NESTLÉ PAKISTAN

Groundwater Resource Assessment

Sheikhupura

INTP180164 – May 2019 – Report No: A96946

Prepared for:

Nestlé

Nestlé Pakistan

GeoScience Associates
Integrated GeoScience for economy
Safety & environmental responsibility
GSA

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Executive summary

Sheikhupura is located in the Indus Plain that is drained by a number of tributary rivers to the Indus River that flows in a south-westerly direction towards the Indian Ocean. The project lies in the upper part of the Upper Rechna Doab, the area between the River Ravi and the River Chenab.

Pakistan has one of the largest irrigation systems of the world. After Independence in 1947, problems between India and Pakistan arose over the distribution of water. Rivers in Pakistan's Punjab Province originate in India. To solve this water distribution dispute, a treaty brokered by the World Bank known as the Indus Water Treaty, was signed by the two countries in 1960. The Indus Water Treaty gave India exclusive rights to the eastern rivers Ravi, Beas and Sutlej. The supply of surface water from these rivers, and from the Upper Bari Doab Canal to the Bari Doab (and Lahore) was stopped over time. This changed surface water distribution induced a **lower recharge to the underlying aquifers** in the eastern part of the province, as the main recharge was occurring from seepage of rivers and associated irrigation canals. Furthermore, **groundwater became in these areas (including the project area) the main water source.** In order to relieve the shortage created by the lower flow in the eastern rivers Sutlej, Beas and Ravi, link canals were constructed to transfer the surplus water available in western rivers (Chenab, Jhelum, and Indus) to the eastern rivers.

The **factory is located in Quaternary alluvium deposits** (**alluvial flood plain**), overlying semi-consolidated Tertiary rocks or Precambrian rocks (metamorphic and igneous). The upper 200 meter of the alluvium consists of fine to medium sand, silt, and silty clay.

Sheikhupura lies in an alluvial aquifer in the upper part of the Upper Rechna Doab, the area between the River Ravi and the River Chenab. The project area is drained by these rivers and associated surface water network. The aquifer in the whole area of the Indus Plains is considered as one large unconfined and interconnected aquifer. The alluvial plain of the Punjab is an **unconfined aquifer with alluvial sands and complex sediments**. Despite the heterogeneous composition, **the aquifer is highly transmissive and unconfined**.

Nestlé Sheikhupura factory was the first Nestlé factory to be certified AWS (Alliance for Water Stewardship) worldwide. During the journey to accreditation, several crucial steps were implemented including stakeholder engagement, construction of 3 filtration water treatment plants to provide potable water to 30,000 people, raise awareness on water preservation etc.

Nestlé factory is supplied by three wells, named Well 1, Well 2 and Well 3. The factory is also equipped with three tubewells, called locally as Turbine 1, 2 and 3. Turbine 1 is used for the Beverage section of the factory and Turbine 2 and 3 for the Utilities. In 2018, about 2 Mm^3 was abstracted from the factory, including all wells. The maximum total abstraction was recorded in 2017 with a total of about 2.5 Mm^3. Since 2016, **Nestlé Waters represents a maximum of 25 % of the total abstraction from Sheikhupura factory.**

Available step rate test on Well 1 and Well 3 were interpreted. For Well 1, according to the results of the test performed in April 2014, it can be said that the well could be safely operated at 40 m^3/h. Step rate tests were performed on Well 3 in October 2007, March 2015 and January 2019. Greater drawdown is observed in Well 3 over time. The specific capacity is hence significantly decreasing over time. This difference in drawdown and specific capacity can be explained either by an ageing of the well condition and/or by the influence of the nearby pumping wells that was observed during the SRT testing. **However, it seems that the productivity of Well 3 is decreasing over time due to ageing conditions (e.g. clogging).**

According to Nestlé monitoring data, the static water level is around 10 mbgl and the dynamic water level up to about 18 mbgl. Overall, a slight decreasing trend can be observed according to the onsite monitoring data. Well 3 recorded a high decreasing trend of about 1-meter year. This decrease can be the results of different possibilities: over abstraction, aquifer overall decrease of the water levels or borehole ageing.). A slightly increasing trend (at least stabilised) can however be observed in 2018;

Monitoring data between 2013 and 2018 were obtained from several piezometers managed by the Punjab irrigation department. The data confirmed that the general groundwater flow direction is from the north-east to the south-west. A **cone of depression** was observed 13 km to the south-west of Nestlé factory. The **increase of this cone of depression can be observed over the years**. This area, near Kharianwala, is heavily populated (29,832 according to the 2017 census) with a strong industrial development (textiles, chemical, paper, leather etc.), inducing probable strong abstraction volumes. **Abstraction from the industrial area of Nestlé factory is likely contributing to this cone of depression (large water users around the factory).**

Onsite wells are sampled by Nestlé team and analysed in NQAC Vittel. Compared to the guidelines, all parameters are below the thresholds with the exception of **barium** values for all three wells (up to 214 mg/l compare to 100 mg/l), **arsenic** (up to 40 µg/l compare to the 10 µg/l from the national regulations, PSQCA and PFA, and international regulations WHO and EU) and **TDS** (up to 535 mg/l compare to 500 mg/l). Nestlé Waters treatment plant is however adequately dimensioned to remove the contaminants from the raw groundwater. The detailed results didn't highlight the presence of microcontaminants. Except for a trace of styrene (VOC) in Well 2, which was recorded just at the detection limit (0.1 µg/l). The contaminant was not recorded in the other wells and could potentially be the results of a cross contamination while sampling. It should however be noted that pesticides and fertilisers were not tested in these analyses even though large agricultural field are present in the project area.

The geochemical signature of Nestlé groundwater samples is characterised by a strong **bicarbonate geochemical facies**. Regarding the cations, there is no obvious dominance, with the samples being located in the centre of diagram. The geochemical signature of the groundwater abstracted from the three different onsite wells is almost identical.

These water chemistry results reveal that, for the analysed parameters, collected groundwater meets the selected criteria for Bottling Water.

The town of Sheikhupura is supplied in municipal water by the Tehsil Municipal Administration (TMA). The water is sourced from groundwater. The municipal supply is only supplying the urban area. Outside the city, in more rural area like the project area, potable supply is sourced from individual private wells. Industries are relying almost solely on groundwater and agriculture is sourcing 40 % of its water needs from groundwater. **The total estimated abstraction volume from the project area (10 km radius around the factory) is about 70 Mm^3/year. Nestlé factory abstraction represents 3.5 % of the total estimated abstraction in the project area.** When looking solely art Nestlé Waters (excluding Food & Beverage and Utilities), the average abstraction represents **less than 1 %** of the total estimate abstraction in the project area (70 Mm3).

The **intrinsic vulnerability is high for the porous alluvial aquifer**. The unconfined aquifer could be exposed to potential pollutant substances that could infiltrate through the unsaturated zone as there is a no capping clay cover and the water level is shallow (about 10 mbgl). Several potential contamination sources are present in the project area (waste dumps, waste water, industries, agriculture etc.) and can be threats to the water quality. **The risk of contamination to the local aquifer is considered as high.**

Groundwater recharge from the rainfall is limited. The main groundwater recharge mechanism is from the surface water. The mean rainfall recharge value for the aquifer is 63 mm/m²/yr which amounts to 7 Mm^3/yr in the considered aquifer recharge area (110 km²). This recharge value considers only the infiltration from the efficient rainfall. The estimated seepage from the Upper Chenab Canal infiltration is 15 Mm^3/year and from the associated smaller canals and drains 2 Mm^3/year.

Considering all hypothesis and limitations, it can be considered that the **annual water balance is around zero.** The sensitivity test (+/- 5 % on the recharge and the abstraction to account for uncertainties linked to estimations) shows that the water balance results is oscillating around zero, **with the percentage of total abstraction compare to the total recharge ranging between 87 % and 106 %.** When the abstraction is greater than the recharge, it means that the aquifer is being over abstracted, and the water stress is deemed as very high. It should be reminded that the water balance is made on the recharge entering the system and not the existing reserve. When the abstraction is higher than the recharge, the **deficit is covered at the expense of groundwater storage** causing groundwater level drop. When the yearly recharge cannot cover the abstraction, withdrawing is using groundwater storage year after year, inducing a depletion of the resource over time.

A future water balance scenario was run taken into account a decrease of 10 % of the recharge (rainfall and river) due to climate change and an increase of 20 % of the abstraction volume to population growth and industrial development. **These types of scenarios are arbitrary and aim at taking into account potential worsening conditions in the future. They do not reflect the current situation.** With this scenario, the water balance appears negative, and the total abstraction represents 130 % of the recharge.

When looking solely at Nestlé Factory abstraction (up to 2.5 Mm^3/y), this represents about 3.5 % of the total estimate abstraction in the project area (70 Mm3) and 11 % of the abstraction in the considered area of influence. Nestlé abstraction represents 10 % of the total recharge in the considered area of influence.

According to the results, in the current situation, the water balance appears to be oscillating around zero, meaning that the amount of total recharge would be equivalent to the amount of abstraction volume. With the level of uncertainties, it is not possible to determine if the result is slightly positive or negative. However, when comparing with the water levels trend in the project area, showing a slight decreasing trend and the presence of a cone of depression, the water balance results do confirm that the pressure applied on the available groundwater resources in the area is very high and over-abstraction is likely occurring, threatening the sustainability of the resource.

According to the available data and current water balance assessment, it seems that water abstraction in the project area is performed in a non-suitable way for the aquifer. Further groundwater monitoring is paramount to follow the groundwater level trends.

It should be reminded that these calculations are based on several assumptions and hypothesis and do not represent exact figures. The final result must be seen as an approximate figure to understand the water balance situation of the considered zone.

1 Introduction

1.1 Context of the study

Nestle Pakistan is producing bottled water and beverages in their Sheikhupura factory of Pakistan. The facility is located about 25 km to the north-west of Lahore and on the eastern outskirt of the Sheikhupura city (Figure 1 and Figure 2). The bottling water factory is supplied by three wells, with two of them used as the main sources (Well 2 and Well 3) and one used as back-up (Well 1). One other well (Turbine 1) is supplying the beverage factory. Two other wells are present on site for utilities purpose (Turbine 2 and 3).

An initial groundwater resource assessment was performed in 2014. Antea Group was commissioned to update and provide a more comprehensive study of the water resources in the area. The main objectives of the hydrogeology survey are to:

- estimate the quantitative water resource sustainability in the area based on detailed hydrogeological survey;
- identify main water abstractions in the surrounding area of the factory;
- specify the water quality and groundwater characteristics; and
- define the vulnerability of the aquifer and potential contamination risks.

The present report describes, based on documentary review and field observations by Antea France and associated local partner, the recommended option for sustainable groundwater management. This report concludes on detailed recommendations in terms of works and hydrogeological investigations.

1.2 Activities

A field mission was conducted between the 07/01/2019 and the 17/01/2019 by GSA, our local partner in Pakistan. During the site survey, the following activities were conducted by the team:

- visit of **the bottling plant** with data collection;
- meeting with relevant **project stakeholders**;
- visit of the **study area** to identify all points of interest: geological outcrops, water bodies and water users, land use and agricultural practices, wastewater discharge points, potential contamination points etc.

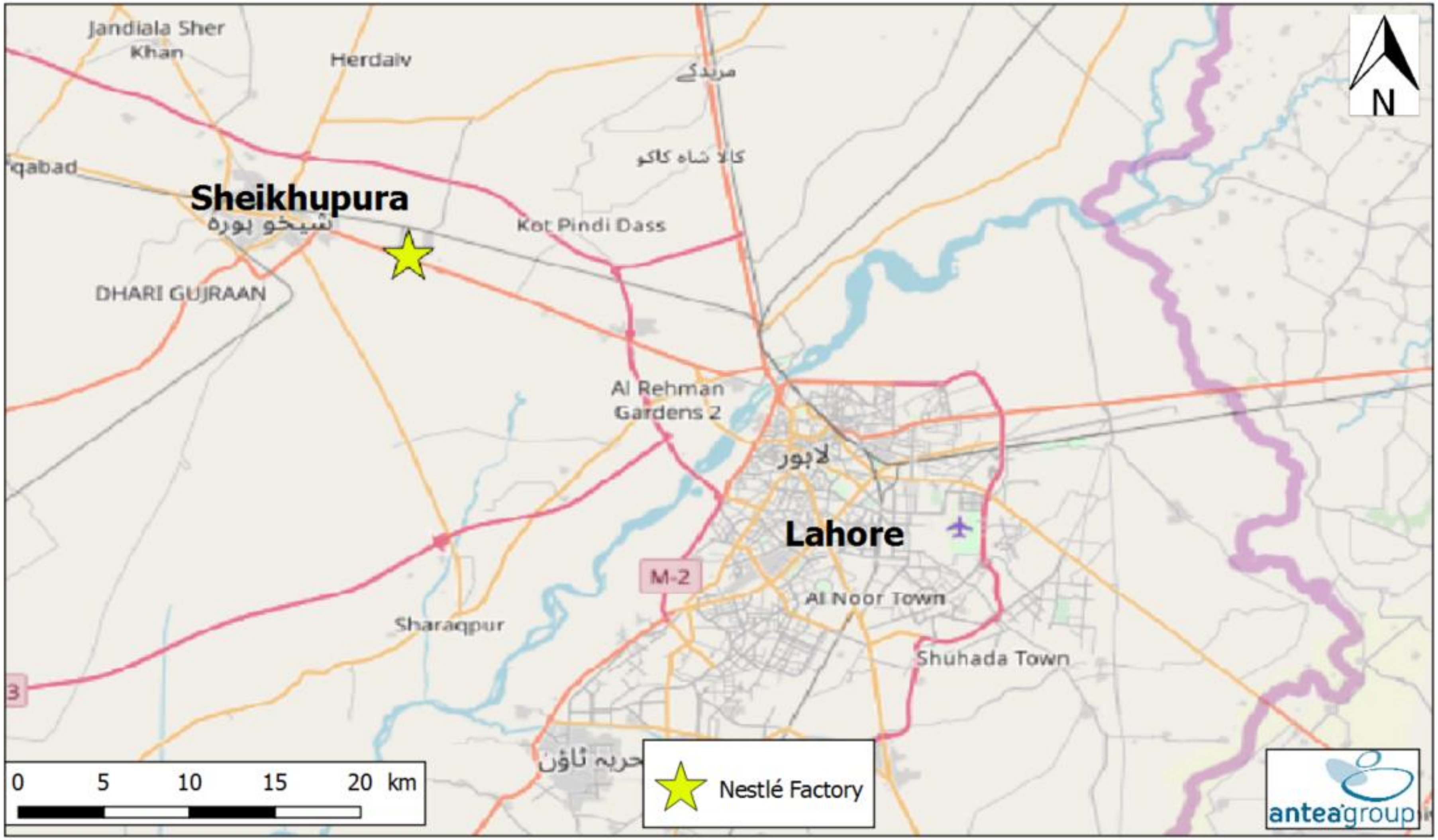

Figure 1 - Project location

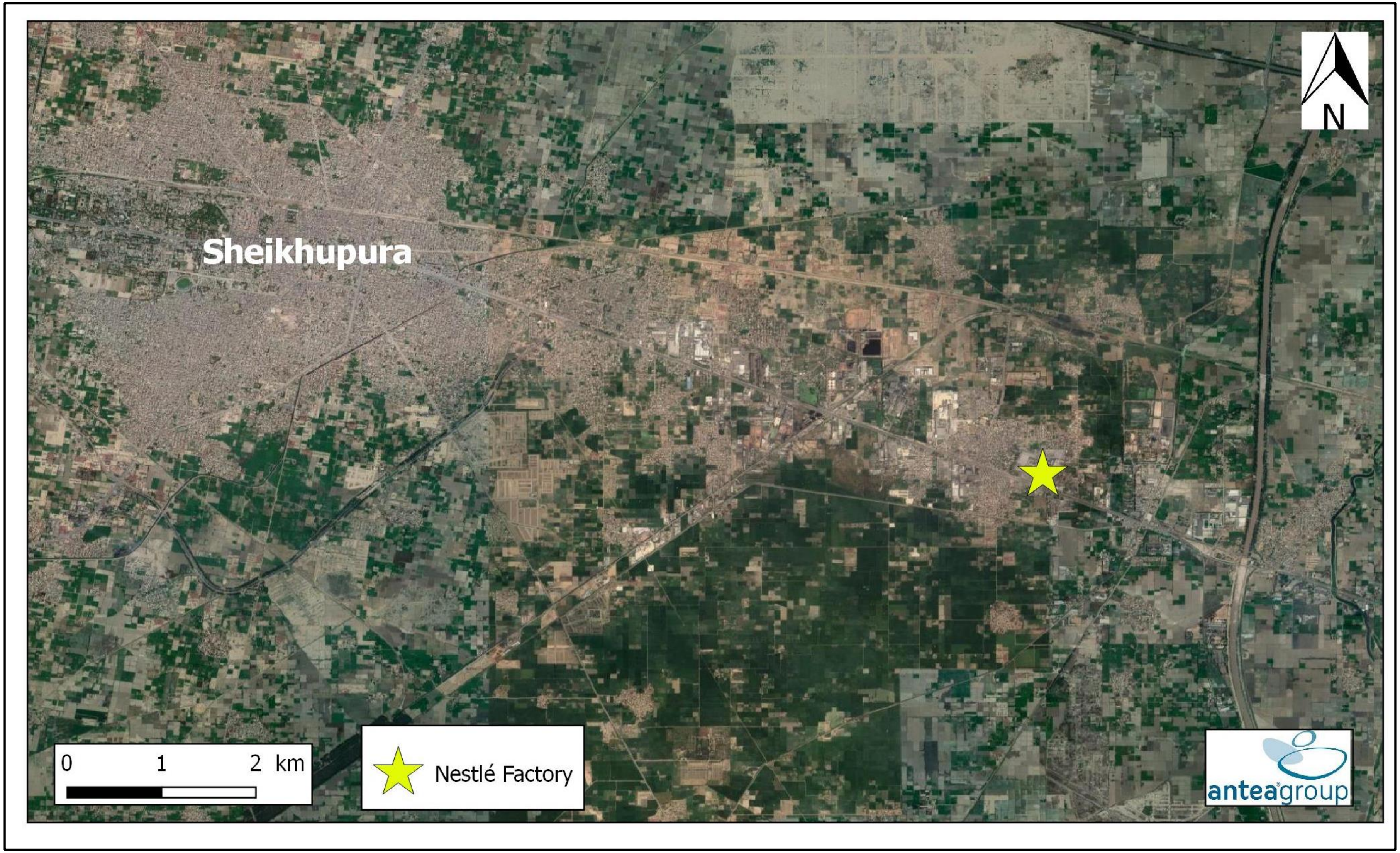

Figure 2 - Aerial view of the project area

2 Institutional and regulatory context

2.1 Main water agencies

The main water agencies in Pakistan are listed below:

Ministry of Water Resources (MoWR):

Formerly the highest policy making body in the water sector in Pakistan was the Ministry of Water and Power. Since the 4th of August 2017, the tasks concerning the water sector have been moved to separate ministry, the Ministry of Water Resources. This was done to improve the speed of policy implementation; it is still too soon to see the actual benefit as of early 2019.

The tasks of the Ministry of Water Resource remain much the same and will continue to exercise macro level administrative and budgetary control over the Federal organizations of the water sector.

Water and Power Development Authority (WAPDA):

The Water and Power Development Authority (WAPDA) will continue to operate under the Ministry of Water Resources. WAPDA remains responsible for water and hydropower development. The duties of the WAPDA include:

- Generation, transmission and distribution of power;
- Irrigation, water supply and Drainage;
- Prevention of water Logging and reclamation of water logged and saline lands;
- Flood Management;
- Inland Navigation.

In odds with the MoWR, the WAPDA retains its power section. This is due to dams providing both water storage and hydro electro power in Pakistan.

Water and Sanitation Agency (WASA)

Water and Sanitation Agency is a regulatory body for water projects and sanitation programs in Pakistan. WASA is responsible for planning, designing and construction of water supply, sewerage and drainage facilities. WASA is also responsible for billing and collection of all rates, fees and charges for the services provided to its consumer.

WASA have plans to build a small dam near Lahore which will act as a reservoir in the city. This dam should alleviate the groundwater stress in the region.

Tehsil Municipal Administration (TMA)

The Tehsil Municipal Administration is an organization association with each tehsil of Pakistan. The organization relevant to the project area is Sheikhupura Tehsil. The TMA is the municipal water supplier for the city of Sheikhupura.

Irrigation Department of Punjab (IPD)

The Irrigation Department of Punjab (IDP) works under the legal framework comprising of the Canal and Drainage act of 1873, revised in 2006. The Irrigation Department of Punjab is responsible for allocation and distribution of canal water to the various irrigation zones in Punjab.

Indus River System Authority (IRSA)

The Indus River System Authority was created following the signing of the Water Apportionment Accord between provinces in 1991. The IRSA comprises members nominated by each Province and Federal Government and in theory should act as an authority with the goal to impartial implement the accord.

2.2 Legislation

Table 1 presents the main legal documents related to water resources and environment in Pakistan.

Legal Document	Details
Pakistan Environmental Protection Act, 1997 (No. XXXIV of 1997)	This Act principally makes provision for administration of matters affecting the environment and, marginally, for environmental impact assessment and the handling of hazardous matters. It also defines environmental offences and prescribes penalties for those offences.
Punjab Environmental Protection Act, 1997 (No. XXXIV of 1997) (amended 2012)	This Act provides for the protection, conservation, rehabilitation and improvement of the environment, for the prevention and control of pollution, and promotion of sustainable development.
Punjab Flood Plain Regulation Act, 2016 (No. XXVII)	This Act aims to regulate any construction in the flood plains in the Punjab. It regulates in particular construction in flood plains for flood mitigation and development of water resources; and to deal with ancillary matters.
Punjab Disaster Response Plan 2014	The purpose of this plan is to clarify the roles and responsibilities of different stakeholders, and to introduce coordination mechanisms for immediate response and fast track rehabilitation.
Pakistan Environmental Protection Act, 1997 (Act No. XXXIV of 1997)	This Act principally makes provision for administration of matters affecting the environment and, marginally, for environmental impact assessment and the handling of hazardous matters.
Punjab Irrigation and Drainage Authority Act, 1997 (No. XI of 1997)	This Act makes provision for a new administration of irrigation and drainage management in Punjab.
Punjab Soil Reclamation Act, 1952 (Punjab Act XXI of 1952)	This Act provides for the speedy reclamation and improvement of waterlogged and saline areas and the prevention of damage to maximize agriculture production.
Punjab Local Government Act 2013 (No. XVIII of 2013)	The local governments established under this Act shall function within the Provincial framework and establish the succession of rights, assets and liabilities of local governments in adherence to the Punjab Local Government Ordinance No. XIII of 2001. Local areas shall divide a District into urban and rural areas.
Indus River System Authority Act, 1992 (Act No. XXII of 1992)	This Act provides for the establishment of the Indus River System Authority and defines its composition. Powers and duties of the Authority include: to lay down the basis for the regulation and distribution of surface waters amongst the Provinces according to the policies spelled

Legal Document	Details
	out in the Water Accord; review and specify river and reservoir operation patterns; and coordinate and regulate the activities of the Water and Power Development Authority.

Table 1 - Main legislation related to water

3 Site Description

3.1 Site location

Nestlé factory is located in the upper Indus plain in the Punjab province. The facility is located about 25 km to the north-west of Lahore and 9 km to the east of Sheikhupura, along the Lahore-Sargodha road. Figure 3 presents the aerial view of the surrounding area.

Name	Longitude	Latitude	Elevation	Description
Nestlé Sheikhupura factory	74° 4.320'E	31° 41.173'N	208 masl	The factory is located on the northern side of the Lahore-Sargodha road. The surrounding area is relatively dense with industries and housing, particularly to the west and the north. Some agricultural land is also present to the south and east of the factory.

Table 2 - Site description

Figure 3 - Aerial view of Nestlé factory

3.2 Topography

Topographic maps of the project area are present in Figure 4 and Figure 5. The area around the factory is relatively plat as it lies in a plain. The ground elevation varies between 204 and 211 m above sea level. Figure 6 presents the topographic map at a scale of 1/25,000.

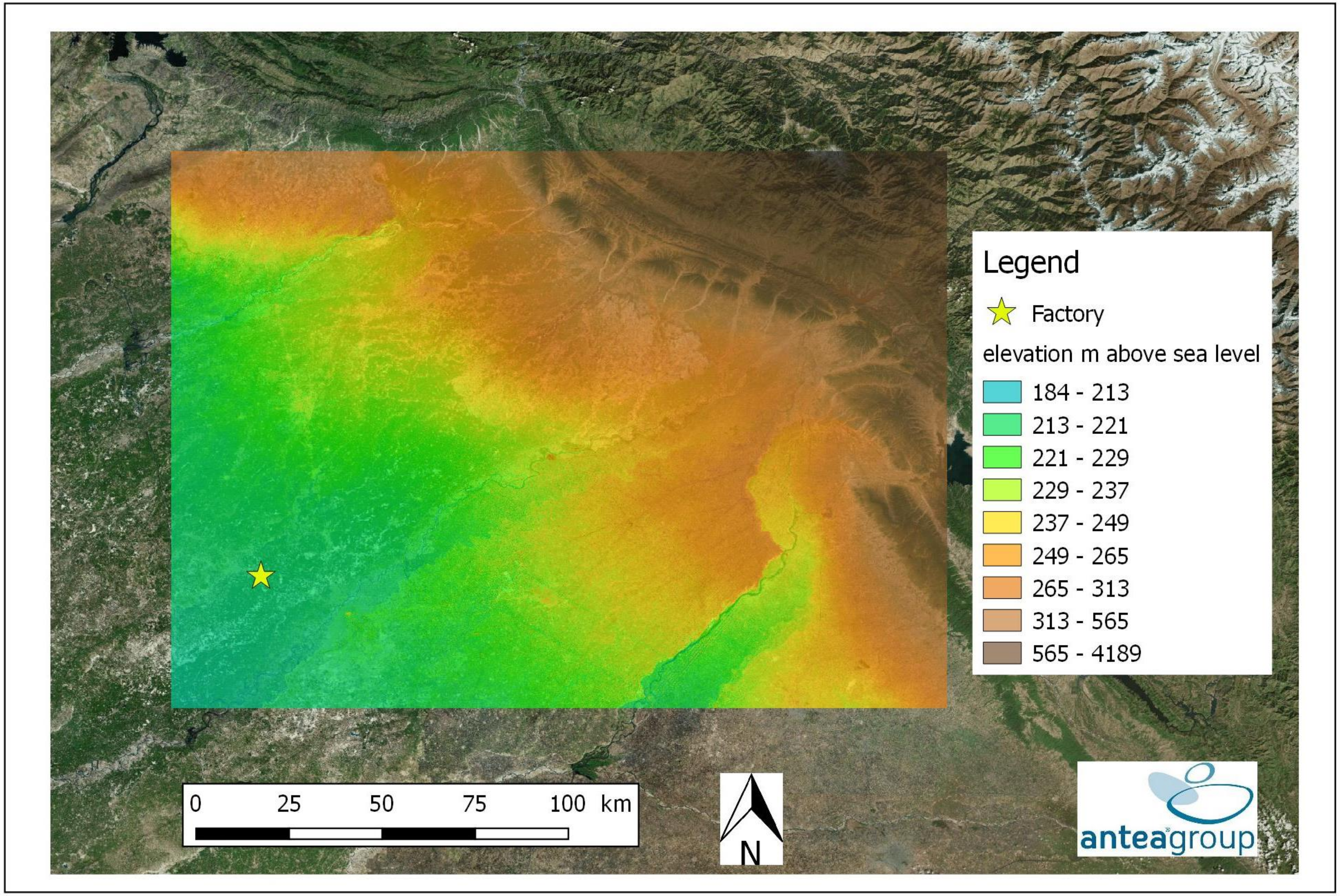

Figure 4 - Regional topographic map

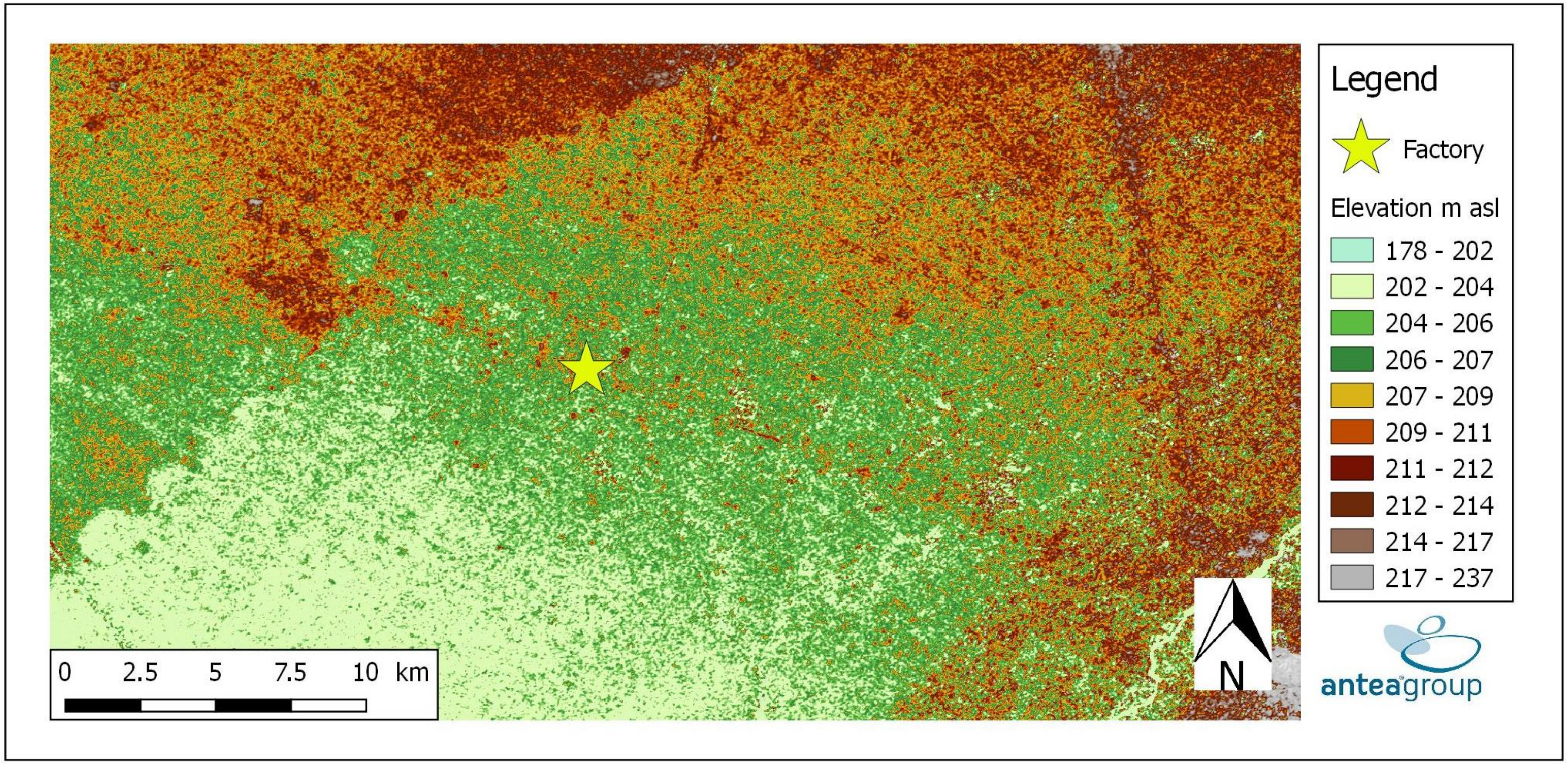

Figure 5 - Topographic map around the factory

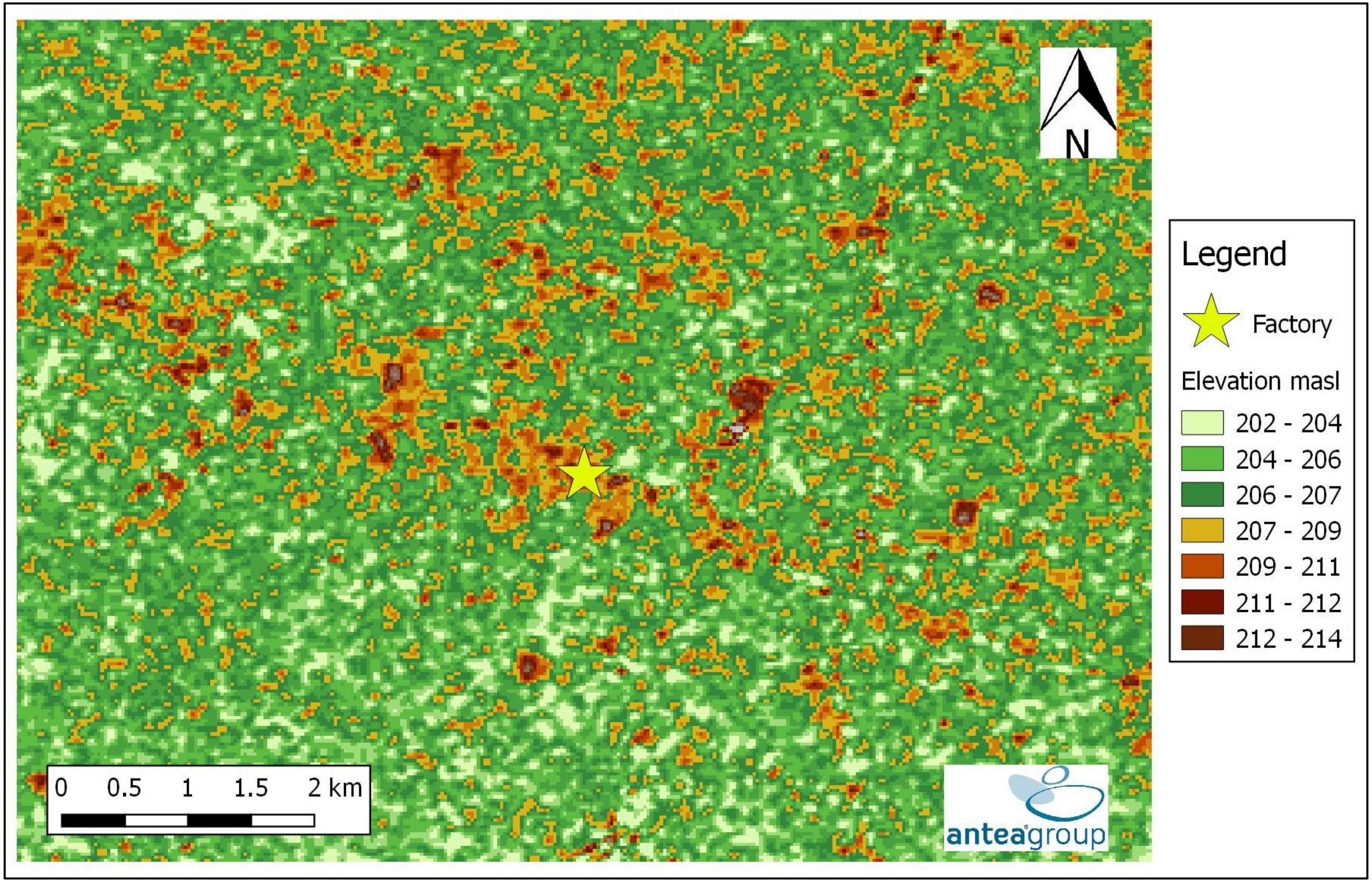

Figure 6 - Topographic map zoom at 1/25000

3.3 Administrative settings

Nestlé factory is located in the **Sheikhupura district**, one the 36 districts of the Punjab province (Figure 7). The latest survey (2017), recorded a population of 3.46 million inhabitants in the Sheikhupura district, covering a surface of 5,960 km². The population density was recorded at 580 inhabitants per km². This district is divided into 5 tehsils (administrative sub-division of a district). The project is located in the **Sheikhupura tehsil**, with the city of Sheikhupura being its headquarter. The 2017 census recorded a total population in this tehsil of 1.56 million inhabitants, with 39 % located in urban area and 61 % located in rural area. The city of Sheikhupura is an industrial center, acting as a satellite town of Lahore. The facility is located in **the Upper Rechna Doab**, one of the main regions of the Punjab province delimited by the **Chenab and Ravi rivers** (Figure 8).

Figure 7 - Sheikhupura district

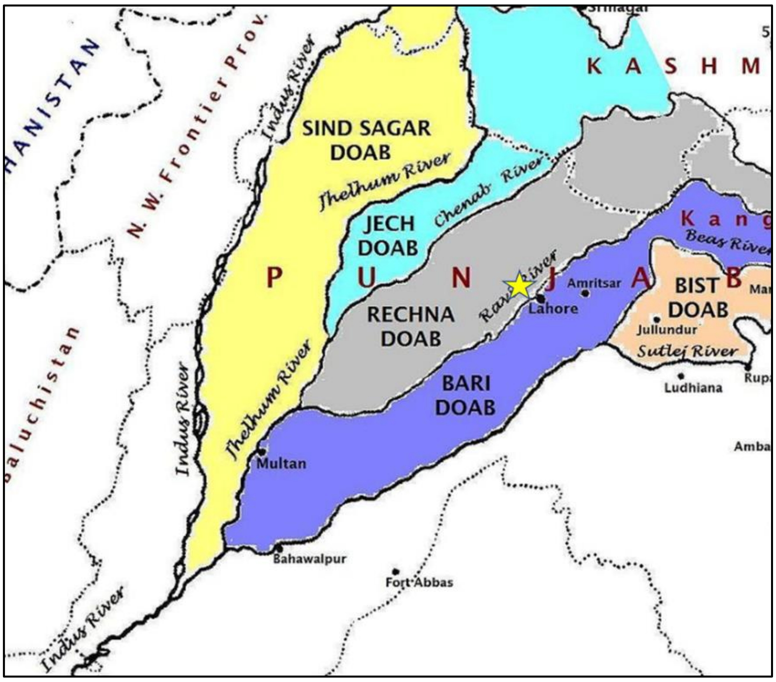

Figure 8 - Project location in the Rechna Doab region

4 General description of the Study Area

4.1 Climate

Sheikhupura is located in a semi-arid climate zone, with rainy, long hot summers (> 40°C), dry and warm winters, a monsoon and dust storms. The monsoon season starts from late June until August. In the Köppen Classification, it falls in the “Bsh” category: Mid-Latitude Steppe and Desert Climate.

The closest weather station to the project is in Lahore. The following subchapters present the available data from this station for of rainfall, temperature and evaporation.

4.1.1 Rainfall

Table 3 presents the monthly average rainfall from the Lahore station between 2007 and 2017. The wettest months of the year are July, August and September. The driest months of the year are October, November and December. The interannual average is 692 mm per year. During the 2007-2017 period, the driest year was recorded in 2009 with 372 mm and the wettest year in 2013 with 903 mm.

Month / Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2007	0	106	65	0	19	197	82	102	76	0	10	3	**660**
2008	24	6	0	38	37	68	118	287	22	6	0	7	**614**
2009	20	27	52	20	6	20	111	92	20	3	1	0	**372**
2010	0	9	5	3	7	5	288	119	88	0	0	15	**541**
2011	0	28	7	16	6	148	244	254	154	0	0	0	**857**
2012	19	7	10	50	0	13	38	197	199	29	0	21	**583**
2013	13	71	19	7	1	136	242	352	31	18	5	7	**903**
2014	4	23	32	65	30	50	43	57	450	3	29	0	**786**
2015	20	61	142	5	32	46	328	93	127	4	0	0	**857**
2016	29	3	27	3	31	118	152	315	128	1	0	0	**807**
2017	70	7	28	20	10	202	149	70	52	0	7	15	**630**
Average	18	32	35	21	16	91	163	176	122	6	5	6	**692**

Table 3 - Monthly average precipitation in mm from Lahore weather station between 2007 and 2016

4.1.2 Temperature

Table 4 and Table 5 present respectively the monthly average minimum and maximum temperature from Lahore station between 2008 and 2017. The hottest months are May and June whereas the coldest month is January. During the month of May and June temperature above 40°C are frequently recorded.

Month / Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2008	7.0	9.5	18.4	21.4	25.5	27.2	28.4	26.7	25.2	22.2	14.8	11.0
2009	10.0	12.5	16.8	21.8	26.5	28.5	27.1	27.7	25.9	20.1	13.6	9.1
2010	7.8	11.9	19.2	24.3	26.8	27.9	27.6	26.9	24.6	22.0	14.3	7.9
2011	6.9	11.1	16.3	20.2	27.5	27.0	26.7	26.4	25.7	21.2	16.0	8.9
2012	7.4	8.3	14.4	20.1	25.4	28.7	27.7	26.1	24.5	18.4	12.8	7.5
2013	5.6	9.9	14.9	19.8	25.1	26.5	25.2	24.8	24.4	20.5	11.3	7.3
2014	6.2	8.1	12.9	17.9	22.9	27.3	26.4	25.9	25.2	21.5	13.0	7.6
2015	7.7	11.6	14.4	20.8	25.3	26.3	25.4	26.6	25.1	20.2	13.5	8.4
2016	8.1	9.9	15.9	21.2	25.7	27.6	25.9	25.6	25.5	20.5	13.0	9.3
2017	8.5	11.6	15.7	22.4	25.9	26.2	27.0	26.8	24.1	20.8	12.8	8.9
Average	**7.5**	**10.4**	**15.9**	**21.0**	**25.7**	**27.3**	**26.7**	**26.4**	**25.0**	**20.7**	**13.5**	**8.6**

Table 4 - Monthly average minumum air temperature (°C) from Lahore weather station between 2008 and 2017

Month / Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2008	17.9	21.2	30.9	33.3	37.7	35.9	35.6	33.6	33.7	32.3	28.1	22.3
2009	20.0	23.3	28.3	33.8	39.3	40.2	36.5	35.6	35.0	32.9	26.1	22.2
2010	17.3	22.8	30.9	38.0	39.8	39.2	34.8	33.8	32.9	32.1	27.3	21.2
2011	16.6	21.2	28.0	32.9	39.9	37.2	34.2	33.3	33.2	32.5	28.0	22.0
2012	18.0	20.3	27.4	33.3	39.3	41.8	38.5	34.4	33.5	31.3	26.6	19.7
2013	16.9	20.5	28.1	34.0	40.3	38.7	35.3	32.0	35.1	32.1	26.5	20.9
2014	19.2	20.0	25.1	32.1	37.2	41.2	36.5	36.2	32.9	31.3	26.5	19.0
2015	16.6	22.6	25.1	32.7	39.1	38.1	34.2	34.6	34.5	32.0	26.6	21.8
2016	17.6	23.6	28.0	35.6	40.2	39.6	35.8	34.1	35.1	33.8	27.7	23.1
2017	18.4	24.4	28.0	36.5	39.0	36.9	35.6	35.4	35.0	34.2	24.5	22.7
Average	**17.9**	**22.0**	**28.0**	**34.2**	**39.2**	**38.9**	**35.7**	**34.3**	**34.1**	**32.5**	**26.8**	**21.5**

Table 5 - Monthly average maximum air temperature (°C) from Lahore weather station between 2008 and 2017

4.1.3 Evapotranspiration

Table 6 presents the monthly average evaporation from the Lahore station between 2013 and 2017. According to the available data, the average yearly total evaporation is 1,414 mm.

Month / Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2013	45	56	134	196	352	252	170	NA	NA	NA	NA	NA	
2014	36	0	82	127	248	NA	178	192	101	112	110	88	
2015	52	80	92	169	213	216	121	112	111	96	64	63	1,389
2016	61	103	133	149	177	174	118	63	84	92	78	64	1,295
2017	64	81	111	145	165	123	111	96	95	NA	NA	NA	
Average	52	64	110	157	231	191	139	116	98	100	84	72	1,414

Table 6 - Monthly average evaporation in mm from Lahore weather station between 2013 and 2017

4.1.4 Climate summary

Table 7 and Figure 9 present a summary of the available average monthly climate parameters according to the data presented in the above paragraphs.

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	13	34	36	21	17	80	165	187	130	6	5	5
Evaporation	52	64	110	157	231	191	139	116	98	100	84	72
Temperature	12.7	16.2	22.0	27.6	32.5	33.1	31.2	30.4	29.6	26.6	20.2	15.1

Table 7 - Monthly average climate parameters in Lahore

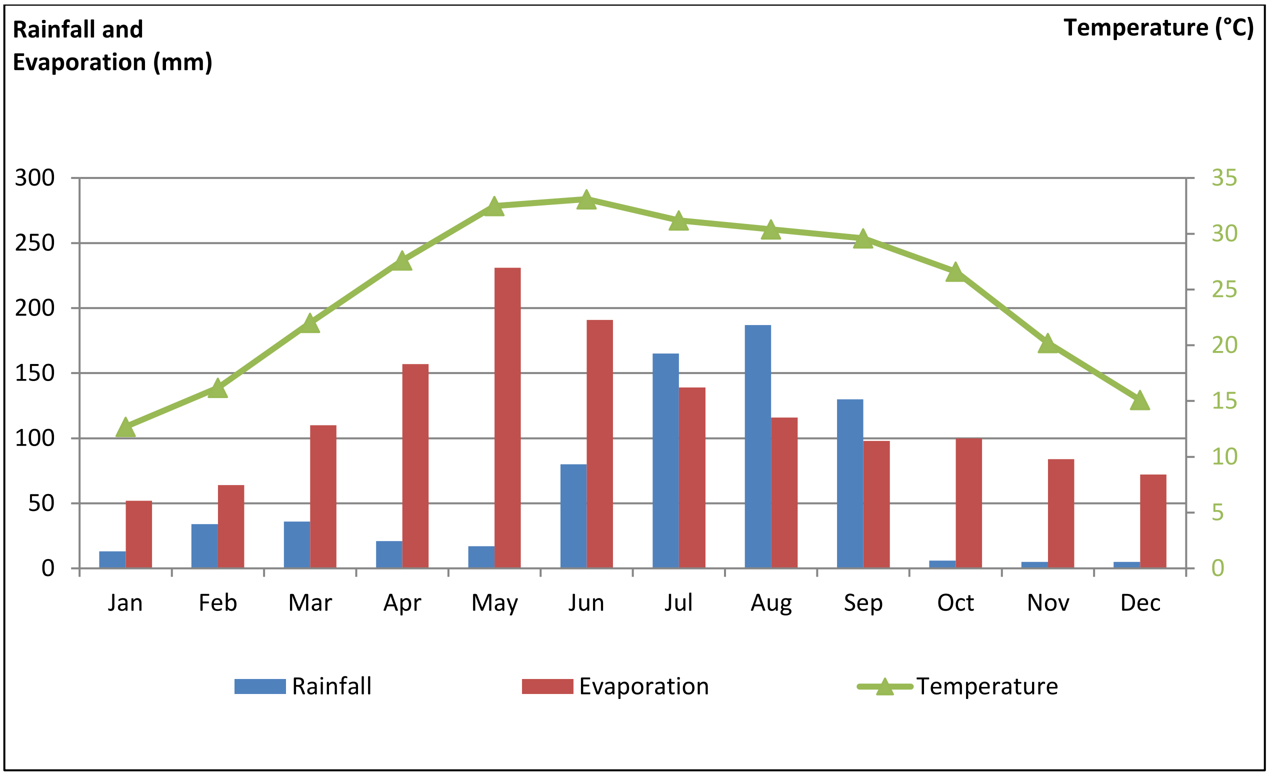

Figure 9 - Monthly average climate values in Lahore

4.1.5 Climate Change related events and potential consequences

Global Climate Change has been traced to a number of factors, mostly human. Although natural factors such as methane (CH_4) emissions from swamps, and carbon-dioxide (CO_2) emissions from forest fires resulting from lightning, contribute in no small measure towards Climate Change, the most significant input of Climate Change (CC) factors result from 100 human activities, especially industrialization. Climate Change factors such as Ozone Depleting Substances (ODS) emission and noxious gases (CO_2, N_2O, etc.), from gas flaring etc. are direct effects of industrial activities.

