SAMPLE ANALYSIS 03-6-15.qgm
Org Method File	: C:\GCMSsolution\Data\Project1\SAMPLE ANALYSIS 03-6-15.qgm
Report File	:
Tuning File	: C:\GCMSsolution\System\Tune1\tuning file 08-09-2014.qgt
Modified by	: Admin
Modified	: 1/1/2001 12:14:07 AM

Chromatogram 327 (3) WATER C:\GCMSsolution\Data\Project1\Samples Analysis- 10-09-2015. QGD4 327 (3) WATER.QGD



Sample Information

Analyzed by	: ADMIN
Analyzed	: 9/10/2015 11:19:26 AM
Sample Type	: Unknown
Level #	: 1
Sample Name	: WATER NES-WELL 3
Sample ID	: 327 (3) WATER
IS Amount	: [1]=1
Sample Amount	: 1
Dilution Factor	: 1
Vial #	: 5
Injection Volume	: 1.00
Data File	: C:\GCMSsolution\Data\Project1\Samples Analysis- 10-09-2015 QGD4 327 (3) WATER.QGD
Org Data File	: C:\GCMSsolution\Data\Project1\Samples Analysis- 10-09-2015 QGD4 327 (3) WATER.QGD
Method File	: C:\GCMSsolution\Data\Project1\SAMPLE ANALYSIS 03-6-15.qgm
Org Method File	: C:\GCMSsolution\Data\Project1\SAMPLE ANALYSIS 03-6-15.qgm
Report File	:
Tuning File	: C:\GCMSsolution\System\Tune1\tuning file 08-09-2014.qgt
Modified by	: Admin
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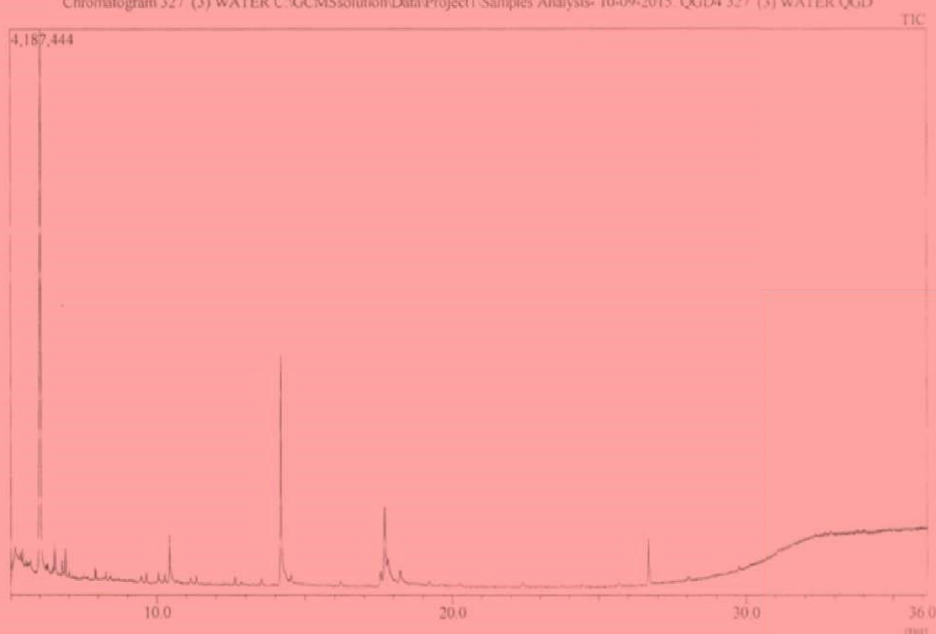

