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IDB-India

International Development

of Bank Filtration –

Case study India

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Dr. Birgit Fritz

Freie Universität Berlin

Prof. Dr. Asaf Pekdeger, Dipl.-Geol. Gunnar Lorenzen,
Dipl.-Geol Christoph Sprenger, Dr. Thomas Taute,

Address for correspondence:

- Dr. Birgit Fritz, KompetenzZentrum Wasser Berlin gGmbH, Cicerostr. 24, 10709 Berlin, tel.: +49 30 53653814, fax: +49 30 53653888, e-mail: **birgit.fritz@kompetenz-wasser.de**
- Prof. Dr. Asaf Pekdeger, Freie Universität Berlin, Hydrogeology Group, Malteserstr. 74-100, 12249 Berlin, Germany, tel.: +49 30 83840612; fax: +49 30 83870742; e-mail: **pekdeger@zedat.fu-berlin.de**
- Dr. Thomas Taute, Freie Universität Berlin, Hydrogeology Group, Malteserstr. 74-100, 12249 Berlin, Germany, tel.: +49 30 83840612; fax: +49 30 83870742; e-mail: **ttaute@zedat.fu-berlin.de**
- Dipl.–Geol. Gunnar Lorenzen, Freie Universität Berlin, Hydrogeology Group, Malteserstr. 74-100, 12249 Berlin, Germany, tel.: +49 30 83840612; fax: +49 30 83870742; e-mail: **lorenzen@zedat.fu-berlin.de**
- Dipl.–Geol. Christoph Sprenger, Freie Universität Berlin, Hydrogeology Group, Malteserstr. 74-100, 12249 Berlin, Germany, tel.: +49 30 83840612; fax: +49 30 83870742; e-mail: **christoph_sprenger@yahoo.de**

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1 Introduction

Different aspects of bank filtration are subject of scientific investigations in many parts of the world. Due to a long experience and good cooperation of research institutes, water suppliers and local authorities the research done in the city of Berlin has contributed important results to the international community.

Bank filtration is a valuable method for both drinking water production and water treatment thus providing for a sustainable resources management. The treatment of highly loaded surface water has become a global issue of growing urgency. The implementation of innovative and cost-efficient technologies is getting increasingly essential for numerous countries. The experiences with bank filtration, sewage field irrigation and artificial groundwater recharge gained in Berlin during both practical and research and development status, could contribute to resolve these issues.

1.1 Objectives

The project was the feasibility study previous to the (EU-funded) TECHNEAU research project and mainly analysed the geological, geochemical and hydraulic data. The project's objective is to assess the site's suitability for the technology referred to considering the subsequent development towards its commercial exploitation. Another objective is the validation of the knowledge and guidelines yielded by the NASRI project.

The transferability of the process understanding is not given yet. Different climate conditions and a considerably higher contamination of the water bodies could limit the purification capacity thus involving a suitable additional treatment.

1.2 Strategy

Since the start of the project a systematically and detailed investigation about the local climate, geology, hydrogeology, ground and surface water quality, water supply and available data and literature associated to the project has been carried out.

A GIS (Geo Information System) was created for the area of Delhi including the field sites and the whole catchment area of the river Yamuna.

During field trips the contacts to the local partners, authorities and potential contractors were established. The time was used to look for data, literature and the cost and availability of the required equipment. To save costs most of the equipment (see appendix) was bought in India. Some devices are very special and could not be find easily in India. Veolia India and the IIT Delhi are helping us to find and order everything. The exact locations of the field sites have been selected and two drilling campaigns were carried out at the 3 sites (Palla, Najafgarh, Nizamuddin) between September and November 2006. At each field site several piezometers have been drilled for groundwater sampling and monitoring of water level. First water sampling campaign has been carried out in October and November 2006 to detect seasonal changes of hydraulic and hydrochemical parameters through the annual cycle.

The tasks according to the proposed time schedule could not be performed entirely in time. Since the issue of a governmental document needed for the permission procedure was delayed and all depended activities needed to be postponed as well. Therefore drillings was started not until September 2006 but after the monsoon rains.