According to IPPC 2014 reports on Climate Changes, (Climate Changes, Synthesis report, Summary for Policy Makers, 2014), at the scale of the world and according to different models and scenario, the temperature will increase between 0.3 and 0.7°C for 2016 – 2035 period in comparison with 1986 – 2005. At the end of the century (2081 – 2100) the average global warming over the period 1986-2005 will probably have reached between 0.3°C and 1.7°C; according to RCP[1]$_{2,6}$, between 1.1°C and 2.6°C; according to $RCP_{4,5}$, between 1.4°C and 3.1°C according to $RCP_{6,0}$ and between 2.6°C and 4.8°C according to $RCP_{8,5}$.

This report underlines the fact that it is almost certain that continental regions will face an increase of extremely hot periods with limited extreme cold periods. It is also mentioned that change in rainfall will not be homogenous.

[1] RCP : representative Concentration Profiles

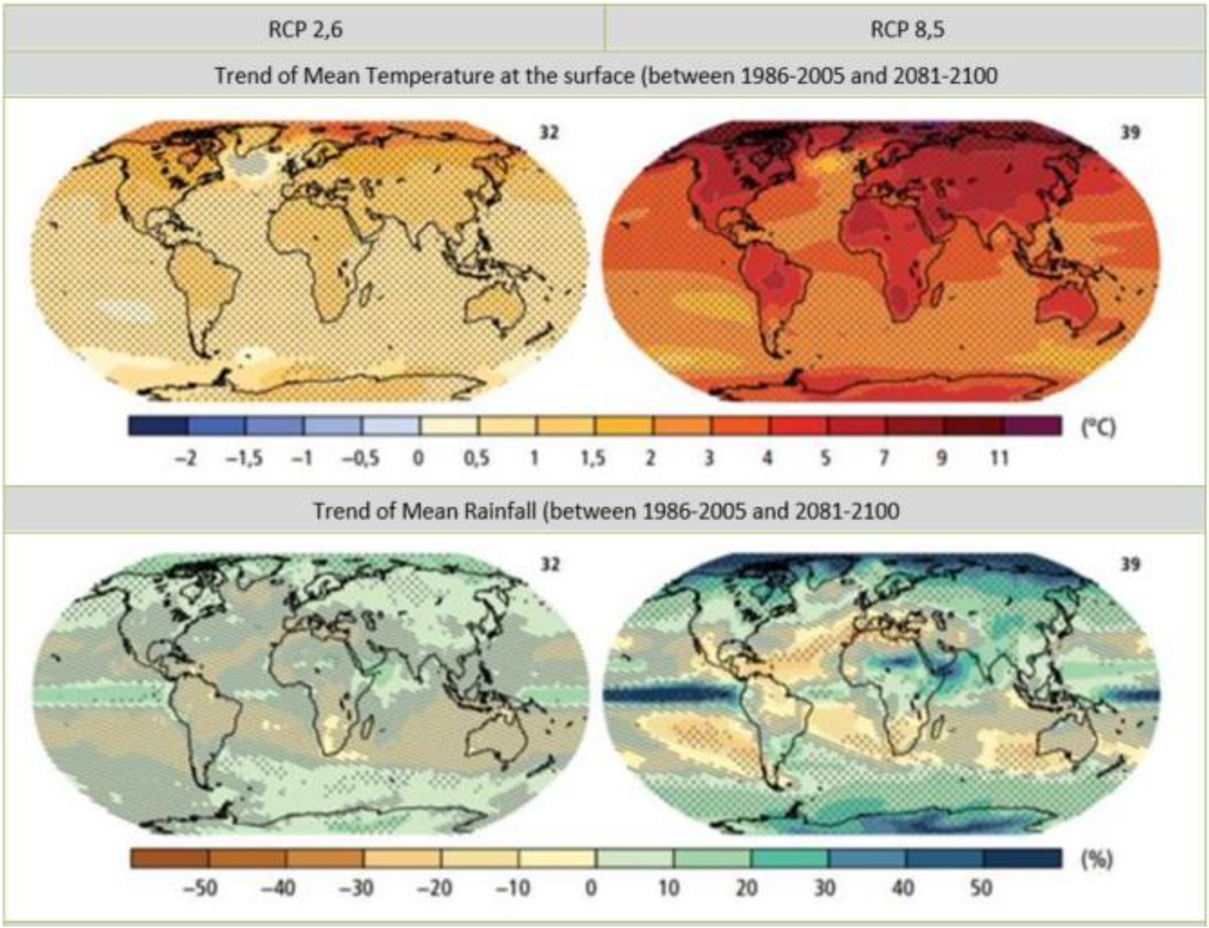

Figure 10 - Climate change projections (IPPC, 2014)

5 Water Resources

Pakistan as one of the largest irrigation systems of the world. After Independence in 1947, problems between India and Pakistan arose over the distribution of water. Rivers in Pakistan's Punjab Province originate in India. To solve this water distribution dispute, a treaty brokered by the World Bank known as the Indus Water Treaty, was signed by the two countries in 1960. The Indus Water Treaty gave India exclusive rights to the eastern rivers Ravi, Beas and Sutlej. The supply of surface water from these rivers, and from the Upper Bari Doab Canal to the Bari Doab (and Lahore) was stopped over time. This changed surface water distribution induced a **lower recharge to the underlying aquifers** in the eastern part of the province, as the main recharge was occurring from seepage of rivers and associated irrigation canals. Furthermore, **groundwater became in these areas the main water source.** In order to relieve the shortage created by the lower flow in the eastern rivers Sutlej, Beas and Ravi, link canals were constructed to transfer the surplus water available in western rivers (Chenab, Jhelum, and Indus) to the eastern rivers. Except for the Ravi, Sutlej, Chenab, and Jelum Rivers there are no cross-border surface waters anymore that are of relevant to the project area.

The share of water between provinces of Pakistan is managed by the Indus River System Authority (IRSA) established under the inter-provincial Water Appointment Accord (WAA) 1991. The Punjab Irrigation and Drainage Authority (PIDA) is responsible for receiving irrigation supplies at the barrages falling within the province and from the inter-provincial or link canals. PIDA delivers the water in agreed quantities to the various water users and Area Water Boards in the Province. Water is distributed to each individual user by a system of locks and sluices (warabandi).

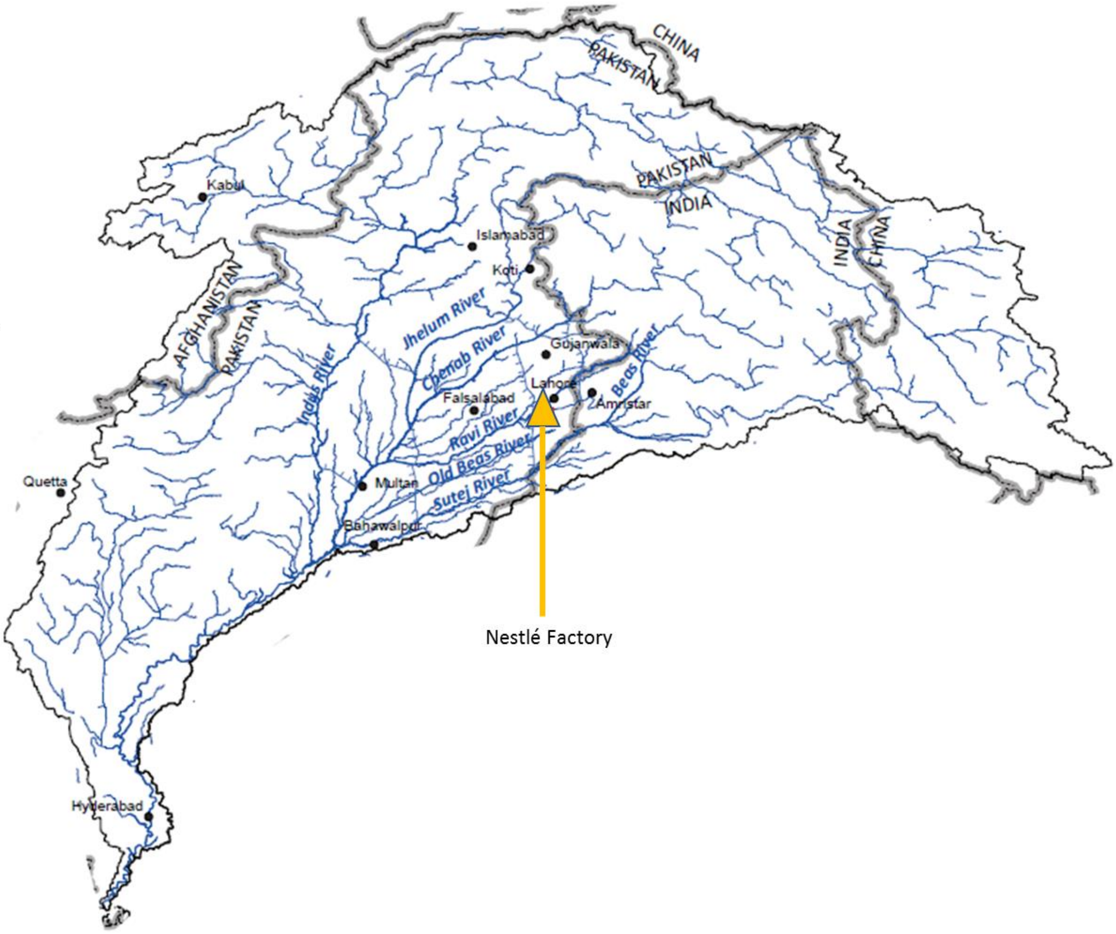

Figure 11 - Indus river watershed

The World Research institute (WRI) developed the Aqueduct Water Risk atlas, using 12 global indictors including water quantity, water variability, water quality, public awareness of water issues, access to water, and ecosystem vulnerability. The data used for the study were developed in consultation with experts and are publicly available.

Figure 12 presents the "Overall Water Risk" ranking map and Figure 13 the "Groundwater Stress" ranking map. As it can be observed, in both maps, the project falls into the highest risk category.

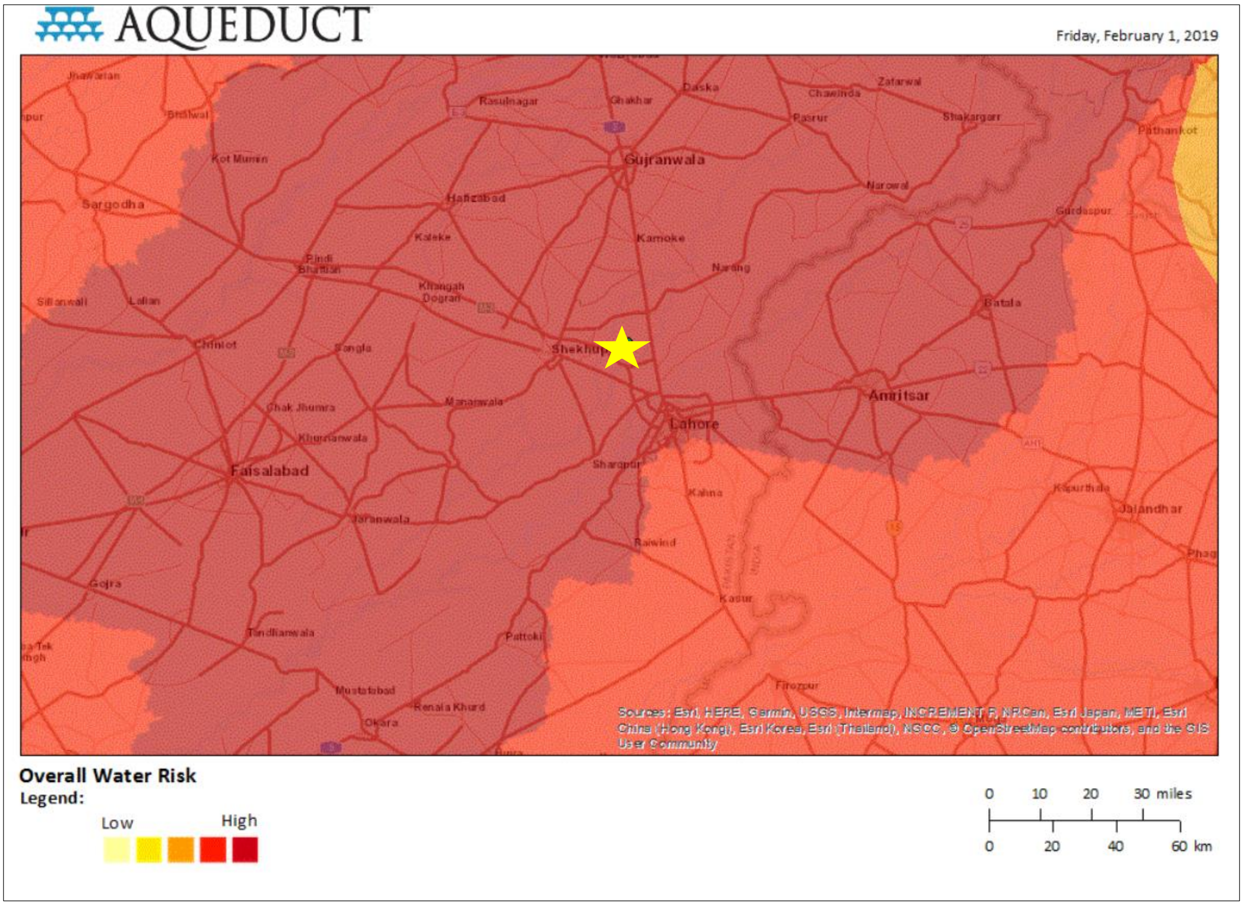

Figure 12 - Overall water risk in the project area (WRI, Aqueduct)

The Combined Water Stress Index (CWSI) used by Nestlé gives a VWSI ranking of 4.8 on a scale of 5, categorising the area as Water Scarce.

Both water risk evaluations, WRI and CWSI, are affecting high level of risk ranking.

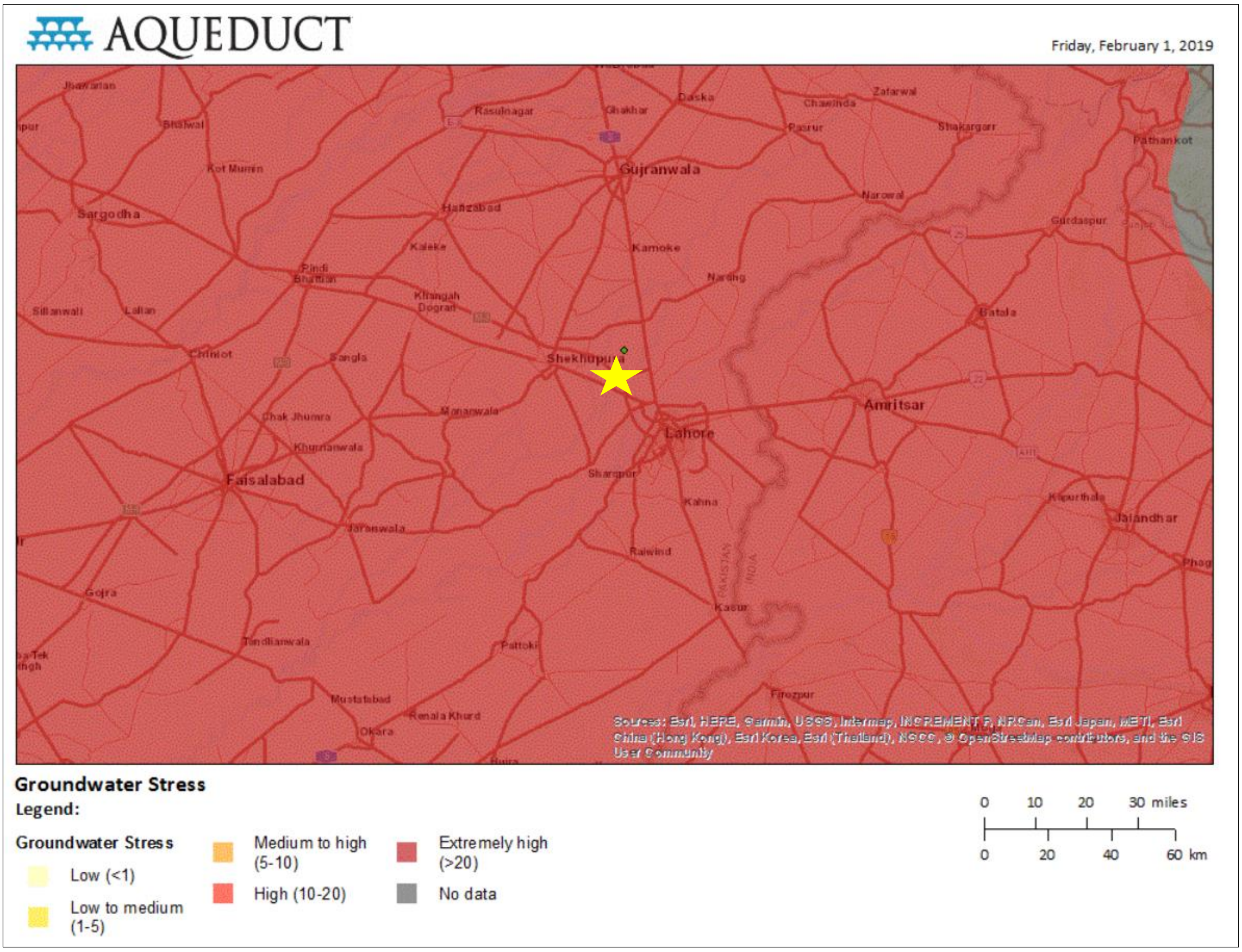

Figure 13 - Groundwater stress in the project area (WRI, Aqueduct)

5.1 Surface Water resources

Sheikhupura is located in the Indus Plain that is drained by a number of tributary rivers to the Indus River that flows in a south-westerly direction towards the Indian Ocean. The project lies in the upper part of the Upper Rechna Doab, the area between the River Ravi and the River Chenab (Figure 14).

Chenab River is a 960 kilometres long river which originates from Chandra Taal in the Lahul & Spiti District of Himachal Pradesh in India where it is known as Chandrabhaga. It is one of the 5 major rivers of the Punjab region. The waters of the Chenab were allocated to Pakistan under the terms of the Indus Waters Treaty. Nestlé factory is located about 90 km east of the Ravi River (Figure 16).

Ravi River is a 960 kilometres long river which originates from the Kangra district of Himachal Pradesh, India. The waters of Ravi are allocated to India under Indus Water Treaty. As it can be observed on Figure 15, water level on the Shahdrah barrage have significantly decreased following the Indus treaty and use of the river by India. Nestlé factory is located about 22 km west of the Ravi River (Figure 16).

Nullah Deg is a twisted channel originating from India, flowing 3 km east of Nestlé factory, before discharging into River Ravi near Lahore.

Several canals are connecting these two rivers, allowing to transfer water from the Chenab river to the Ravi river with lower levels due to the Indian upstream usage. About 2 km east of the factory, the **Upper Chenab Canal** is flowing. The canal is design with a width of 68 meters and a design discharge rate of 231 m^3/s. The average flow rate is 63 m^3/s. Water is distributed to the agricultural land via a complex network of channels and weirs (Figure 17). Large number of small drains are present all over the area.

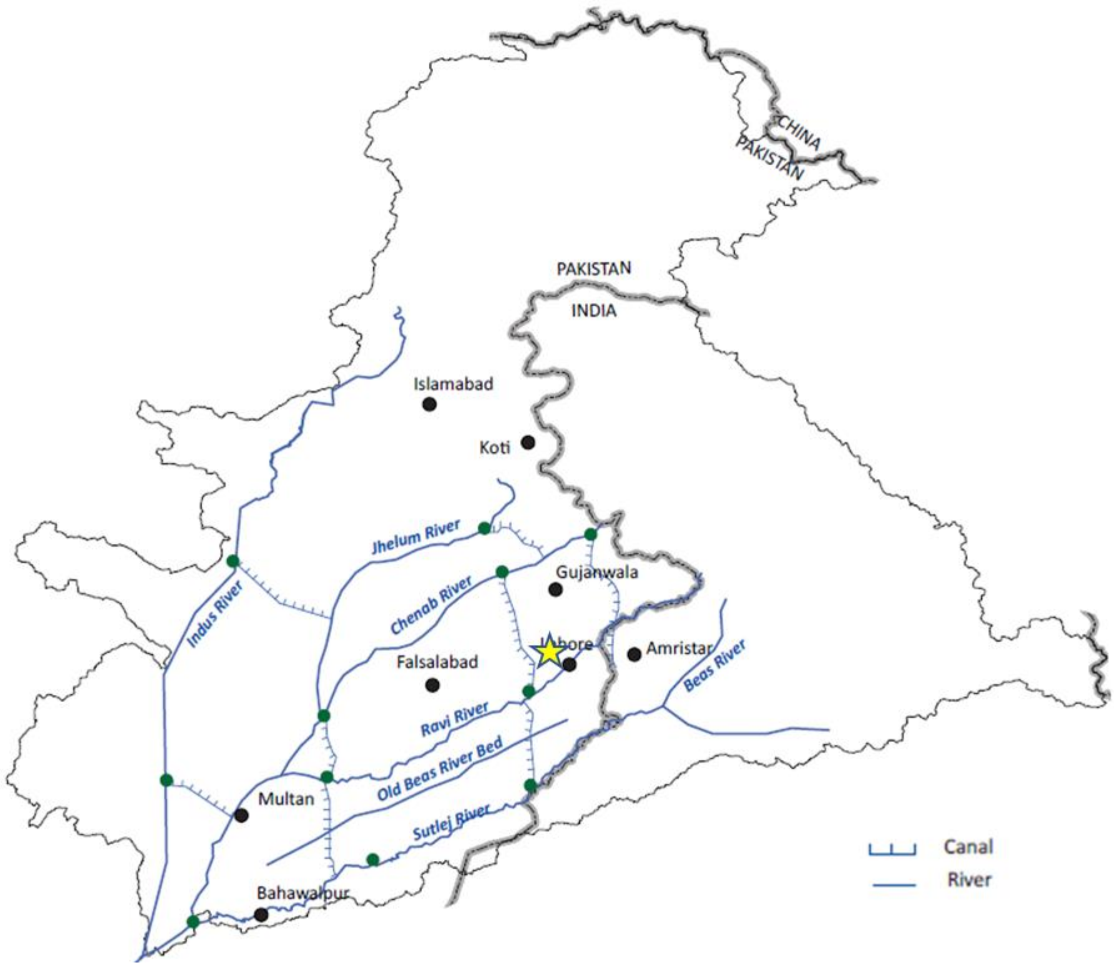

Figure 14 - Upper Indus river and canals

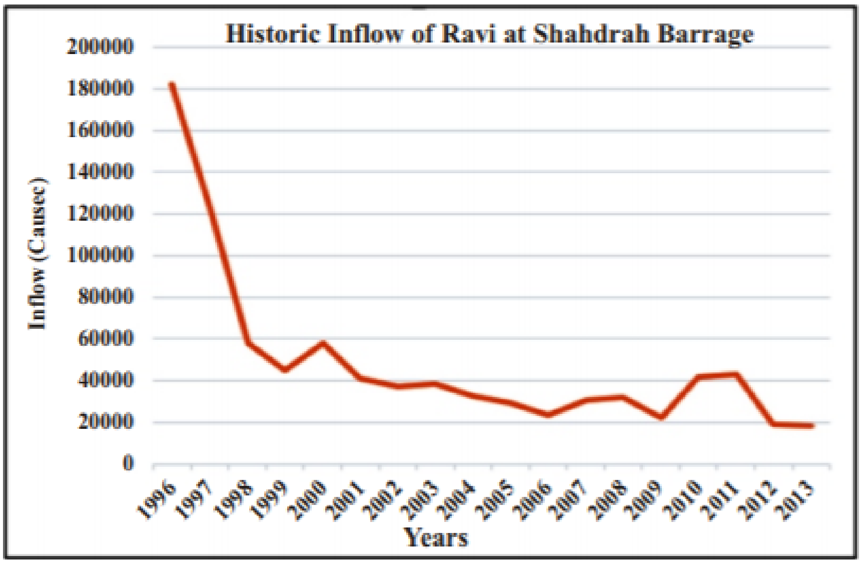

Figure 15 - Evolution of River Ravi inflow at Shahdrah barrage (Kanwal, et al., 2015)

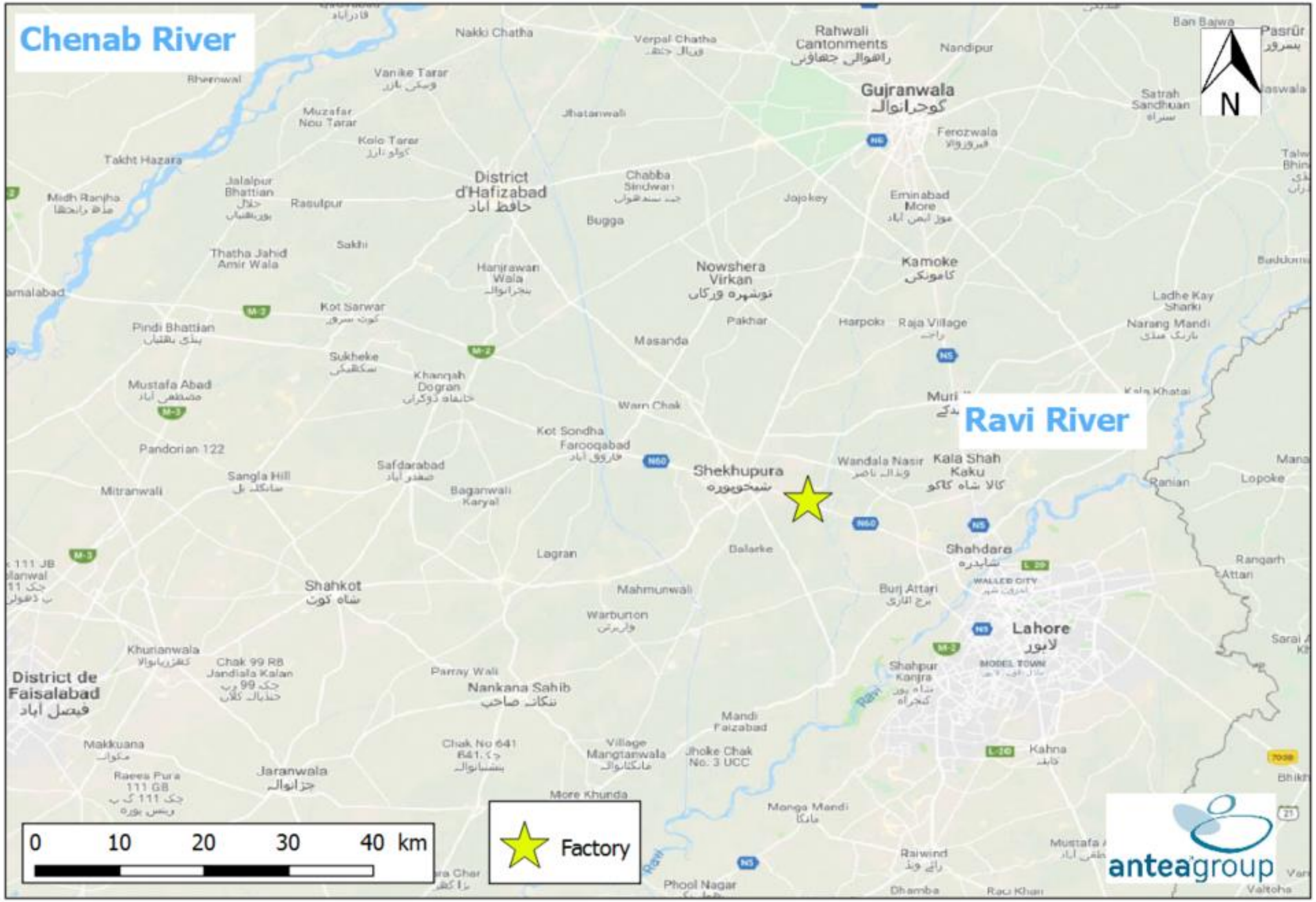

Figure 16 - Project location in between the main rivers

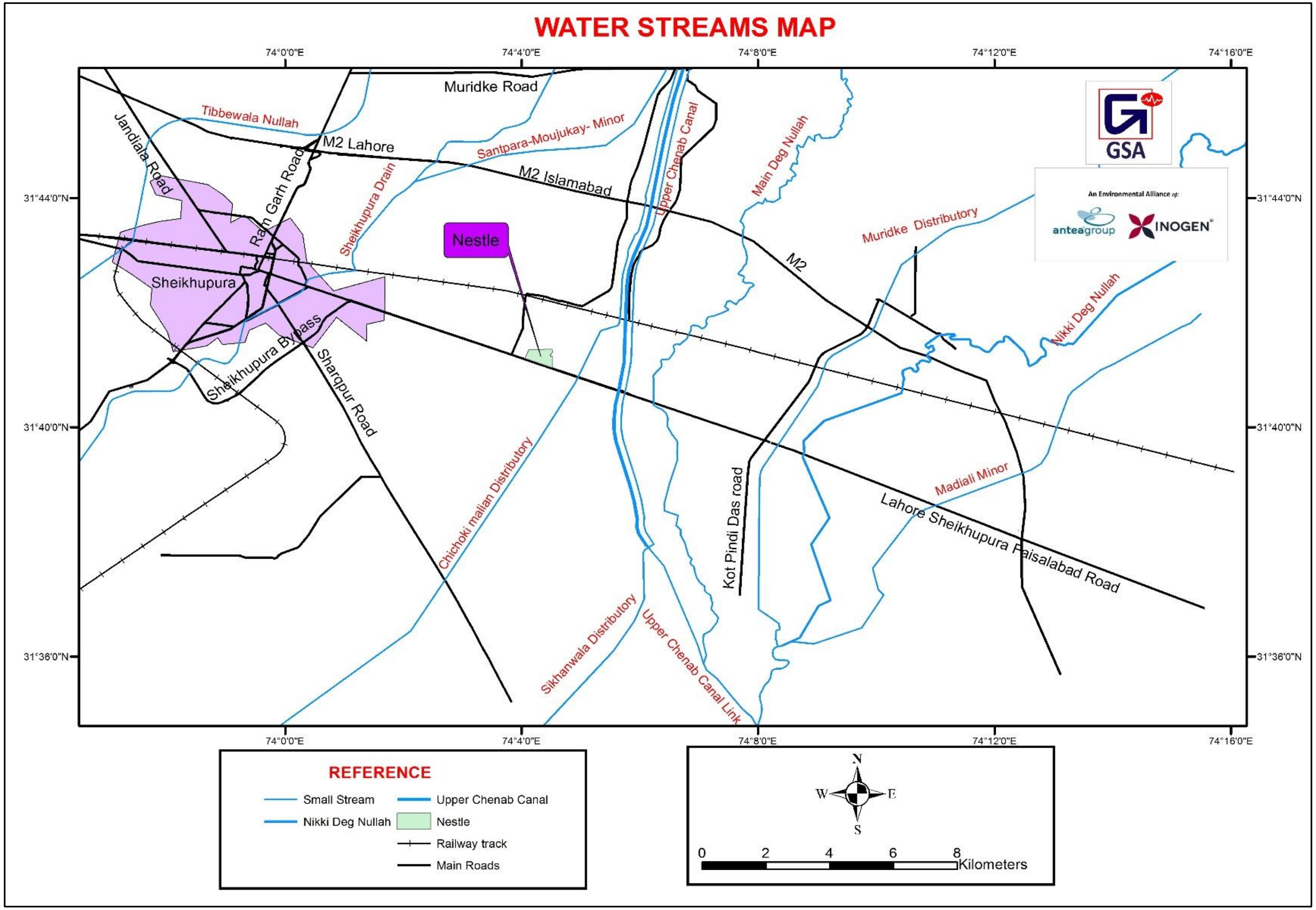

Figure 17 - Local surface water network

5.2 Groundwater resources

As mentioned previously, groundwater is the main source for water supply in the area, including potable and industrial needs. At the same time, groundwater recharge significantly decreased compare to previous historical rate due to the significant reduction of water volume in the rivers “managed” by India. Furthermore, industrialization and increase of the population are additional factors that are putting additional pressure on the available groundwater resources. Groundwater over abstraction and aquifer depletion in the Lahore area is a significant national and public concern. Average decline in groundwater level of Lahore is presented in Table 8. **The values are only representative of Lahore city. It should be reminded that the project area is located 20 km away from L**ahore, on the other side of the Ravi River. The study will therefore focus of the project area and not Lahore city.

Significant pressure is applied by the authorities of Pakistan on the large groundwater consumers, particularly the industrials.

Period	Rate of Decline	
	ft/year	m/year
1960 - 1967	0.984	0.30
1967 - 1973	1.804	0.55
1973 - 1980	1.969	0.60
1980 - 2000	2.133	0.65
2007 - 2011	2.6	0.792
2011 - 2013	3	0.9144

Table 8 - Average annual rate of groundwater decline (Kanwal, et al., 2015)*

**no data available from this publication (or equivalent) for the 2014-2018 period yet.*

From a qualitative point of view, groundwater in Pakistan is known to be affected by very **high concentration of geogenic arsenic, affecting the local population’s heath**. International organisations (WHO and Codex) as well as Pakistan authorities (PSQCA and PFA) have set the **guideline value for arsenic to 10 µg/l as the permissible concentration in drinking water**. As it can be observable by the map developed by Podgorski (Figure 18), a large amount of collected groundwater samples are above the 50 µg/l, largely above the 10 µg/l threshold. It should be noted that the 1,200 groundwater samples collected for this study between 2013 and 2015 were collected at an interval range of 3 to 70 m below ground level. High arsenic concentrations are principally located in the Indus plain. **The project area is subject to high concentration of arsenic. However, it should be noted that the national guideline regarding bottling water (PCRWR guidelines) is setting the threshold at 10 µg/l as per WHO guideline and that Nestlé Waters water treatment is adequate to efficiently remove this contaminant.**

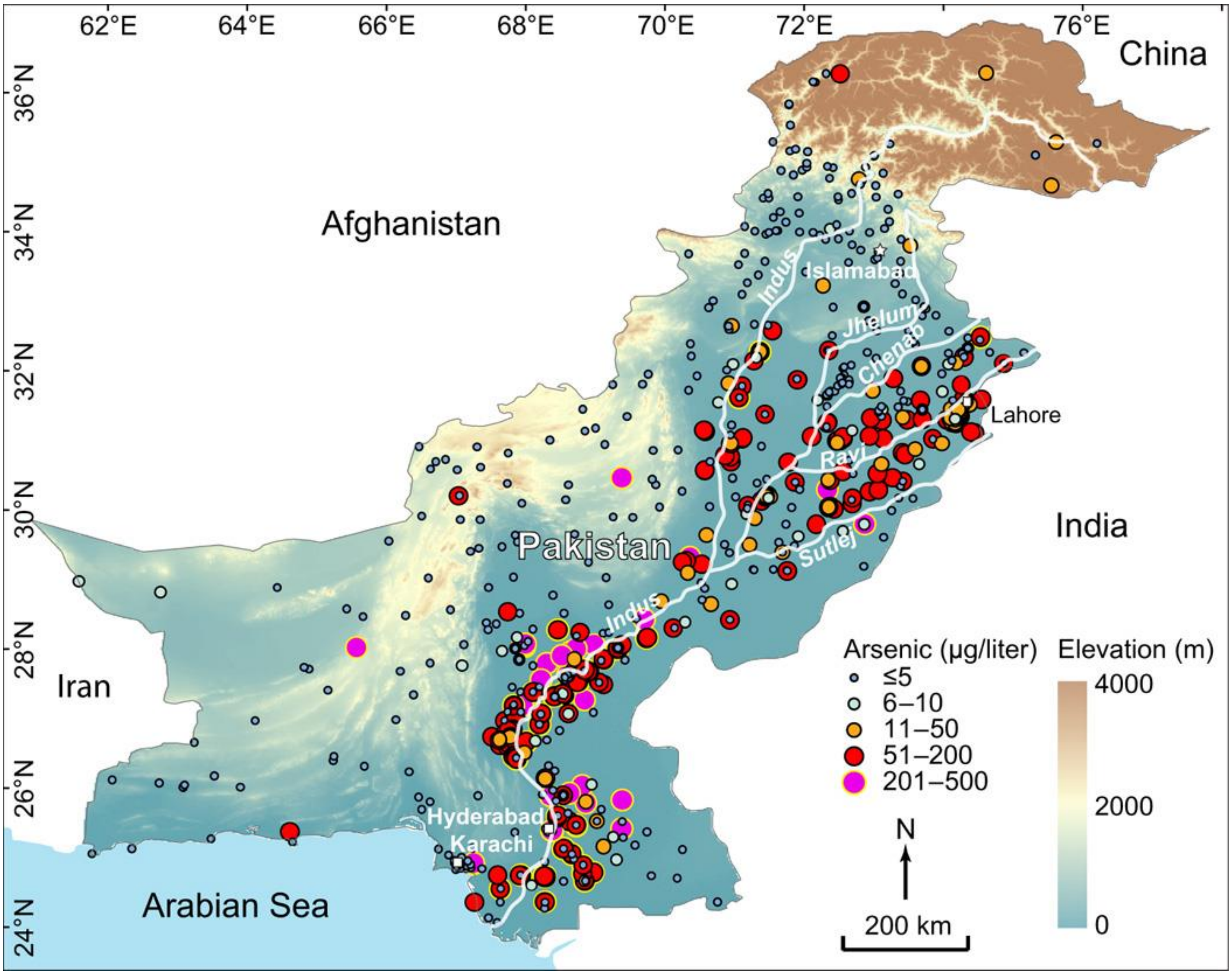

Figure 18 - Arsenic concentration in groundwater samples (Podgorski, 2017)

6 General Presentation of the Geological and Hydrogeological contexts

The geological and hydrogeological contexts in the study area were established from secondary information and confrontation with observations on the ground.

6.1 Geological context

The geological structure and stratigraphy of the project area is very complex due to the convergence of the Pakistan-India and Eurasian tectonic plates and their collision that began about 20 million years ago.

The geological history records a long period of gentle geological fluctuations and slow deposition in the study area while the Pakistan-India plate drifted northward. This period is followed by more vigorous tectonic processes and rapid deposition since the convergence of the Pakistan-India and Eurasian plates. Therefore, the period from the Middle Jurassic to the Lower Miocene (150 million years) is represented by only 675 m of primarily marine sedimentary rocks, whereas the last 20 million years are represented by more than 7 570 m of continental sedimentary rock.

The last 1.5 million years are characterized by a domination of erosion over deposition, hence, the preserved sediments are thin and discontinuous alluvium and eolian silt.

The **Indus Basin** is the largest basin in Pakistan, oriented in NE-SW direction including the 25,000 km^2 of SE part of Pakistan. Tectonically, Indus Basin is much stable area as compared to other tectonic zones of Pakistan. The main feature which controlled the sedimentation in the proto-Indus Basin up to Jurassic was Precambrian Indian Shield whose topographic highs exist in the form of Kirana Hills (Sargodha High) and Nagar Parker. It is the Sargodha High which is considered to be a divide between Upper Indus Basin and Lower Indus Basin (Asim et al., 2014). The Indus basin is subdivided into Kohat and Potwar Plateau and Punjab Platform. The stratigraphy is presented in Figure 20 and Figure 21.

The local geology is presented in Figure 22. The **project is located in Quaternary alluvium deposits** (**alluvial flood plain**), overlying semi-consolidated Tertiary rocks or Precambrian rocks (metamorphic and igneous). **The upper 200 meter of the alluvium consists of fine to medium sand**, silt, and silty clay mixed with concretions of kankar[1], siltstone and mudstone. The alluvial complex is heterogeneous and individual strata have little lateral or vertical extent. **The depth to the underlying stratigraphy (Tertiary rocks or Precambrian) is not exactly known but it is at least greater than 200 meters.**

[1] Kankar is a sedimentological term derived from Hindi, occasionally applied to detrital or residual rolled, often nodular calcium carbonate formed in soils of semi-arid regions.