Sample Information

Analyzed by	ADMIN
Analyzed	9/10/2015 12:20:36 PM
Sample Type	Unknown
Level #	: 1
Sample Name	WATER TMA-KB WELL 4
Sample ID	: 328 (7) WATER
IS Amount	: [1]=1
Sample Amount	: 1
Dilution Factor	1
Vial #	: 6
Injection Volume	: 1.00
Data File	: C:\GCMSsolution\Data\Project1\Samples Analysis- 10-09-2015. QGD5 328 (7) WATER.QGD
Org Data File	: C:\GCMSsolution\Data\Project1\Samples Analysis- 10-09-2015. QGD5 328 (7) WATER.QGD
Method File	: C:\GCMSsolution\Data\Project1\SAMPLE ANALYSIS 03-6-15.qgm
Org Method File	: C:\GCMSsolution\Data\Project1\SAMPLE ANALYSIS 03-6-15.qgm
Report File	:
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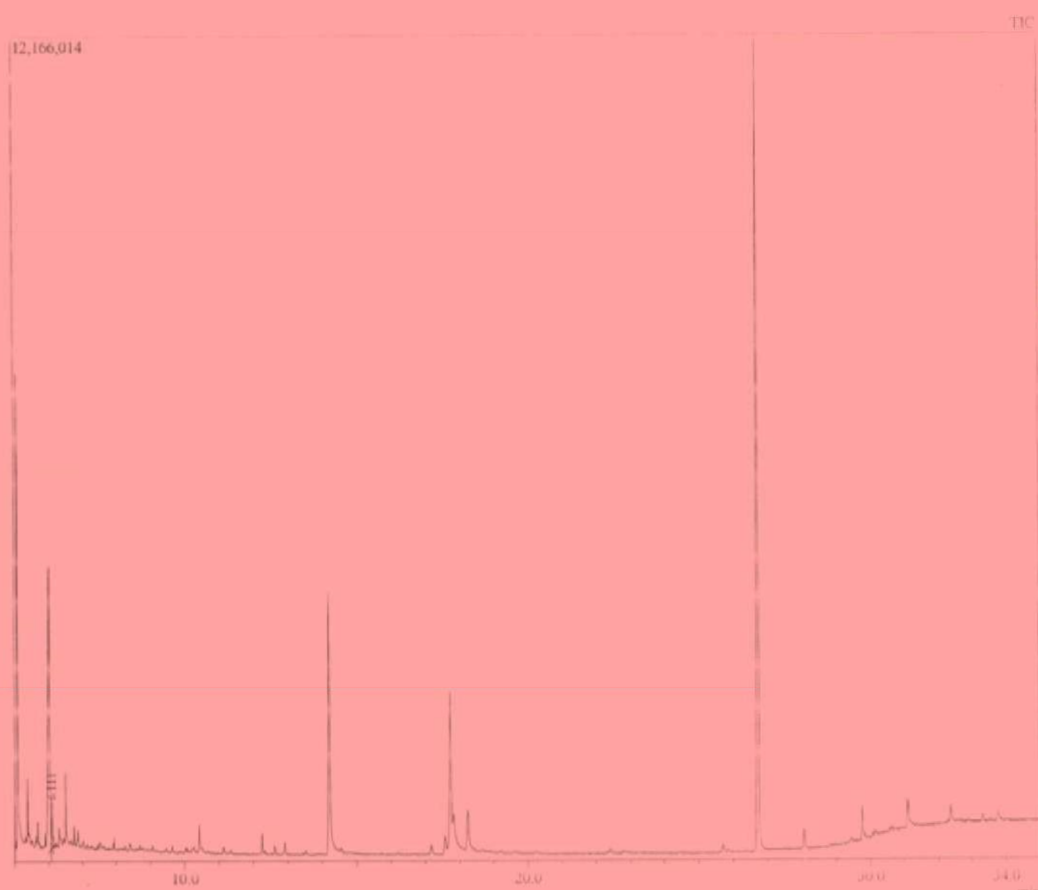
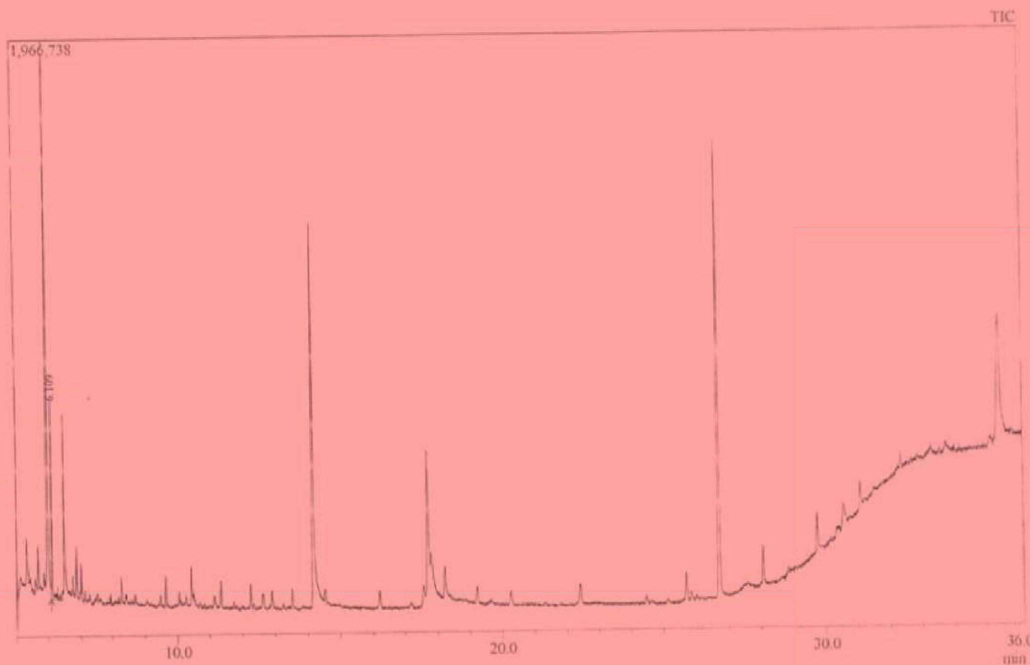