Since we are not located in Delhi all the time and do not know the local procedure needed for the permission request the decision was made to hire a local expert. Dr. Singh (former member of the Central Ground Water Board) joined the group in April 2006.

The following report is a summary of the most important results.

2. Delhi - the study area:

2.1 Geographical characteristics

The city of Delhi is situated in the central northern part of the Indian Subcontinent on the bank of the river Yamuna, approximately 200 km southwest of the himalayan mountain front. It is located in the National Capital Territory of Delhi which spreads over a total area of 1483 km^2, of which more than 60% is now urban (Maria 2004). Physiographically the territory consists of flat and level plains (Gangetic plains of the Himalayan foreland) interrupted by cluster of sand dunes (197 ton 260 m a.m.s.l.) and a long continuous chain of rocky ridges (known as the Delhi Ridge; up to 340 m a.m.s.l.) (Kaul & Pandit 2004, www.rainwaterharvesting.org).

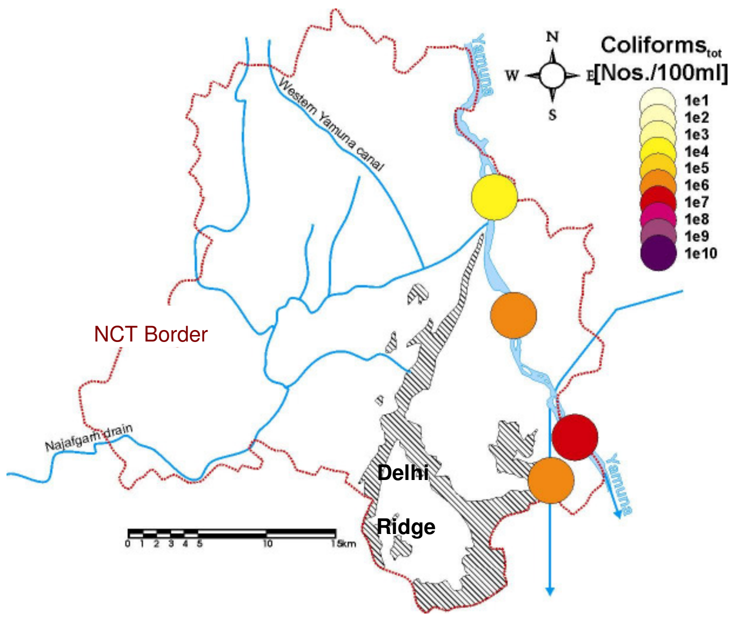


Figure 2.1: Total coliforms in Yamuna River (data source: Central Pollution Control Board).

The Yamuna River, a tribute to the Ganga, flows in a southerly direction in the eastern part of the NCT is the only perennial river in the area (www.rainwaterharvesting. org). It is dammed in the northern part of the Delhi at Wazirabad Barrage (where water quality is relatively good) and in the southern part of the city at Oklah barrage (where water quality is dramatically degraded; **Figure 2.1**). Between these barrages the River Yamuna is joined by a number of tributaries. These so called drains are generally channelled water bodies used for disposal of urban wastewater and flood control during monsoon season. The most important one is the Najafgarh Drain which has it's source in the western state of Haryana and flows north-eastwards into the to join the Yamuna River in the northern part of the city below Wazirabad Barrage. At several points, the city of Delhi is connected to the irrigation canal network that has been built up in Northern India in order improve temporal and spatial distribution of river water throughout the region by river management and inter basin water transfer.

The area is located in the path of the Indian southwest monsoon through movement and receives about 80% of annual rainfall during July to September (Datta & Tyagi 2004?). The climate of the Delhi region is of semiarid nature due to marked diurnal differences of the temperature, high saturation deficit and low to moderate rainfall. The climate is markedly periodic and is characterized by dry, gradually increased hot seasons between March and June, a dry and cold winter from October to February and the warm, monsoon period from July to September (**Figure 2.2**). The average rainfall (1954-2004) is 721 mm and the average annual temperature recorded in Delhi is 31.5°.