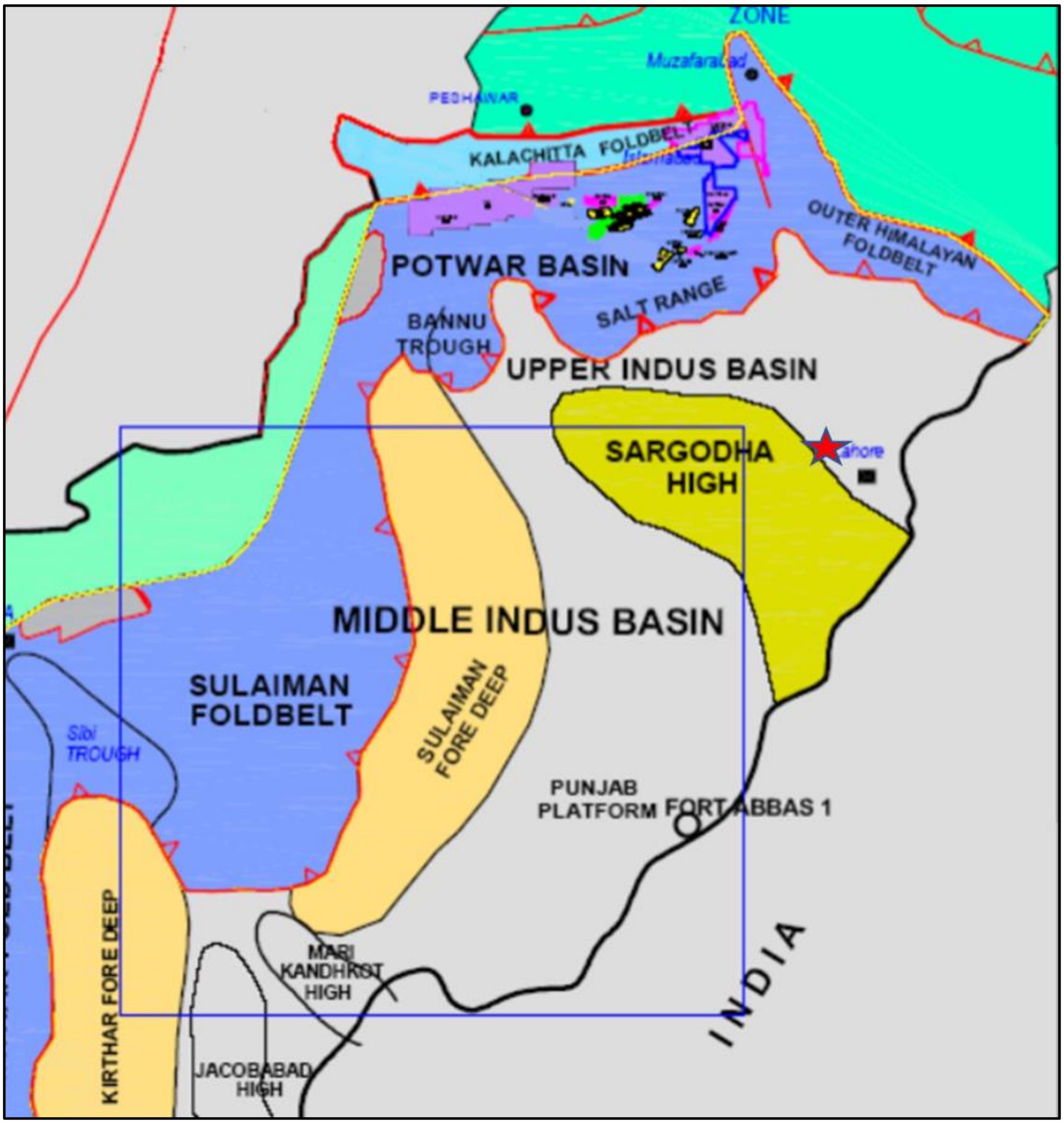

Figure 19 - Major basins in the project area (Asim et al., 2014)

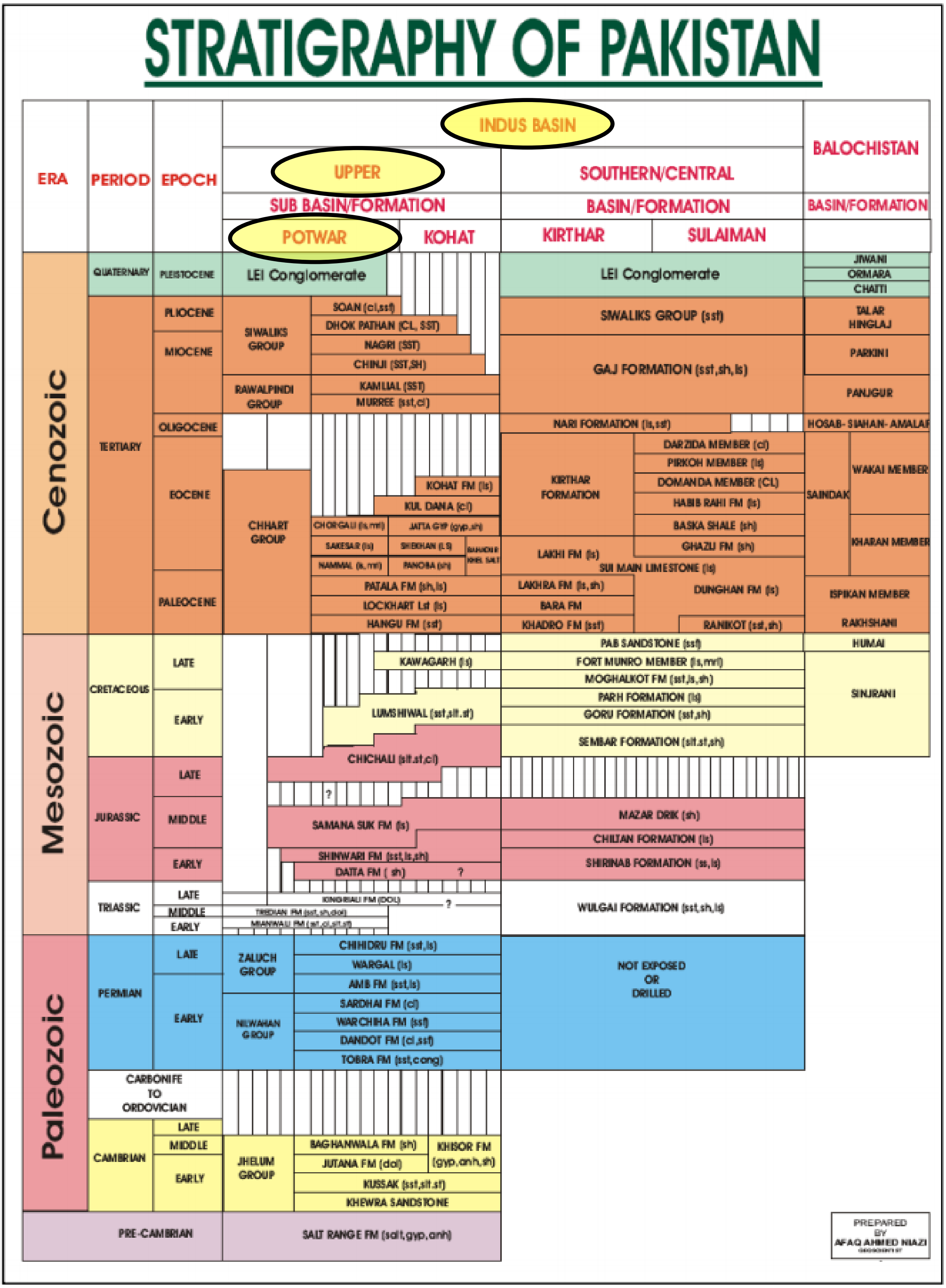

Figure 20 - Stratigraphy of Pakistan (yellow circle relevant to project area)

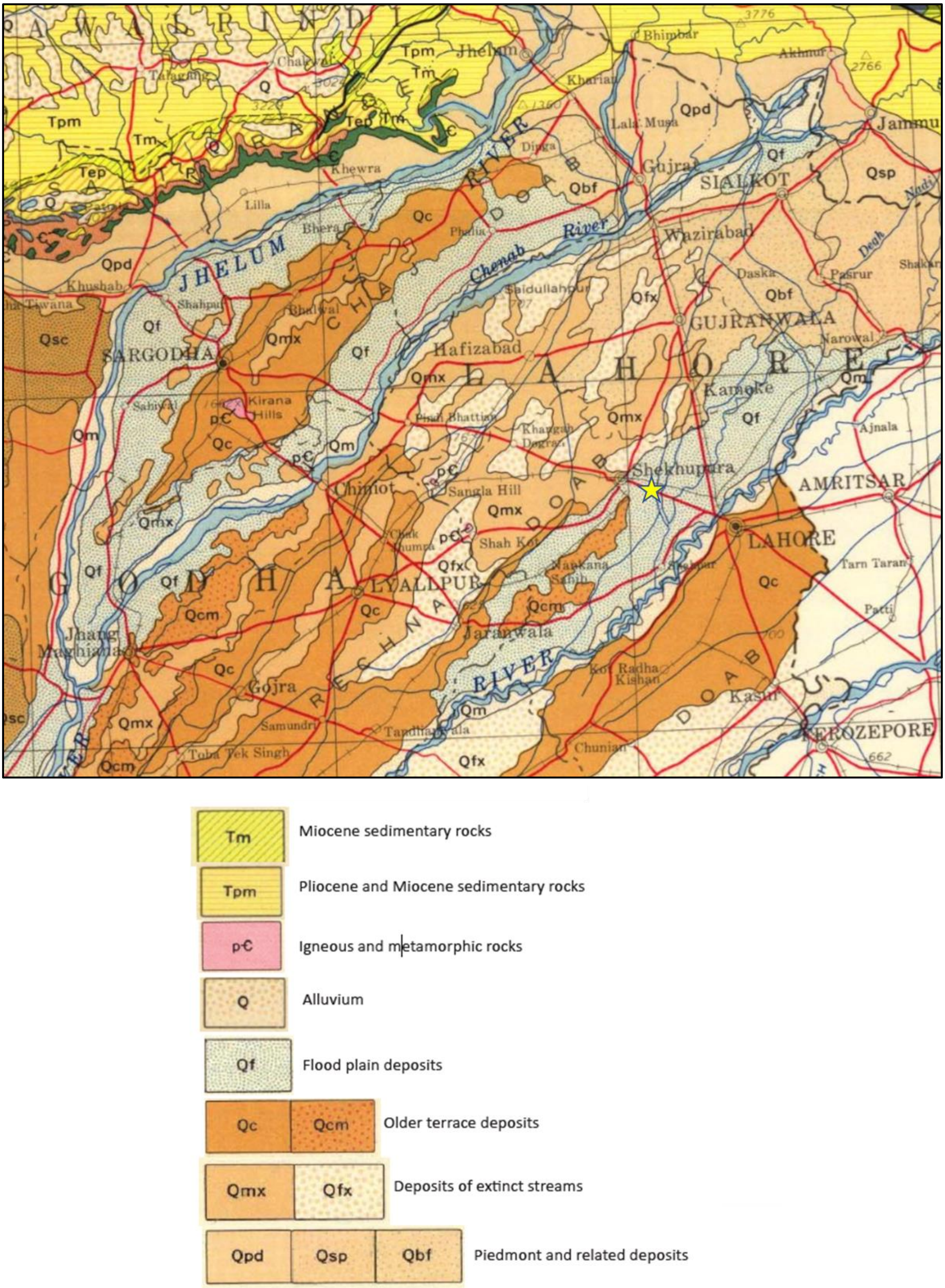

Figure 21 - Regional geology

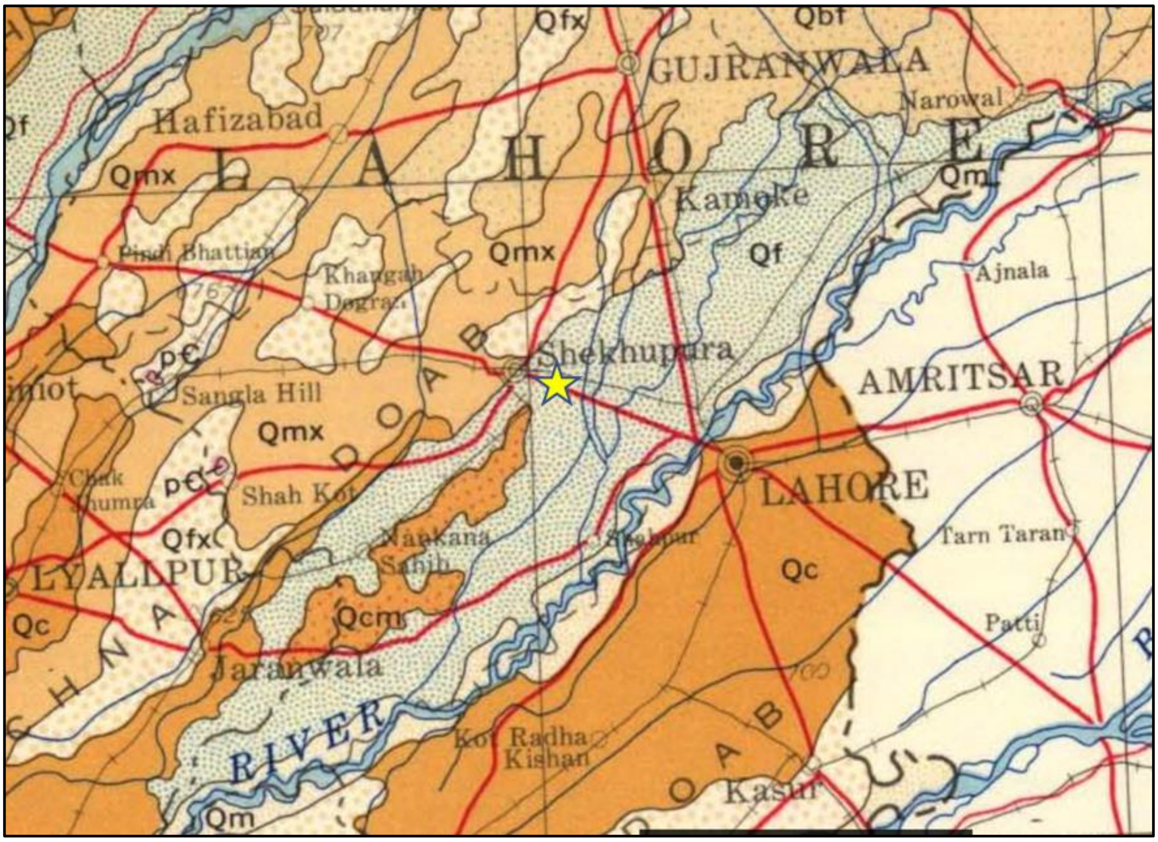

Figure 22 - Geological zoom on the project area

6.2 Hydrogeological context

Sheikhupura lies in an alluvial aquifer in the upper part of the Upper Rechna Doab, the area between the River Ravi and the River Chenab. The project area is drained by these rivers and associated surface water network. The aquifer in the whole area of the Indus Plains is considered as one large unconfined and interconnected aquifer. The alluvial plain of the Punjab is an **unconfined aquifer with alluvial sands and complex sediments**. Despite the heterogeneous composition, **the aquifer is highly transmissive and unconfined**. The sediments comprise of **fine to coarse sand with lenses of silty clay and clay**. Borehole logs show that the lenses of less permeable material are neither thick nor continuous. Hydraulic conductivity varies between 20 to 40 meters per day. Very little information is available on the underlying tertiary sediments.

Table 9 presents a summary of the aquifer characteristics.

Period	Aquifer type	K	Depth	Lithology
Quaternary	Porous	++	0 to > 180 m	Fine to coarse sand with lenses of silty clay and clay
Tertiary	Porous	?	< 180 to ? m	Semi-consolidated Tertiary rocks. Very limited data available

Legend

Type: **F:** **fractured,** **P:** **porous**

k (permeability): **+: slightly permeable, ++: highly permeable.**

Table 9 - Aquifer characteristics

Groundwater flow direction is following the surface drainage, with a general direction from the north-east to the south-west (Figure 23). The groundwater velocity was estimated at about 1 to 1.5 m/day (Muhammad et al., 2015).

Hydraulic conductivity of the aquifer was estimated at 34 m/d in average (Muhammad et al., 2015).

Groundwater recharge from the rainfall is limited. The main groundwater recharge mechanism is from the surface water. The recharge rate from Ravi river to the underlying unconfined aquifer vary between 0.18 mm/day and 0.5 mm/d according to available literature data (Muhammad et al., 2015). In addition to the Ravi River, the large canals such as the Upper Chenab Canal as wells as the irrigation /drainage network are providing an important source of recharge via direct seepage. The seepage estimation, sourced from the Punjab Irrigation Department, are presented in Table 10. The seepage from agricultural land is estimated to 88 Mm^3/y in the Sheikhupura region according to the same source.

Parameter	Upper Chenab Canal (UCC)	Upper Gugera Branch canal (UGBC)
Total flow (Mm^3/year)	1,920	286
Seepage to groundwater (Mm^3/year)	77	11

Table 10 - Seepage estimation in the Sheikhupura region (Punjab Irrigation Department)

At a very large scale, recharge from the snow and glacier of the mountain area is also occurring. For the purpose of this study, only the Indus plain area will be considered.

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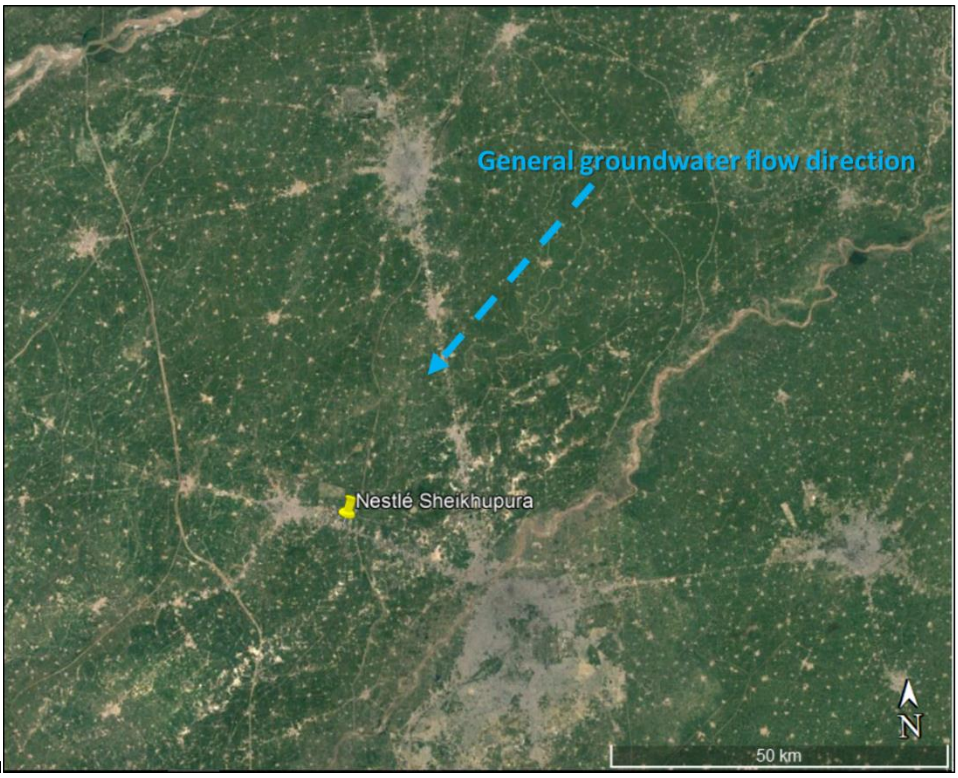


Figure 23 - general groundwater flow direction

7 Hydrogeological investigation conducted as part of the study

The following chapters describe the investigations carried out by Antea Group. A site visit was held between the 07/01/2019 and the 17/01/2019 by our local partner. It involved the following:

- assessing the general hydrogeological context via the geological outcrops and geomorphology;
- assessing the local context in terms of water resources and identifying the different water uses;
- identifying and listing the water supply points present locally and determining major competitors;
- identifying and listing possible water contamination sources;
- performing *in situ* physicochemical measurements on the water when possible (pH, conductivity and temperature).

The results and interpretation of field data are presented further on in the below sections.

7.1 Site settings

Nestlé factory is supplied by three wells, named Well 1, Well 2 and Well 3. The last two are the main ones for production and well 1 is used as a back-up. The factory is also equipped with three tubewells, called locally as Turbine 1 for the Beverage section and Turbine 2 and 3 for utilities. Table 11 presents the general characteristics of the onsite wells, Figure 26 to Figure 31 their technical logs and Figure 25 their location Table 12 presents the yearly abstraction from each of the onsite water source. In 2018, about 2 Mm^3 was abstracted from the factory, including all wells. The maximum abstracted volume between 2013 and 2018 was taken in 2017, with a total of about 2.5 Mm3. A monitoring well is also present on site but no construction details are available.

Name	Purpose	Material	Diameter (inch)	Depth (m)	Screen sections (m)	Static Water level (mbgl) Feb 2019	Static Water level (mbgl) March 2019
Well 1	Production but back-up	Galvanised steel blank and stainless-steel screens	8”	138	107 – 132 m	10.33	10.35
Well 2	Production	Galvanised steel blank and stainless-steel screens	8”	138	107 - 132 m	10.44	10.45
Well 3	Production	Galvanised steel blank and stainless-	10”	144.8	112 – 137 m	10.40	10.42

		steel screens					
Utility Well 1	Beverage	Fiberglass	8”	120	48 - 112 m	NA	NA
Utility Well 2	Utilities	Fiberglass	8”	160	112 – 134 m 137 – 151 m	NA	NA
Utility Well 3	Utilities	Fiberglass	8“	149	73 – 82 m 109 – 128 m 140 – 146 m	NA	NA

Table 11 - General characteristics of the onsite wells

In average (2015-2018), Well 1 is pumping 556 m^3/day, Well 2 is pumping 458 m^3/day and Well 3 is pumping 928 m^3/d. Percentage of abstraction repartition between Nestlé Waters, Food & Beverage and Utilities are also presented in the below table. **As it can be observed, since 2016, Nestlé Waters represents a maximum of 25 % of the total abstraction from Sheikhupura factory.**

ID	2013	2014	2015	2016	2017	2018
Well 1	227,897	198,381	23,862	233,539	193,686	117,787
Well 2	208,845	213,342	433	0	36,776	15,071
Well 3	-	-	206,096	340,170	351,019	291,503
Utility Well 1	-	-	-	689,627	787,999	442,647
Utility Well 2	-	-	-	481,559	566,920	544,869
Utility Well 3	-	-	-	554,851	533,591	692,678
Total	436,742	411,723	230,391	2,299,746	2,469,991	2,104,555
% Nestlé Waters	100 %	100 %	100 %	25 %	24 %	20 %
% Beverage	0 %	0 %	0 %	30 %	32 %	21 %
% Utilities	0 %	0 %	0 %	45 %	24 %	59 %

Table 12 - Yearly abstraction volume from each onsite well (in m^3)

Figure 24 - Photo of Well 1

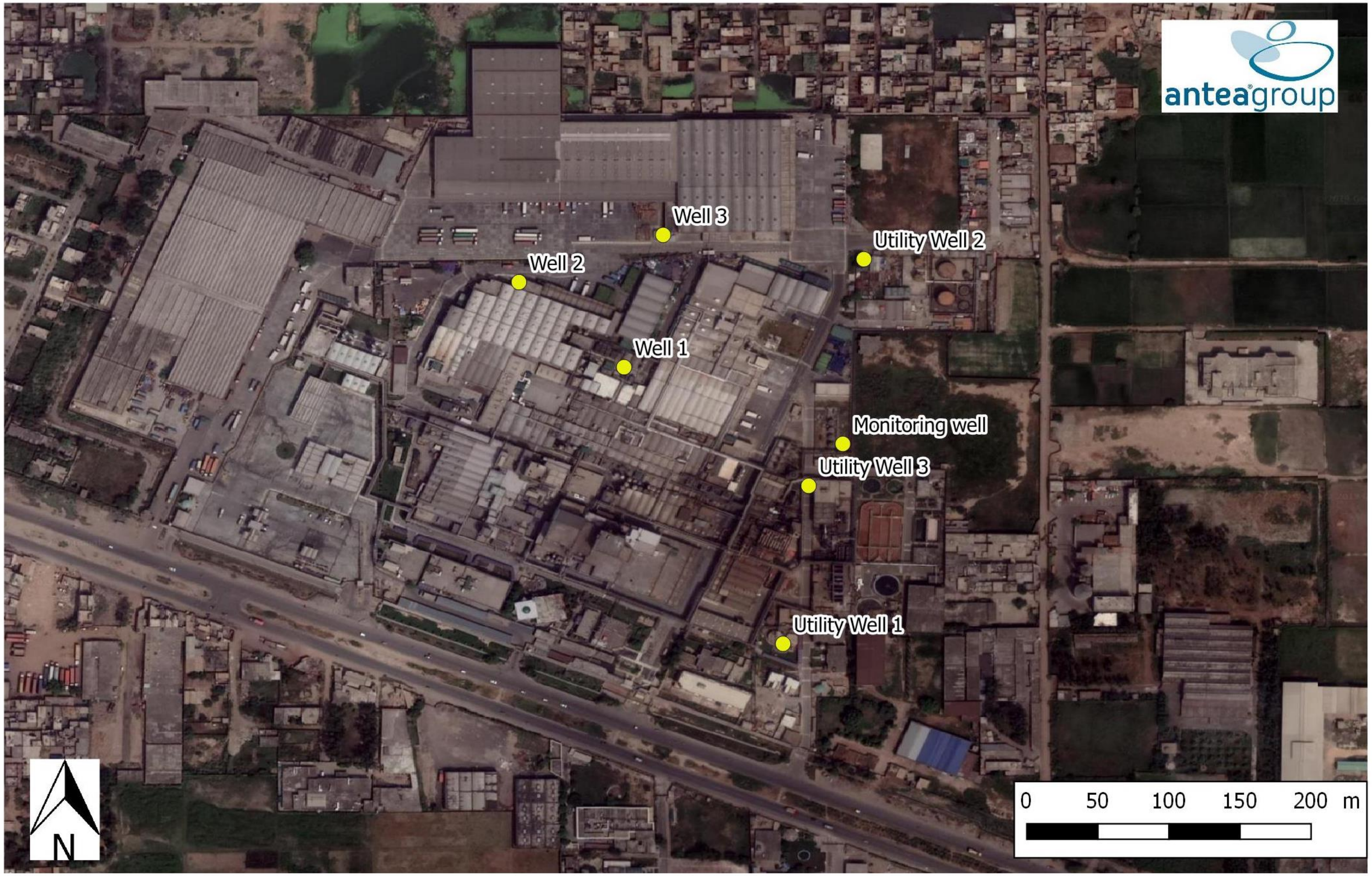


Figure 25 - Location of the onsite wells

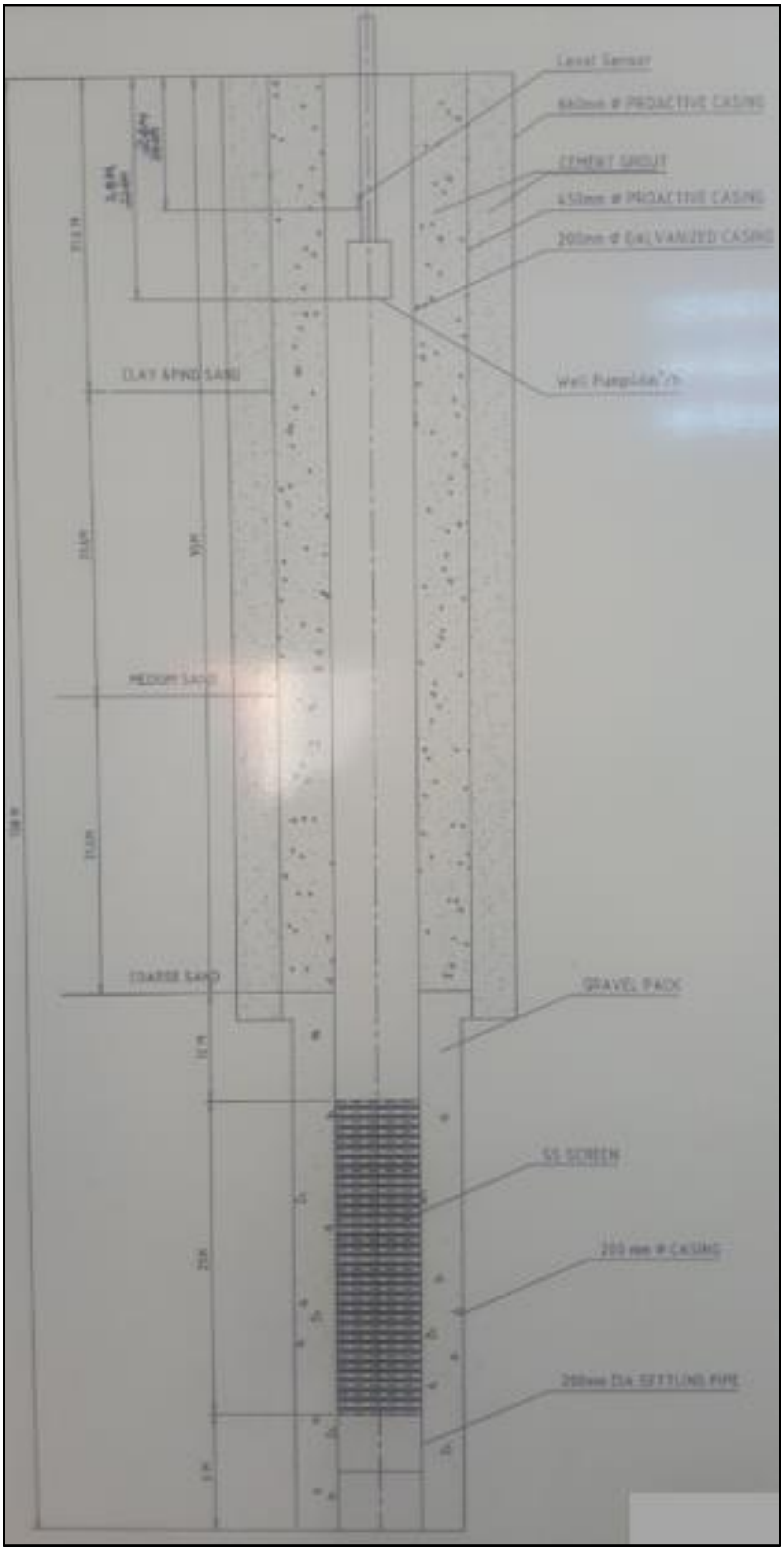


Figure 26 - Well 1 design

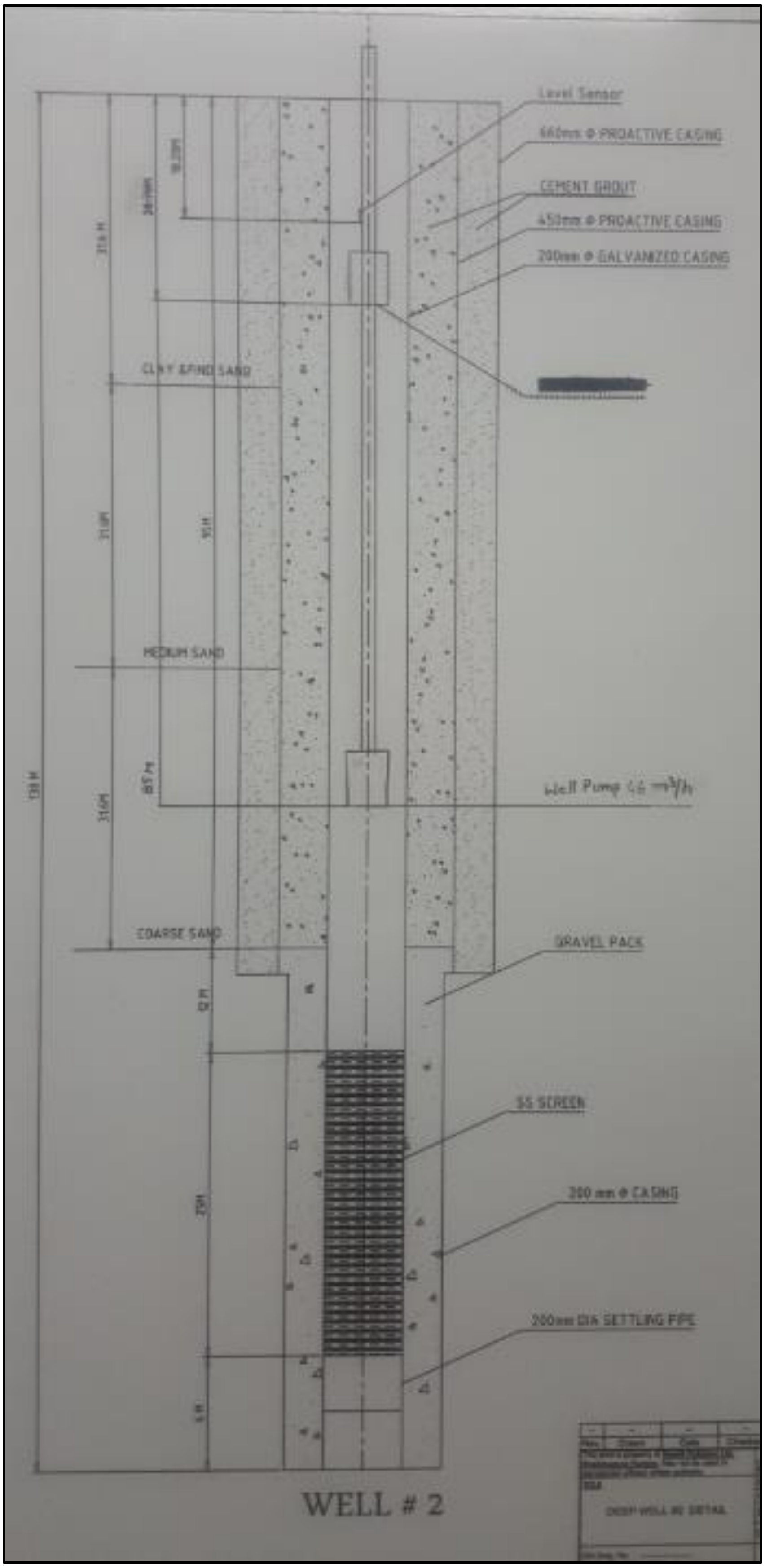


Figure 27 - Well 2 design

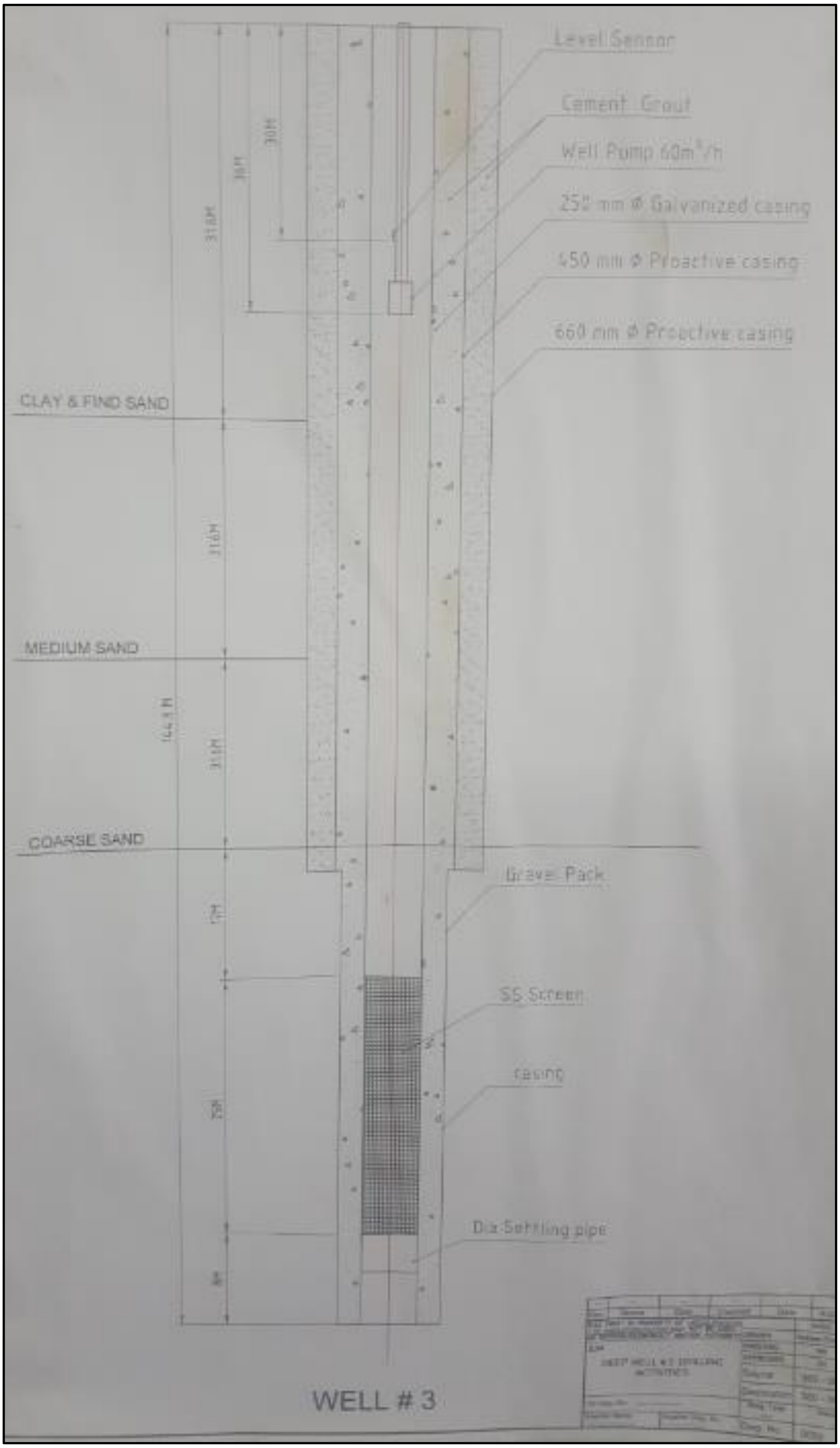


Figure 28 - Well 3 design

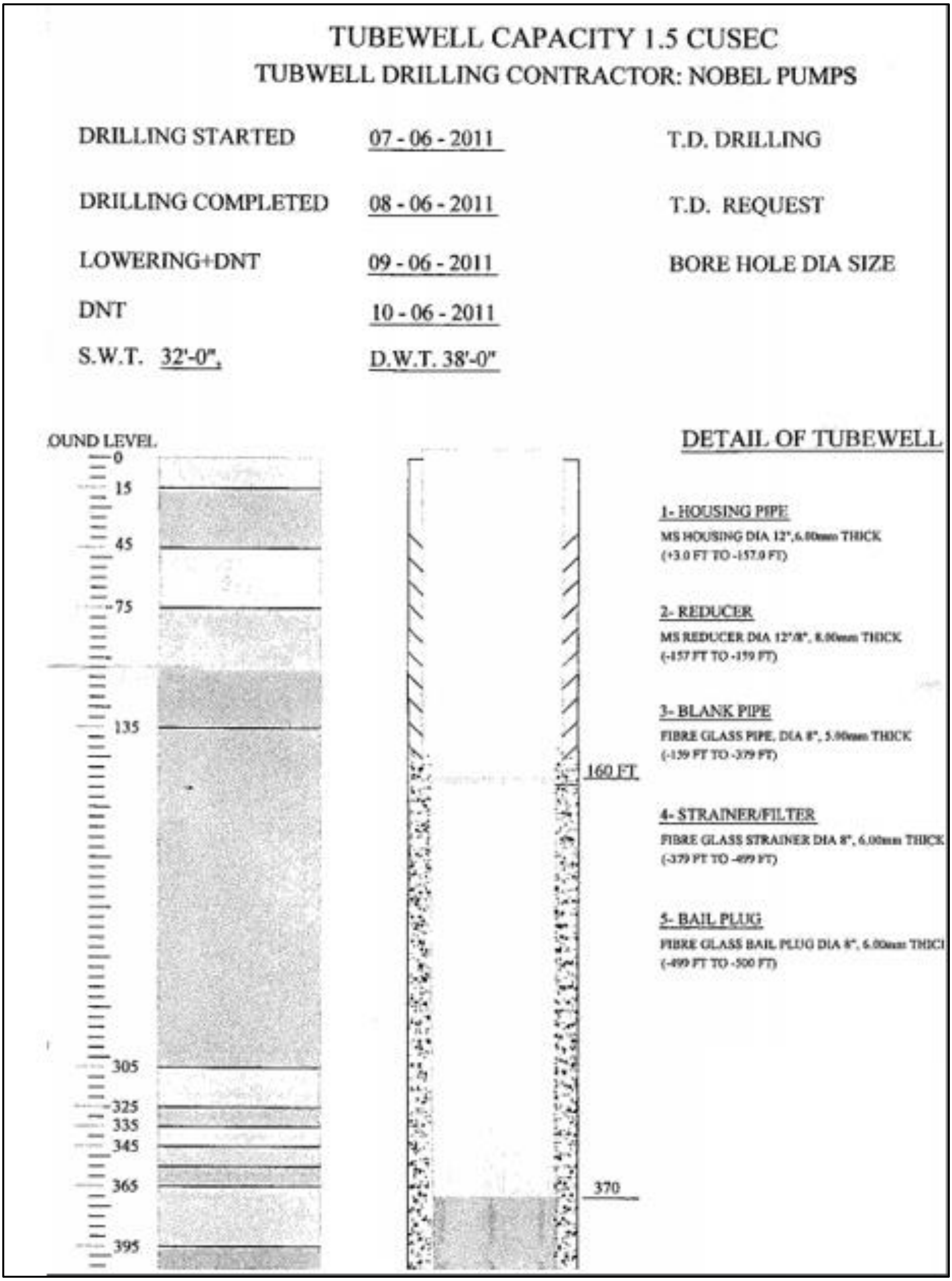


Figure 29 - "Turbine " 1

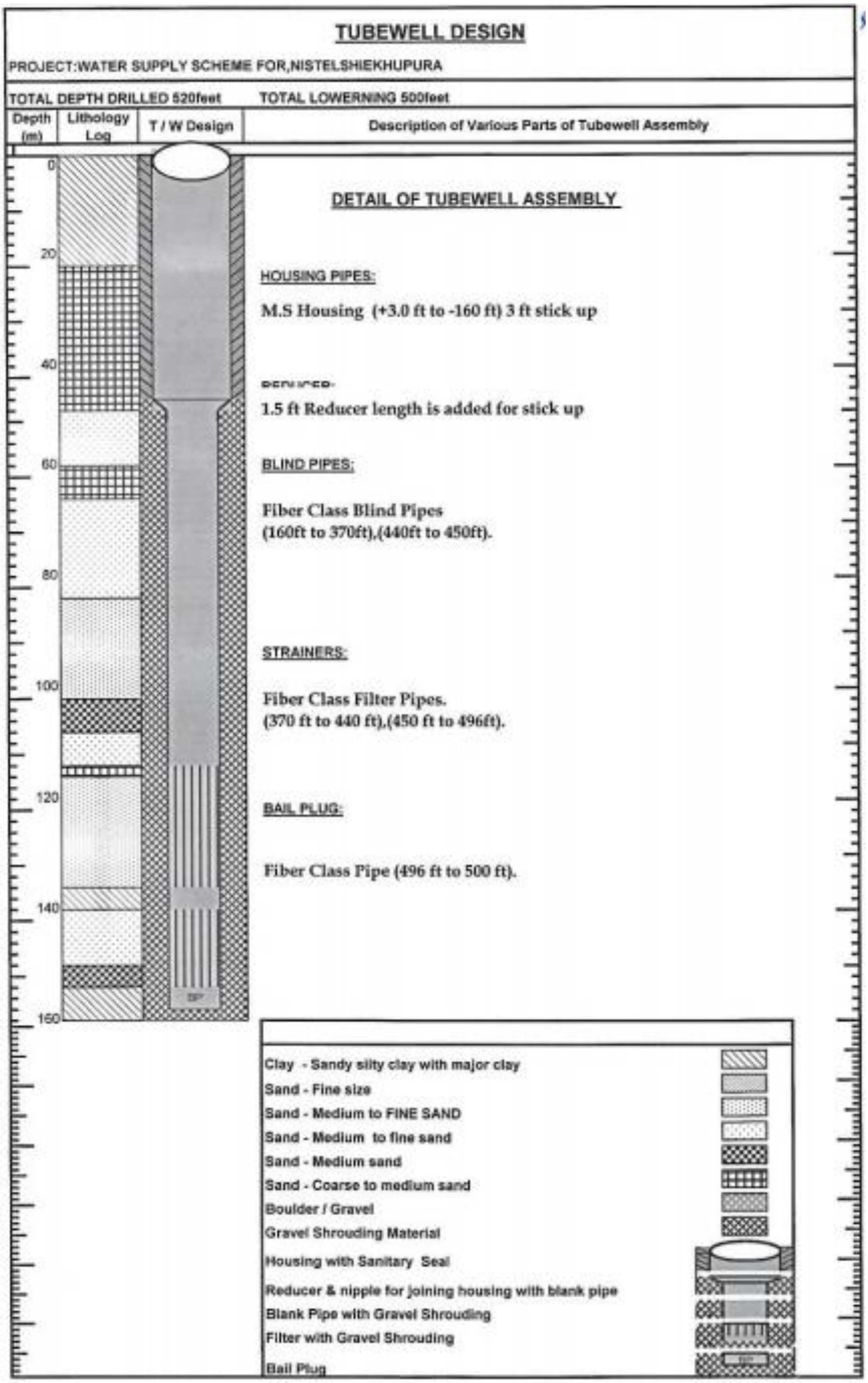


Figure 30 - "Turbine " 2

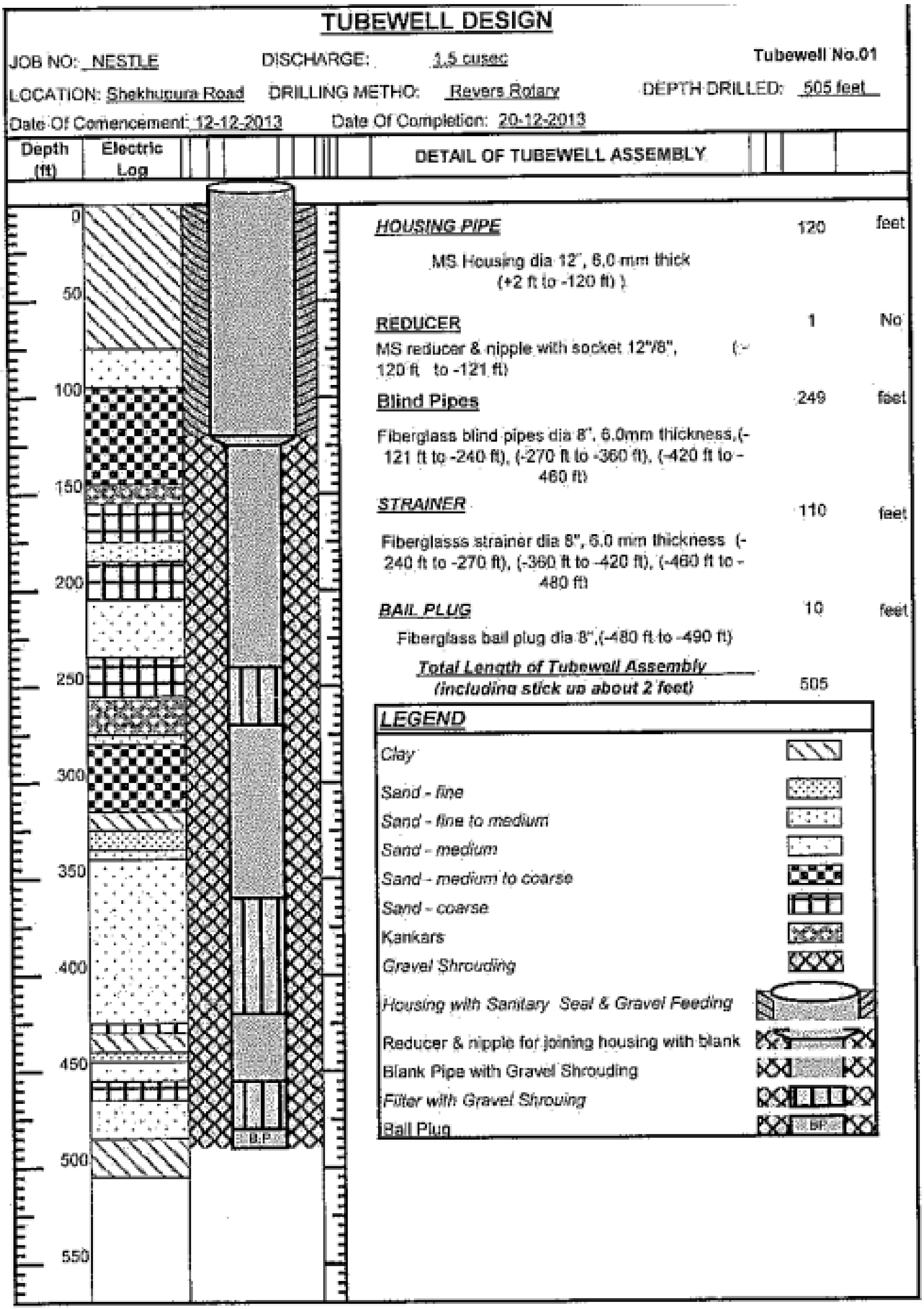


Figure 31 - "Turbine " 3

7.2 Site specific geology

Figure 32 presents the log lithology of selected wells in the vicinity of the Nestlé factory. According to the available data, the underlying geology is a succession of sand from fine to coarse, with thin lenses of clay.

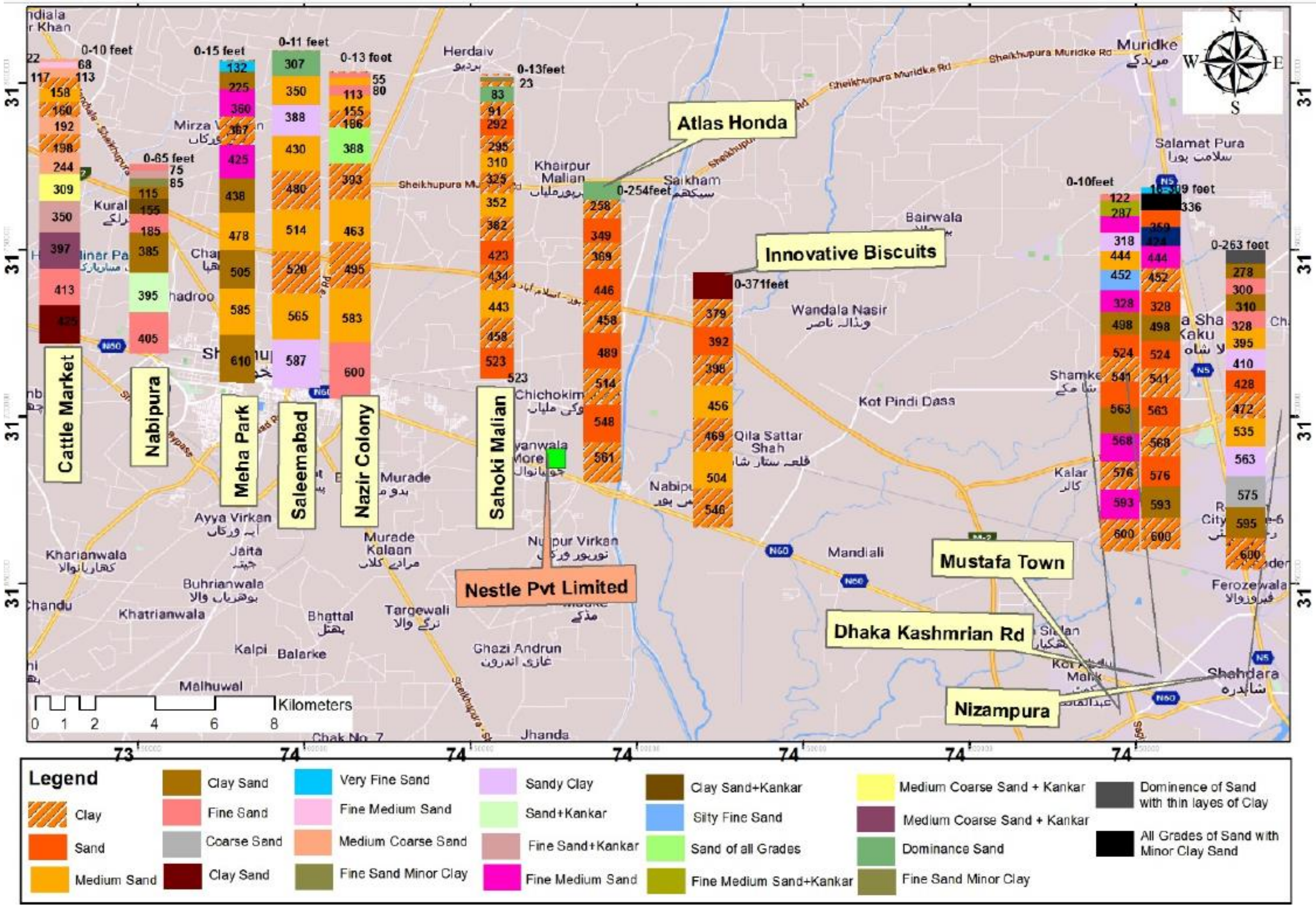


Figure 32 - Wells lithology in the project area (depth in feet)

7.3 Groundwater levels and direction

7.3.1 Nestlé factory

The factory is monitoring the abstraction volume, the water levels (static and dynamic) as well as the conductivity on each of the three wells. Figure 33, Figure 34 and Figure 35 present the water level and conductivity data for Well 1, Well 2 and Well 3 respectively. Figure 36 to Figure 38 present the daily abstraction volume with the associated drawdown. Nestlé factory is also monitoring the specific capacity of the wells and the graphs are presented in Figure 39 and Figure 41. Specific capacity will be further discussed in the step test section. A monitoring well is also located on the factory premises. The monitoring data of this well are presented in Figure 42.