Sample Information

Analyzed by	: admin
Analyzed	: 9/10/2015 1:10:46 PM
Sample Type	: Unknown
Level #	: 1
Sample Name	: WATER KB-AGRI WELL 5
Sample ID	: 325 (1) WATER
IS Amount	: [1]=1
Sample Amount	: 1
Dilution Factor	: 1
Vial #	: 4
Injection Volume	: 1.00
Data File	: C:\GCMSsolution\Data\Project1\Samples Analysis- 10-09-2015. QGD6 325 (1) WATER.QGD
Org Data File	: C:\GCMSsolution\Data\Project1\Samples Analysis- 10-09-2015. QGD6 325 (1) WATER.QGD
Method File	: C:\GCMSsolution\Data\Project1\SAMPLE ANALYSIS 03-6-15.qgm
Org Method File	: C:\GCMSsolution\Data\Project1\SAMPLE ANALYSIS 03-6-15.qgm
Report File	
Tuning File	: C:\GCMSsolution\System\Tune1\tuning file 08-09-2014.qgt
Modified by	: Admin
Modified	: 1/1/2001 12:08:02 AM



37. Radioactive Nuclides Drinking-

water may contain radioactive substances ("radionuclides") that could present a risk to human health. These risks are normally small compared with the risks from microorganisms and chemicals that may be present in drinking-water. Except in extreme circumstances, the radiation dose resulting from the ingestion of radionuclides in drinkingwater is much lower than that received from other sources of radiation. In terms of health risk assessment, the Guidelines do not differentiate between radionuclides that occur naturally and those that arise from human activities. However, in terms of risk management, a differentiation is made because, in principle, human-made radionuclides are often controllable at the point at which they enter the water supply. Naturally occurring radionuclides, in contrast, can potentially enter the water supply at any point, or at several points, prior to consumption. For this reason, naturally occurring radionuclides in drinkingwater are often less amenable to control.

37.1. GUIDELINES FOR DRINKING WATER QUALITY

Naturally occurring radionuclides in drinking-water usually give radiation doses higher than those provided by artificially produced radionuclides and are therefore of greater concern. Radiological risks are best controlled through a preventive risk management approach following the framework for safe drinking-water and the water safety plan approach. When considering what action to take in assessing and managing radiological risks, care should be taken to ensure that scarce resources are not diverted away from other, more important public health concerns. The screening levels and guidance levels for radioactivity presented in these Guidelines are based on the latest recommendations of the International Commission on Radiological Protection (ICRP, 2008). Some drinking-water supplies, in particular those sourced from groundwater, may contain radon, a radioactive gas. Although radon can enter indoor air in buildings through its release from water from taps or during showering, the most significant source of radon in indoor air arises through natural accumulation from the environment. An evaluation of international research data (UNSCEAR, 2000) has concluded that, on average, 90% of the dose attributable to radon in drinking-water comes from inhalation rather than ingestion. Consequently, the setting of screening levels and guidance levels to limit the dose from ingestion of radon contained in drinking-water is not usually