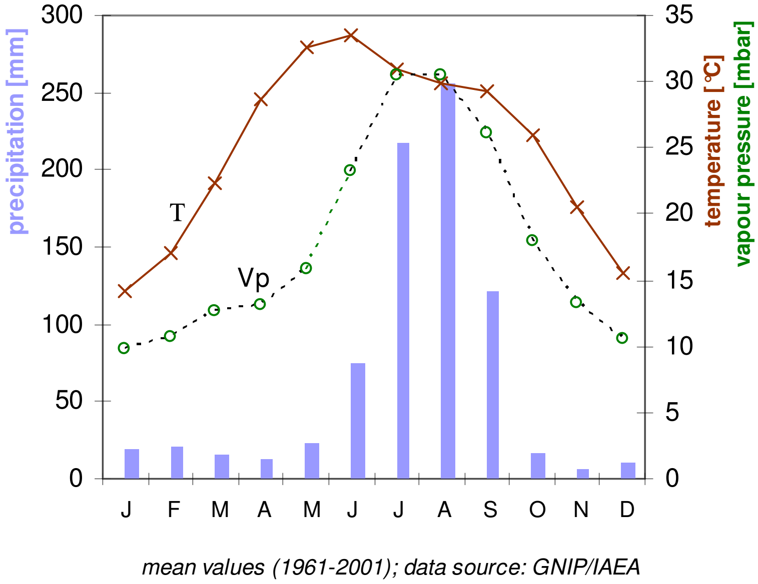


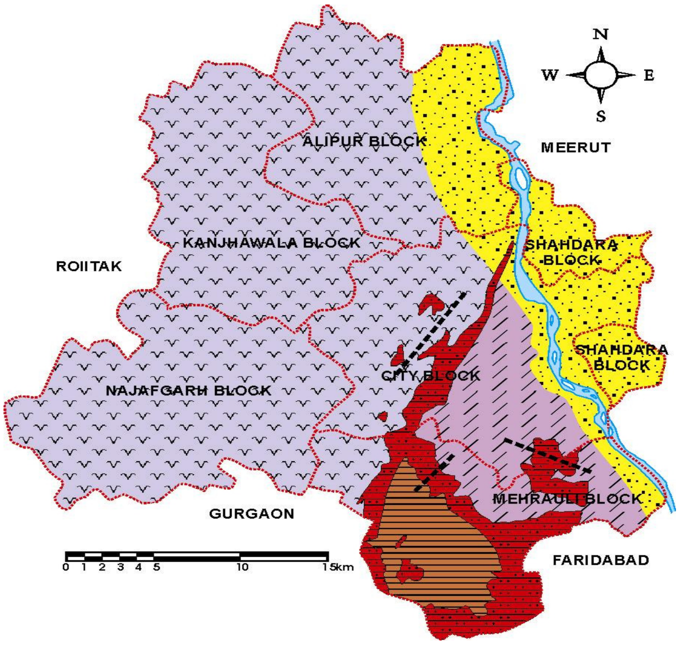
Figure 2.2: Climatic parameters for the city of Delhi.

2.2 Geology and aquifer characteristics

The study area is situated within the world's largest terrestrial foreland basin, the Himalayan molasses basin. It has been formed as a result of the collision of India-Asia collision which was initiated about 65 Ma ago. Due to ongoing convergence subduction, uplift, and erosion there has been a continuous sedimentation in a variety of fluvial regimes into the foreland basin (Brozovic & Burbank 2000). The only outcrop of the bedrock is represented by the so called Delhi Quarcitic Ridge, a spure of precambian metamorphic rock jutting into the unconsolidated sediments (Kaul & Pandit 2004).

In a local scale, four different units can be distinguished within the study area, having quite different physical properties and aquifer characteristics (**Figure 2.3**):

1. Yamuna flood plain deposits: Adjacent to the course of river Yamuna quaternary alluvial deposits of sand, silt and clay with gravel reach thickness of about 30 to 40 meters. They build up unconfined to semi-confined aquifers with very large yield potential of 100-280 m^2/hr.