Overall, the following observations can be made:

- the static water level is in average 10 mbgl (m below ground level);

- the dynamic water level (DWL) is relatively shallow with values mainly ranging between 12 and 18 meters below ground level. The dynamic water level fluctuations are linked to the abstraction patterns;

- seasonal patterns are observed on the DWL, with highest levels in winter, around the November / December period (particularly observable on Well 1 and Well 2). This pattern doesn't match with the main rainfall period (June to August) and could be linked seasonal pattern of the surface water recharge. According to the abstraction data, it seems that the abstracted volumes are lower during this period which could also explain the DWL pattern;

- a decreasing trend can be observed on the DWL of Well 3 (Figure 35), with an approximate decrease of 4 meters between 2014 and 2018. This decrease represents about 1 meter per year, which is considered as very high. The decrease can be the results of different possibilities: over abstraction, aquifer overall decrease of the water levels or borehole ageing. Well 3 is the highest abstracting well. A slightly increasing trend (at least stabilised) can however be observed in 2018;

- as it can be observed from the monitoring well data in Figure 42, it appears that the static water level is fluctuating with an observable decreasing trend over the years (red linear regression on the figure). It should be noted that the utility well 3 is located very closely to the monitoring well. According to site information, the recent decrease in level (2018) is linked to an increase of abstraction from this well. The last two points of the graph (February and March 2019) were taken during maintenance day (12 hours without operation). The water level is higher (around 10.4) in 2019 than the previously recorded levels at around 11 mbgl during the end of 2018. The monitored level in 2019 seems not impacted by nearby abstracting onsite wells and therefore more representative of the static water level ;

- slight fluctuations are occurring with the conductivity values, but overall no decreasing or increasing trend can be observed. The values are ranging mainly between 550 and 650 µS/cm. The variations can be linked to local recharge or abstraction pattern.

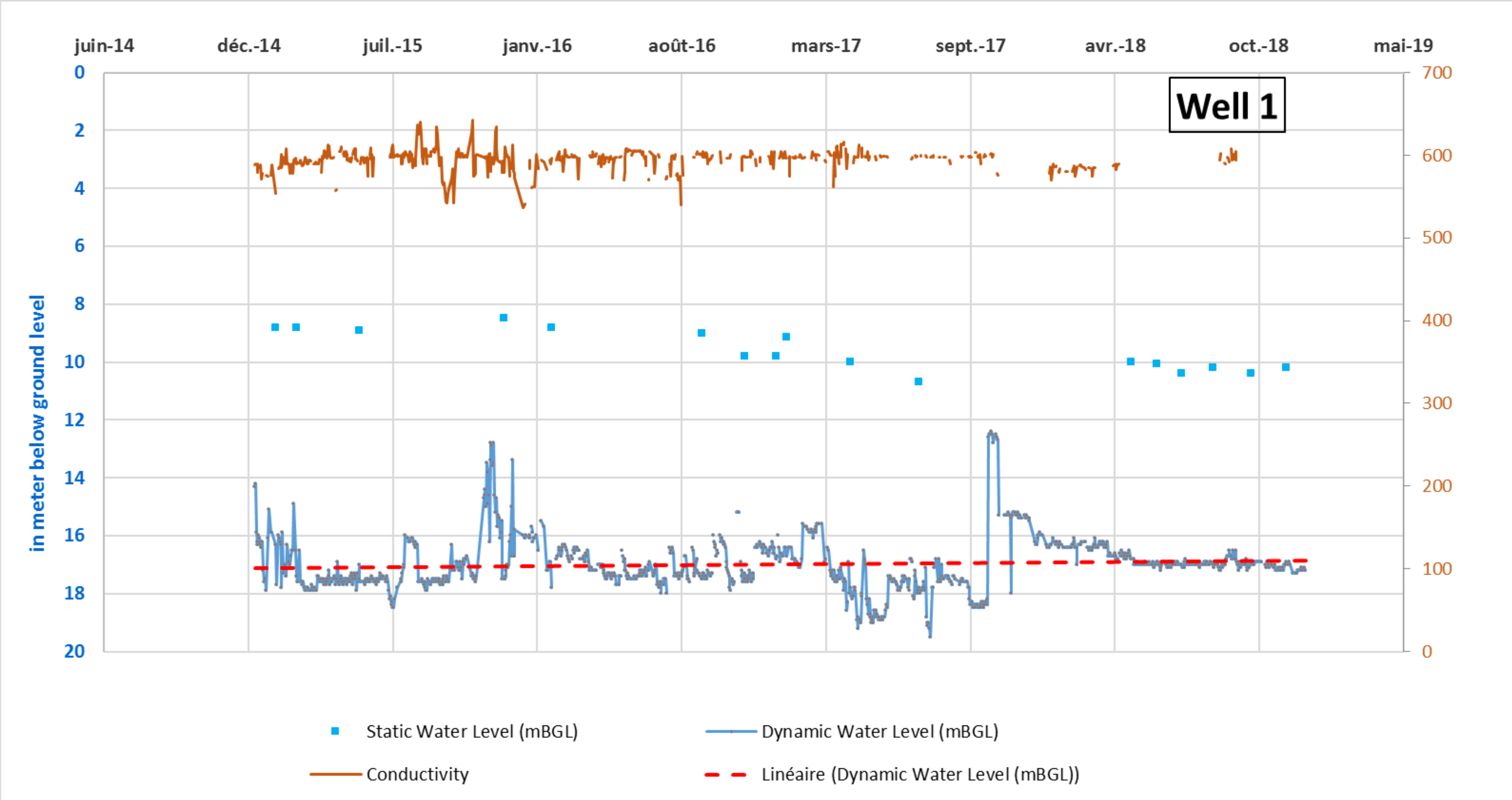


Figure 33 - Well 1 water monitoring data

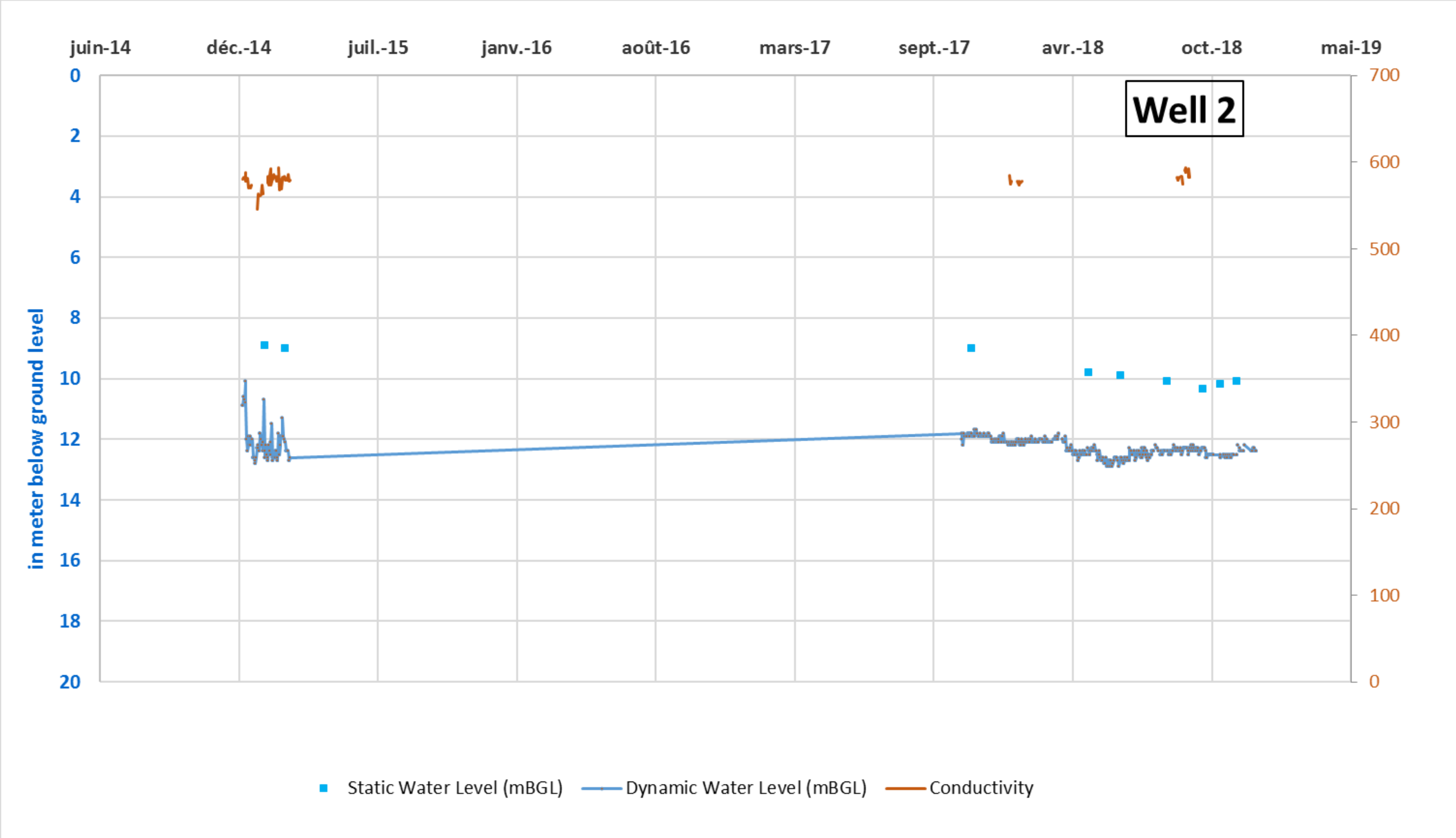


Figure 34 - Well 2 water monitoring data

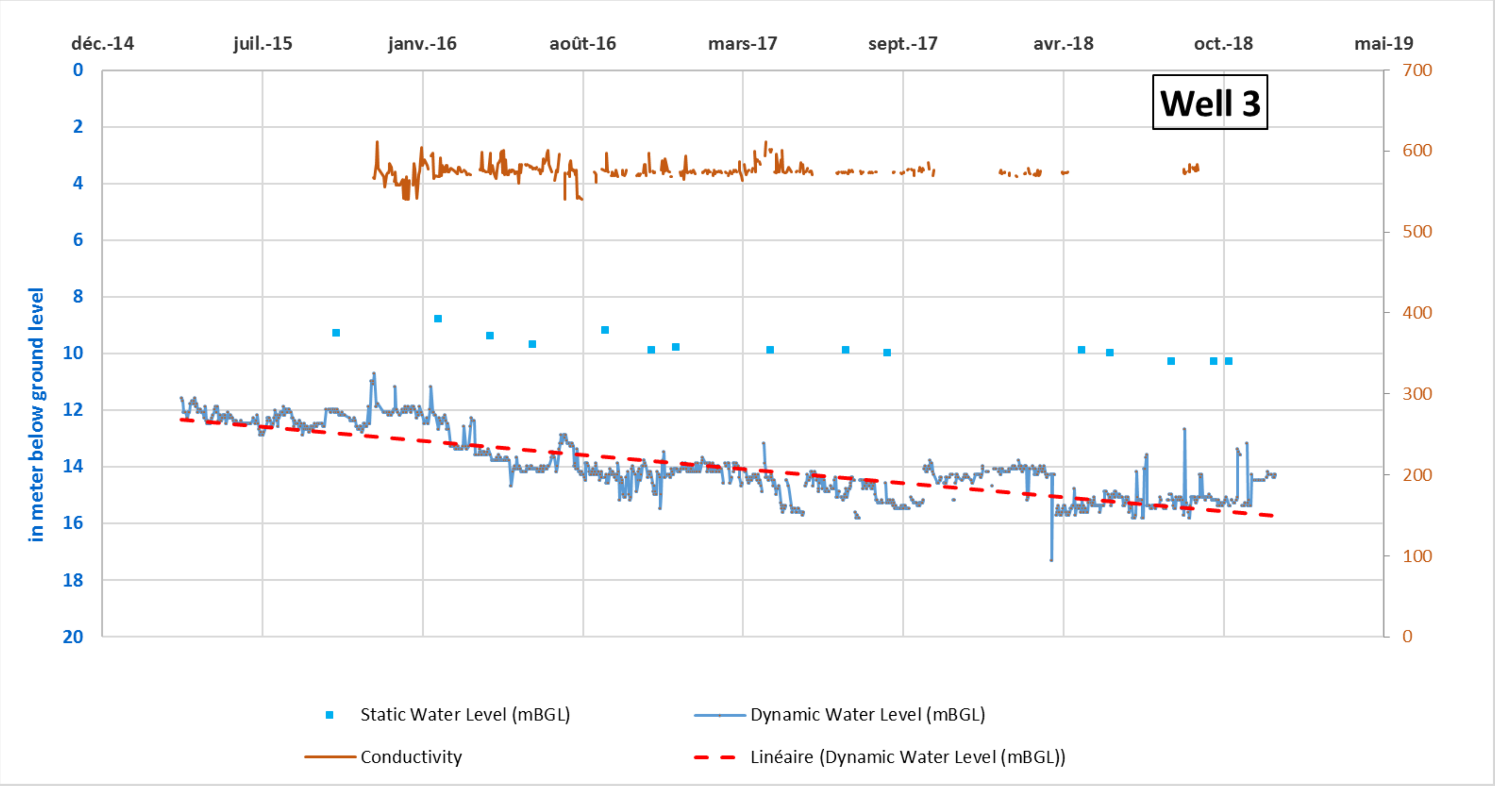


Figure 35 - Well 3 water monitoring data

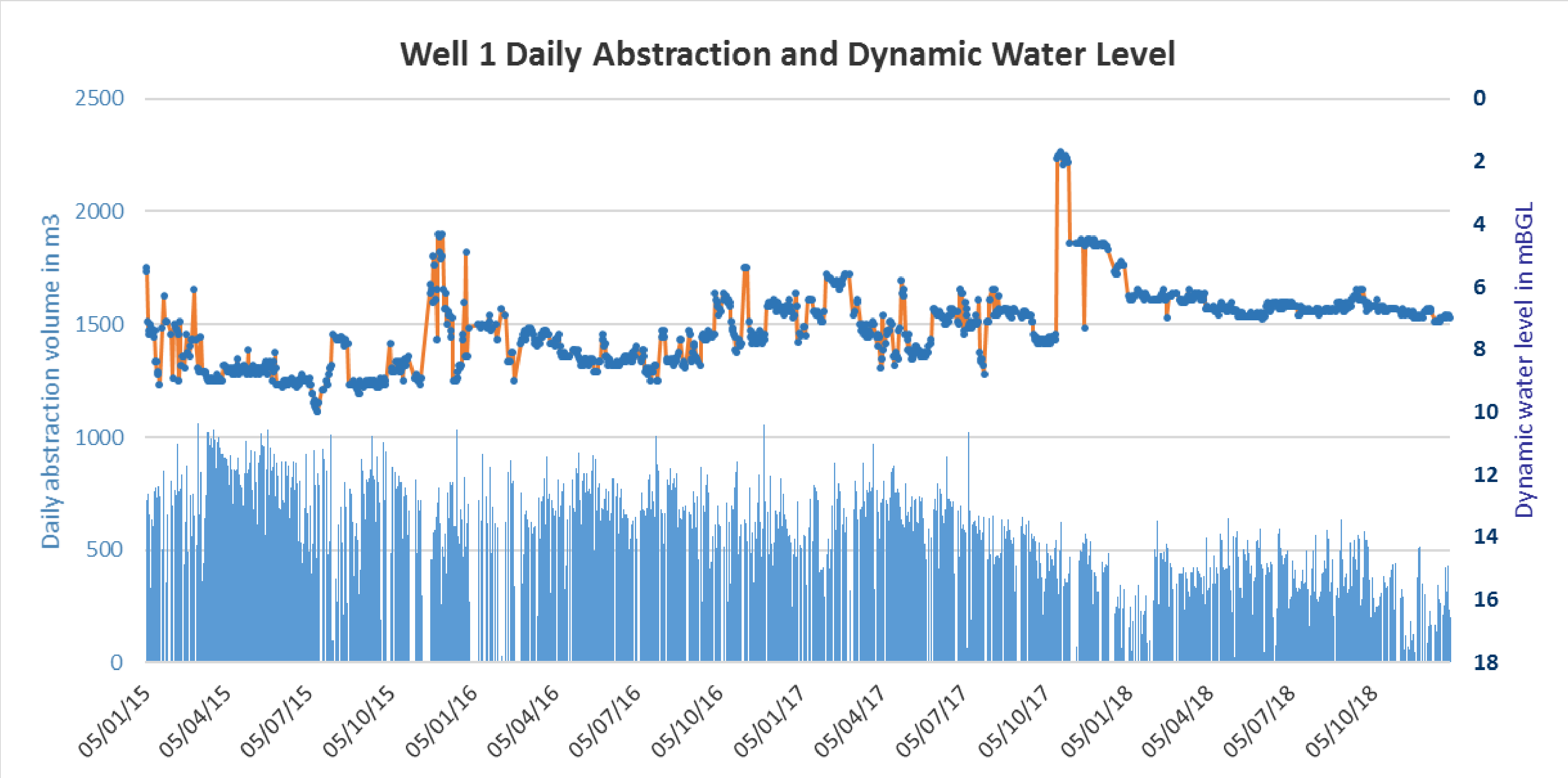


Figure 36 - Well 1 daily abstraction vs drawdown

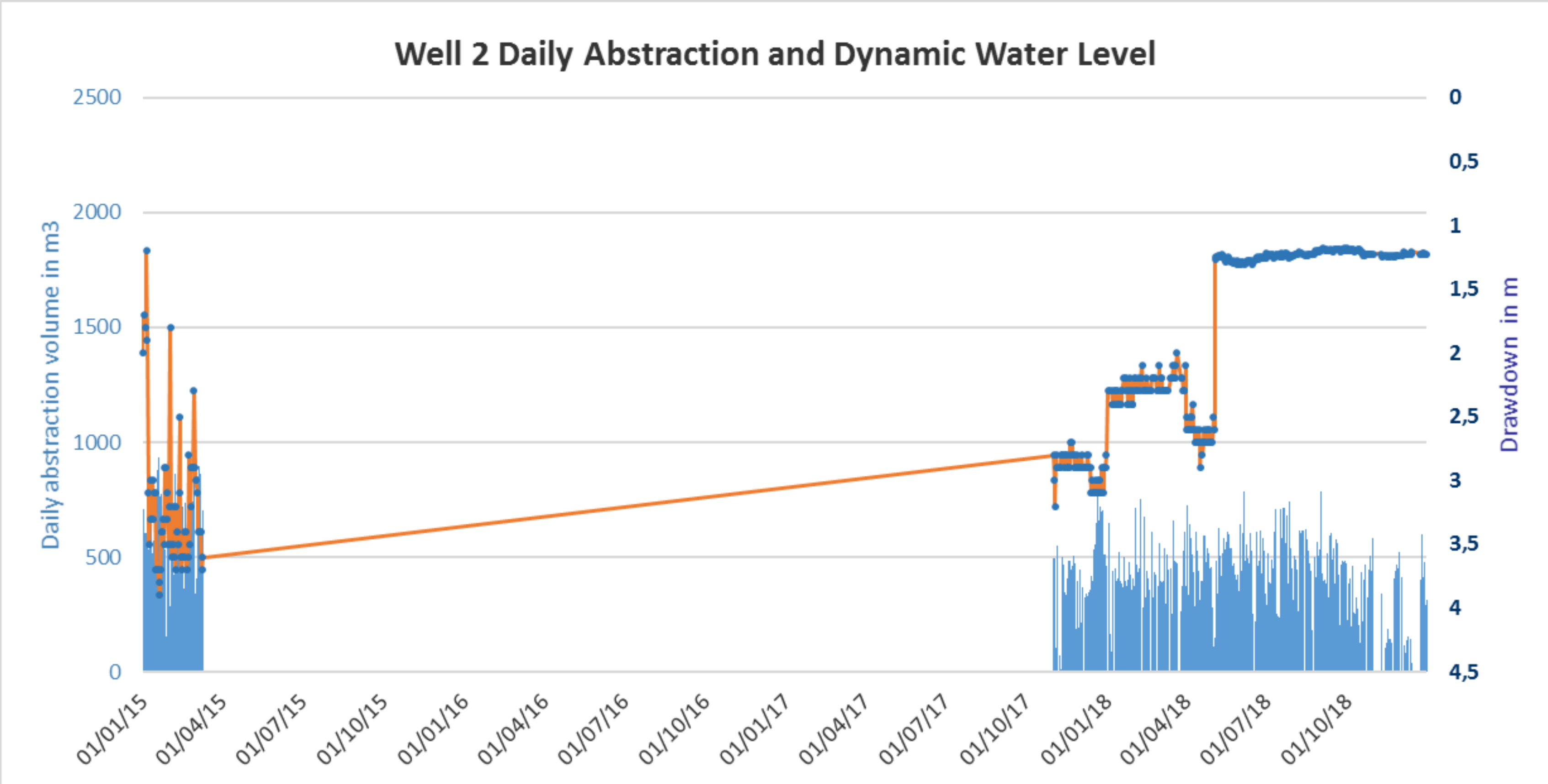


Figure 37 - Well 2 daily abstraction vs drawdown

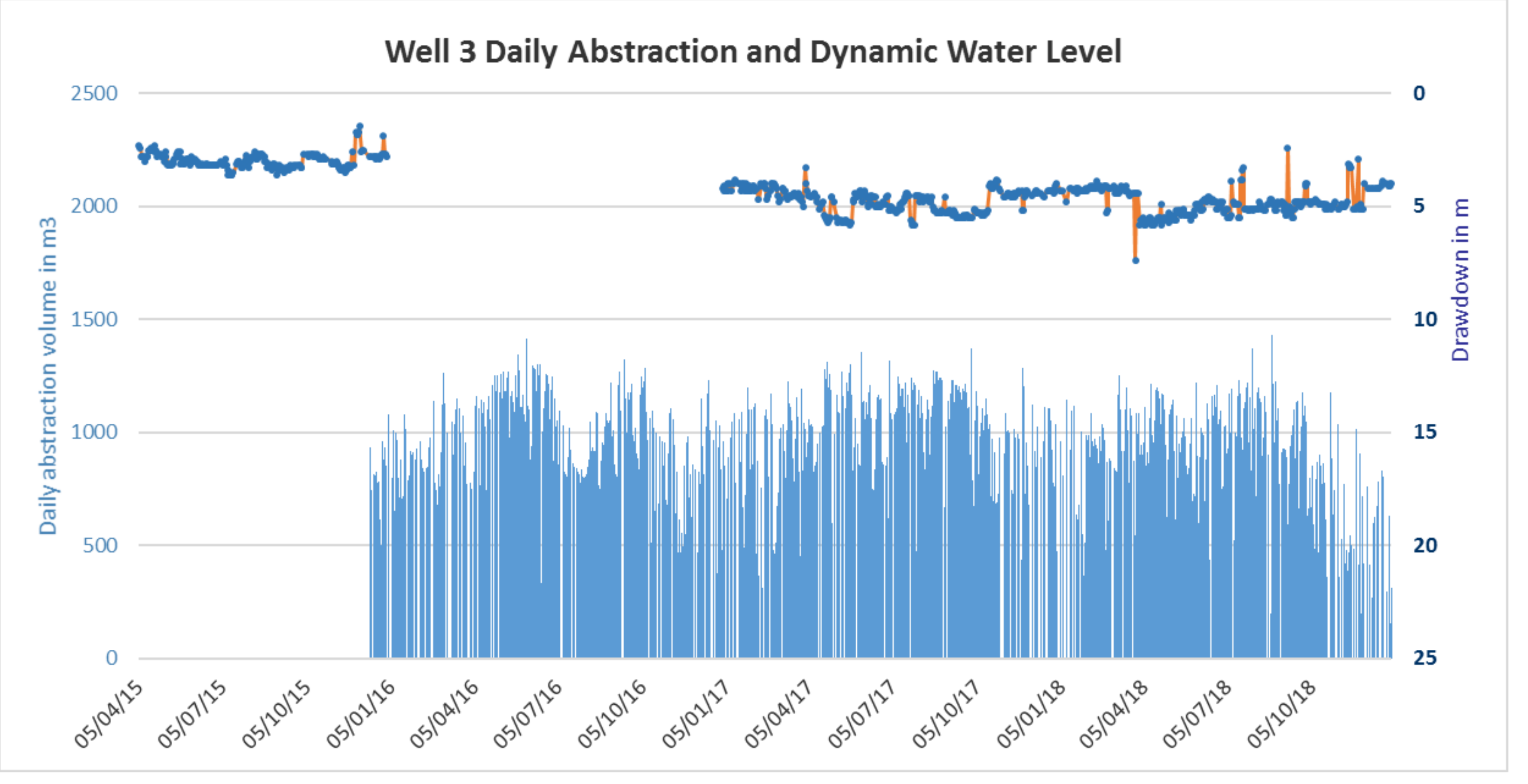


Figure 38 - Well 3 daily abstraction vs drawdown

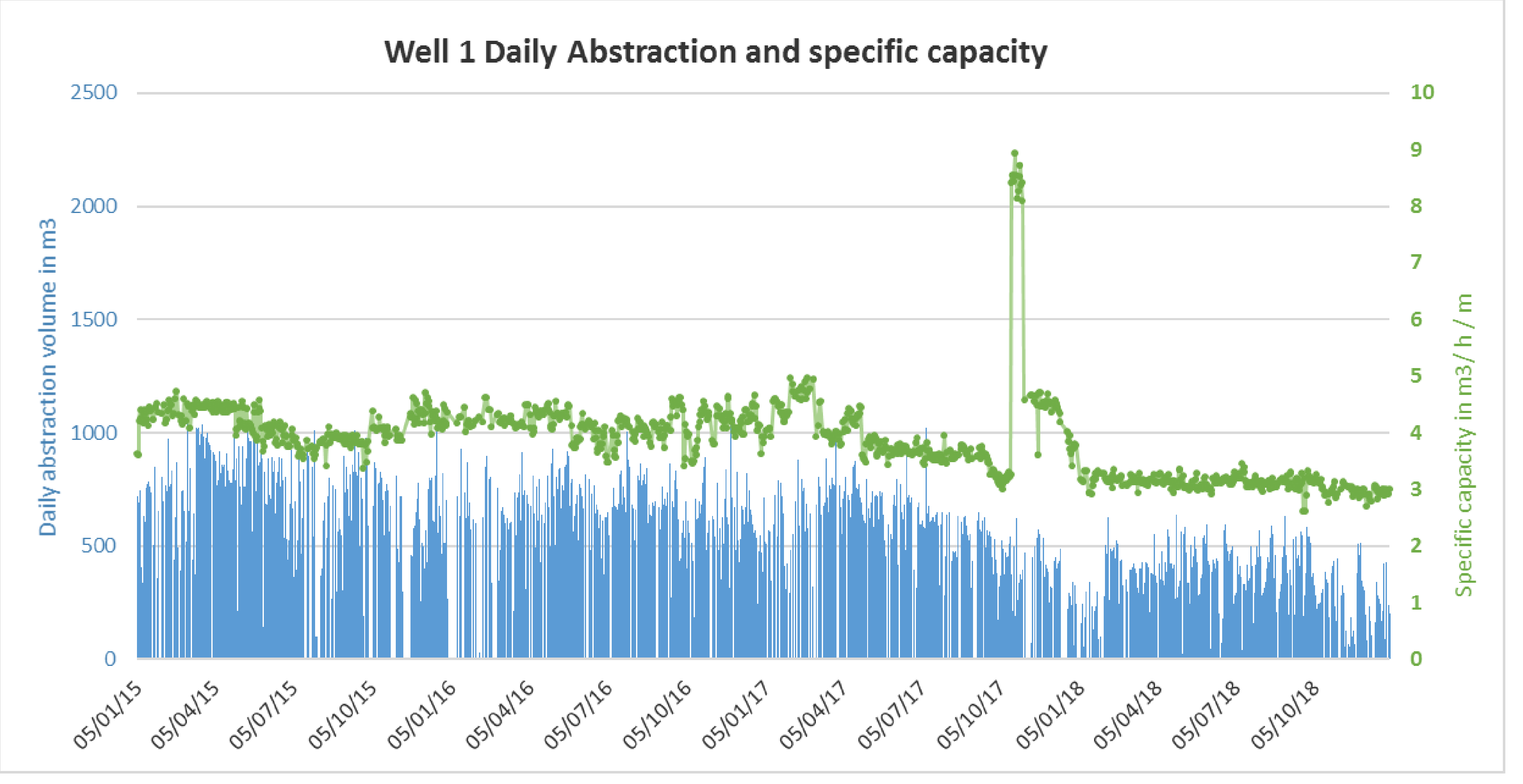


Figure 39 - Well 1 daily abstraction vs specific capacity

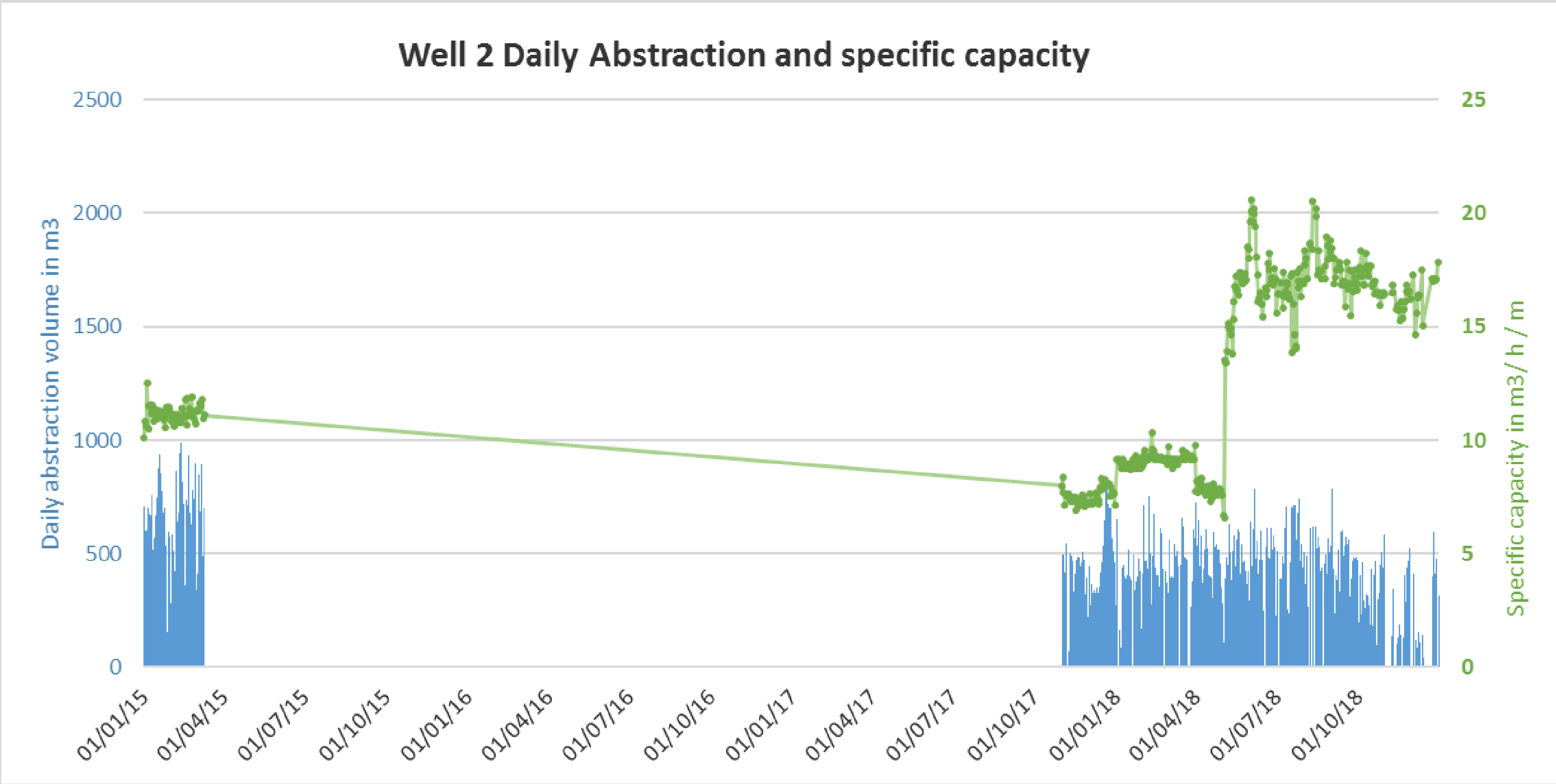


Figure 40 - Well 2 daily abstraction vs specific capacity

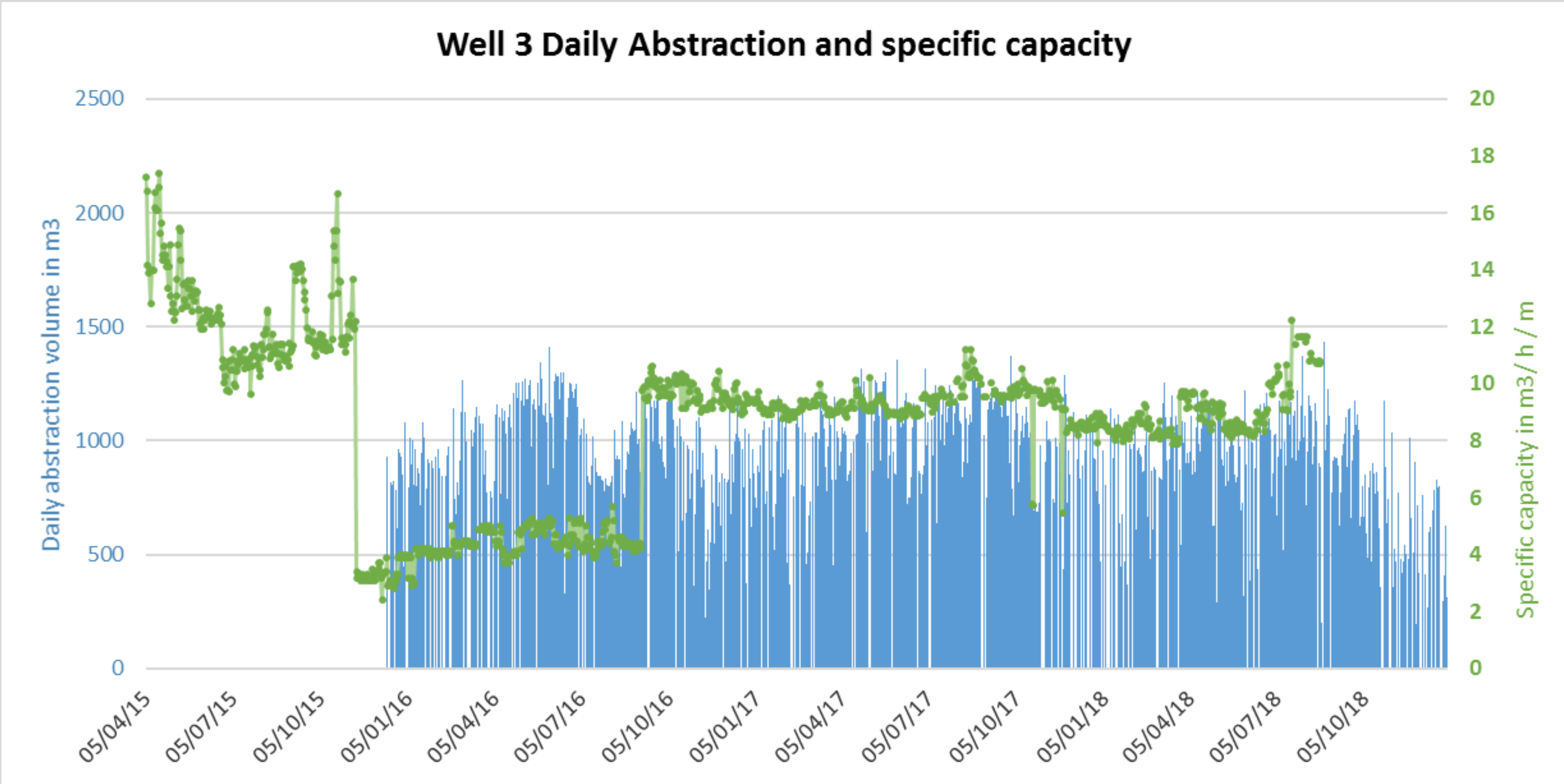


Figure 41 - Well 2 daily abstraction vs specific capacity

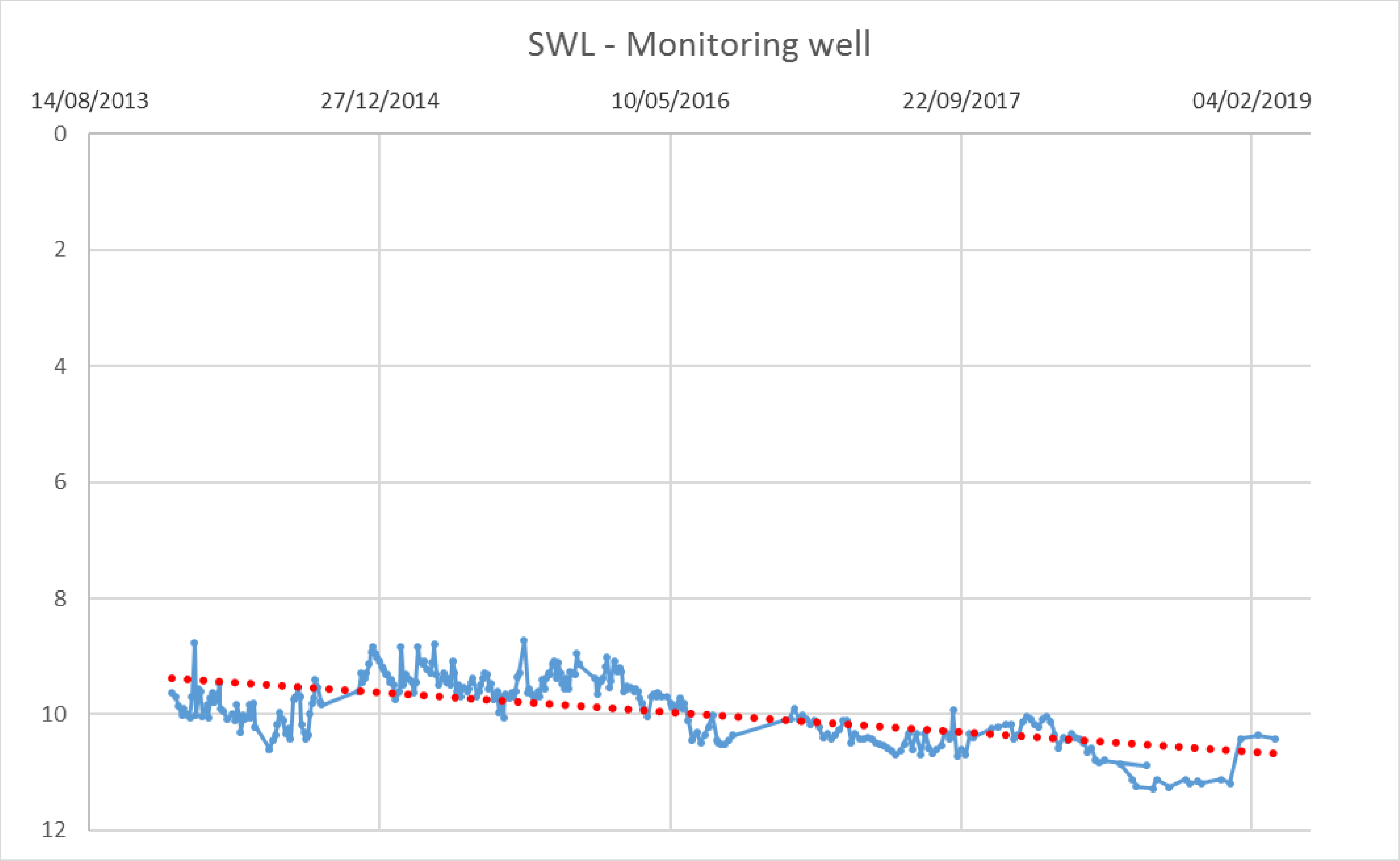


Figure 42 - Monitoring well static water level

7.3.2 Water level outside the factory premises

Groundwater level monitoring data were collected from available 20 piezometers sourced from the Punjab irrigation department. Groundwater levels are measured twice a year, before and after the monsoon season. Collected data range between 2013 and 2018.

Table 13 presents the piezometers details and Figure 43 their location in the project area. Groundwater elevation data are presented in Table 14 and Figure 44. Overall fluctuations are occurring, with increase and decrease of the levels with an amplitude of 1 or 2 meters. Data were used to generate groundwater contour maps (masl) to properly observed potential trends. The maps are presented in Figure 44 to Figure 56. The following can be observed:

- the maps confirm the general groundwater flow direction, from the north-east to the south-west;
- it is important to note that the bottom right corner shouldn't be considered for the interpretation as there is no piezometer to control the isolines interpolation;
- overall, the Sheikhupura area is influenced by relatively strong abstraction (isolines intervals are smaller);
- a cone of depression can be observed 13 km to the south-west of Nestlé factory. The increase of this cone of depression can be observed over the years. The 194 masl contour significantly stepped back over the years, particularly in 2018. This area, near Kharianwala, is heavily populated (29,832 according to the 2017 census) with a strong industrial development (textiles, chemical, paper, leather etc.), inducing probable strong abstraction volumes. Abstraction from the industrial area of Nestlé factory is likely contributing to this cone of depression.

ID	Easting	Northing	Ground elevation (masl)	Village name	Address
1	74,568	31,969	214	Mari kalan	Govt. Boys Primary School, Mari Kalan, Muridke-Narowal road, Tehsil Ferozwala District Sheikhupura.
2	74,474	31,778	213	chak lahorian	Chak Lahorian Boys Primary School,Kala Khatai road,Tehsil Ferozwala District Sheikhupura.
3	74,501	31,908	218	Rafiq abad	Govt. Boys High School, Rafiq Abad , Narang,Tehsil Ferozewala, District Sheikhupura.
4	74,603	31,964	224	Mehta Suja	Govt. Boys Primary School , Mehta Suja, Tehsil Ferozwala District Sheikhupura.
5	73,797	31,920	203	Keelay	Keelay Govt.Boys Middle School, Hafizabad Road, Tehsil & District Sheikhupura.
6	73,827	31,897	207	Kakar Gill	Kakar gill, Dogar Rice Mill, Hafizabad Road, Tehsil and District Sheikhupura.
7	73,894	31,830	203	Dera jarman wala	Dera Jerman Wala,Jandiala-Jhabran road. District Sheikhupura.
8	73,841	31,814	212	Lalkay	Lalkay, Govt.Boys Middle School, Farooqabad road, District Sheikhupura.
9	73,872	31,804	213	Warn	Warn,Govt.Boys Middle School, Farooqabad road, District Sheikhupura.
10	73,941	31,789	204	chak shah pur	Chak Shah pur, Govt.Boys Primary School (Chak Gurdas) Hafizabad road, District Sheikhupura.
11	73,958	31,784	204	jahangir pur	Jahangir Pura, G.P. School, Hafizabad road, District Sheikhupura.
12	74,046	31,804	213	Hardev	Hardev, G.B.H. School Gujranwala road, Sheikhupura.
13	74,088	31,811	216	Qila Gian singh	Qila Gian Singh, Govt.Girls Primary chool, Gujranwala road, Sheikhupura.
14	74,148	31,789	212	Pindi Machhain	Pindi Machhian B.H.Muridkey road, Sheikhupura.
15	74,493	31,937	222	Kotli Virk	Kotli Virk Near mosque,Muridke Narowal road,Sheikhupura.
16	73,931	31,654	200	Kharian wala	Kharian wala, G.B.H School.Farooqabad road, District Sheikhupura.
17	74,033	31,642	204	Targay wali	Targay wali, Govt.Boys Middle School.Sharqpur road, Sheikhupura.
18	74,156	31,634	205	Bhattian wala	Govt. Boys Primary School Bhattian wala, Mandiali Stop, Lahore Sheikhupura road, Tehsil & District Sheikhupura.
19	74,068	31,711	200	Joian wala More	Boys High School, Joianwala More, Sahoki Mallian, Sheikhpura- Lahore road,Tehsil & District Sheikhupura.
20	74,104	31,469	206	Sharakpur	Govt. Boys High School, Sharakpur, Sheikhupura.