necessary. The screening measurements for gross alpha and gross beta activities
will include the contribution from radon progeny, which is the principal source of dose from ingestion of radon present in drinking-water supplies. Radioactivity from several naturally occurring and human-made sources is present throughout the environment. Some chemical elements present in the environment are naturally radioactive. These are found in varying amounts in soils, water, indoor and outdoor air and even within our bodies, and so exposure to them is inevitable. In addition, Earth is constantly bombarded by high-energy particles originating both from the sun and from outside the solar system. Collectively, these particles are referred to as cosmic radiation. Everybody receives a dose from cosmic radiation, which is influenced by latitude, longitude and height above sea level. The use of radiation in medicine for diagnosis and treatment is the largest human-made source of radiation exposure today. The testing of nuclear weapons, routine discharges from industrial and medical facilities and accidents such as Chernobyl have added human-made radionuclides to our environment. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2008) has estimated that the global average annual dose per person from all sources of radiation in the environment is approximately 3.0 mSv/year. Of this, 80% (2.4 mSv) is due to naturally occurring sources of radiation, 19.6% (almost 0.6 mSv) is due to the use of
radiation for medical diagnosis and the remaining 0.4% When the term "source" appears in the context of "radiation source". For any other purpose, additional information is provided (e.g. "water source").

37.2. RADIOLOGICAL ASPECTS (around 0.01 mSv) is due to other sources of human-made radiation. There can be large variability in the dose received by individual members of the population, depending on where they live, their dietary preferences and other lifestyle choices. Individual radiation doses can also differ depending on medical treatments and occupational exposures.

37.3. Key Term Quantity and Units

Becquerel (Bq) the becquerel is the unit of radioactivity in the International System of Units (abbreviated SI from the French Système international d'unités), corresponding to one radioactive disintegration per second. In the case of drinking-water, it is usual to talk about the activity concentration, expressed in units of Bq/l. Effective dose—When radiation interacts with body tissues and organs, the radiation dose received is a function of factors such as the type of radiation, the part of the body affected and the exposure pathway. This means that 1 Bq of radioactivity will not always deliver the same radiation dose. A unit called "effective dose" has been developed to take account of the differences between different types of radiation so that their biological impacts can be compared directly. The effective dose is expressed in SI units called Sieverts (Sv). The sievert is a very large unit, and it is often more practical to talk in terms of milli-sieverts (mSv). There are 1000 mSv in 1 Sv. Effective half-life—Radioisotopes have a "physical" half-life, which is the period of time it takes for one half of the atoms to disintegrate. Physical half-lives for various radioisotopes can range from a few microseconds to billions of years. When a radioisotope is present in a living organism, it may be excreted. The rate of this elimination is influenced by biological factors and is referred to as the "biological" half-life. The effective half-life is the actual rate of halving the radioactivity in a living organism as determined by both the physical and biological half-lives. Whereas for certain radionuclides, the biological processes are dominant, for others, physical decay is the dominant influence.

Prescribed safe limits by WHO

For radioactive cesium: 200 Becquerel per kilogram (Drinking water standard)
Radon concentration lower than 11.1 Bq/kg as normal level. Results fall within the safe limits.

Sample No.	Ra-226 (Bq/Kg)	Ra-228 (Bq/Kg)	Cs-137 (Bq/Kg)	Cs-134 (Bq/Kg)	K-40 (Bq/Kg)
TMA Khanewal Well 1	<0.41	1.66	<0.03	<0.03	15
Nestle Well 1	1.72	<0.51	<0.03	<0.03	14
Nestle Well 2	<0.41	<0.51	<0.03	<0.03	16

TMA Kabirwala Well	2	<0.51	<0.03	<0.03	17
Kabirwala Agricultural Well	<0.41	<0.51	<0.03	<0.03	16

38. Conclusions

Interpretative results of the entire studies including hydrology and hydrogeology, temperature, rainfall, relative humidity, and spatial distribution of rainfall and temperature in Multan, Khanewal, TobaTek Singh, Jhang, Faisalabad, onsite data collection about fifty three (53) sites for water table, hydraulic heads, construction methodology, year of installation of wells, tentative well discharges and drawdown have led to the following conclusions.