	Age-Group		Lithology	Hydrogeological Cond.
Unconsolidated	Quarternary Newer Alluvium		Yamuna sand, silt and clay with gravel	30-40m thick unconfined to semiconfined aquifers
	Tertiary Older Alluvium		Predominantly clay associated with fine graind aeolian deposits	Fairly thick, regional extensive, semi-confined aquifers
			Predominantliy clay with silt and kankar	Local, limited thick semi-confined aquifers
Consolidated	Delhi super group (Pre-Cambrian)		Mainly sand with minor silt clay and kankar (chattarpur basin)	Fairly thick regionally extensive aquifers
			Quarzite interclated with mica shist, intuded by pegmatites and quartz veins	weathered, fractured quarzite, highly jointed

Figure 2.3: Geological subdivisions in the NCT.

2. Older Alluvium: Extensive tertiary sediments of clay associated with fine grained aeolian deposits form fairly thick aquifers to the eastern and western side of the ridge. They are generally semi-confined with large yield prospects between 30 and 100 m^3/hr.

3. Chattapur Sediments: Isolated alluvial deposits derived from the quartzitic ridge form a fairly thick regionally extensive aquifer. They are consolidated and consist of mainly sand with minor portions of silt, clay and kankar. Yield prospects are low (10-30 m^3/hr).

4. Quarzitic Ridge: The NNE-SSW trending hard rock acts as a groundwater divide between the western and eastern parts of Delhi (MARIA 2004). Groundwater abstraction potential in the fracturated quartzite is very limited with yield prospects as low as 10-30 m^3/hr.

2.3 Situation of groundwater

The use of groundwater for water supply is limited as a consequence of qualitative and quantitative problems: Fluctuation of water level in Delhi has been mapped by the Central Ground Water Board of India over several decades, indicating a steady decline of groundwater level in huge parts of the territory (**Figure 2.4**; www.rainwaterharvesting.org).

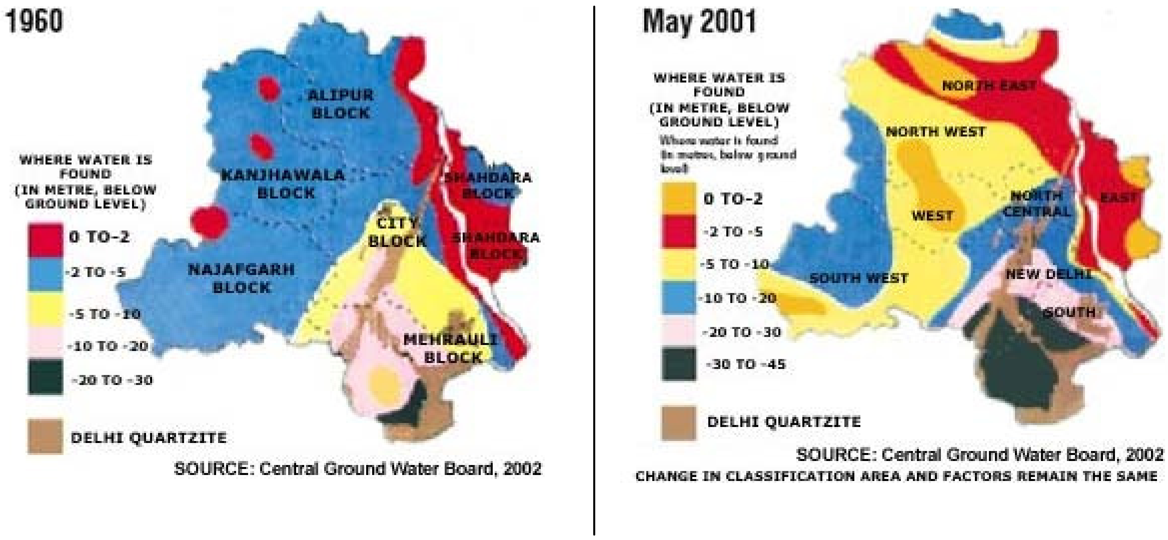


Figure 2.4: Groundwater level in the NCT in 1960 and 2001 (source: www.rainwaterharvesting.org).