Table 13 - Piezometers location

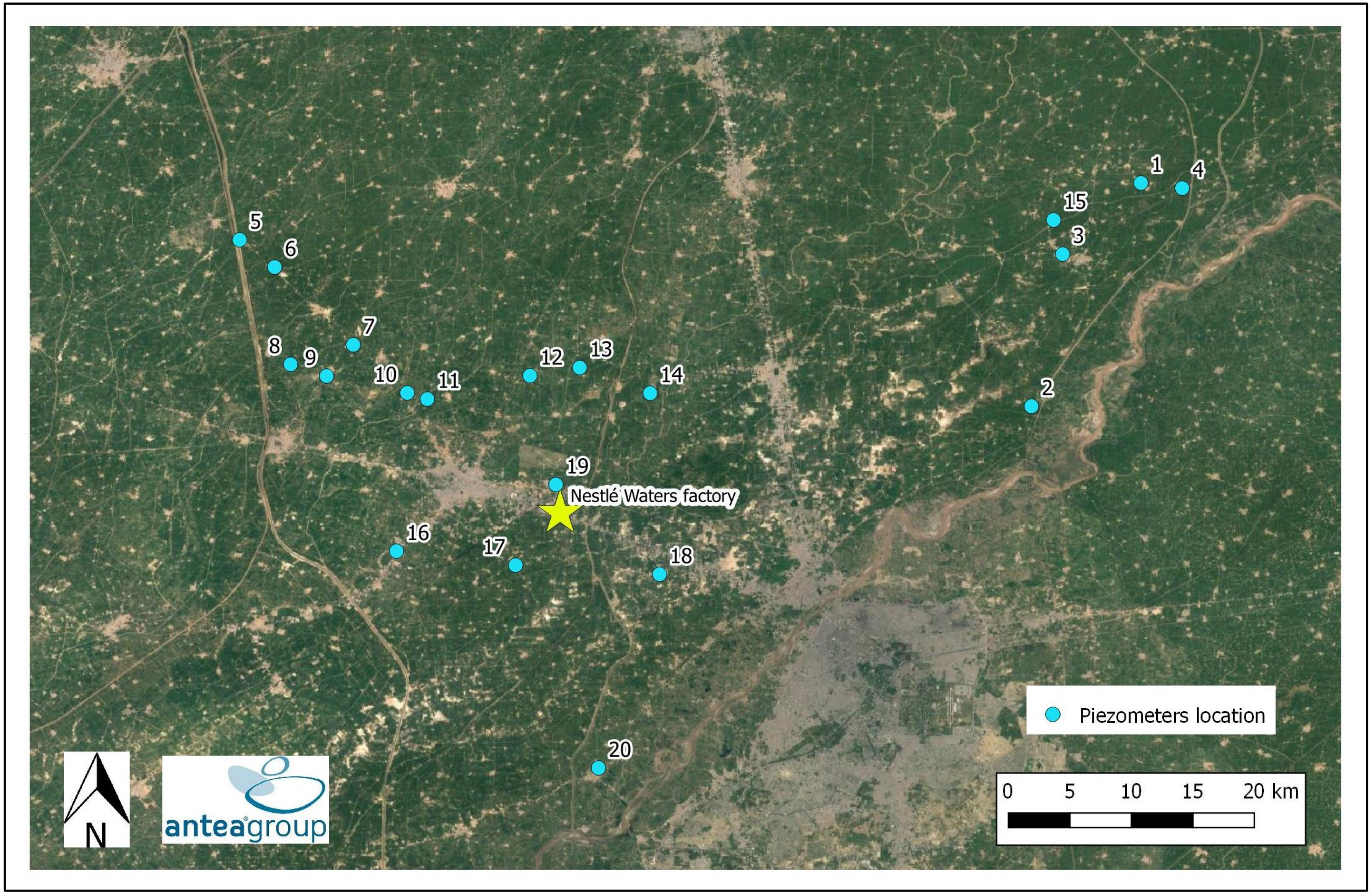


Figure 43 - Piezometers location

Piezo ID	Pre-M 2013	Post-M 2013	Pre-M 2014	Post-M 2014	Pre-M 2015	Post-M 2015	Pre-M 2016	Post-M 2016	Pre-M 2017	Post-M 2017	Pre-M 2018	Post-M 2018
1	211.6	211.6	211.1	211.4	210.0	211.9	212.0	211.8	210.1	208.8	209.6	209.9
2	213.0	-	-	-	-	210.7	210.7	210.1	209.8	209.3	208.8	209.2
3	213.8	214.1	214.3	215.6	214.5	216.0	216.0	215.5	214.5	215.0	213.5	214.3
4	221.7	222.4	220.9	222.5	221.5	222.8	222.6	222.5	221.6	219.0	-	-
5	198.6	199.9	198.5	198.2	197.5	198.8	199.0	199.0	198.9	198.8	198.9	199.2
6	202.1	202.7	202.0	201.8	201.7	202.0	202.3	202.4	202.4	202.0	201.9	202.3
7	195.5	195.2	195.5	195.4	195.5	195.8	197.1	197.2	197.3	195.8	195.4	196.7
8	207.1	207.0	205.9	206.9	206.8	208.1	204.9	204.9	205.1	208.1	207.4	206.2
9	-	206.5	206.9	207.0	207.1	207.5	206.7	206.8	206.7	207.5	207.1	206.3
10	196.8	197.1	197.4	198.0	198.0	198.3	198.5	198.4	198.5	198.3	197.5	197.8
11	198.0	-	197.3	198.1	198.1	198.1	198.3	198.2	198.3	198.1	197.0	198.0
12	208.5	208.7	208.5	209.2	208.3	208.5	207.9	208.7	207.9	207.8	207.9	207.7
13	212.0	212.1	212.0	213.3	214.4	212.6	214.2	212.5	214.1	213.2	214.2	213.0
14	209.3	209.3	209.2	209.1	207.4	208.6	207.5	208.5	207.6	-	-	-
15	220.6	220.6	220.3	220.3	219.0	-	221.0	220.5	219.2	221.0	220.2	219.8
16	189.2	189.9	189.8	189.2	190.0	189.6	189.7	189.8	189.8	190.0	188.5	188.2
17	196.9	196.9	196.7	196.6	196.5	197.1	196.7	196.8	197.0	197.1	-	-
18	195.2	195.3	195.3	195.9	195.7	196.9	196.0	197.1	196.1	197.0	196.0	195.7
19	193.8	194.1	193.9	193.2	193.2	193.3	193.4	193.3	193.3	193.2	192.7	192.5
20	-	199.8	199.4	199.2	199.4	199.4	198.8	198.7	198.8	198.8	198.1	198.2

Table 14 - Piezometers groundwater level elevation (msal) monitoring (pre and post monsoon between 2013 and 2018)

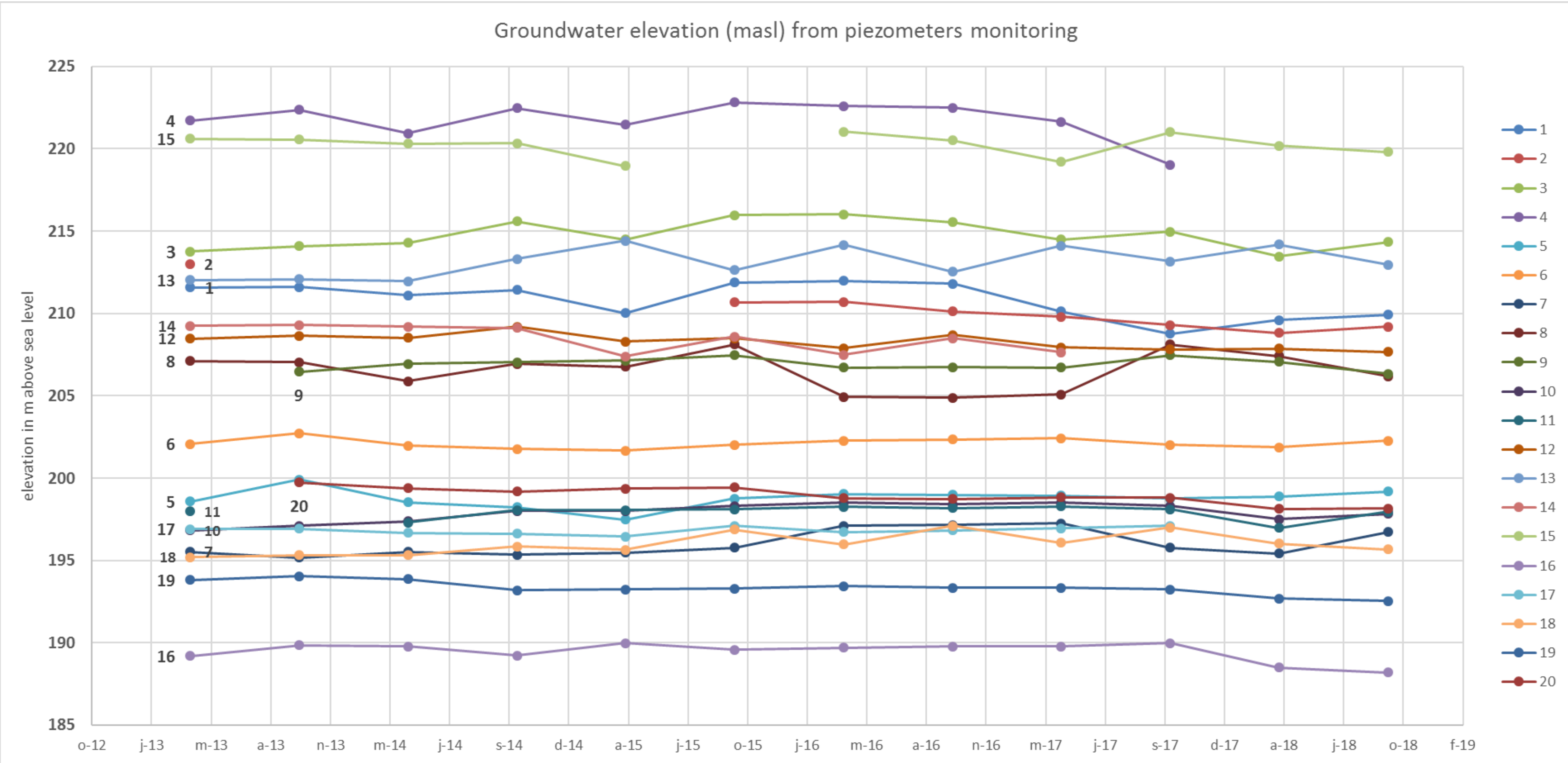


Figure 44 - Groundwater elevation (masl) between 2012 and 2018 from piezometer network (refer to Figure 43 for location)

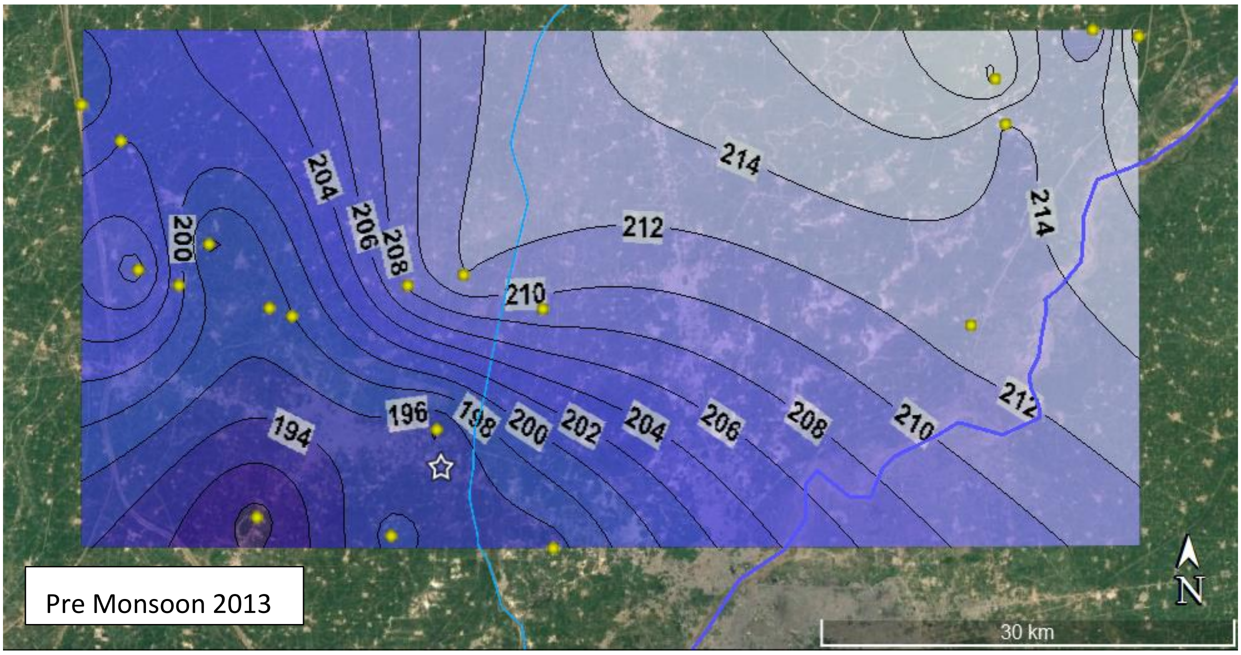


Figure 45 - Groundwater elevation contour (masl) from piezometer network (pre-monsoon 2013)

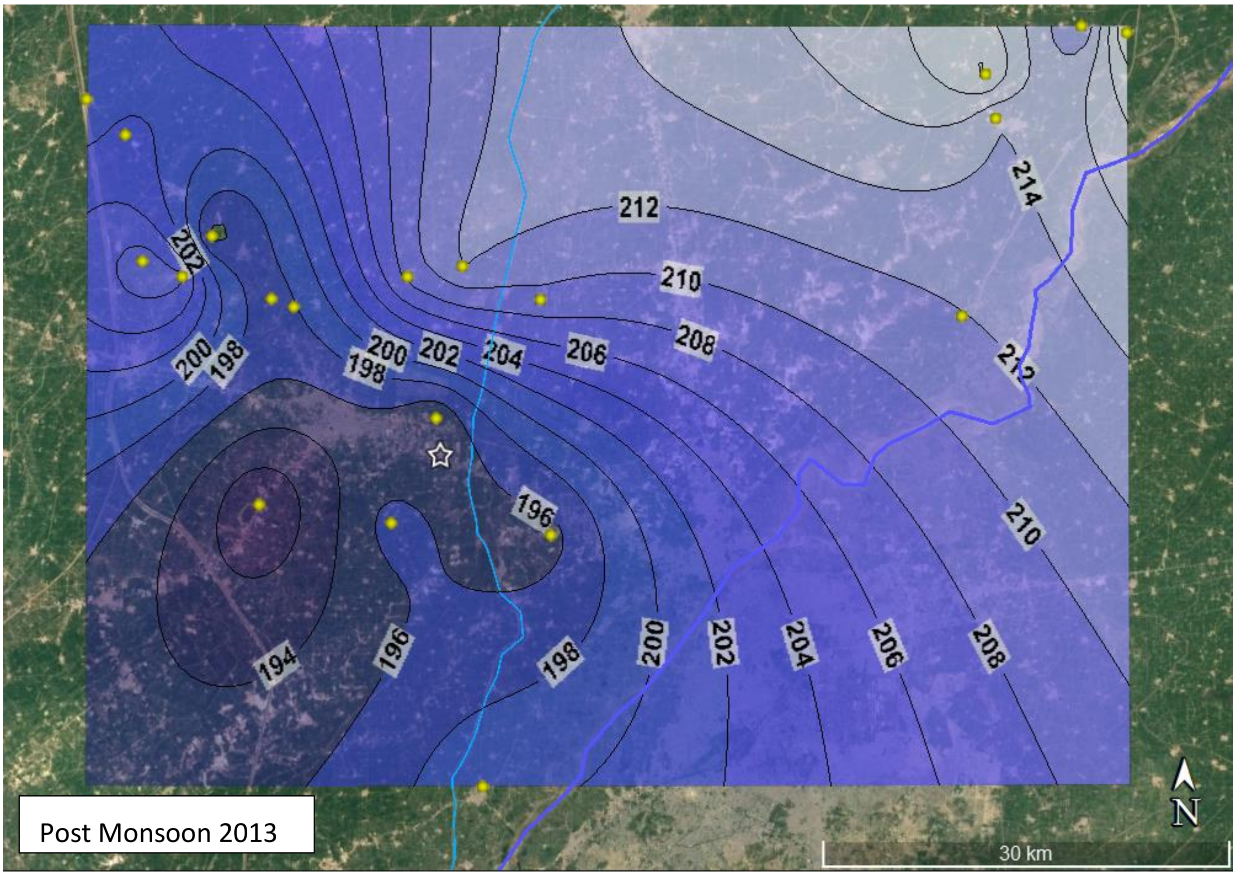


Figure 46 - Groundwater elevation contour (masl) from piezometer network (post-monsoon 2013)

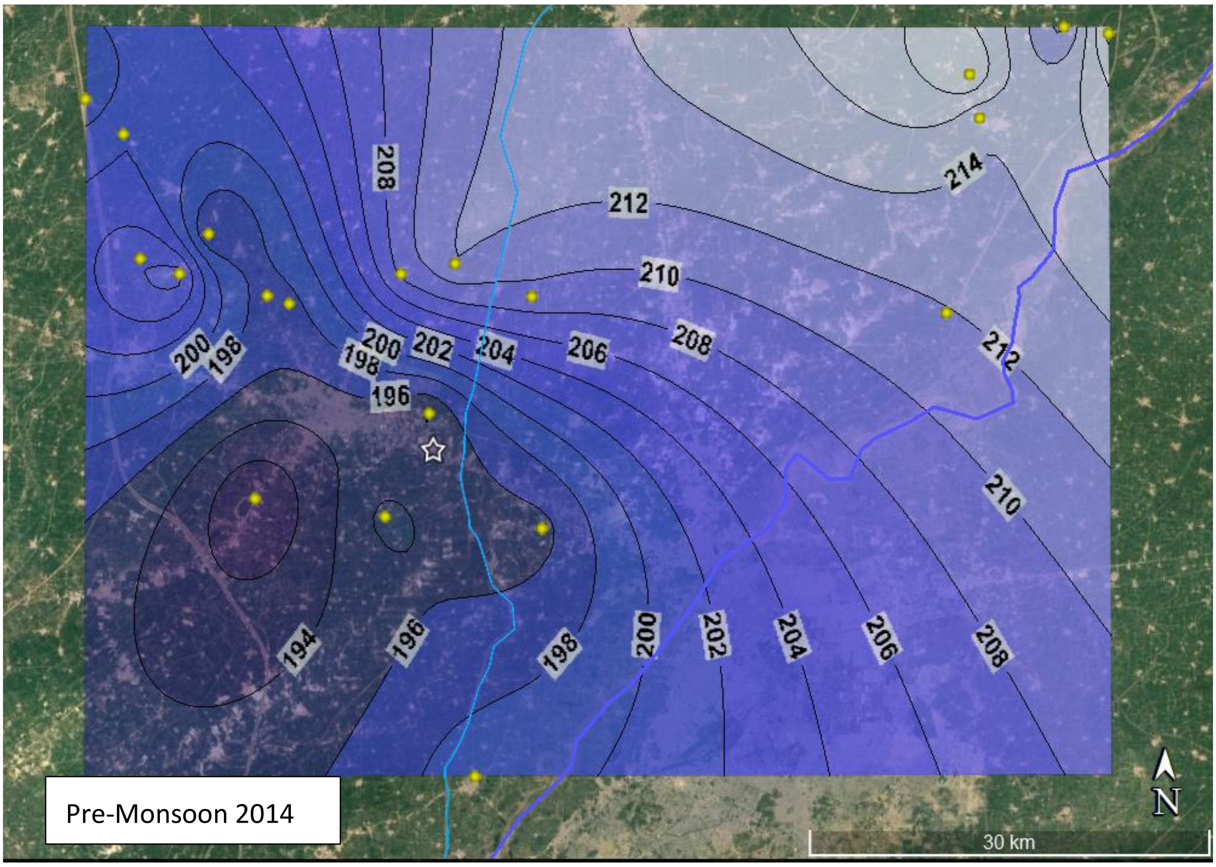


Figure 47 - Groundwater elevation contour (masl) from piezometer network (pre-monsoon 2014)

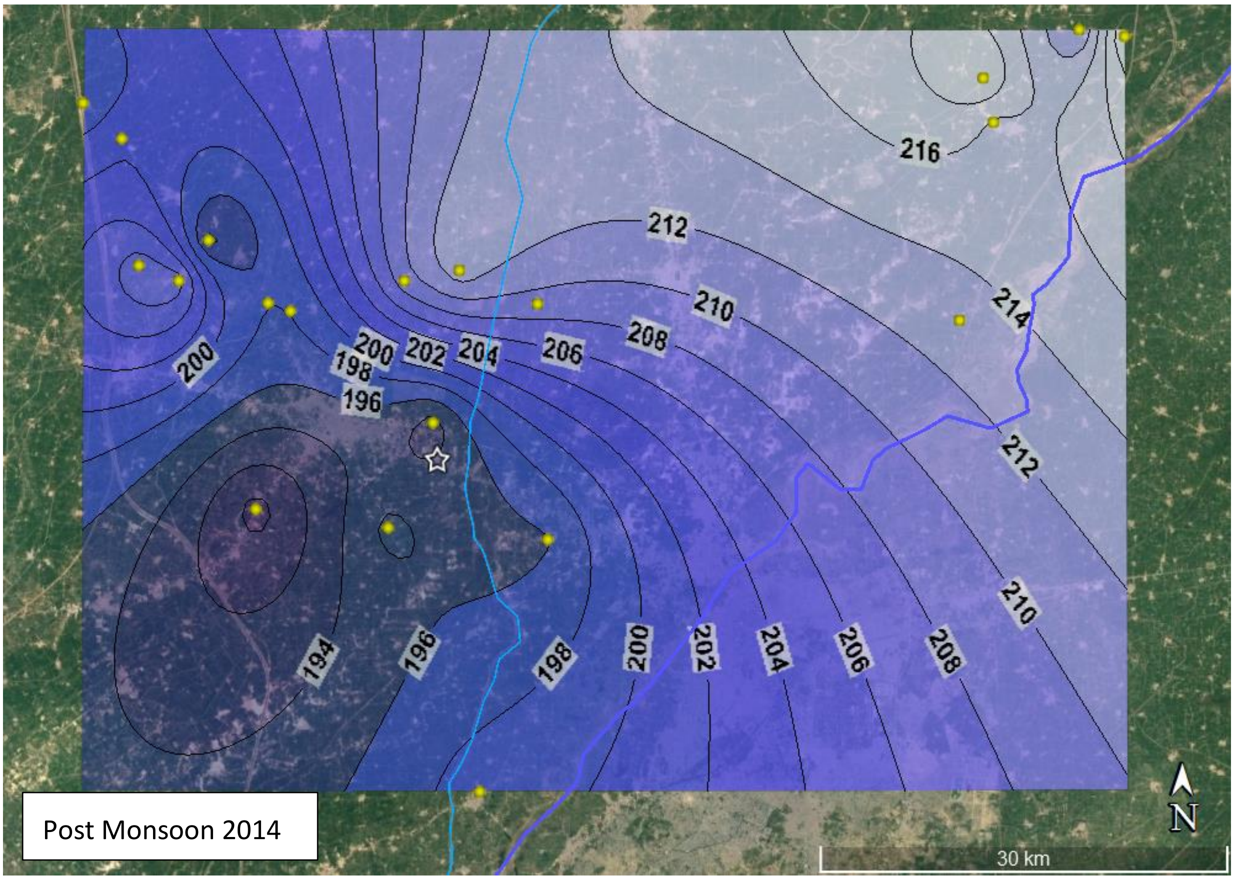


Figure 48 - Groundwater elevation contour (masl) from piezometer network (post-monsoon 2014)

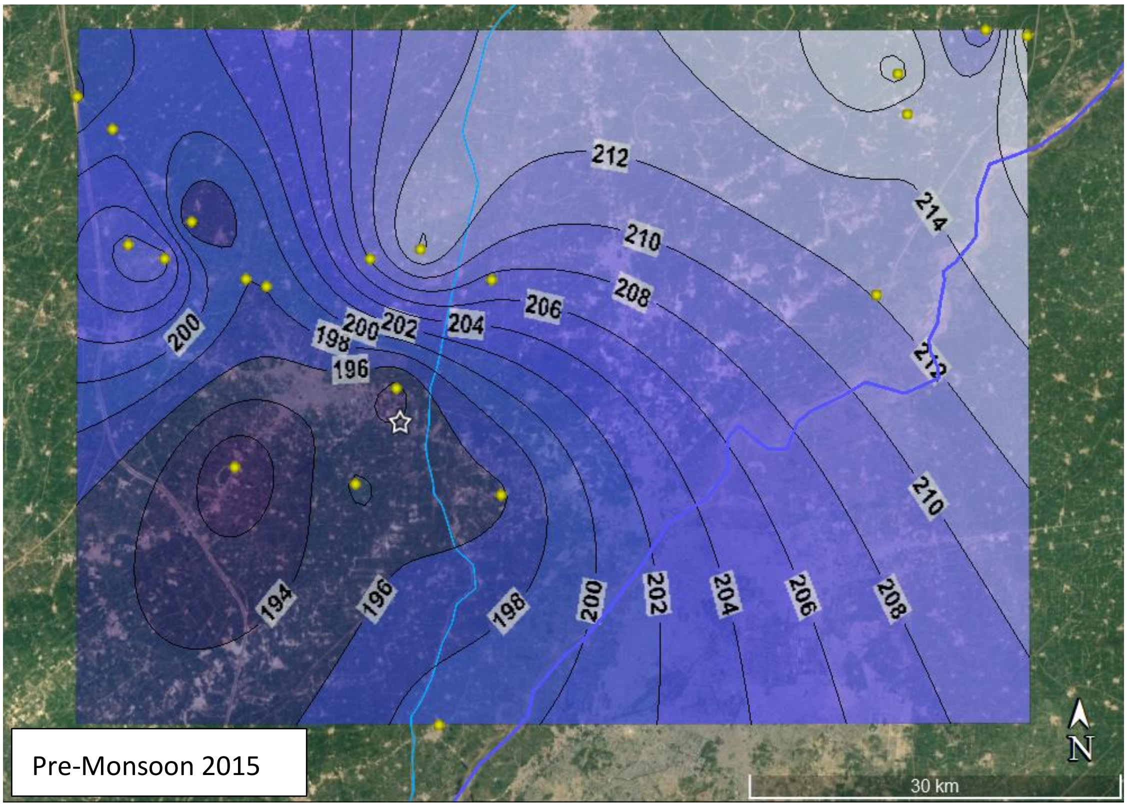


Figure 49 - Groundwater elevation contour (masl) from piezometer network (pre-monsoon 2015)

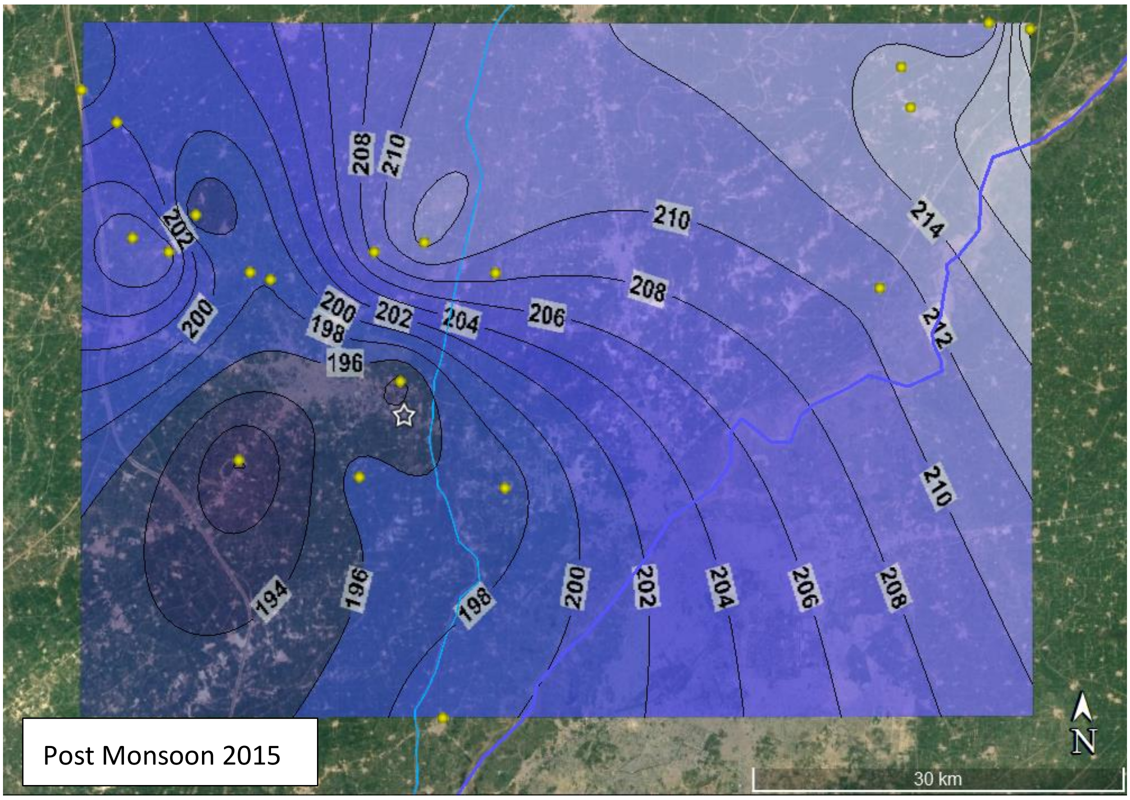


Figure 50 - Groundwater elevation contour (masl) from piezometer network (post-monsoon 2015)

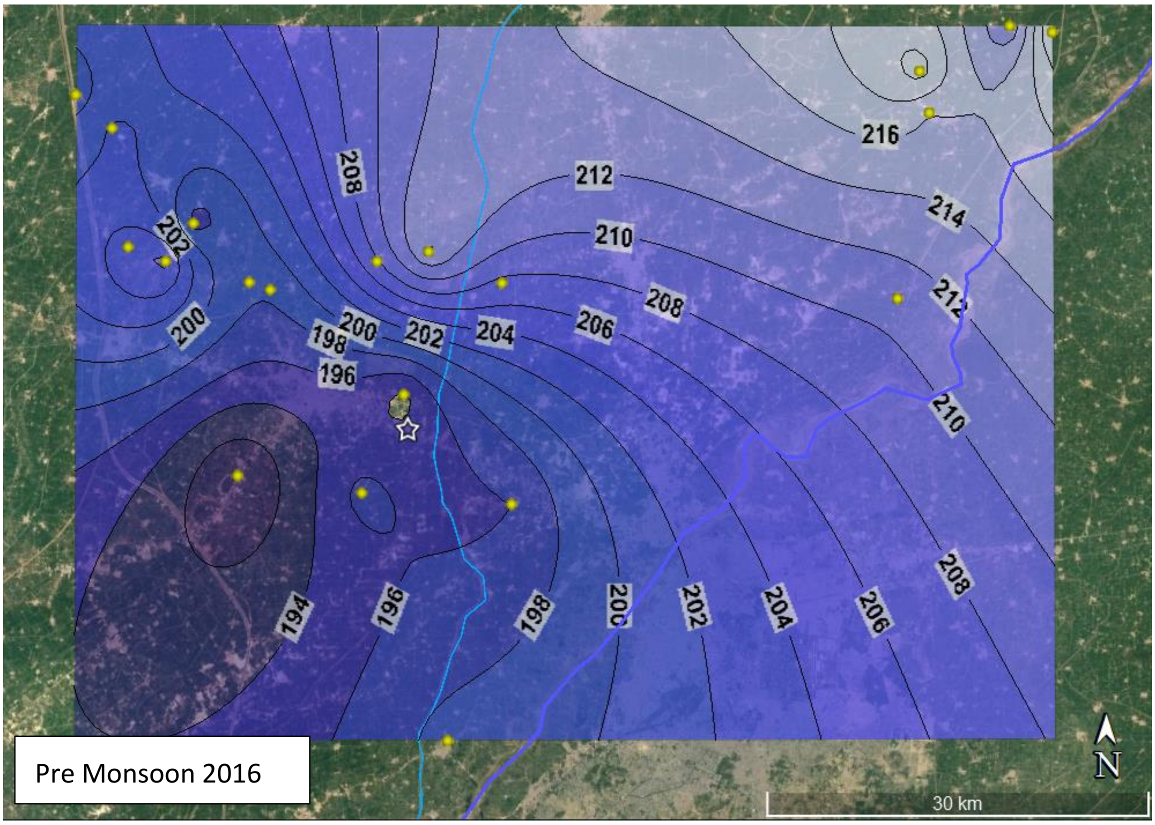


Figure 51 - Groundwater elevation contour (masl) from piezometer network (pre-monsoon 2016)

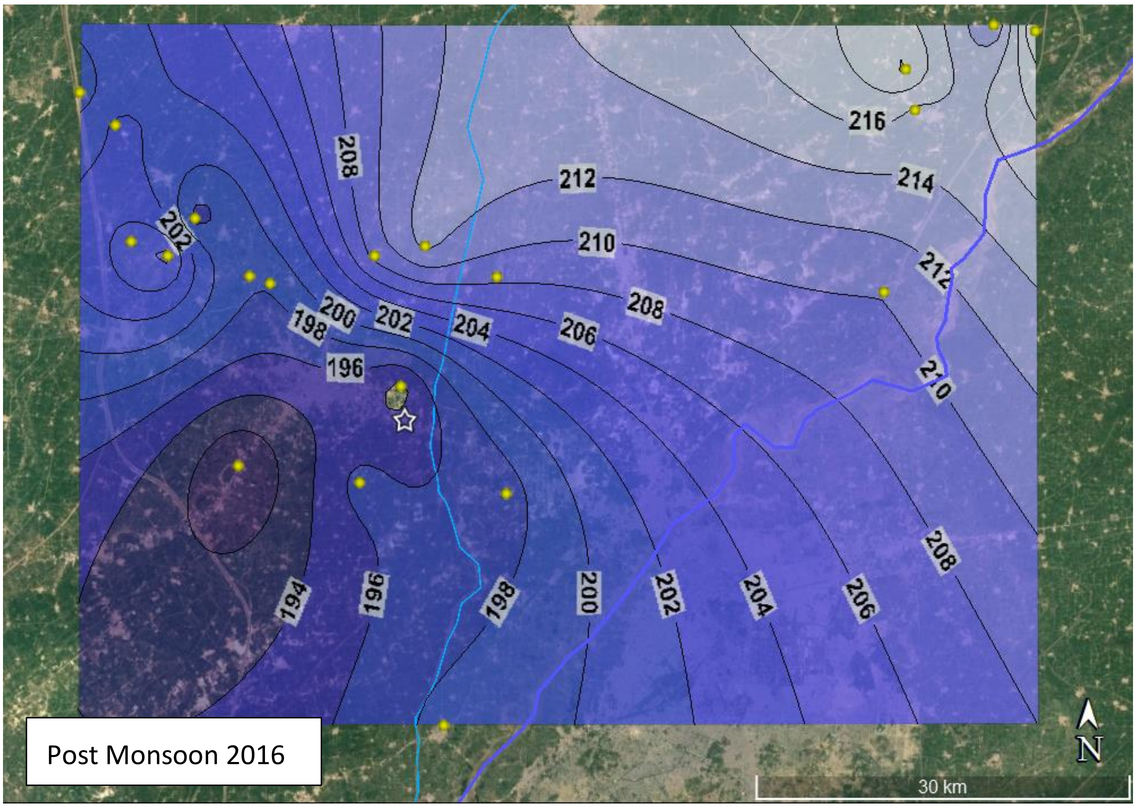


Figure 52 - Groundwater elevation contour (masl) from piezometer network (post-monsoon 2016)

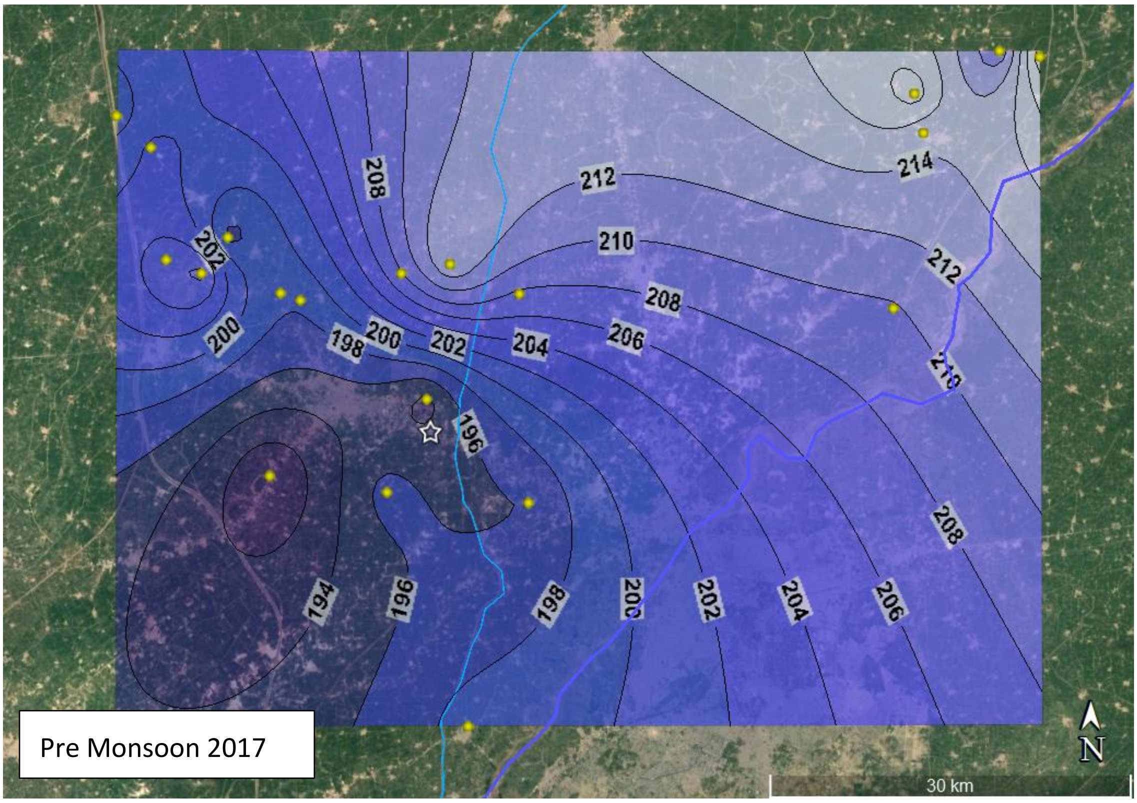


Figure 53 - Groundwater elevation contour (masl) from piezometer network (pre-monsoon 2017)

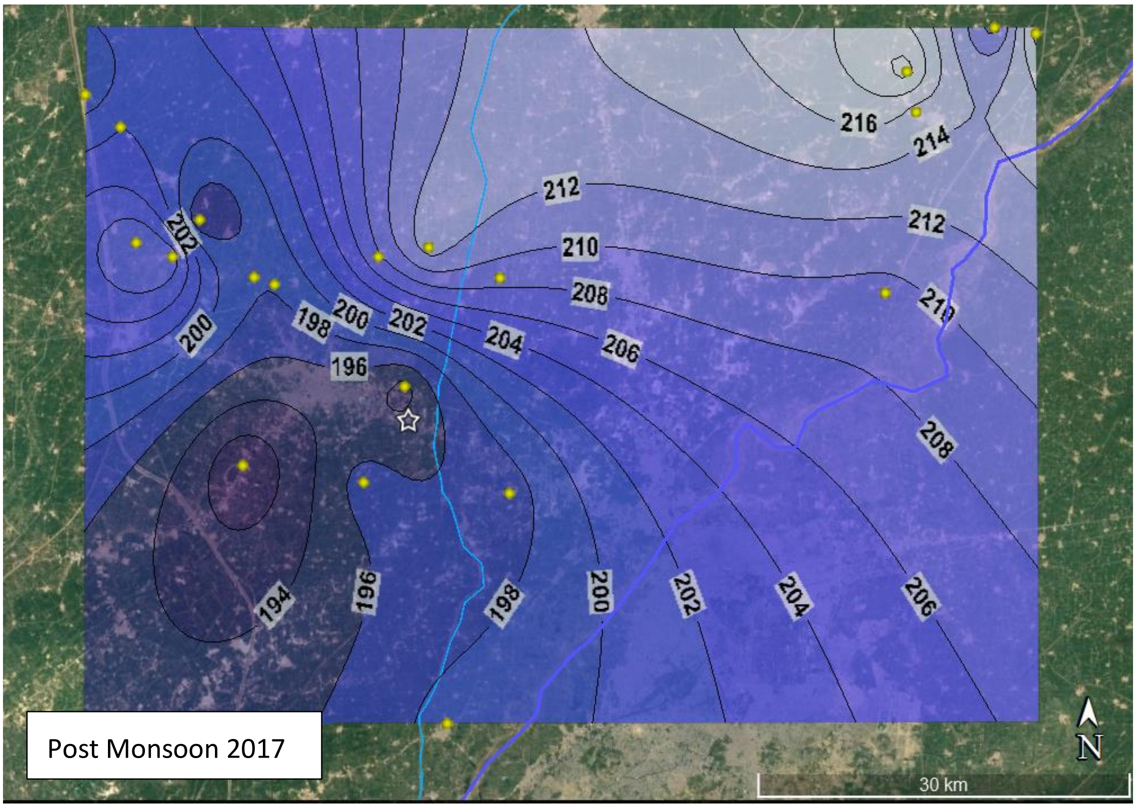


Figure 54 - Groundwater elevation contour (masl) from piezometer network (post-monsoon 2017)

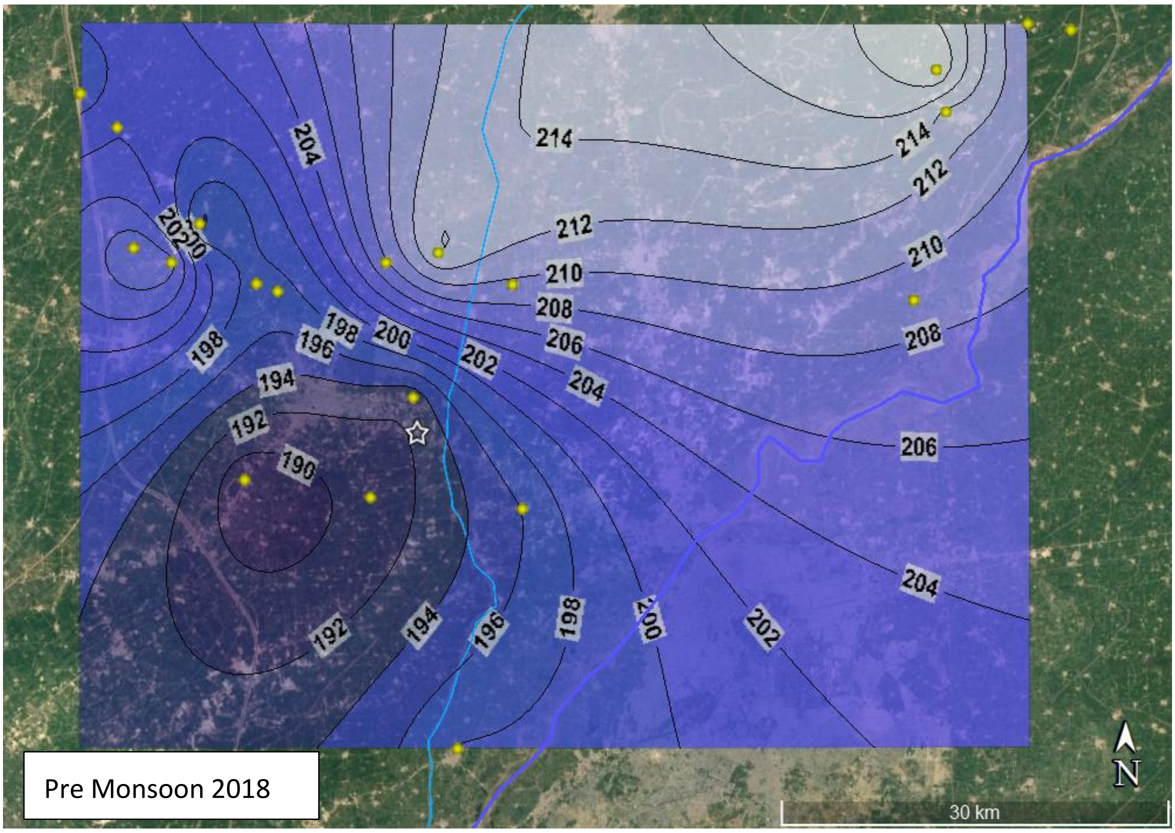


Figure 55 - Groundwater elevation contour (masl) from piezometer network (pre-monsoon 2018)

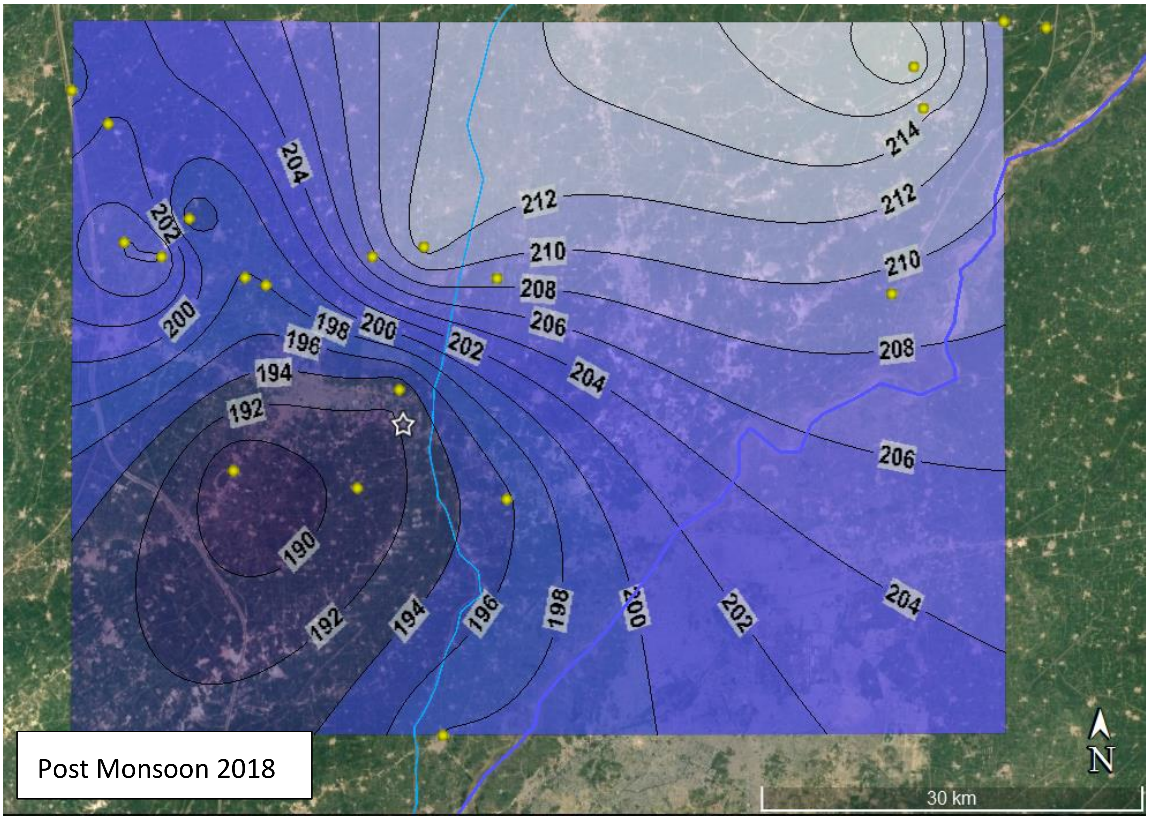


Figure 56 - Groundwater elevation contour (masl) from piezometer network (post-monsoon 2018)

7.4 Aquifer parameters

Step Rate Tests (SRT) were performed on Well 1 and Well 3 between 2007 and 2015. SRT on Well 2 were not performed (at least not available). Constant rate tests are not available for any of the three abstracting wells. Therefore, the estimation of the hydrodynamic parameters of the local aquifer (transmissivity and hydraulic conductivity) is not possible. According to the available literature, Hydraulic conductivity of the aquifer was estimated at 34 m/d in average (Muhammad et al., 2015).