i) Aquifers underlain in the subsurface formation are composed of sand of various grain sizes that contain good potentially enriched groundwater with lesser amount of drawdown in response to abstraction of groundwater. Nestle Kabirwala Factory is operating only two water wells with low yielding capabilities of 0.50 to 0.75 cusecs, although higher rating submersible pumps could be installed as well to abstract larger quantity of groundwater within safe yield phenomena (without degrading the environmental issues and or creating trough in the water levels).

ii). Numerical groundwater modeling study on a regional scale has also been carried out using 3-D Numerical groundwater flow and transport model (Visual ModFlow Software 2013) to develop steady-state and transient (non-steady state) flow models of the historic past in 1962 and most recent version in 2015. Model has indicated the groundwater flows are in the southwest and southeast directions on the regional trend.

iii) Water Budget 2015 of the Bari Doab based on the recharge (rainfall, irrigation system, and return flow from groundwater abstraction) and discharge (groundwater abstraction from public and private tube-wells, and evaporation loss) have shown a close balance between the recharging component 35.08 MAF and discharging components 35.54 MAF. Results are valid over a decade with ± change of 1%.

iii). Particle tracking (Contaminants) as a part of modeling study based on artificially generated point source and their direction of dispersion have been simulated with MODPath transport utility of the Visual Modflow, which tend to move towards the Ravi River, and in the middle of the area southwest of the Nestle Kabirwala Factory (figures 33, 34, and 35). However, as such no apparent contamination appears to exist within the Nestle Factory and also in its surroundings.

iv). Electrical Resistivity Sounding Survey (ERSS) carried out within the Nestle Factory Kabirwala over seventeen (17) different locations have shown mostly aquifers of unconfined in nature and they represent large quantity of groundwater with negligible drawdown of about 2~4 meters in response to pumping of 0.5 to 0.75 cusecs. Water wells up to 1.5 cusecs can also be installed within the premises of Nestle factory.

v). To study the distribution of chemical concentrations in and around the Nestle Kabirwala Factory, five (5) samples each of different quantities were collected to determine the trace elements, Volatile organic compounds (VOCs), THMs, Pesticides, and radioactivity. The samples are taken from the existing water wells that are located in the Google Map (Figure 52) and also listed in the following Table A with reference to their latitude and longitude.

Table A. Locations of water sample collection sites for Chemical Analyses

Locations of Water Samples Collection Sites		
Latitude (degree-min-sec)	Longitude(degree-min-sec)	Remarks
1) 30-18-12 N	71-55-26 E	TMA Khanewal Well 1 that is 350 feet deep, year of installation 1987
2) 30-22-22 N	71-52-99 E	Nestle Well 2 (in actual well 1) 350 feet deep, year of installation 1989
3) 30-22-24 N	71-52-56 E	Nestle Well 3 (in actual well 2) 350 feet deep
4) 30-24-29 N	71-52-06 E	TMA Kabirwala Well 4, 450 feet deep, year of installation 1998
5) 30-23-07 N	71-52-16 E	Kabirwala Agricultural Well 5 200 feet deep

vi). The results of the trace elements, Volatile organic compounds (VOCs), THMs, Pesticides, and radioactivity fall within the permissible limits for the Nestle Water Wells 1 and 2, but for the TMA Khanewal well results of total dissolved solids (TDS), total hardness, Nitrate are relatively high.

vii). Field data acquisition of water table depth within 10 Km radius varies between 35 to 55 feet depth and it is recharged by the annual rate of rainfall, and runoff that spills over the Ravi River, tributaries and the Indus Plain.

viii. No undesirable results and environmentally degradation have shown by this study. X. The Nestle Kabirwala Factory is meeting all requirements of safe yield operation.

39. Recommendations

1. Suitable probes recommended for future drilling for tube-wells are provided in the following Table B. The locations of ERSS sites are provided in figure 36. Sites ERSS-1 or ERSS-8 can be used for drilling a new tube-well up to 390 feet depth.

Table B. Recommendations of ERSS Points for future drilling

Nestle Factory Kabirwala	RECOMMENDATION DEPTH
ERSS-1, ERSS-8	Water Well of 390 feet depth
ERS-2, ERSS-4, ERSS10, ERSS-15	Water Well of 370 feet depth
ERSS-5	Water Well of 380 feet depth
ERSS-13	Water Well of 365 feet depth

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