Abstraction is mainly caused by private borewells and tubewells that are present in almost every colony or complex in Delhi, as a result of the shortage in public water supply (Daga 2003). Withdrawal of ground water can by far not be compensated by natural recharge through rainwater infiltration which is generally low with most parts of Delhi receiving less than 5% recharge. Lateral flow from surrounding areas, canal/river seepage and localized infiltration of highly degraded agricultural and urban surface run-off through stagnant water pools, are the main contributors to the recharge (Datta & Tyagi 2003).

A widespread problem making the groundwater unfit for its different application are high contents of dissolved salts of chloride (**Figure 2.5**)and sulphate due to the occurrence of geogenetic saline waters in deeper layers. In general, high chloride contents are found in topographic low areas corresponding to discharge zones, while topographic high areas correspond to recharge zones with low chloride concentrations (Datta et al 1996). Along with salinity, fluoride concentration is a major constraint to safe groundwater use for water supply. Fluoride concentration exceeds the WHO norms of 1.5 mg/L in about 30% of the NCT area (Maria 2004).

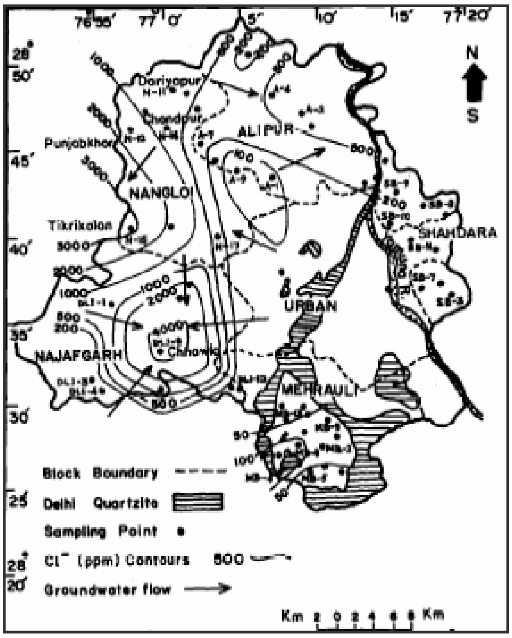


Figure 2.5: Distribution maps of chloride in shallow aquifers in the NCT: Iso - chloride ion contours [mg/l]. (source: Datta & Tyagi 2001)

In addition to the increasing salinization [nature borne contaminants], groundwater in Delhi area is getting severely contaminated with nitrate, fluorite, pesticides and heavy metals from anthropogenic toxic waste sources. Unplanned disposal of anthropogenic wastes resulted in excessive accumulation of pollutants on land, into river, unlined drains and landfills. Subsequent leaching of these pollutants causes severe degradation of the groundwater (Datta & Tyagi 2001). Amongst these contaminants Nitrate contamination (**Figure 2.6**) is assessed to be the most alarming problem in Delhi´s groundwater and may mainly be caused by agricultural input of fertilizers and by landfill leachate.

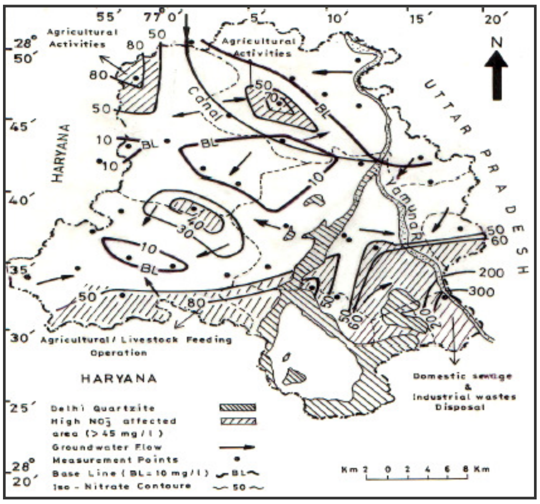


Figure 2.6: Distribution of Nitrate (Nitrate ion contours [mg/l]) in shallow aquifers in the NCT (source: Datta & Tyagi 2001)

2.4 Water Supply

Increasing water demand due to a rapid growth of population (**Figure 2.7)** along with increasing urbanisation and industrialisation has put Delhi water supply infrastructure under severe pressure. The government agency responsible for water supply In 2003 Delhi Jal Board (DJB) reported to have a capacity of supplying of about 650 MGD of which 550 MGD were extracted from surface water and only 100 MGD from groundwater (Daga 2003). Most of the surface water originates from Yamuna River, additional water is supplied through inter basin transfer. The most important reservoir of groundwater being exploited by DJB is the floodplain in Palla area upstream of Wazirabad barrage. The shallow floodplain unconfined aquifer underlying the floodplain periodically gets filled during monsoon after being partially dewatered by abstraction during dry season.