The raw results of the available SRT are interpreted in the below paragraphs. It should be noted that Antea Group was not present during the SRTs and cannot ensure the reliability of the raw data. The interpretation of pumping tests has been carried out with the aid of software, developed by Antea Group and the French Geological Survey (BRGM). SRT are been undertaken to assess borehole ageing and to acquire field-scale measurements of hydrogeological properties. Step drawdown tests aim to determine specific capacity of the well at various discharge rates and the percentage of total head loss attributable to laminar flow (aquifer) or turbulent flow (clogging issues of the slotted screens). This information can be used to select optimum discharge rates (sustainable yield). When turbulent flow occurs, the specific capacity declines dramatically as the discharge rate is increased. Step test results might be compared to those realized in the past or on completion of boreholes (evolution of ageing state).

7.4.1 Well 1 Step Rate Test

SRT were performed in April 2014 on Well 1. Step test results are presented in Table 15and Figure 57. As it can be observed from the graph, flow rates of step 2 to 4 fluctuated slightly, inducing fluctuations in the water levels. Although it cannot be said with 100 % certainty, it seems that all the steps reached stabilisation (other than the fluctuations linked to the flow rate).

Step	Duration	Flow rate	Static water level	Dynamic water level	Drawdown	Specific capacity	Specific drawdown
n°	hour	m^3/h	m/ref.	m/ref.	m	$m^3/h/m$	$m/m^3/h$
1	2	10.2	9.5	11.2	1.7	6	0.17
2	2	19.2		13.0	3.5	5.5	0.18
3	2	29.5		15.0	5.5	5.4	0.19
4	2	39.0		16.7	7.2	5.4	0.18

Table 15 - Well 1 step rate test April 2014

The test has been interpreted in terms of specific capacity and total head losses (Figure 58). The performance curve of Well 1 is represented by the following equation (with s in meter and Q in m3/h):

$$s = 0.176 \times Q + 2.55 \times 10^{-4} \times Q^2$$

Figure 58 shows a theoretical characteristic curve very similar from a linear head losses line. Head losses are attributable to laminar and turbulent flows. Calculations of head losses attributable to laminar and turbulent flows are presented in Table 16. As it can be observed, the quadratic head losses (turbulent) are very small, indicative of a well in very good condition. This well is also likely not being pumped at its maximum capacity. If Nestlé wish to withdraw more groundwater from this well, a bigger pump should be installed and a new SRT should be performed with pump rate up to 100 m^3/h tested. **In the current condition and according to the results of this test realised in April 2014, it can be said that the well could be safely operated at 40 m^3/h.**

Discharge Rate (m^3/h)	10.2	19.2	29.5	39
Head losses Laminar flow	1.8	3.4	5.2	6.9
Head losses turbulent flow	0.03	0.09	0.22	0.39
Total head losses	1.83	3.49	5.42	7.29
% non-linear head losses	**1 %**	**3 %**	**4 %**	**5 %**

Table 16 - Head losses calculation BH3

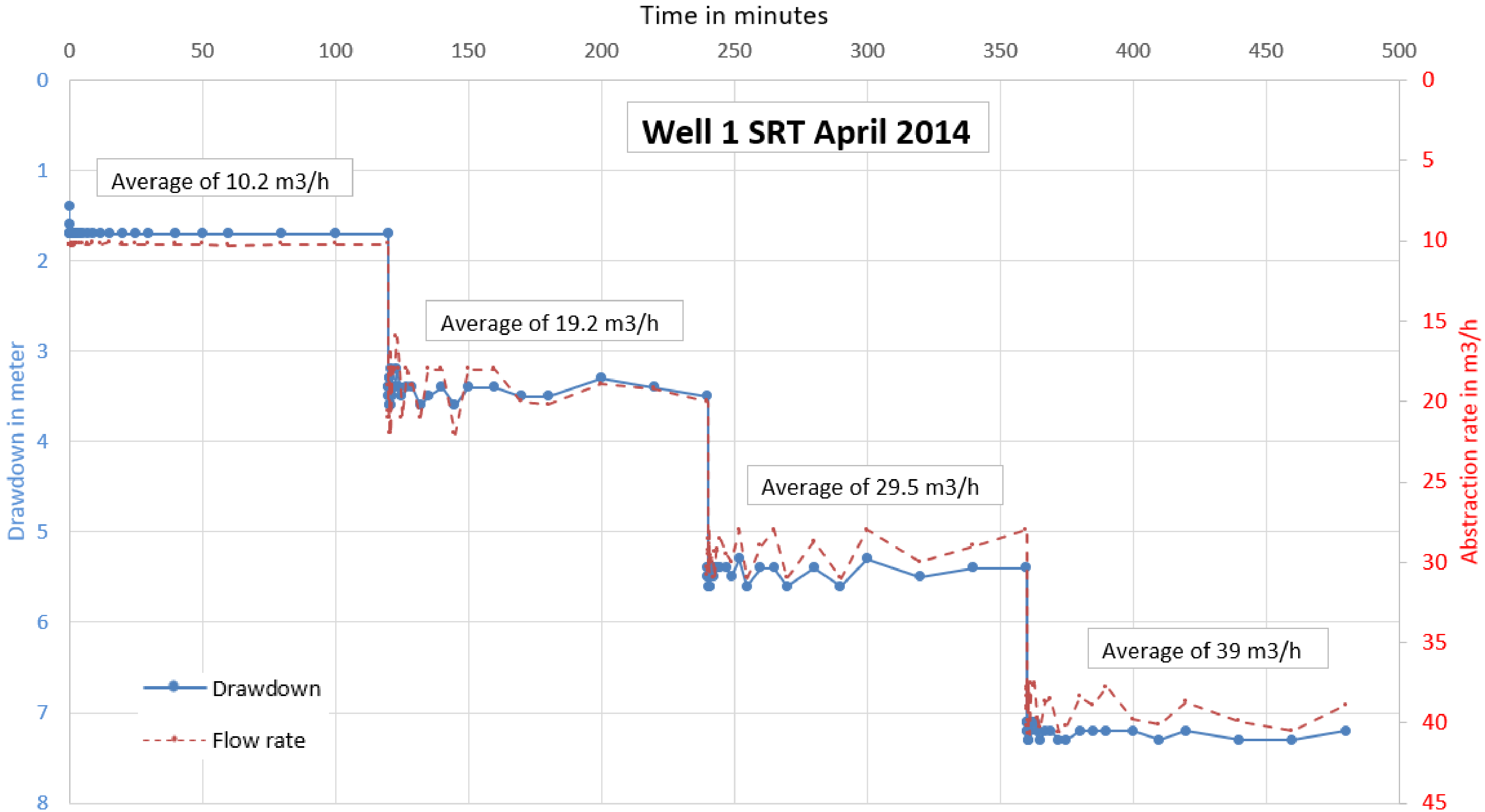
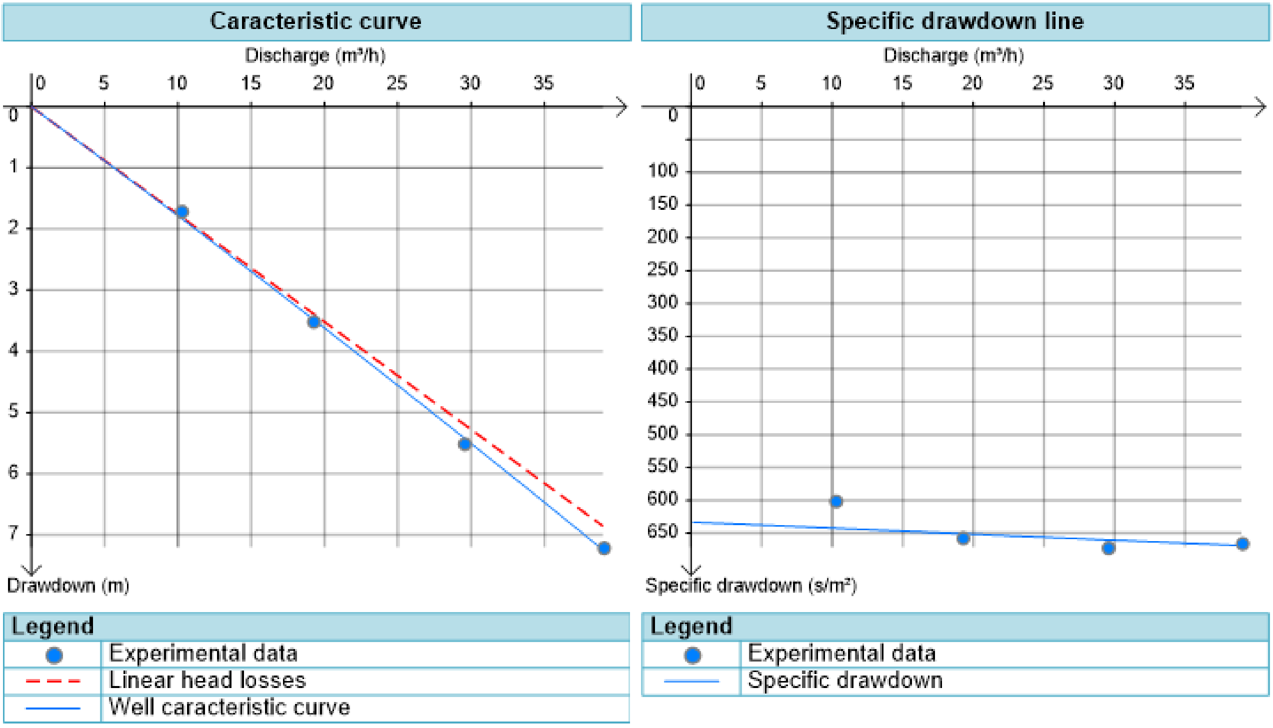


Figure 57 - Well 1 SRT April 2014

Well 1 April 2014

Well type	Well



Discharge step	Discharge (m^3/h)	Measured drawdown (m)	Pumping duration (min)	Recovery duration (min)	Computed linear head losses (m)	Computed quadratic head losses (m)	Observed specific drawdown (h/m²)	Computed specific drawdown (h/m²)	Error (sim-obs) (m)
Step 1	10,2	1,7	120	-	1,8	$2,7\times10^{-2}$	0,167	0,179	0,121
Step 2	19,2	3,5	120	-	3,4	$9,4\times10^{-2}$	0,182	0,181	$-2,82\times10^{-2}$
Step 3	29,5	5,5	120	-	5,2	0,22	0,186	0,183	$-8,81\times10^{-2}$
Step 4	39	7,2	120	-	6,9	0,39	0,185	0,186	$4,93\times10^{-2}$

Adjustement parameters		
Linear head losses coefficient (B)	0,176 h/m²	633 s/m²
Quadratic head losses coefficient (C)	$2,55\times10^{-4}$ h²/m⁵	3 310 s²/m⁵
Exponent (n)	2,00	

Figure 58 - Well 1 SRT interpretation

7.4.2 Well 3 Step Rate Test

Step Rate Tests (SRT) were performed on Well 3 in October 2007, March 2015 and January 2019.

2007 WELL 3 SRT

The results of 2007 SRT are presented in Table 17 and Figure 59. As it can be observed from the graph, step 3 and 4 didn't reach stabilisation at the end of the 2 hours steps, with a dynamic water level continuing to decrease. The applied rate was likely too high for this well. According to this graph, the maximum recommended abstracting rate is at maximum 60 m^3/h as it seems that step 1 and 2 reached stabilisation. It however seems that a 3-hour step rate test would be more appropriate to confirm these results. Step 4 didn't record a significant additional drawdown step, which could suggest that this testing was also done under the influence of a nearby abstracting well.

Step	Duration	Average flow rate	Static water level	Dynamic water level	Drawdown	Specific capacity	Specific drawdown
n°	hour	m³/h	m/ref.	m/ref.	m	m³/h/m	m/m³/h
1	2	40	8.3	9.8	1.5	26.7	0.04
2	2	60		11.5	3.1	19.1	0.05
3	2	75		13.6	4.6	16.5	0.06
4	2	90		14.0	5.7	15.9	0.06

Table 17 - Well 3 step rate test March 2007

Figure 58 shows a theoretical characteristic curve quite different from a linear head losses line. Head losses are attributable to laminar and turbulent flows. Calculations of head losses attributable to laminar and turbulent flows are presented in Table 18.

Discharge Rate (m³/h)	**40**	**60**	**75**	**90**
Head losses Laminar flow	1.0	1.5	1.8	2.2
Head losses turbulent flow	0.7	1.6	2.5	3.6
Total head losses	1.7	3.1	4.3	5.8
% non-linear head losses	**42 %**	**52 %**	**58 %**	**62 %**

Table 18 - Head losses calculation BH3 March 2007

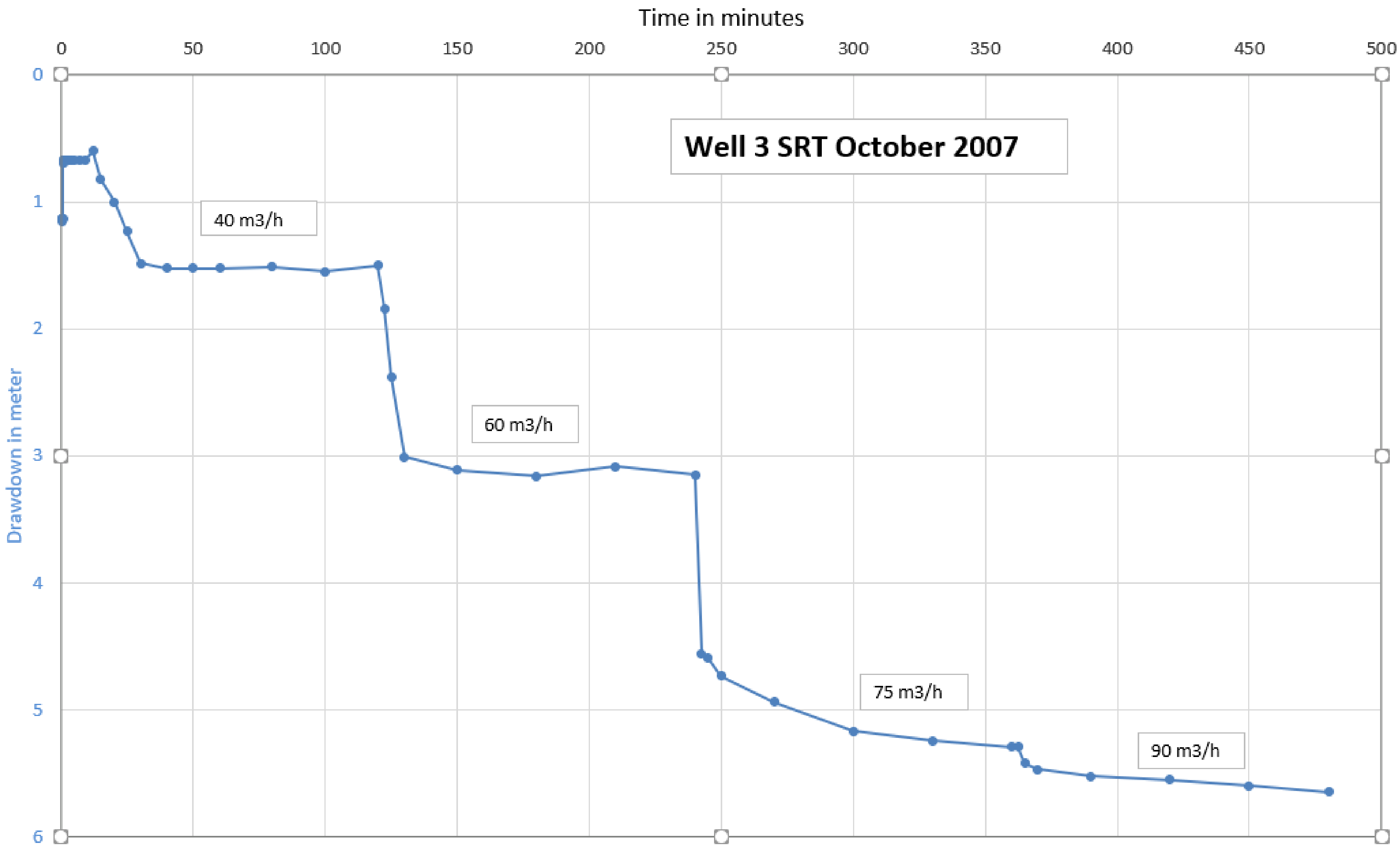
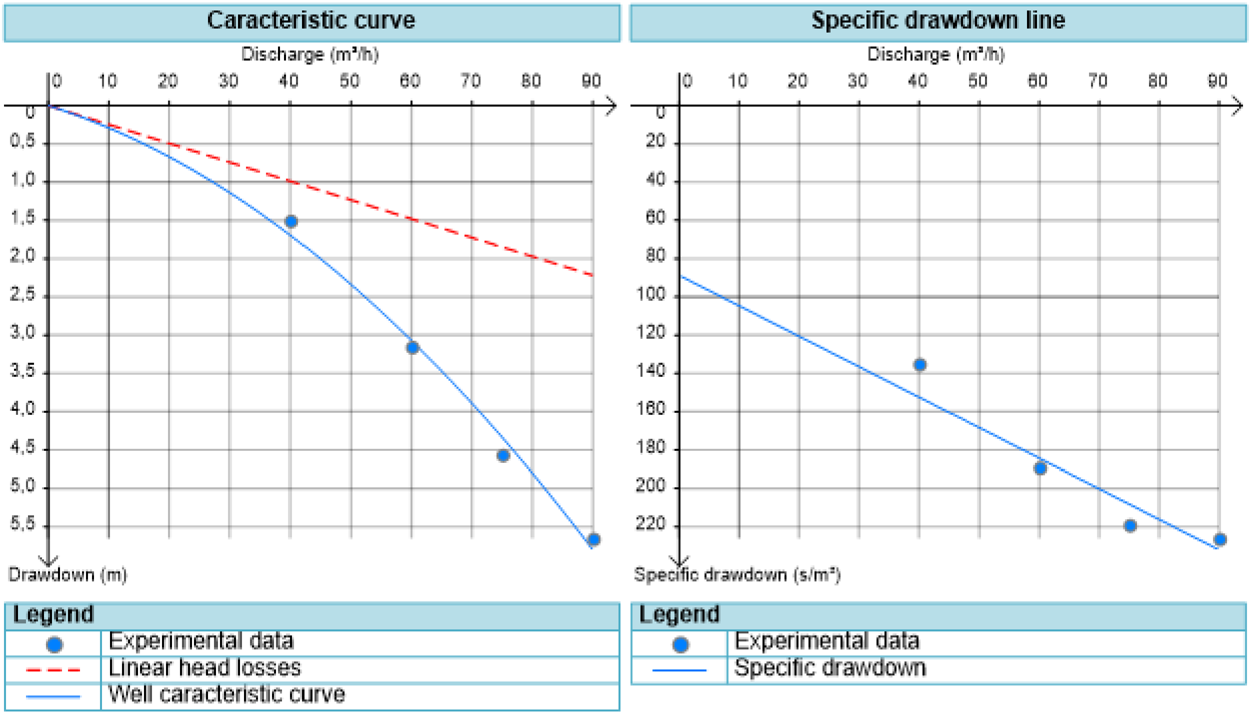


Figure 59 - Well 3 SRT October 2007

Well 3 2007

Well type	Well



Discharge step	Discharge (m³/h)	Measured drawdown (m)	Pumping duration (min)	Recovery duration (min)	Computed linear head losses (m)	Computed quadratic head losses (m)	Observed specific drawdown (h/m²)	Computed specific drawdown (h/m²)	Error (sim-obs) (m)
Step 1	40	1,499	120	-	0,99	0,71	$3,75\times10^{-2}$	$4,23\times10^{-2}$	0,195
Step 2	60	3,149	120	-	1,5	1,6	$5,25\times10^{-2}$	$5,12\times10^{-2}$	$-7,76\times10^{-2}$
Step 3	75	4,559	120	-	1,8	2,5	$6,08\times10^{-2}$	$5,78\times10^{-2}$	-0,222
Step 4	90	5,651	120	-	2,2	3,6	$6,28\times10^{-2}$	$6,45\times10^{-2}$	0,15

Adjustement parameters		
Linear head losses coefficient (B)	$2,47\times10^{-2}$ h/m²	88,8 s/m²
Quadratic head losses coefficient (C)	$4,42\times10^{-4}$ h²/m⁵	5 730 s²/m⁵
Exponent (n)	2,00	

Figure 60 - Well 3 2007 SRT interpretation

2015 WELL 3 SRT

The results of 2015 SRT are presented in Table 19 and Figure 61. As it can be observed from the graph, the drawdown is not smooth and strong fluctuation are occurring, particularly in step 2. It could be linked to the flow rate fluctuations (even very short pump stop) and/or influence of nearby abstracting wells. With the current results it is difficult to properly assess the trends. However, it seems that none of the steps reached stabilisation. It is not possible with these results to conclude on the suitable abstracting rate for this well. Attempts were made to interpret the recovery curve to obtain hydrodynamic parameters of the aquifer, but no curve matching was possible. However, according to the recovery curve, it can be definitely said that the test was influenced by nearby abstracting well(s). It can be observed that an influencing well stopped pumping 540 minutes into the test, inducing a jump in the recovering levels.

Step	Duration	Average flow rate	Static water level	Dynamic water level	Drawdown	Specific capacity	Specific drawdown
n°	hour	m^3/h	m/ref.	m/ref.	m	$m^3/h/m$	$m/m^3/h$
1	2	34.1	9.7	11.5	1.8	18.9	0.05
2	2	40.0		12.1	2.4	16.7	0.06
3	2	50.2		12.8	3.1	16.2	0.06
4	2	60.1		13.44	3.74	16.1	0.06

Table 19 - Well 3 step rate test March 2015

The test has been interpreted in terms of specific capacity and total head losses (Figure 62Figure 58). The performance curve of Well 3 is represented by the following equation (with s in meter and Q in m3/h):

$$s = 0.0473 \text{ x } Q + 2.61 \text{ x}10^{-4} \text{x} Q^2$$

Figure 58 shows a theoretical characteristic curve slightly different from a linear head losses line. Head losses are attributable to laminar and turbulent flows. Calculations of head losses attributable to laminar and turbulent flows are presented in Table 20.

Discharge Rate (m^3/h)	34	40	50	60
Head losses Laminar flow	1.6	1.9	2.4	2.8
Head losses turbulent flow	0.3	0.4	0.7	0.9
Total head losses	1.9	2.3	3.1	3.7
% non-linear head losses	**16 %**	**18 %**	**22 %**	**25 %**

Table 20 - Head losses calculation BH3

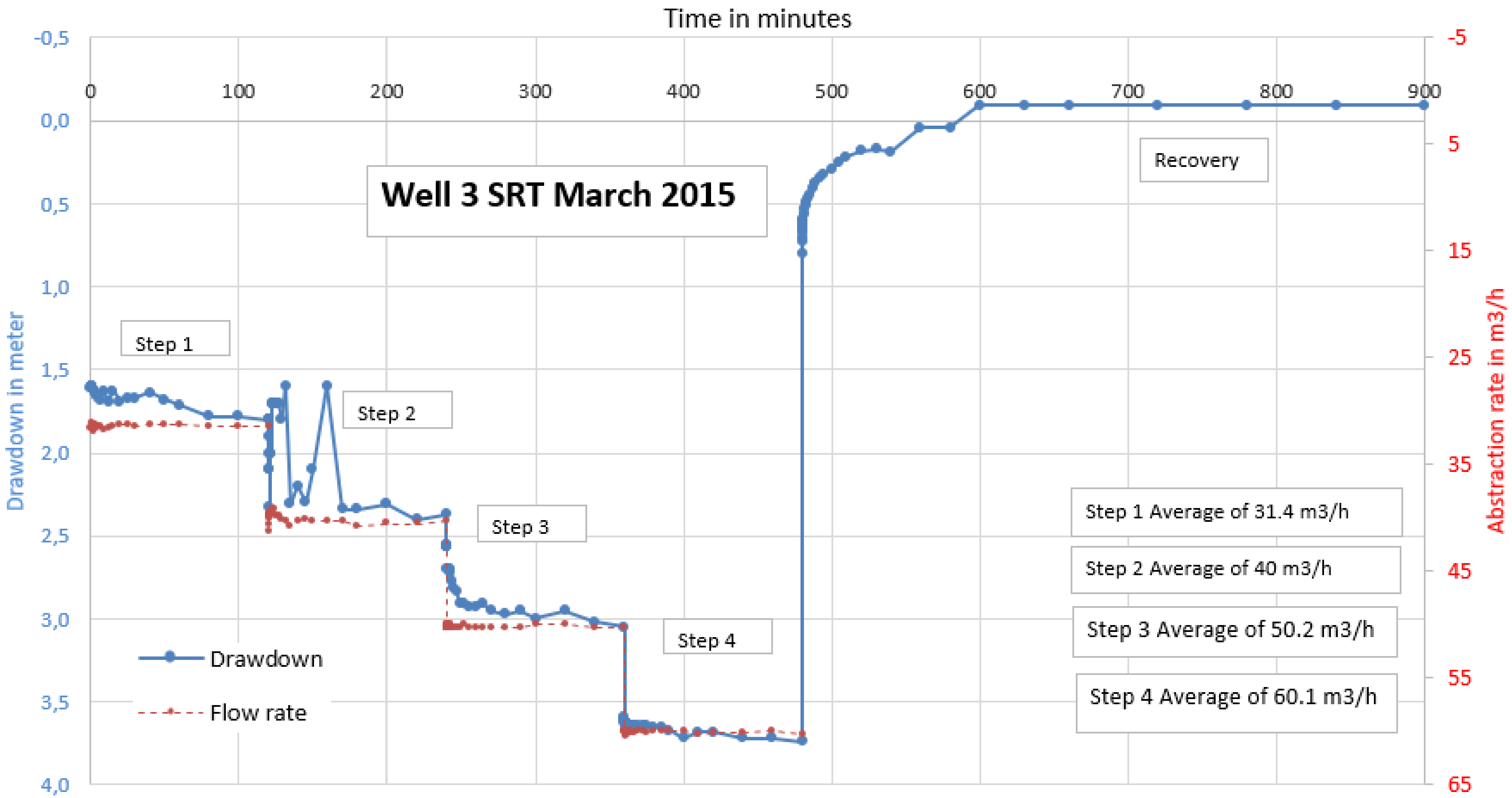


Figure 61 - Well 3 SRT March 2015

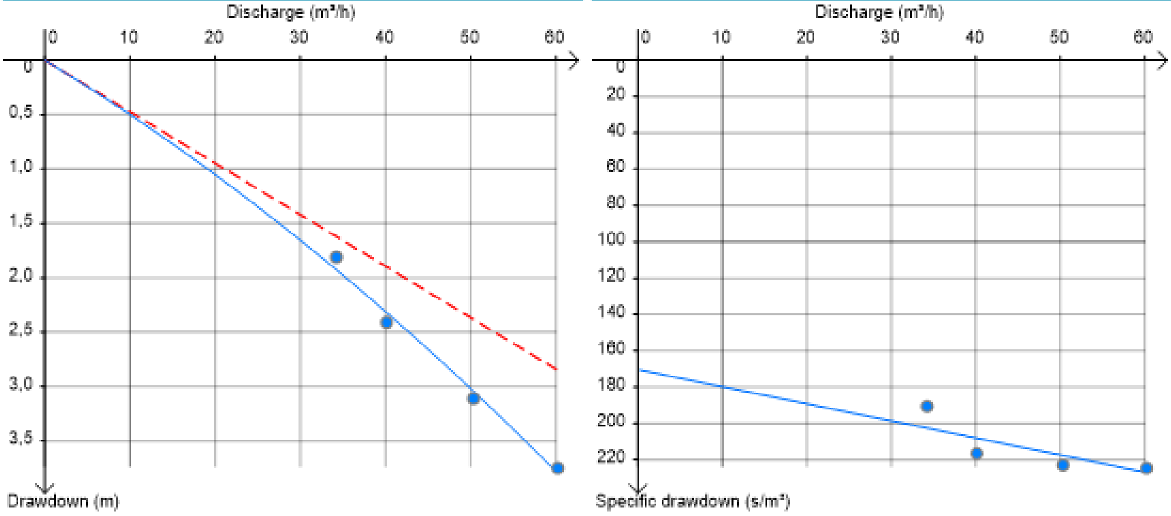
anteagroup

Well 3 March 2015

OUAIP

Well type	Well

Caracteristic curve	Specific drawdown line



Legend	
●	Experimental data
– – –	Linear head losses
——	Well caracteristic curve

Legend	
●	Experimental data
——	Specific drawdown

Discharge step	Discharge (m^3/h)	Measured drawdown (m)	Pumping duration (min)	Recovery duration (min)	Computed linear head losses (m)	Computed quadratic head losses (m)	Observed specific drawdown (h/m^2)	Computed specific drawdown (h/m^2)	Error (sim-obs) (m)
Step 1	34,1	1,8	120	-	1,5	0,3	$5,28\times10^{-2}$	$5,62\times10^{-2}$	0,118
Step 2	40	2,4	120	-	1,9	0,42	6×10^{-2}	$5,78\times10^{-2}$	$-8,91\times10^{-2}$
Step 3	50,2	3,1	120	-	2,4	0,66	$6,18\times10^{-2}$	$6,04\times10^{-2}$	$-6,62\times10^{-2}$
Step 4	60,1	3,74	120	-	2,8	0,94	$6,22\times10^{-2}$	$6,3\times10^{-2}$	$4,73\times10^{-2}$

Adjustement parameters		
Linear head losses coefficient (B)	$4,73\times10^{-2}$ h/m^2	170 s/m^2
Quadratic head losses coefficient (C)	$2,61\times10^{-4}$ h^2/m^5	3 380 s^2/m^5
Exponent (n)	2,00	

Figure 62 - Well 3 2015 SRT interpretation

2019 WELL 3 SRT

The results of 2019 SRT are presented in Table 21 and Figure 63. Except step 1 that had fluctuating levels, the three following steps reached stabilisation without fluctuations. According to these results, the well can be operated at least at 40 m^3/h. Once again, the recovery pattern showed an influence by a nearby pumping well. Attempts were made to interpret the recovery curve to obtain hydrodynamic parameters of the aquifer, but no curve matching was possible.

Step	Duration	Average flow rate	Static water level	Dynamic water level	Drawdown	Specific capacity	Specific drawdown
n°	hour	m^3/h	m/ref.	m/ref.	m	$m^3/h/m$	$m/m^3/h$
1	2	15	10.66	12.38	1.72	8.72	0.11
2	2	20		12.82	2.16	9.26	0.11
3	2	30		13.97	3.31	9.06	0.11
4	2	40		14.8	4.16	9.62	0.10

Table 21 - Well 3 step rate test January 2019

Figure 64 presents the Well 3 interpretation results. The head losses cannot be properly calculated as the applied flow rates during this test are relatively low (max 40 m^3/h) and are not creating a turbulent regime only the well (only laminar flow).

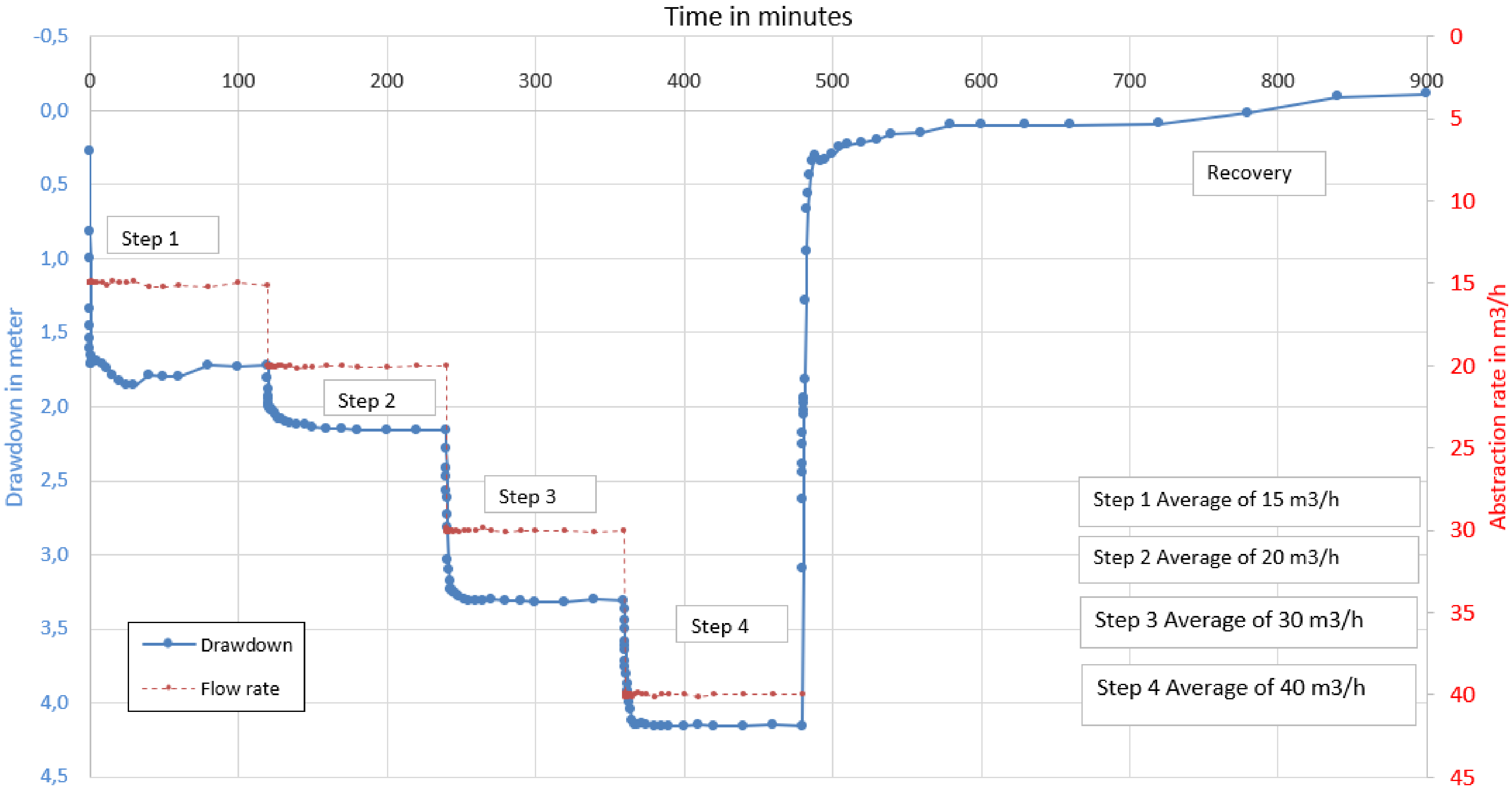
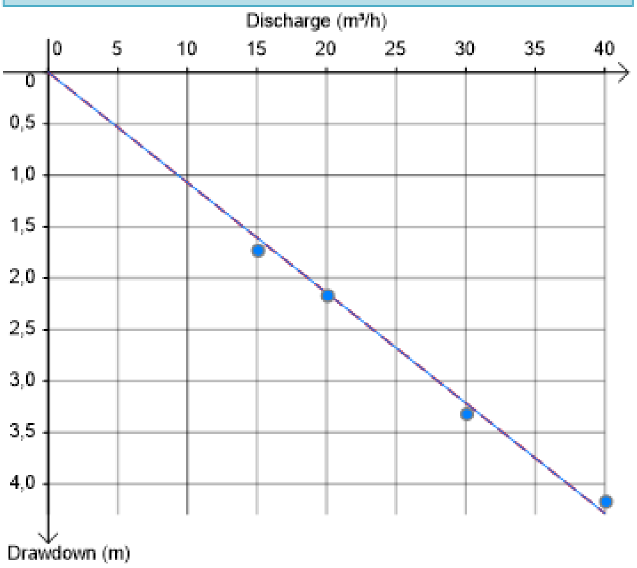


Figure 63 - Well 3 SRT January 2019

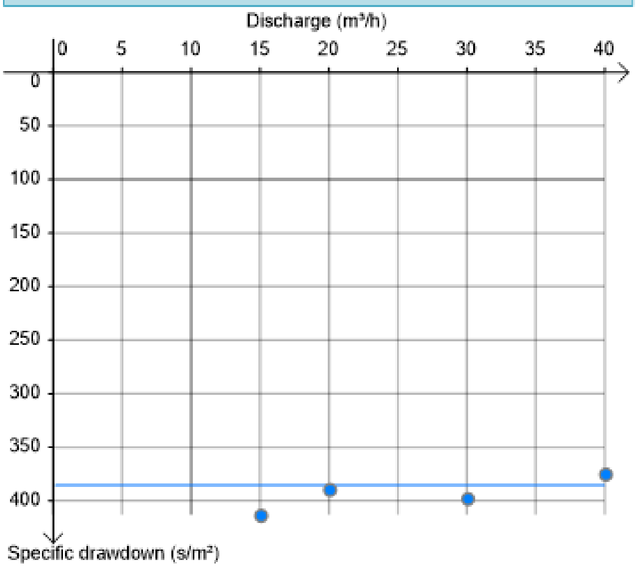
Well 3 SRT January 2019

Well type	Well

Caracteristic curve



Specific drawdown line



Legend	
●	Experimental data
– – –	Linear head losses
——	Well caracteristic curve

Legend	
●	Experimental data
——	Specific drawdown

Discharge step	Discharge (m³/h)	Measured drawdown (m)	Pumping duration (min)	Recovery duration (min)	Computed linear head losses (m)	Computed quadratic head losses (m)	Observed specific drawdown (h/m²)	Computed specific drawdown (h/m²)	Error (sim-obs) (m)
Step 1	15	1,72	-	-	1,6	0	0,115	0,107	-0,113
Step 2	20	2,16	-	-	2,1	0	0,108	0,107	$-1{,}78\times10^{-2}$
Step 3	30	3,31	-	-	3,2	0	0,11	0,107	$-9{,}67\times10^{-2}$
Step 4	40	4,16	-	-	4,3	0	0,104	0,107	0,124

Adjustement parameters		
Linear head losses coefficient (B)	0,107 h/m²	386 s/m²
Quadratic head losses coefficient (C)	0 h²/m⁵	0 s²/m⁵
Exponent (n)	2,00	

Figure 64 - Well 3 January 2019 SRT interpretation

2007, 2015 AND 2019 SRT COMPARAISON

Table 22 and Figure 65 presents a comparison of the main results. As it can be observed, greater drawdown can be observed over time, with an additional 0.6 to 0.9 m in 2015 and an additional 2.7 m in 2019. The specific capacity is hence significantly decreasing over time. This difference in drawdown and specific capacity can be explained either by an ageing of the well condition and/or by the influence of the nearby pumping wells that was observed during the SRT testing. **However, it seems that the productivity of Well 3 is decreasing over time due to ageing conditions (e.g. clogging).**

Flow rate	Drawdown (m)			Specific capacity (m3/h/m)		
m^3/h	2007	2015	2019	2007	2015	2019
40	1.5	2.4	4.2	26.7	16.7	9.62
60	3.1	3.74	NA	19.1	16.1	NA

Table 22 - 2007 and 2015 Well 3 SRT comparaison

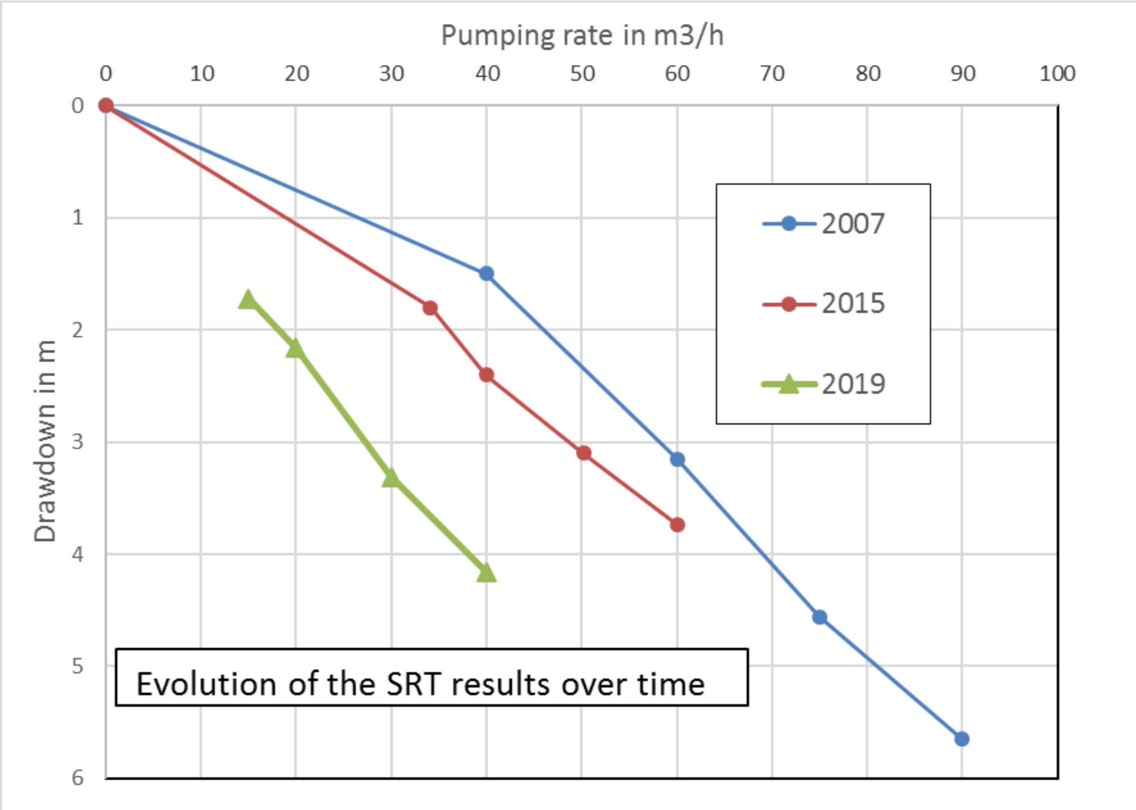


Figure 65 - Evolution of Well 3 SRT results over time

7.5 Well census

During the field survey, a detailed well census was performed, and 354 wells were identified in the radius of 10 km², around the Nestlé factory. When possible, the owners were interviewed, and field data collected (water level, pH, TDS etc.). Figure 66 presents the location of these identified wells. The list of all collected data is presented in Appendix 1. The wells have different depth ranging from very shallow to depth similar to Nestlé wells. As no confining layer is present to distinguish shallow from deeper aquifers, it can be considered that the wells are abstracting form the same aquifer. However most of the wells are shallower (less than 100 m) that Nestlé wells.

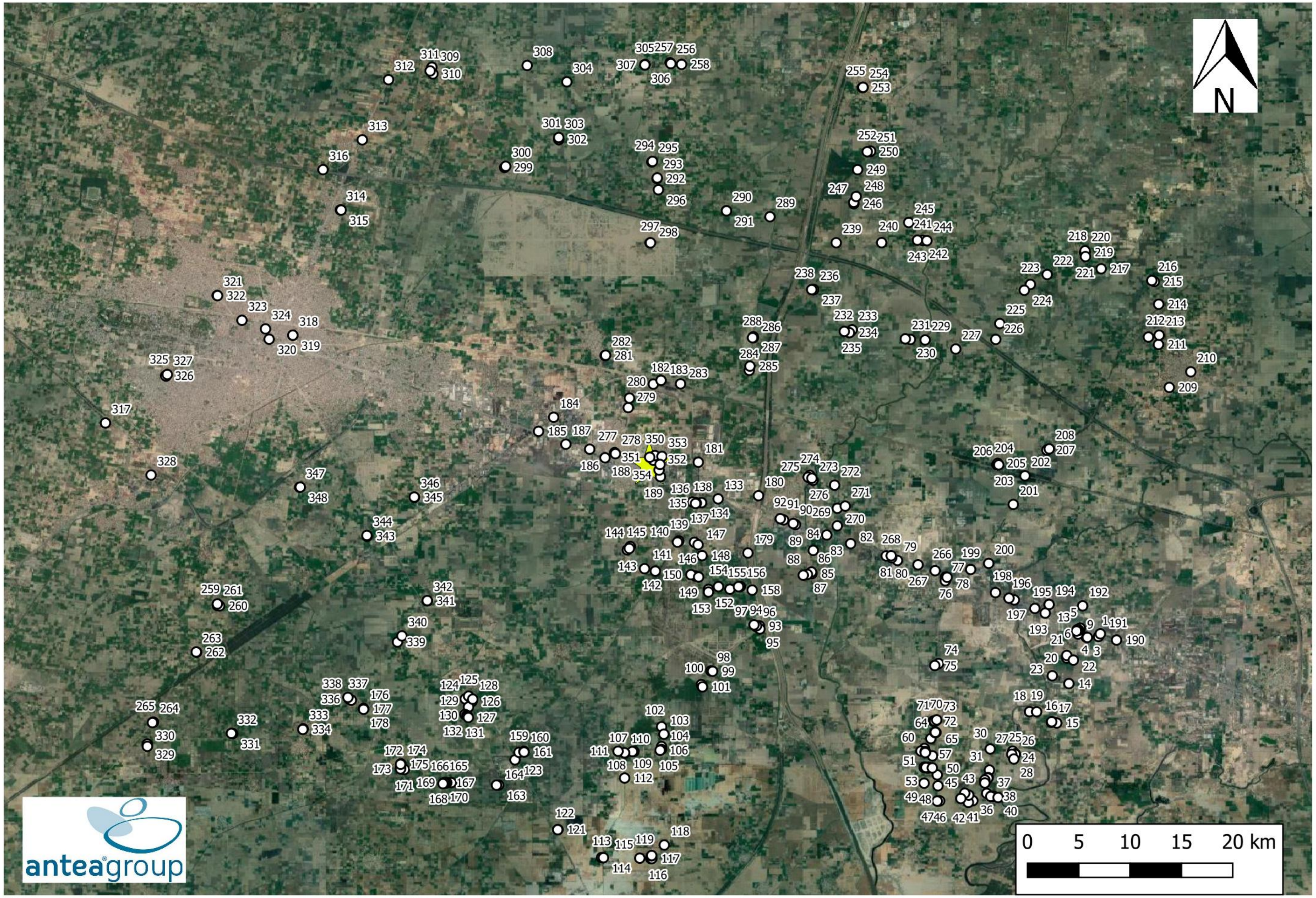


Figure 66 - Well census

7.6 Physico-chemical measurements

Physicochemical parameters were collected from 243 wells during the field survey. TDS values are ranging between 100 and 1,100 ppm. TDS contour map was generated and presented in Figure 67. Areas with higher TDS can be observed, but no obvious spatial distribution pattern can be observed. Higher TDS area could be linked to infiltration of drains or areas with surface contaminations.

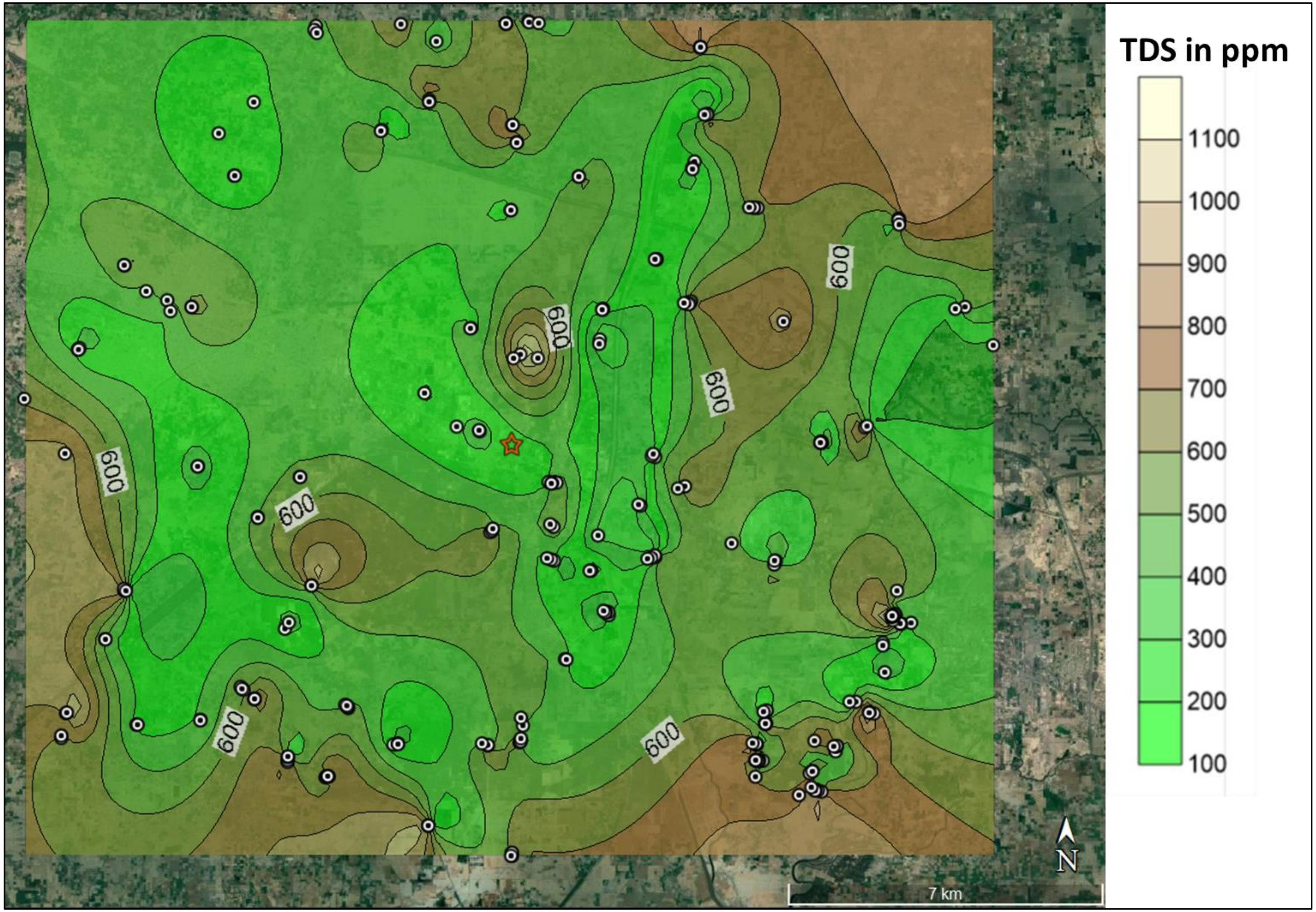


Figure 67 - TDS contour map (ppm) according to collected field data

7.7 Groundwater quality

The onsite wells are regularly sampled by the local staff. NQAC samples are performed and sent to Vittel for detailed analysis. The following parameters were analyzed:

- Macro-chemistry and inorganic;
- Heavy metals;
- Micropollutants;
- Hydrocarbons and PAH.

Main analysis results from the latest analyses (February 2018) are summarized in Table 23 and compared with the WHO guideline (2001). Compared to the guidelines, all parameters are below the thresholds with the exception of the **barium** values for all three wells (up to 214 mg/l compare to 100 mg/l) as well as **arsenic** (up to 40 µg/l compare to 10 µg/l). TDS values are also above the Pakistan guidelines (PSQCA and PFA) that sets the threshold at 500 mg/l. **Nestlé onsite treatment is adequate and efficient for the removal of undesirables in the finished product.** The full results are presented in Appendix 2. The detailed results didn't highlight the presence of microcontaminants. Except for a trace of styrene (VOC) in Well 2, which was recorded just at the detection limit (0.1 µg/l). The contaminant was not recorded in the other wells and could potentially be the results of a cross contamination while sampling. It should be noted that pesticides and fertilisers were not tested in these analyses. It is recommended to do so as the project area is made of large agricultural land and the aquifer is shallow and unconfined.

Parameter	Unit	WHO guideline (2011)	Well 1 (06/02/2018)	Well 2 (06/02/2018)	Well 3 (06/02/2018)
pH			7.77	7.75	7.82
TDS	mg/l	*500**	535	518	511
Conductivity at 25°C	µs/cm		598	580	576
Bicarbonate	mg/l	350	335	325	319
Ammonia	mg/l		0.12	0.16	0.15
Calcium	mg/l	200	42	43	40
Chloride	mg/l	250	18,8	17	17,4
Fluoride	µg/l		121	139	146
Iron	mg/l	0.3	0.05	0.103	0.112
Magnesium	mg/l	150	26,6	24,4	24
Nitrate	mg/l	45	<0.1	<0.1	<0.1
Nitrite	mg/l		<0.005	<0.005	<0.005
Potassium	mg/l		4,17	4,21	3,99
Sodium	mg/l	200	54,31	52,15	57,2
Sulphur as sulphate	mg/l	250	30	28	30

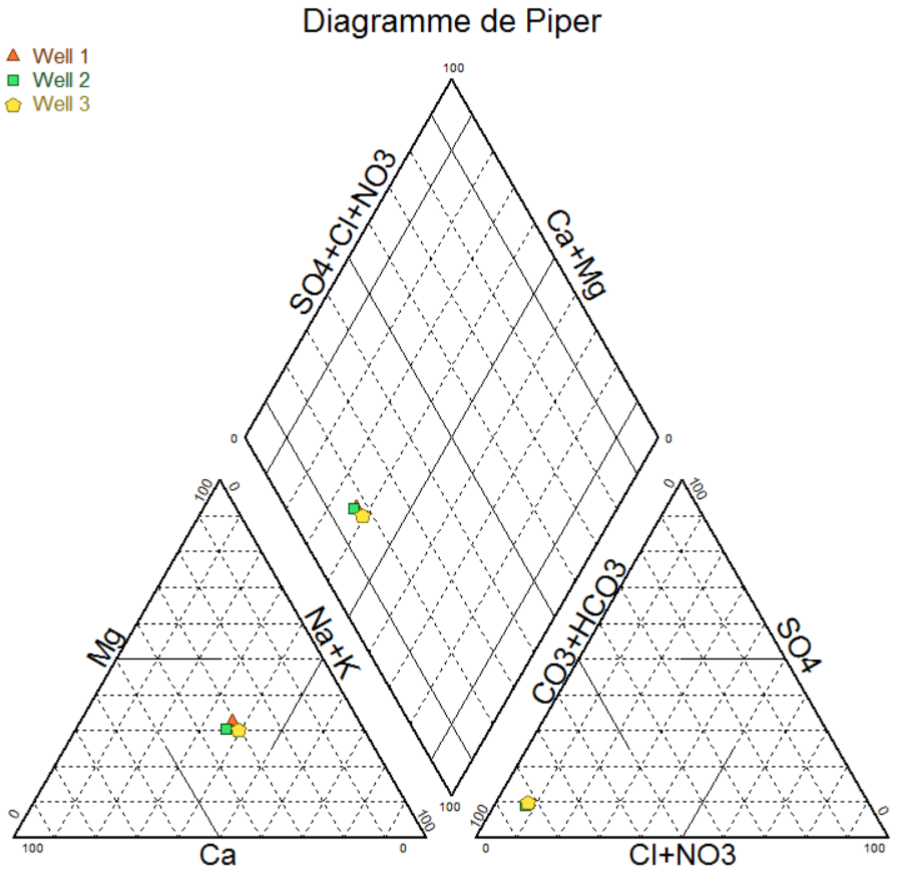
Silicon as Silica	mg/l		22.5	22.6	19.6
Aluminium	µg/l	200	2	1.9	2.2
Antimony	µg/l	5	<1	<1	<1
Arsenic	µg/l	10	**24.2**	**39.9**	**36.3**
Barium	µg/l	100	**213.8**	**196.4**	**189.5**
Boron	µg/l		50	49	49
Cadmium	µg/l	3	<0.25	<0.25	<0.25
Chromium	µg/l	50	<1	<1	<1
Copper	µg/l	1000	<1	<1	<1
Total mercury	µg/l		0.04	0.03	<0.03
Molybdenum	µg/l		<1	2.6	2.5
Nickel	µg/l		<1	<1	<1
Lead	µg/l	10	<1	<1	<1
Lithium	µg/l		7.3	7.2	7
Rubidium	µg/l		1.1	1.1	<1
Selenium	µg/l	10	<0.25	<0.25	<0.25
Silver	µg/l		<0.25	<0.25	<0.25
Vanadium	µg/l		<1	<1	<1
Zinc	µg/l	3000	<3.3	<3.3	<3.3

Table 23 - Water chemistry analysis (NQAC sampling)

**according to PSQCA and PFA standards*

Figure 68 and Figure 69 present the Piper and Schoeller-Berkaloff diagrams for the groundwater samples of each well. As it can be observed from the Piper diagram, the geochemical signature of the groundwater samples is characterised by a strong **bicarbonate geochemical facies**. Regarding the cations, there is no obvious dominance, with the samples being located in the centre of diagram. The geochemical signature of the groundwater abstracted from the three different onsite wells is almost identical.

These water chemistry results reveal that, for the analysed parameters, collected groundwater meets the selected criteria for Bottling Water.



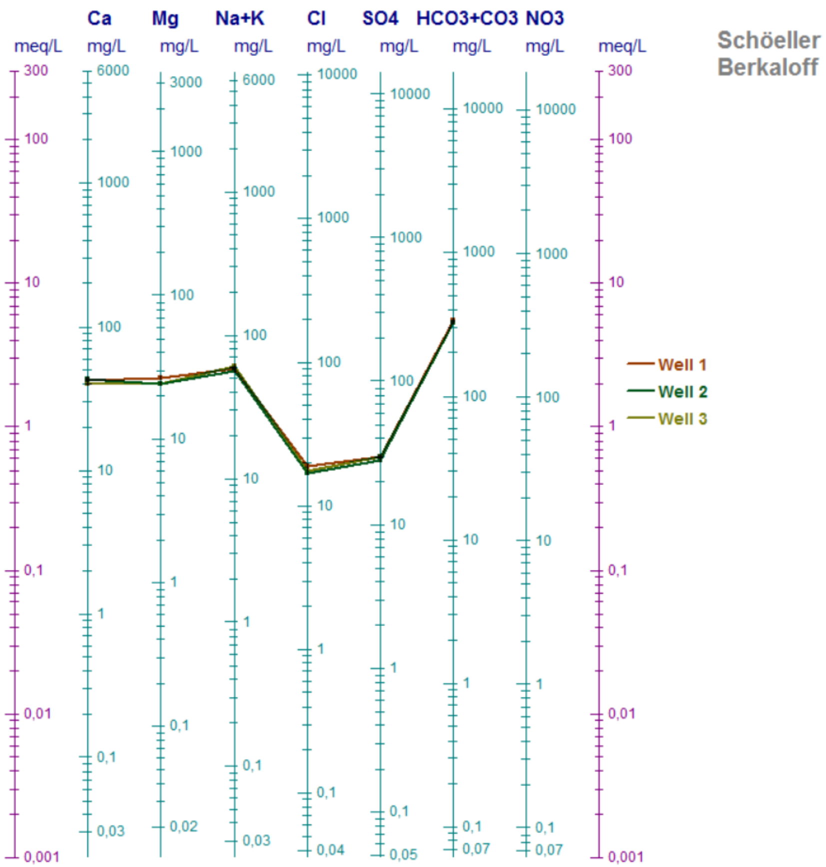


Figure 68 - Schoeller Berkaloff diagram (right)

Figure 69 - Piper diagram (left)

7.8 Identification of competing users

7.8.1 Industries

In the study area, along the Lahore Sheikhupura Road, a large number of industries are located. To fulfill their water requirements these industries are abstracting groundwater from onsite wells. During the field survey, 21 industries were identified in the immediate vicinity of Nestlé factory. Among these, **only 10 industries authorized the site access**. The capacity of these wells is ranging from 25 to 200 m^3/hour with an average depth of 150 meters. According to the collected data, the total abstraction from these wells is 2.35 Mm^3/y. **The largest water consumers didn't allow to collect their information on water consumption.** The list of the 21 visited industries are presented in Appendix 8, highlighting the ones that allowed the access and the ones that didn't.

The total estimated groundwater abstraction in 2018 by the 21 industries in the vicinity of Nestlé factory is estimated by using a ratio rate at 4.9 Mm^3 per year. To account for other industries, the total **abstraction volume for industrial purpose is estimated at 10 Mm^3/year in the immediate vicinity of Nestlé factory.**

7.8.2 Municipal water supply

The town of Sheikhupura is supplied in municipal water by the Tehsil Municipal Administration (TMA). The water is sourced from groundwater. Figure 70 presents the location of the wells. Groundwater abstraction from municipal wells in the 10 km radius around Nestlé factory was estimated at **0.8 Mm^3 per year.** The municipal supply is only supplying the urban area. Outside the city, in more rural area like the project area, potable supply is sourced from individual private wells.

7.8.3 Domestic water supply

In the project area, most of the potable supply is sourced from shallow individual wells, often equipped with hand pumps or small pumps.

The total population (urban and rural) was estimated at about 694,853 inhabitants in the study area (census 2017 with a normal growth rate of 2.1%). In average, it can be considered that a person is using 200 l/day. As most of the households have livestock in the area, an estimate of 220 l/day can be considered. Using this rate (estimate only), the total annual groundwater **abstraction for domestic use is estimated at 55.8 Mm^3 per year.**

7.8.4 Agriculture

The two canals, Upper Chenab Canal (UCC) and Upper Gugera Branch Canal (UGBC) are feeding the Sheikhupura region and are the main source of water for the irrigation. The canals are a main source of groundwater recharge via seepage.

The total agriculture land in the study area is about 250 km^2. About 60 % of the agricultural land is supplied by surface water (estimated at 8.2 Mm^3/year) and the remaining 40 % is sourced from groundwater wells. The groundwater abstraction for **agriculture is estimated at 4.9 Mm^3/year.**

7.8.5 Total abstraction

By adding the estimated abstraction volume from each type of consumers, **the total estimated abstraction volume from the project area is about 70 Mm^3/year. Nestlé factory is abstracting up to 2.5 Mm^3/y, which represents about 3.5% of the total estimated abstraction for the considered area. When looking solely art Nestlé Waters, this represents less than 1 % of the total estimated abstraction for the considered area.**

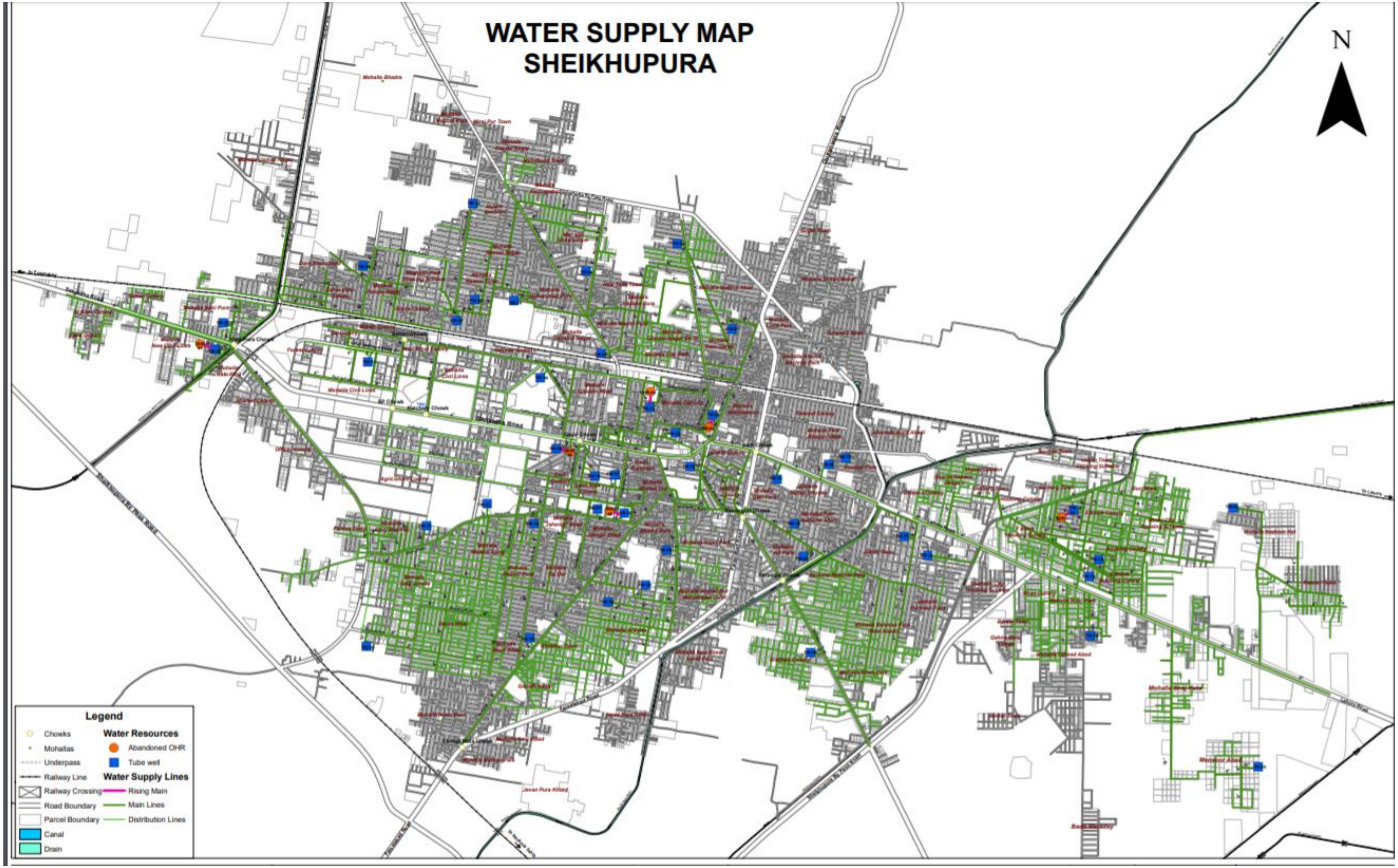


Figure 70 - Sheikhupura water supply map with wells as blue dots (MC Sheikhupura, 2011)

7.9 Identification of potential sources of pollution

A review of the available data and report was performed to assess and identify potential pollution sources. Arial photos were then interpreted to further identify potential contamination sources. A detailed site survey was performed to confirm the desktop study findings and further identify the potential sources. Interviews were conducted with the various land owners (farmers, industrials etc.).

7.9.1 Waste water drains

Large number of waste water drains are presents in the project area, collecting runoff and various type of waste water (domestic, industrials, etc.). The main drains were presented in Figure 17.

7.9.2 Waste water ponds

A total of 47 wastewater ponds were identified in the project area. Figure 71 presents examples of waste water ponds observed during the survey. The locations of all the identified waste water ponds are presented in Figure 77. The full list of identified ponds with coordinates and photos is presented in Appendix 3.

Figure 71 - Examples of waste water ponds

7.9.3 Landfill /dumping sites

A total of 8 landfill and wild dumping sites were identified during the survey and are presented in Figure 78. The full list of identified landfill /dumping sites with coordinates and photos is presented in Appendix 4.


Figure 72 - Examples of landfill/ dumping sites

7.9.4 Industrial waste dumps

During the field survey it was noted that industrial waste was being openly dumped at six different locations adjoining the industrial units (Figure 79). Most of these sites were located along main Lahore-Sargodha road. The full list of identified landfill /dumping sites with coordinates and photos is presented in Appendix 5.

Figure 73 - Example of industrial dump sites (in front of Shaheen Engineering)

7.9.5 Households wastes

The most abundant pollution sources identified in the study area were household waste open dumping sites. Identified household wastes are presented in Figure 80. The full list of identified ponds with coordinates and photos is presented in Appendix 6.

Figure 74 - Example of household wastes

7.9.6 Animal waste dump sites

A total number of 41 animal waste dumping sites were identified during the survey and are presented in Figure 81. The full list of identified ponds with coordinates and photos is presented in Appendix 7.

Figure 75 - Examples of animal waste dump sites

7.9.7 Agriculture

Large agricultural plots are present in the project area. These areas represent potential contamination sources via the seepage of irrigation water with pesticides and fertilisers. Available NQAC results from the onsite wells do not have pesticides and fertilisers results to assess the impact of the agriculture on the local water quality.

Figure 76 - Agricultural land near Nestlé factory

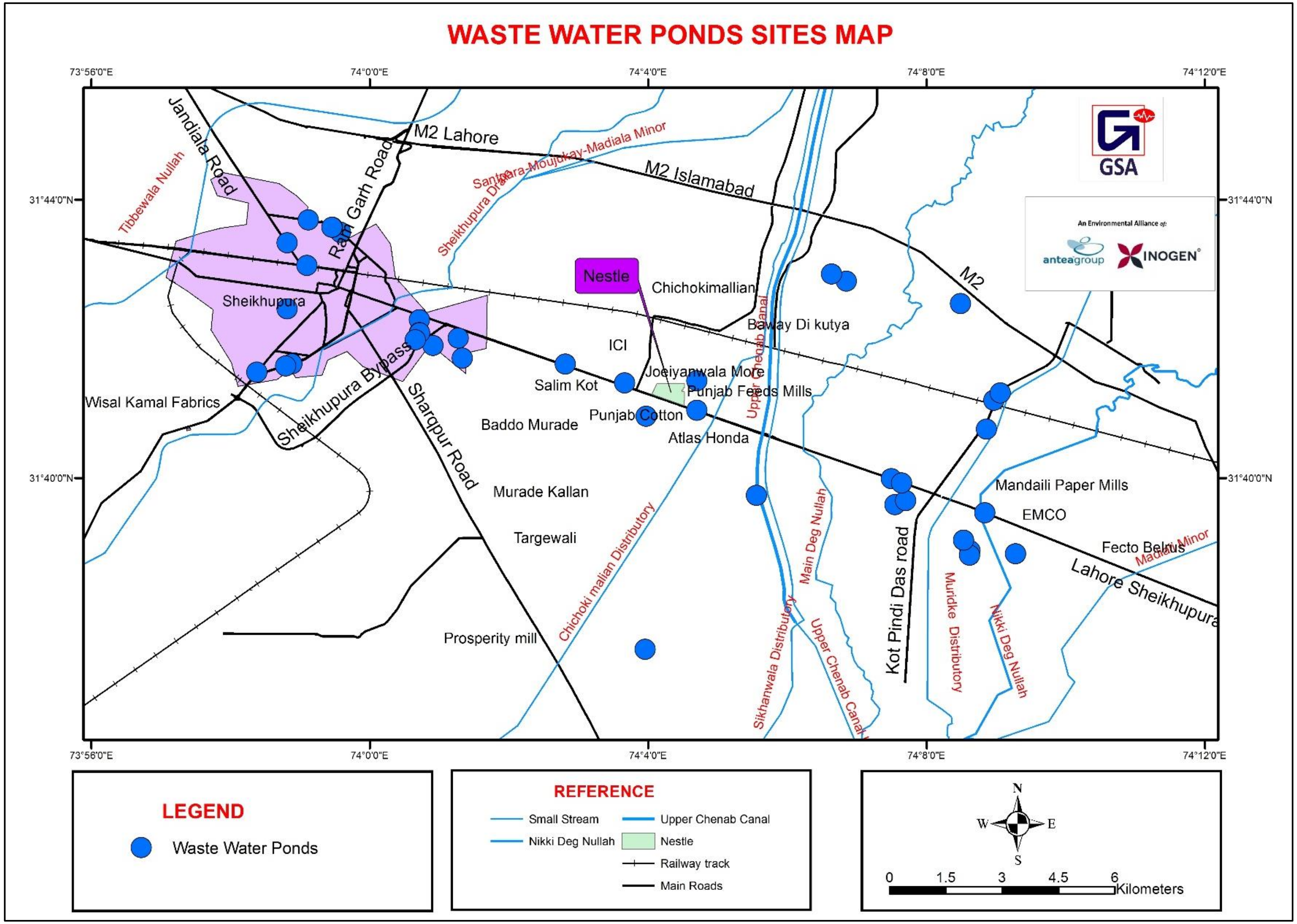


Figure 77 - Waste water ponds (from site survey January 2019)

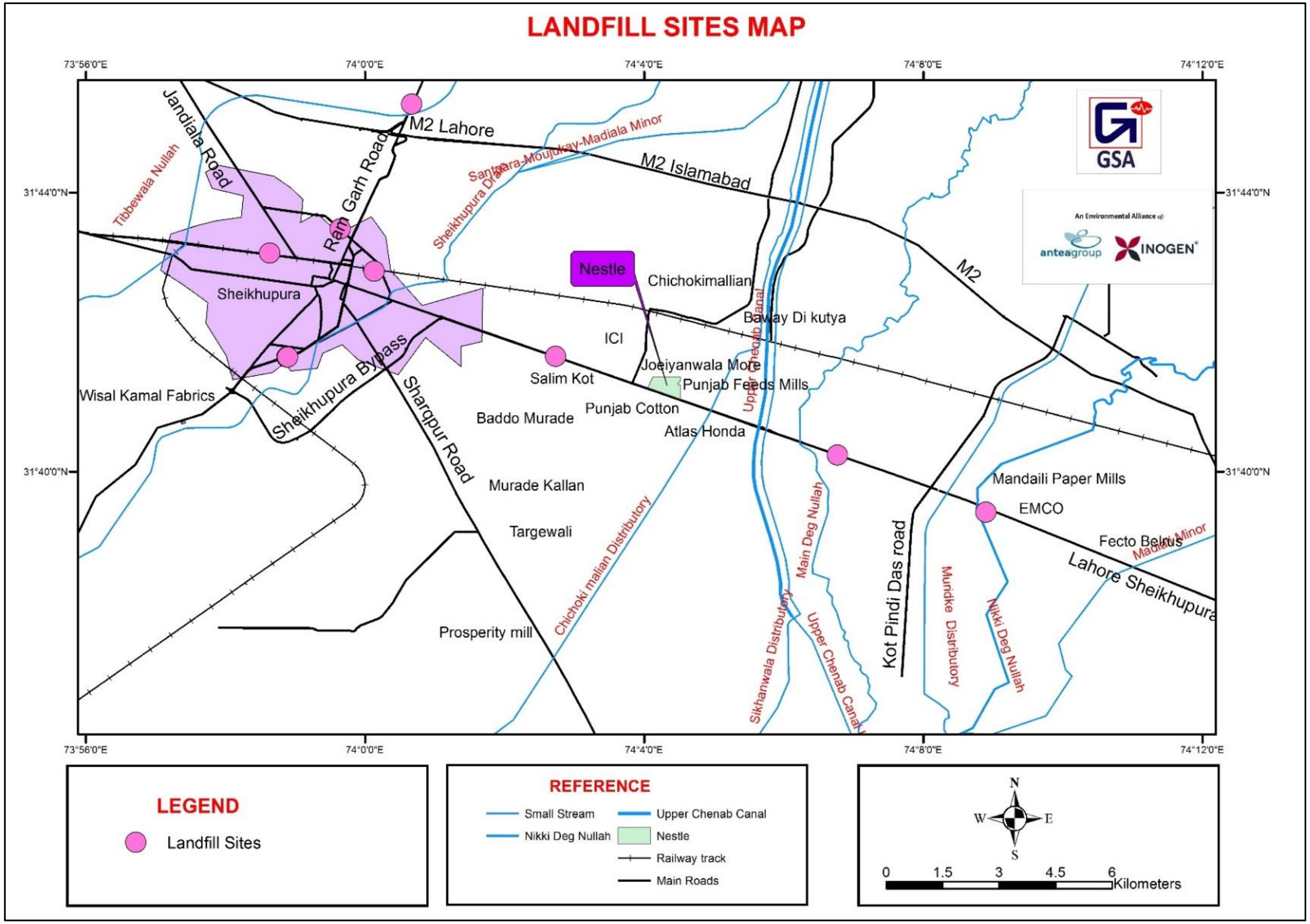


Figure 78 - Landfill sites (from site survey January 2019)

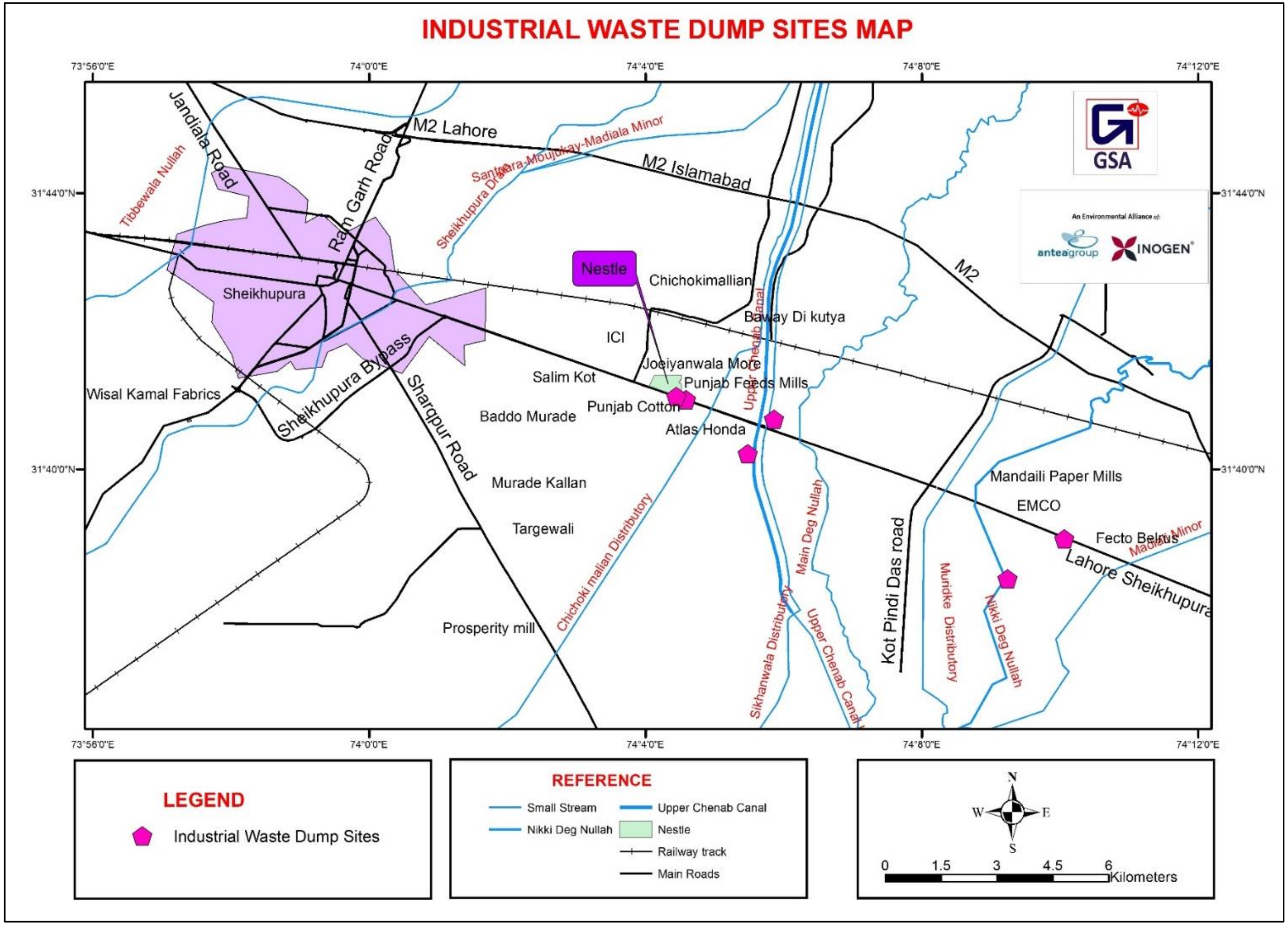


Figure 79 - Industrial waste dump sites (from site survey January 2019)

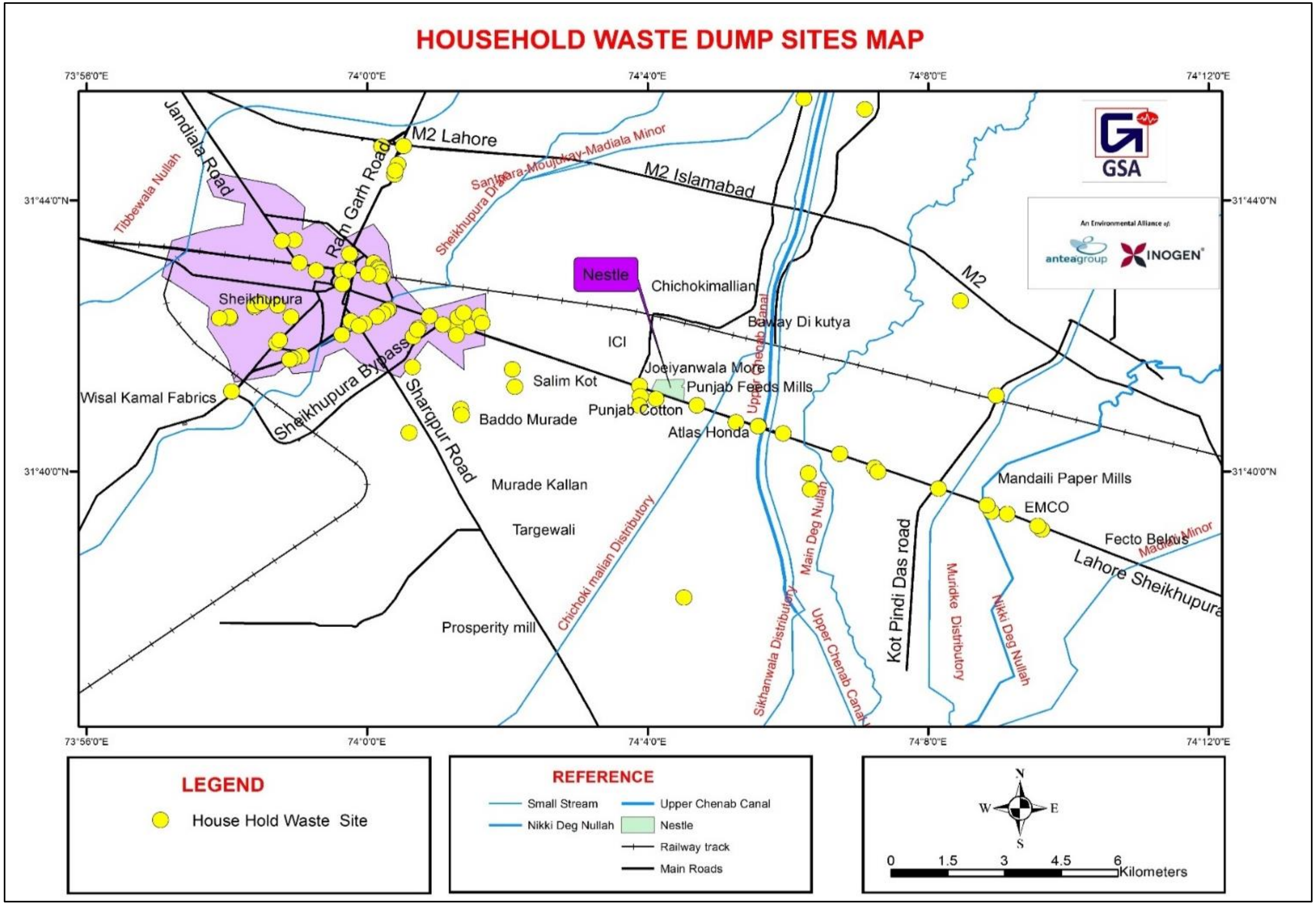


Figure 80 - Households waste dump sites (from site survey January 2019)

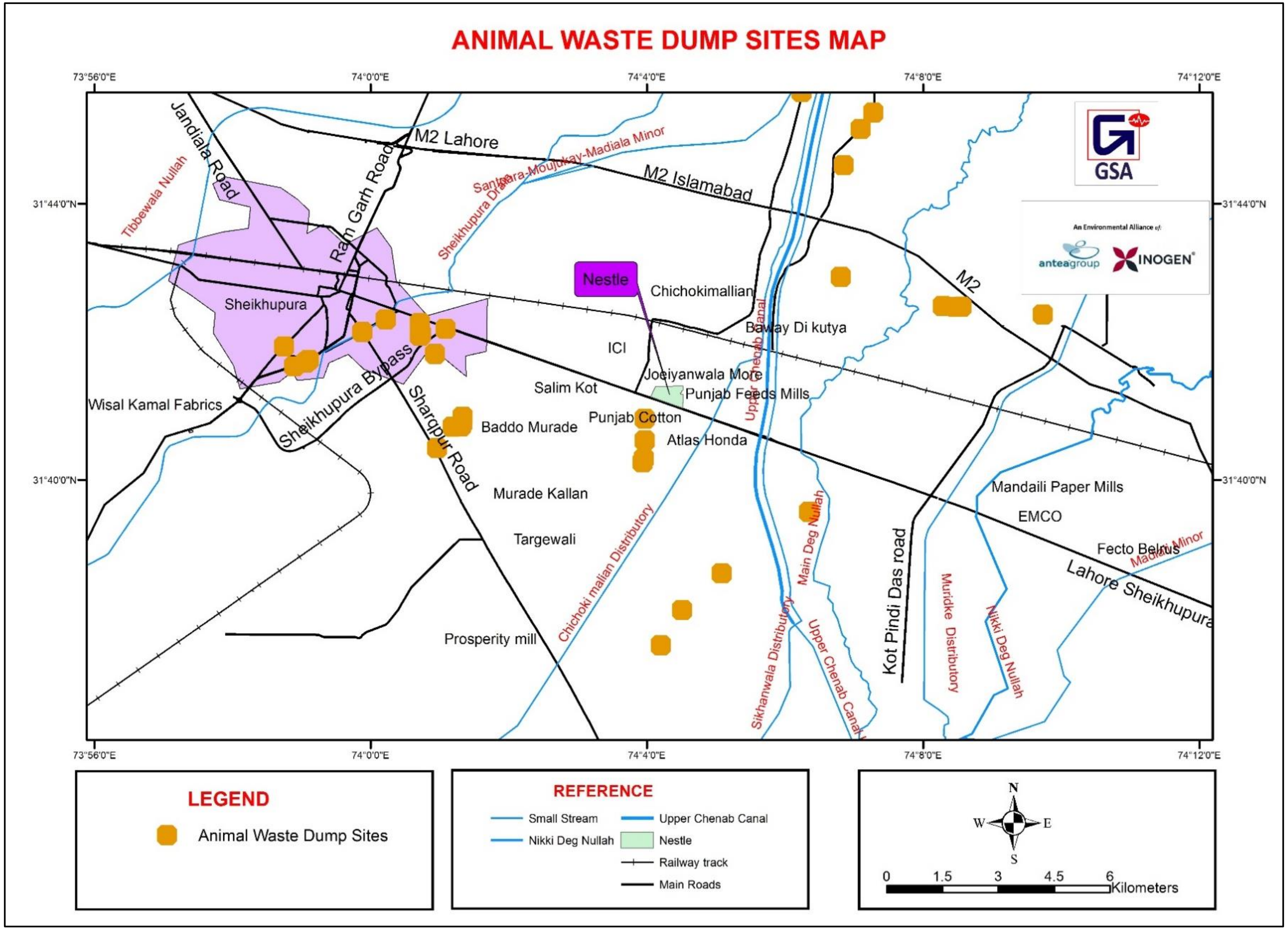


Figure 81 – Animal waste dump sites (from site survey January 2019)

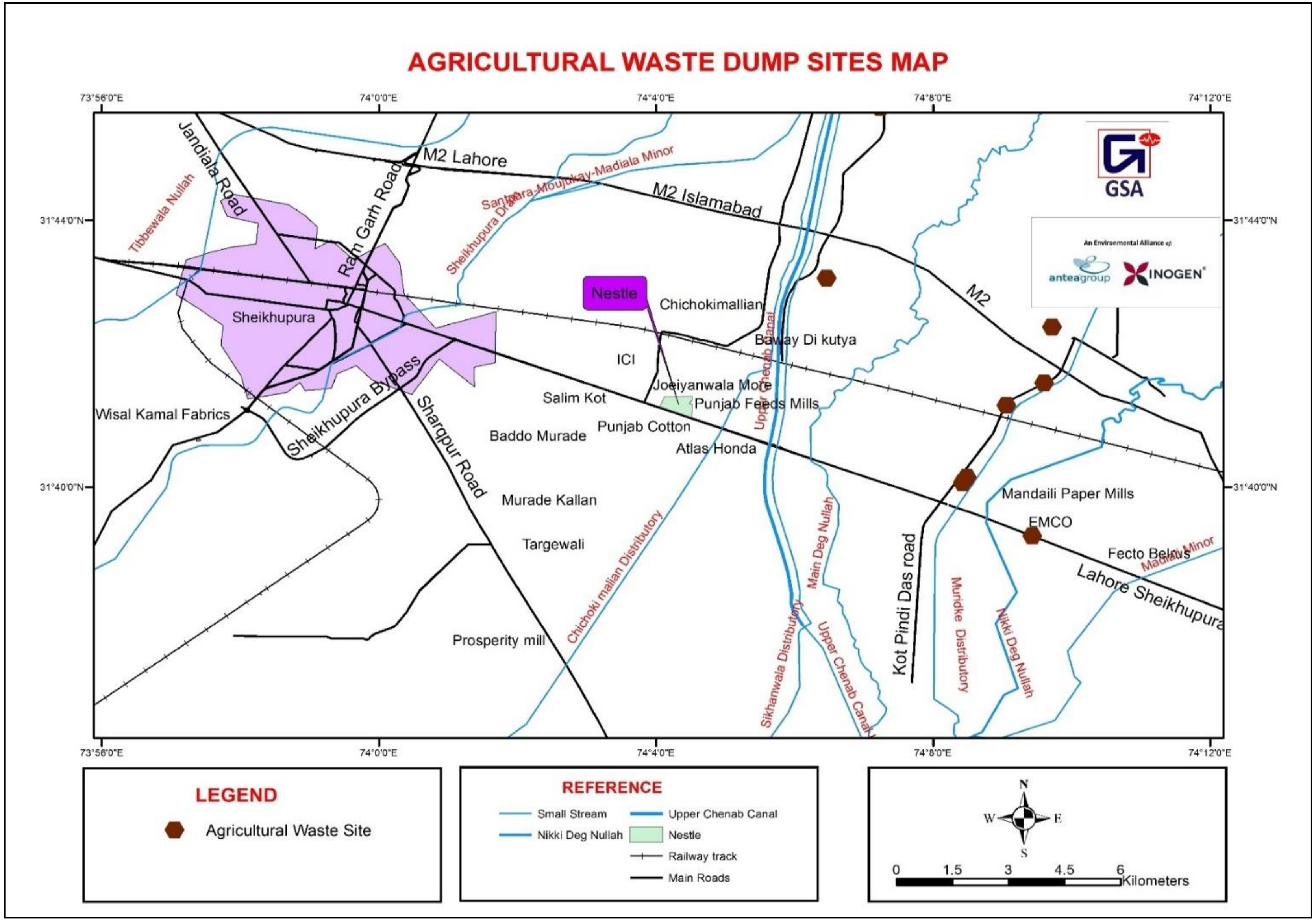


Figure 82 - Agricultural waste dump sites (from site survey January 2019)

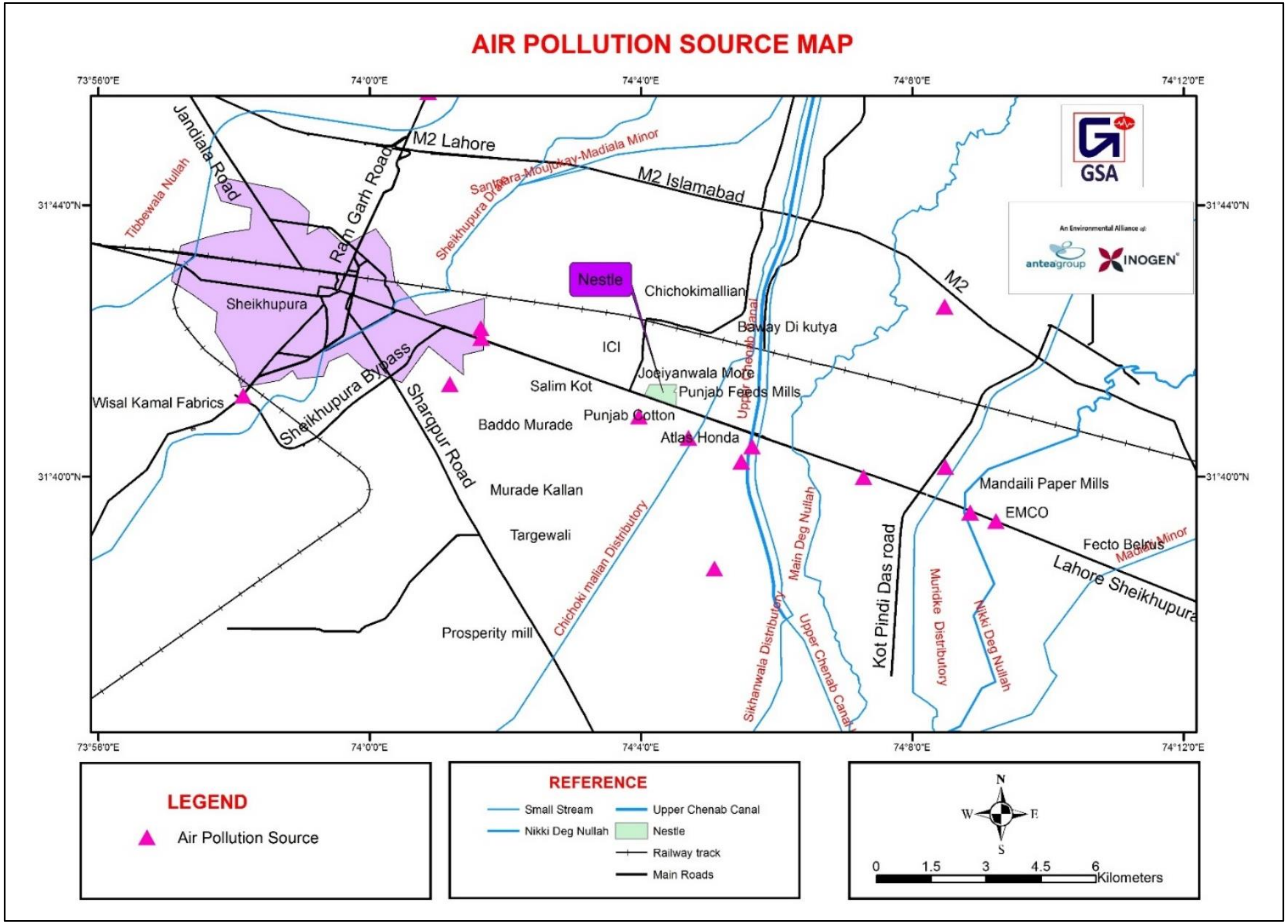


Figure 83 - Air pollution sources (from site survey January 2019)

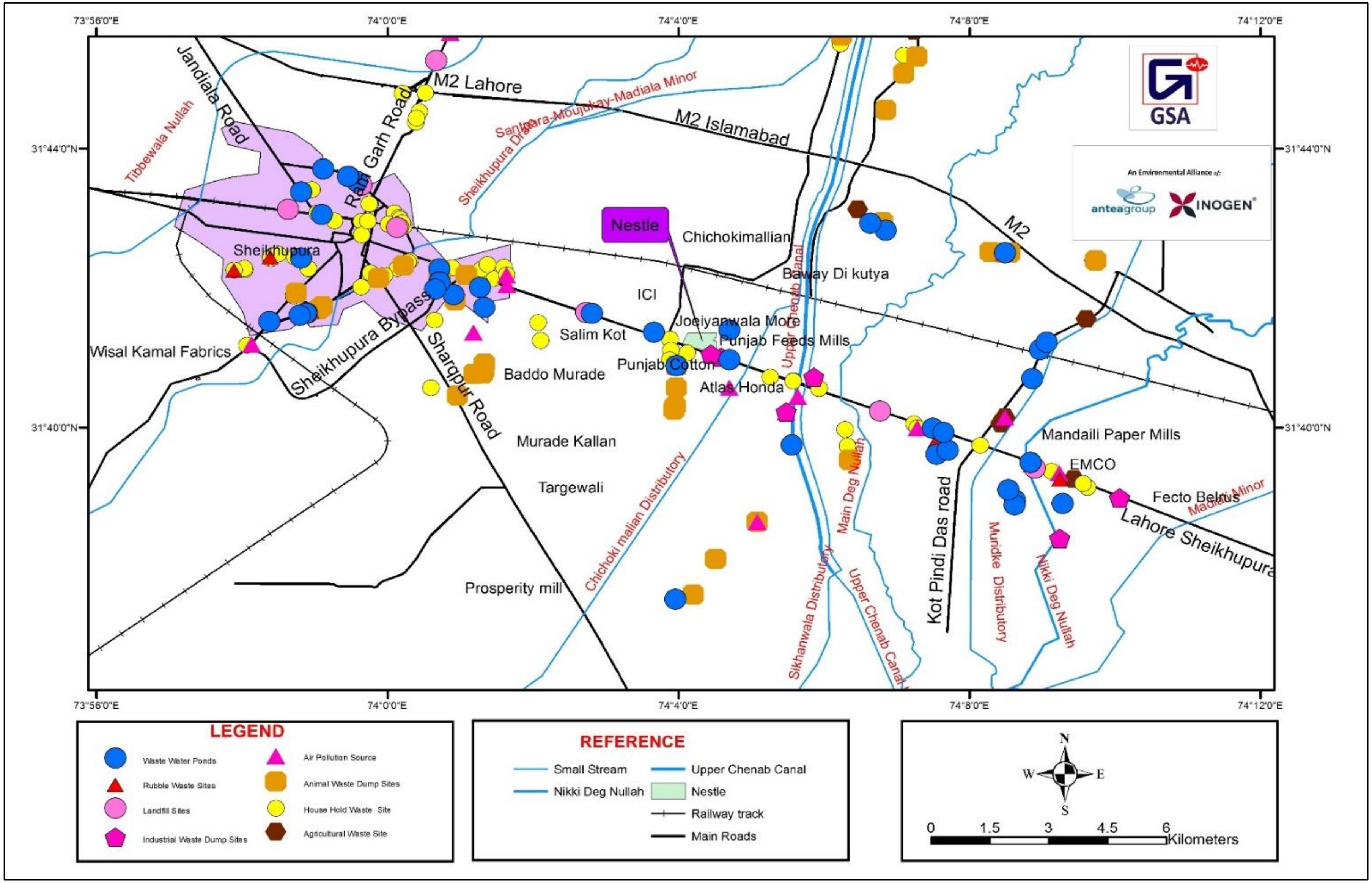


Figure 84 - Potential environemntal hazards map

8 Assessment of the sustainability of the water resource

8.1 Definitions

The assessment of the **sustainability** of the water resource requires a joint approach:

- **a qualitative assessment**: the cross analysis of the following criteria allows the evaluation of the level of pollution risk:
    - evaluation of the intrinsic vulnerability of the aquifer,
    - identification of possible pollution sources, diffuse and punctual, actual and future.
- **a quantitative assessment:** the assessment of the sustainability of the resource is also based on a **detailed watershed water balance**. Actual consumption and future needing (scenario) are to be also integrated.