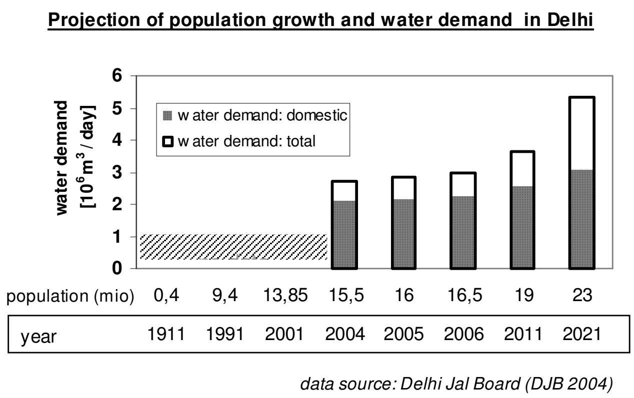


Figure 2.7: Projection of population growth and water demand in Delhi.

The amount of water supplied by the Delhi Jal Board largely is by far not sufficient to satisfy the needs of the metropolis. As a consequence of the scarcity, private connections and public standpoint get water only one to four hours a day, with a great uncertainty on the pressure (MARIA 2004). For coping with the unreliability of the public supply people find alternative means legal as well as illegal to acquire their water supply, like boring private wells, purchasing water from private water tankers and purchasing bottled water (Daga 2003). According to DAGA (2003), almost every colony or complex in Delhi has a borewell or a tubewell to complement or a substitute to the public supply. There are about 100000 private run wells legally registered at the Central Ground Water Authority (CGWB), but different sources estimate the actual number of private tubewells between 200 000 and 360 000 (Maria 2004). Zerah (2006) points out the substantial hidden costs of water supply in Delhi, estimating the collected aggregated cost for coping strategies to represent more than twice the annual expenditures of Delhi public utility. The government of Delhi recognizes the need for comprehensive reforms in the sector to ensure a better service level in the water sector. The government's vision is "Provision of universal 24/7 safe water supply and sewerage services in an equitable, efficient and sustainable manner by a customer oriented and accountable service provider" (DWSSP Part A, 200X). In the "Master Plan Delhi 2021" a slew of measures are suggested by the city planners to meet the city's water needs, like the installation of a dual pipe supply system, the complete tapping of run-off water from rains etc. or the recycling of waste water (Hindustan Times, March 22, 2006).

2.5 Potential use of stable Isotopes as tracers

Growing water demand in India requires large scale engineering and modification of the natural hydrological cycle. Therefore it is essential to have detailed understanding of the natural hydrologic cycle in terms of processes controlling seasonal and spatial distribution of water (Gupta & Deshpande 2005a). In many parts of the country the scarcity of ground water forces to take artificial recharge measures (Kumar & Seth 2000). Stable isotopes of oxygen and hydrogen have a specific potential in addressing water balance, dynamics and interrelationships between surface and groundwater in river basins and catchment areas (Rozanski et al 2001). As the stable isotopes species of Oxygen (16O, 17O, 18O) and Hydrogen (1H, 2H also known as Deuterium; D) are integral compounds of the water molecule, their ratios are very applicable for tracing movements of waters and hold important clues to identify processes within the hydrological cycle. Being the primary source of water on land precipitation primarily controls isotopic composition of continental surface water and groundwater. Major trends within regional and seasonal variations of isotopic composition of precipitation, surface water and groundwater in India and in the study area have been specified by different authors.

Isotopic composition of precipitation in New Delhi is being monitored and data from 1961 to 2001 can be downloaded from the GNIP database (www. isohis.iaea.org).