INTRINSIC VULNERABILITY OF THE AQUIFER

The **vulnerability** of an aquifer defines its sensitivity with regards to the transfer of anthropic pollutions. It translates the possibility that a pollutant has, under natural runoff conditions, to percolate from the surface to the water table, in a first step, then possibly towards an identified target (water well, spring, river, etc.).

The criteria which condition this are as follows:

- in the ***unsaturated zone***: the ease and the speed with which superficial pollutants can reach groundwater and degrade its quality. These depend on the morphology of the surface (and more specifically the slopes), the presence of vegetation, the characteristics of possible overburden formations, and finally the permeability and the thickness of soils;
- in the ***saturated zone***: the nature of the aquifer and its hydrodynamic conditions which will more or less favor natural self-purification (aquifer recharge, turnover time, types of runoff, permeability, exchanges with wetlands or neighbouring aquifers, etc.).

The assessment of the pollution risks for mineral water resources is particular, as it has to consider **the whole geological system**, from the recharge area until the source (in case of natural emergence), and/or the abstracting site.

8.2 Qualitative assessment

The intrinsic vulnerability is high for the porous alluvial aquifer. The unconfined aquifer could be exposed to potential pollutant substances that could infiltrate through the unsaturated zone as there is a no capping clay cover and the water level is shallow (about 10 mbgl). Several potential contamination sources are present in the project area (waste dumps, waste water, industries, agriculture etc.) and can be threats to the water quality.

The risk of contamination to the local aquifer is considered as high.

8.3 Quantitative assessment

8.3.1 Conceptual Model

A conceptual model of an aquifer system is a simplified, qualitative description of the physical system. A conceptual model normally includes a description of aquifers and any confining units that make up the aquifer system, boundary conditions, flow regimes, sources of water and general direction of groundwater flow.

Many of the features relevant to the conceptual model regarding the study have been discussed in previous sections.

The project is located in the Punjab alluvial plain with an **unconfined aquifer in the alluvial sands and complex sediments**. The sediments comprise of **fine to coarse sand with lenses of silty clay and clay**. Borehole logs show that the lenses of less permeable material are neither thick nor continuous. Despite the heterogeneous composition, the aquifer is **highly transmissive** and unconfined. Hydraulic conductivity varies between 20 to 40 meters per day. Groundwater velocity was estimated at about 1 to 1.5 m/day (Muhammad et al., 2015). Very little information is available on the underlying tertiary sediments.

The main **groundwater flow direction is following the surface drainage**, with a general direction **from the north-east to the south-west**. Water levels in the aquifer are shallow, ranging in average between 5 and 12 meters below ground level. A decreasing trend in the groundwater level can be observed in the project area. Particularly, a cone of depression can be observed near Kharianwala (13 km to the south-west of Nestlé factory). The increase of this cone of depression can be observed over the years. Abstraction from the industrial area of Nestlé factory is likely contributing to this cone of depression.

Groundwater recharge from the rainfall is limited. The **main groundwater recharge mechanism is from the surface water**. The recharge rate from Ravi river to the underlying unconfined aquifer vary between 0.18 mm/day and 0.5 mm/d according to available literature data (Muhammad et al., 2015). In addition to the Ravi River, large canals such as the **Upper Chenab Canal as wells as the irrigation /drainage network are providing an important source of recharge via direct seepage**. Seepage from agricultural land is also a large source of recharge to the underlying aquifer. Since the Indus Water Treaty in 1960, lower recharge is occurring to the local aquifer linked to the reducing of flow in the River Ravi. Furthermore, **groundwater became in the project area the main water source for potable and industrial usage.**

At a very large scale, recharge from the snow and glacier of the mountain area is also occurring. As For the purpose of this study, only the Indus plain area was considered. The recharging area could be considered as the whole alluvial fill of the basin, up to the mountain area about 100 km upgradient (Figure 85). **It can be considered as the groundwater watershed boundary.** Performing a water balance calculation on such an area (> 2,000 km²) wouldn't be reasonable nor accurate, the calculations will be focused on what is considered as the area of influence of Nestlé wells (Figure 86). **The area of influence is defined as the area where Nestlé wells have an influence by pumping**. It can be seen as the zone of contribution, where a groundwater drop will be attracted by the pumping effect. This area of influence was estimated at best but accurate hydrodynamic parameters are not available to definite its exactly its geometry.

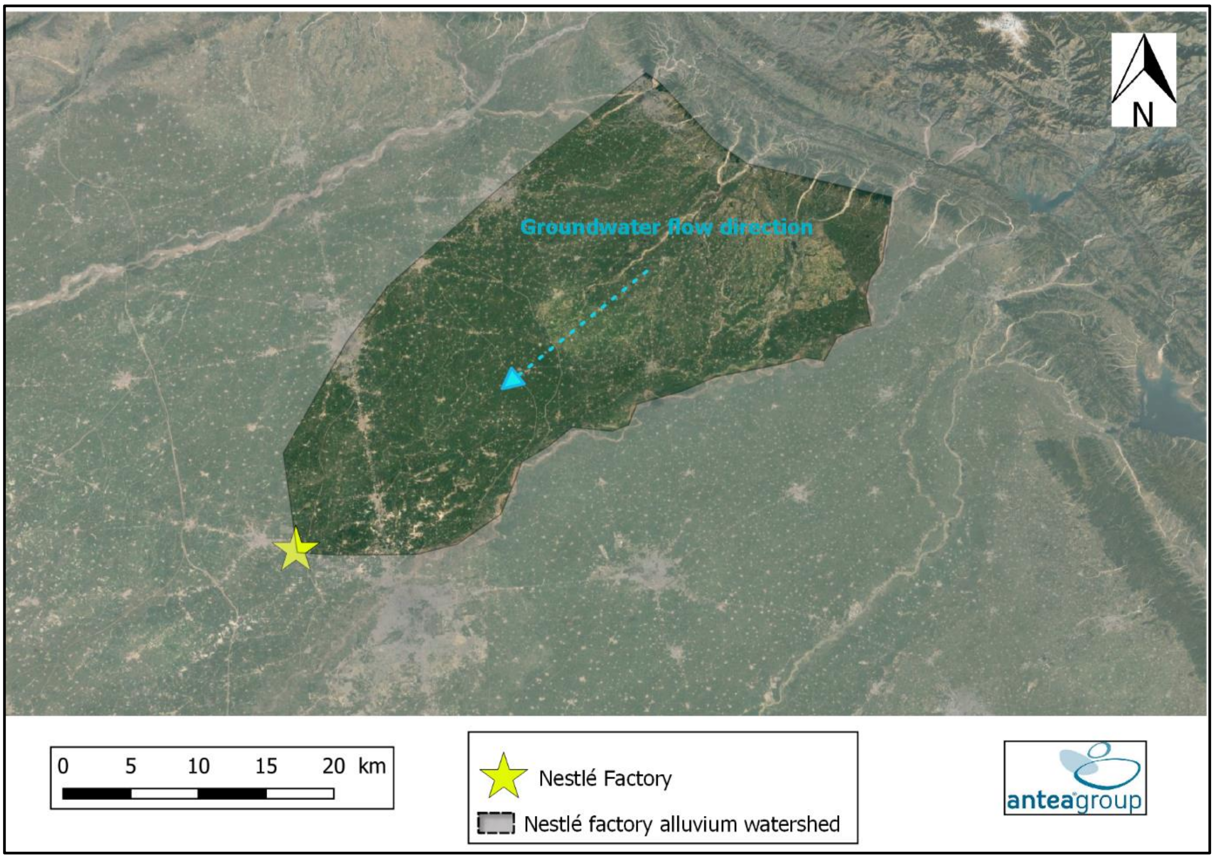


Figure 85 - Sheikhupura factory alluvium watershed area

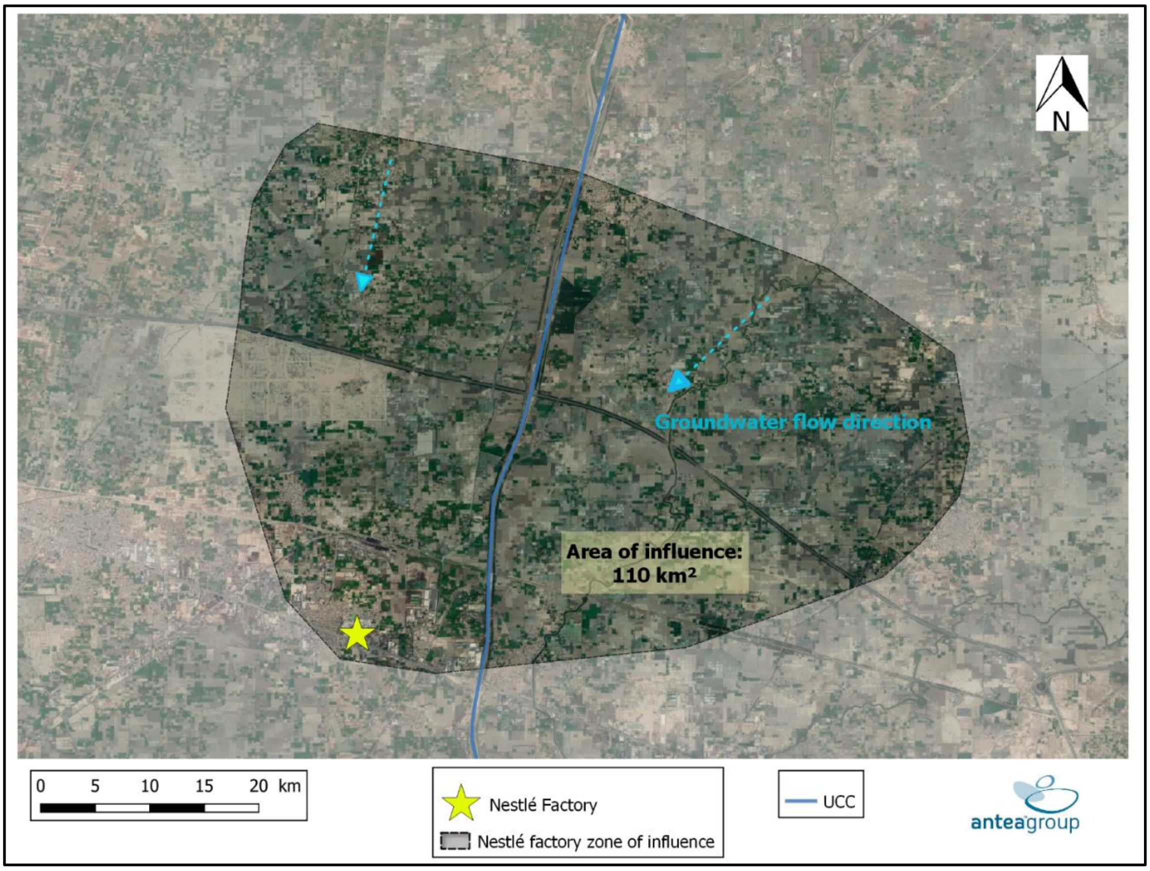


Figure 86 - Considered area of influence for the water balance calculations

8.3.2 Groundwater Balance

In order to calculate an estimated Watershed Water Balance, the available regional water related data had been used (average rainfall and evapotranspiration between 2007 and 2016 in the study area).

A Thornthwaite water-balance-model was run and an estimation of the total available groundwater had been calculated. However, **it must be highlighted that simplification and extrapolation were necessary for some parameters. Therefore, the final result must be seen as an approximate figure, rather than a precise calculation**.

The area of influence considered for the water balance has been defined in the previous section and extent over an area of 110 km². The area of influence is considered for the estimation of the rainfall recharge of the aquifer. In addition to this, an estimation of the recharge via seepage from the surface water will be taken into account in the water balance.

Precipitation

Data between 2007 and 2016 show an annual average precipitation of 692 mm. This gives a **total average annual renewable water volume of 77 Mm^3,** for the considered area of influence.

Potential and Actual Evapotranspiration

Available data between 2013 and 2017 show an annual average potential evaporation of 1414 mm. The total annual potential evapotranspiration for the recharge area is 156 Mm^3 per year. The **actual evaporation** calculated from the water balance computation (see below) shows an actual evaporation of 595 mm which represent **65 Mm3 per year** for the recharge area.

Surface water

Surface water infiltration (rivers, canals, irrigation etc.) is a large component of the groundwater recharge in the project area. Several studies are available regarding the infiltration rate of the different surface water features in the region. In the considered influence zone of Nestlé wells, the main surface water feature that is playing a key role in the aquifer recharge is the Upper Chenab Canal (UCC), over a length of 10 km. The average width of the UCC is about 65 meters. In addition, smaller canals, rivers and drains are also seeping to the underlying shallow unconfined aquifer. River Ravi is too far from the considered recharge area to have a direct impact.

According to the Punjab Irrigation Department, the seepage from the UCC was estimated at 77 Mm^3/year in the Sheikhupura region. The length of the UCC in the Sheikhupura region is about 50 km. Considering the 10 km of UCC crossing the area of influence of Nestlé well, the **estimated seepage from the UCC infiltration is 15 Mm^3 per year.**

The seepage from agricultural land and associated small canals was estimated at 88 Mm^3/y in the Sheikhupura region according the Punjab Irrigation Department. According to the surface of the area of influence, it is estimated that **2 Mm^3 per year** are infiltrating to groundwater from the various different canals and agricultural land.

In total, over the 110 km² of the considered area of influence, **it is estimated according to the available data that 17 Mm^3 per year of surface water are recharging the aquifer.**

Groundwater abstraction

Groundwater users were described in section 7.8. The total estimated abstraction volume from the field survey area (10 km radius around Nestlé factory) was estimated at about 70 Mm^3/year. By considering the area of influence, **the estimated abstraction volume is 23 Mm^3/year.** These abstraction rates are estimated best on the field survey but could be overestimated or underestimated.

Water balance

Multi-year average meteorological data from 2007 to 2016 have been used to run a Thornthwaite water-balance model. **The mean rainfall recharge value for the aquifer is 63 mm/m²/yr which amounts to 7 Mm^3/yr in the considered aquifer recharge area.** This recharge value considers only the infiltration from the efficient rainfall.

The distribution of the recharge from rainfall across the different years is not uniform as well as during the different months of the year (Figure 87 and Figure 88). Rainfall recharge occurs between July and September, due to the fact that rainfall is higher and evapotranspiration is lower within this period. Between October and June, there is theoretically no rainfall recharge because of high evapotranspiration.

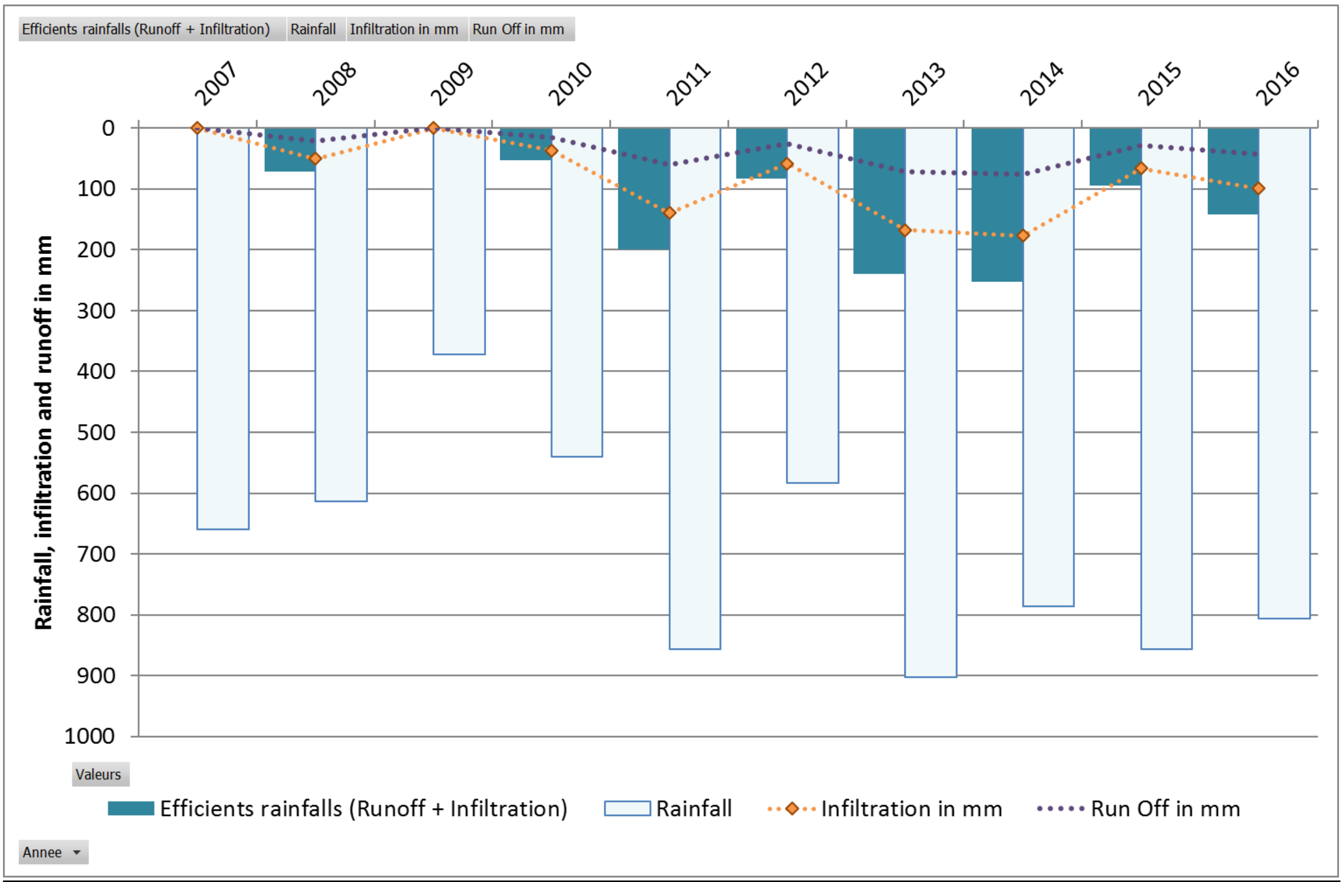


Figure 87 - Annual distribution of rainfall, efficient rainfall (rainfall minus evapotranspiration), runoff and rainfall recharge in the study area (multi-year average data between 2007 and 2016)

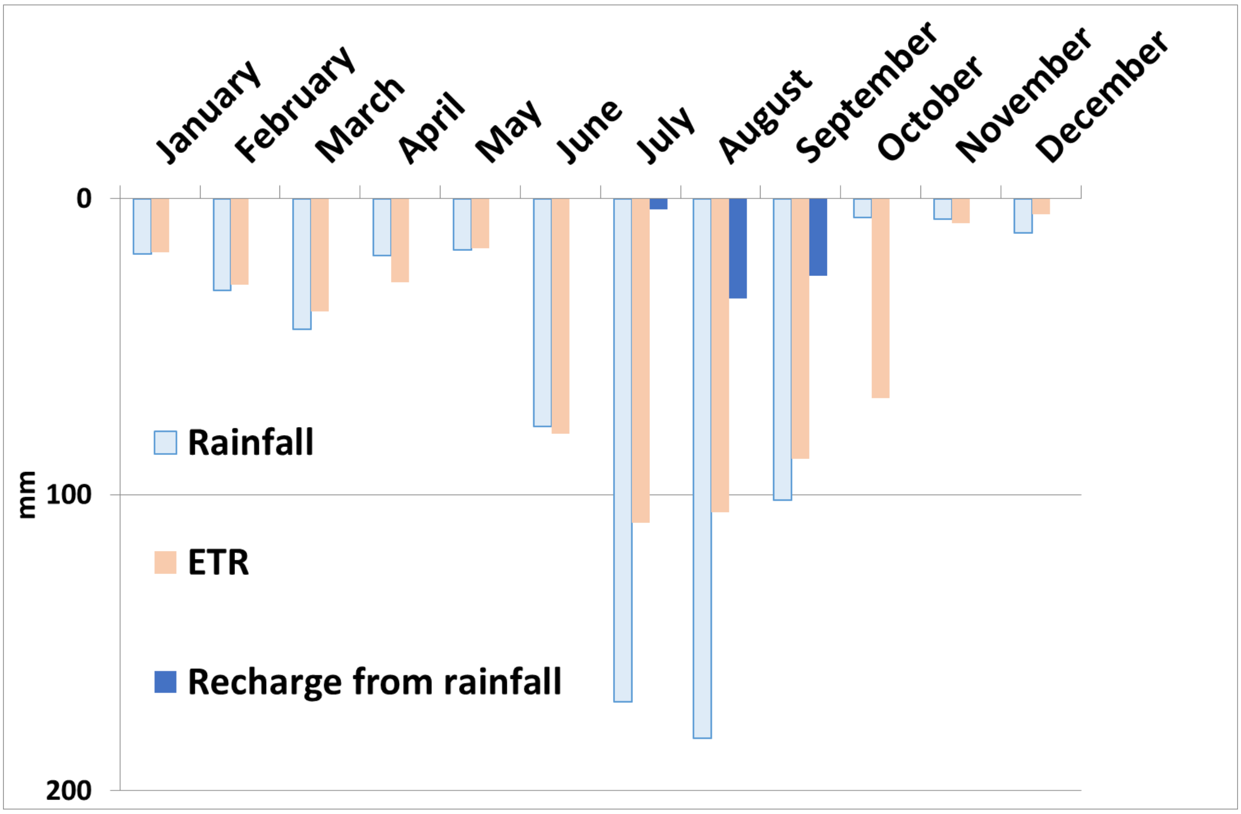


Figure 88 - Monthly distribution of rainfall, actual evapotranspiration (ETR) and recharge from rainfall (infiltration) in the study area (average data between 2007 and 2016)

The water budget in the local watershed can be calculated as follows:

$$\Delta S = R - C$$

Where:

R = Recharge
C = Groundwater abstraction
ΔS = Change in water storage in the watershed

Nestlé wells area of influence (110 km²)			
Water Budget	Current scenario	Sensibility test (+/- 5 %)	Future scenario: -10 % of recharge due to climate change and +20 % increase of abstraction
	Mm^3/year	Mm^3/year	Mm^3/year
Rainfall recharge to aquifer	+7	+ 6.7 to 7.4	+6.3
Surface water infiltration to aquifer (including UCC and smaller canals for irrigation)	+17	+ 16.2 to 17.9	+15.3
Groundwater abstraction from recharge area (including 2.5 Mm^3/year from Nestlé)	-23	21.9 to 24.2	-27.6
% of abstraction compare to total recharge	96 %	87 % to 106 %	130 %
ΔS CHANGE IN STORAGE (GW outflow)	+ 1	-1.3 to + 3.4	- 6

Table 24 - Water balance results

Considering all hypothesis and limitations, it can be considered that the **annual water balance is around zero** (current scenario barely positive). The sensitivity test (+/- 5 % on the recharge and the abstraction to account for uncertainties linked to estimations) shows that the water balance results is oscillating around zero, **with the percentage of total abstraction compare to the total recharge ranging between 87 % and 106 %.** When the abstraction is greater than the recharge, it means that the aquifer is being over abstracted, and the water stress is deemed as very high. It should be reminded that the water balance is made on the recharge entering the system and not the existing reserve. When the abstraction is higher than the recharge, the **deficit is covered at the expense of groundwater storage** causing groundwater level drop. When the yearly recharge cannot cover the abstraction, withdrawing is using groundwater storage year after year, inducing a depletion of the resource over time.

When looking solely at Nestlé Factory abstraction (up to 2.5 Mm^3/y), this represents about 3.5 % of the total estimate abstraction in the project area (70 Mm3) and 11 % of the abstraction in the considered area of influence. Nestlé abstraction represents 10 % of the total recharge in the considered area of influence.

A future water balance scenario was run taken into account a decrease of 10 % of the recharge (rainfall and river) due to climate change and an increase of 20 % of the abstraction volume to population growth and industrial development. **These types of scenarios are arbitrary and aim at taking into account potential worsening conditions in the future. They do not reflect the current situation.** A decrease of 10 % in the precipitation and an increase of 20 % of the abstraction is a common scenario taken in water balance exercises. It can be seen as a bad case scenario. With this scenario, the water balance appears negative, and the total abstraction represents 130 % of the recharge.

According to the results, in the current situation, the water balance appears to be oscillating around zero, meaning that the amount of total recharge would be equivalent to the amount of abstraction volume. With the level of uncertainties, it is not possible to determine if the result is slightly positive or negative. However, when comparing with the water levels trend in the project area, showing a slight decreasing trend with the presence of a depression cone, the water balance results do confirm that the pressure applied on the available groundwater resources in the area is very high and over-abstraction is likely occurring, threatening the sustainability of the resource. Further groundwater monitoring is paramount to follow the groundwater level trends.

It should be reminded that these calculations are based on several assumptions and hypothesis and do not represent exact figures. The final result must be seen as an approximate figure to understand the water balance situation of the considered zone.

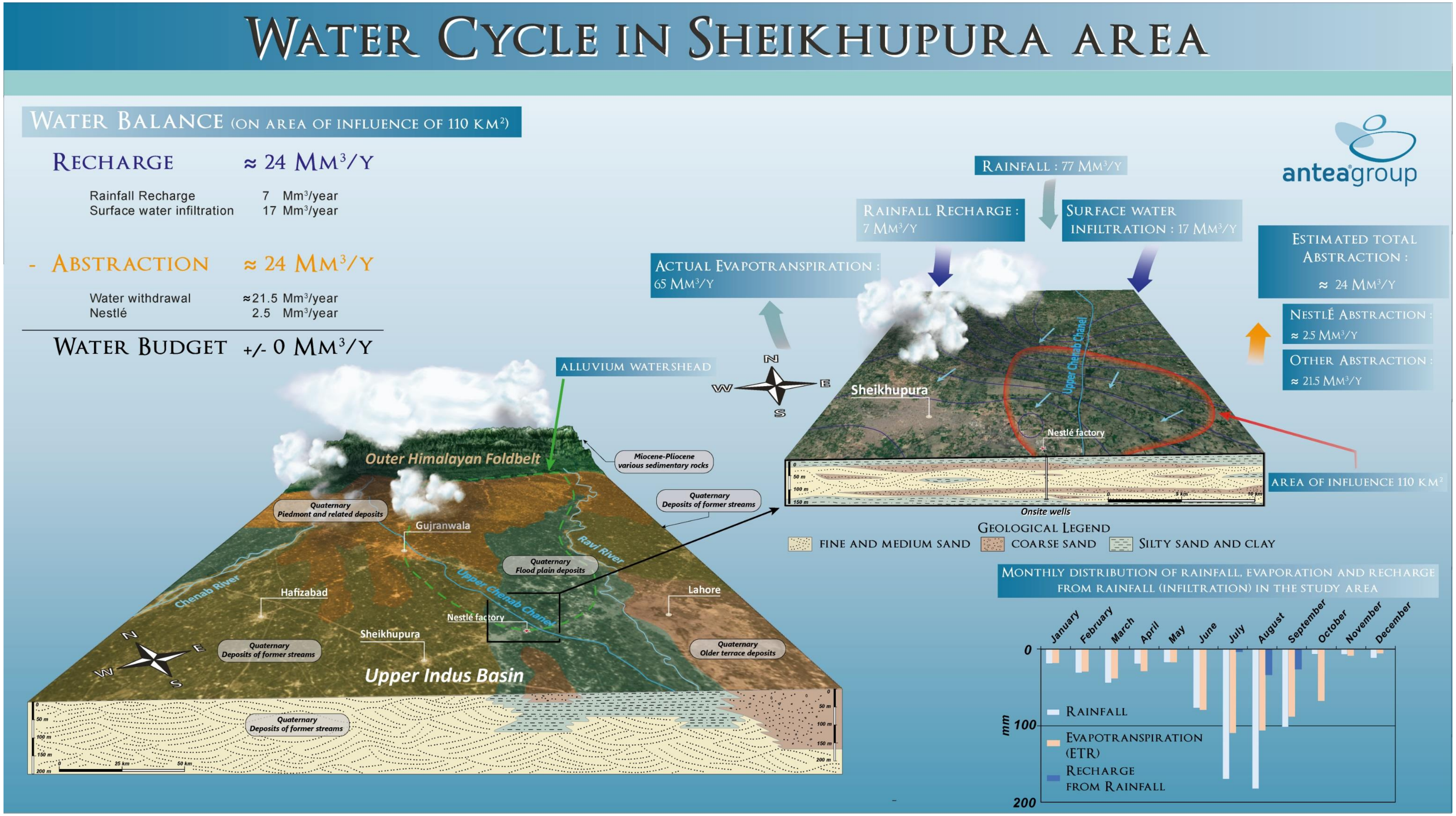


Figure 89 - 3D Bloc diagram with water balance calculations

9 Alliance for Water Stewardship (AWS)

Nestlé Sheikhupura was the first Nestlé factory to be certified AWS (Alliance for Water Stewardship) worldwide. During the journey to accreditation, the following steps were implemented:

1. Detailed Interviews with Stakeholders i.e. local population, local industries, local authorities regarding shared water challenges.
2. Identification & execution of action plan against shared water challenges identified with key stakeholders

    a) Implementation of cow water recovery (recovering water form milk) in Sheikhupura factory resulting in estimated saving of 93.5 Mio liter of water annually;
    b) Implementation of 3 filtration plants around Sheikhupura factory to provide safe drinking water to more than 30,000 people;
    c) Implementation of project WET to educate almost 26,000 children & 90 teachers on how to use water with responsibility;
    d) Implementation of drip irrigation in dairy farms resulting in estimated saving of 96 Mio liter of water annually.

3. Implementation of WASH (Water, Sanitation and Hygiene) at Sheikhupura factory; and
4. Training & knowledge sharing with stakeholders including industries, local population & farmers.

10 Conclusions and Recommendations

10.1 Findings

Sheikhupura is located in the Indus Plain that is drained by a number of tributary rivers to the Indus River that flows in a south-westerly direction towards the Indian Ocean. The project lies in the upper part of the Upper Rechna Doab, the area between the River Ravi and the River Chenab.

Pakistan has one of the largest irrigation systems of the world. After Independence in 1947, problems between India and Pakistan arose over the distribution of water. Rivers in Pakistan's Punjab Province originate in India. To solve this water distribution dispute, a treaty brokered by the World Bank known as the Indus Water Treaty, was signed by the two countries in 1960. The Indus Water Treaty gave India exclusive rights to the eastern rivers Ravi, Beas and Sutlej. The supply of surface water from these rivers, and from the Upper Bari Doab Canal to the Bari Doab (and Lahore) was stopped over time. This changed surface water distribution induced a **lower recharge to the underlying aquifers** in the eastern part of the province, as the main recharge was occurring from seepage of rivers and associated irrigation canals. Furthermore, **groundwater became in these areas (including the project area) the main water source.** In order to relieve the shortage created by the lower flow in the eastern rivers Sutlej, Beas and Ravi, link canals were constructed to transfer the surplus water available in western rivers (Chenab, Jhelum, and Indus) to the eastern rivers.

The **factory is located in Quaternary alluvium deposits** (**alluvial flood plain**), overlying semi-consolidated Tertiary rocks or Precambrian rocks (metamorphic and igneous). The upper 200 meter of the alluvium consists of fine to medium sand, silt, and silty clay.

Sheikhupura lies in an alluvial aquifer in the upper part of the Upper Rechna Doab, the area between the River Ravi and the River Chenab. The project area is drained by these rivers and associated surface water network. The aquifer in the whole area of the Indus Plains is considered as one large unconfined and interconnected aquifer. The alluvial plain of the Punjab is an **unconfined aquifer with alluvial sands and complex sediments**. Despite the heterogeneous composition, **the aquifer is highly transmissive and unconfined**.

Nestlé factory is supplied by three wells, named Well 1, Well 2 and Well 3. The factory is also equipped with three tubewells, called locally as Turbine 1, 2 and 3. These wells are used for the Beverage section of the factory and for utilities purpose. In 2018, about 2 Mm^3 was abstracted from the factory, including all wells.

Available step rate test on Well 1 and Well 3 were interpreted. For Well 1, according to the results of the test realised in April 2014, it can be said that the well could be safely operated at 40 m^3/h. Step rate tests were performed on Well 3 in October 2007, March 2015 and January 2019. Greater drawdown is observed in Well 3 over time. The specific capacity is hence significantly decreasing over time. This difference in drawdown and specific capacity can be explained either by an ageing of the well condition and/or by the influence of the nearby pumping wells that was observed during the SRT testing. **However, it seems that the productivity of Well 3 is decreasing over time due to ageing conditions (e.g. clogging).**

According to Nestlé monitoring data, the static water level is around 10 mbgl and the dynamic water level up to about 18 mbgl. Overall, a slight decreasing trend can be observed according to the onsite monitoring data. Well 3 recorded a high decreasing trend of about 1-meter year. This decrease can be the results of different possibilities: over abstraction, aquifer overall decrease of the water levels or borehole ageing.

Monitoring data between 2013 and 2018 were obtained from several piezometers managed by the Punjab irrigation department. The data confirmed that the general groundwater flow direction is from the north-east to the south-west. A **cone of depression** was observed 13 km to the south-west of Nestlé factory. The **increase of this cone of depression can be observed over the years**. This area, near Kharianwala, is heavily populated (29,832 according to the 2017 census) with a strong industrial development (textiles, chemical, paper, leather etc.), inducing probable strong abstraction volumes. **Abstraction from the industrial area of Nestlé factory is likely contributing to this cone of depression.**

Onsite wells are sampled by Nestlé team and analysed in NQAC Vittel. Compared to the guidelines, all parameters are below the thresholds with the exception of the **barium** values for all three wells (up to 214 mg/l compare to 100 mg/l) as well as **arsenic** (up to 40 µg/l compare to 10 µg/l). TDS values are also above the Pakistan guidelines (PSQCA and PFA) that sets the threshold at 500 mg/l. The detailed results didn't highlight the presence of microcontaminants. Except for a trace of styrene (VOC) in Well 2, which was recorded just at the detection limit (0.1 µg/l). The contaminant was not recorded in the other wells and could potentially be the results of a cross contamination while sampling. It should however be noted that pesticides and fertilisers were not tested in these analyses even though large agricultural field are present in the project area.

The geochemical signature of Nestlé groundwater samples is characterised by a strong **bicarbonate geochemical facies**. Regarding the cations, there is no obvious dominance, with the samples being located in the centre of diagram. The geochemical signature of the groundwater abstracted from the three different onsite wells is almost identical.

These water chemistry results reveal that, for the analysed parameters, collected groundwater meets the selected criteria for Bottling Water.

The town of Sheikhupura is supplied in municipal water by the Tehsil Municipal Administration (TMA). The water is sourced from groundwater. The municipal supply is only supplying the urban area. Outside the city, in more rural area like the project area, potable supply is sourced from individual private wells. Industries are relying almost solely on groundwater and agriculture is sourcing 40 % of its water needs from groundwater. **The total estimated abstraction volume from the project area (10 km radius around the factory) is about 70 Mm^3/year.**

The **intrinsic vulnerability is high for the porous alluvial aquifer**. The unconfined aquifer could be exposed to potential pollutant substances that could infiltrate through the unsaturated zone as there is a no capping clay cover and the water level is shallow (about 10 mbgl). Several potential contamination sources are present in the project area (waste dumps, waste water, industries, agriculture etc.) and can be threats to the water quality. **The risk of contamination to the local aquifer is considered as high.**

Groundwater recharge from the rainfall is limited. The main groundwater recharge mechanism is from the surface water. The mean rainfall recharge value for the aquifer is 63 mm/m^2/yr which amounts to 7 Mm^3/yr in the considered aquifer recharge area (110 km^2). This recharge value considers only the infiltration from the efficient rainfall. The estimated seepage from the Upper Chenab Canal infiltration is 15 Mm^3/year and from the associated smaller canals and drains 2 Mm^3/year.

Considering all hypothesis and limitations, it can be considered that the **annual water balance is around zero.** The sensitivity test (+/- 5 % on the recharge and the abstraction to account for uncertainties linked to estimations) shows that the water balance results is oscillating around zero, **with the percentage of total abstraction compare to the total recharge ranging between 87 % and 106 %.** When the abstraction is greater than the recharge, it means that the aquifer is being over abstracted, and the water stress is deemed as very high. It should be reminded that the water balance is made on the recharge entering the system and not the existing reserve. When the abstraction is higher than the recharge, the **deficit is covered at the expense of groundwater storage** causing groundwater level drop. When the yearly recharge cannot cover the abstraction, withdrawing is using groundwater storage year after year, inducing a depletion of the resource over time.

A future water balance scenario was run taken into account a decrease of 10 % of the recharge (rainfall and river) due to climate change and an increase of 20 % of the abstraction volume to population growth and industrial development. **These types of scenarios are arbitrary and aim at taking into account potential worsening conditions in the future. They do not reflect the current situation.** A decrease of 10 % in the precipitation and an increase of 20 % of the abstraction is a common scenario taken in water balance exercises. It can be seen as a bad case scenario. With this scenario, the water balance appears negative, and the total abstraction represents 130 % of the recharge.

When looking solely at Nestlé Factory abstraction (up to 2.5 Mm^3/y), this represents about 3.5 % of the total estimate abstraction in the project area (70 Mm3) and 11 % of the abstraction in the considered area of influence. Nestlé abstraction represents 10 % of the total recharge in the considered area of influence.

According to the results, in the current situation, the water balance appears to be oscillating around zero, meaning that the amount of total recharge would be equivalent to the amount of abstraction volume. With the level of uncertainties, it is not possible to determine if the result is slightly positive or negative. However, when comparing with the water levels trend in the project area, showing a slight decreasing trend and the presence of a cone of depression, the water balance results do confirm that the pressure applied on the available groundwater resources in the area is very high and over-abstraction is likely occurring, threatening the sustainability of the resource.

According to the available data and current water balance assessment, it seems that water abstraction in the project area is performed in a non-suitable way for the aquifer. Further groundwater monitoring is paramount to follow the groundwater level trends.

It should be reminded that these calculations are based on several assumptions and hypothesis and do not represent exact figures. The final result must be seen as an approximate figure to understand the water balance situation of the considered zone.

10.2 Recommendations

The following recommendations are proposed:

- Well 3 cleaning should be organised to assess if the decrease of levels is associated with clogging issue or reflective of a decrease in the aquifer level. A TV inspection should be organised before the cleaning to evaluate the clogging conditions. Step test should be performed after the cleaning of the well to allow for comparison of the before/after productivity results.

- Step Rate Test on Well 2 should be performed (no available SRT) with interpretation of the results by an experienced hydrogeologist;

- they are no available Constant Rate Test on the existing wells. It is recommended to perform CRT testing as it would provide valuable information such as maximum abstraction rate from the factory well field as well as aquifer parameters to calculate the radius of influence from the wells. These tests will also allow to calculate parameters such as transmissivity and storage coefficient that are important parameters to understand the hydrodynamics of the aquifer. By having this information, the wells can be operated in a sustainable way and the aquifer managed appropriately. A constant rate test is a pumping test at a constant rate (no flow rate change) with measurement of the associated drawdown. Specific software are used to interpret the results (similar to the step test interpretation) suitable pumping test plan with results interpretation can be developed and implemented by Antea Group;

- it is paramount to monitor the water levels in the Food and Beverage wells. A common water level monitoring plan should be implemented. NQAC sampling should also be performed on these wells;

- water level measurements of the monitoring well should be performed in concertation with the Food and Beverage team (i.e. measurements only when the wells are off);

- no construction details are available for the monitoring well and its location is very close to one of the Food and Beverage well. It is recommended to drill two new monitoring wells, with one upgradient (north-east) and one downgradient (south-west). They will allow to proper monitor the water level trends before and after the potential impact of Nestlé factory. These wells should be located at sufficient distance from the existing abstracting wells to ensure that limited interferences are occurring. The location of these monitoring wells could be inside or outside the factory premises. Should Nestlé decide to move forward on this recommendation, Antea Group can assist in the suitable sites selection and implementation;

- pesticides and fertilisers were not tested in the NQAC analyses. It is recommended to do so as the project area is made of large agricultural land and the aquifer is shallow and unconfined.

- As mentioned previously, Nestlé Sheikhupura is accredited as part of the Alliance for Water Stewardship (AWS) program. It is recommended to continue the strong engagement towards that program that has been successful so far, including the helps towards the surrounding community.

Observation 1 -

This report, as well as the maps or documents and all other appendices, constitute an indivisible whole; as a consequence, ANTEA GROUP could not be held responsible for part of this report and appendices being communicated or reproduced, as well as any interpretation beyond its own. The same applies for a possible use for other objectives than those defined for the present study.

Observation 2 -

This study has been carried out based on some exterior information not guaranteed by ANTEA GROUP; it cannot be held responsible with regards to this.

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Appendices

Appendix 1 - Well census data

Appendix 2 - NQAC Water Chemistry Results

Appendix 3 - Waste water ponds in the project area

Appendix 4 - Landfill / dumping sites in the project area

Appendix 5 - Industrial waste dumps in the project area

Appendix 6 - Households wastes in the project area

Appendix 7 - Animal waste dump sites in the project area

Appendix 8 - Visited industries

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