Interpretation of the data (**Figure 2.8**) clearly indicates seasonal variation of isotopic composition in rainfall.

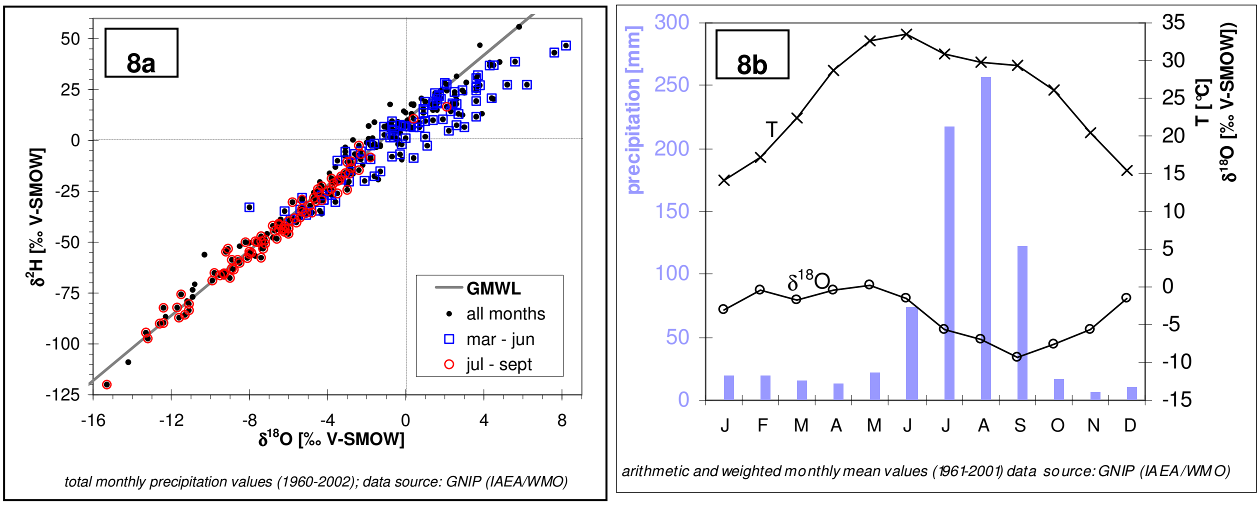


Figure 2.8: Seasonal variations in the isotope content of precipitation in New Delhi. Depletion in heavy isotopes due to the amount effect is evident during Indian summer monsoon (July to September) and evaporation from falling raindrops may cause a relatively high d-excess during warm and dry months (March to June).

Dalai et al (2002) analyzed oxygen and hydrogen isotopes in the source waters of Yamuna and its tributaries in three different seasons (June: summer, October: monsoon, September: post monsoon) and determined seasonal and spatial variations and factors regulating them.

Gupta & Deshpande (2005b) suggest that temporal variability in isotopic character of groundwater is generally small. Spatial inhomogenity is interpreted as a result of the different recharge processes like infiltration of surface runoff water from stagnant water pools, infiltration of from river water or the evaporation from irrigation water during infiltration (Datta et al 1996).

2.6 Geographical Information System (GIS)

Detailed spatial information of the study area is a basic requisite for hydrogeological investigations. For an effective and professional access to information like maps and data from different sources the software ArcGIS is being used to design a Geographical Information System (GIS). Working with the GIS makes it possible to display charts as different layers within the same georefered frame. Charts can be viewed against other data sets and own asset data to greatly improve planning, monitoring and analysis. New thematic maps can be designed for a better understanding of spatial coherences or representation of investigation results. For the design of the GIS of Delhi area and Yamuna catchment a series of different information sources have been used like a city map of Delhi, satellite images or topographical maps in different scales. Maps were digitalised, georefered and added as different layers (**Figure 2.9**). Additionally relevant environmental data from the local authorities and relevant data from research publications was integrated. During field trips in Delhi area, a Global Positioning System Advice (GPS) is used to locate the exact position of specific places (like sampling points). The acquired data can easily be transmitted and displayed in the GIS.

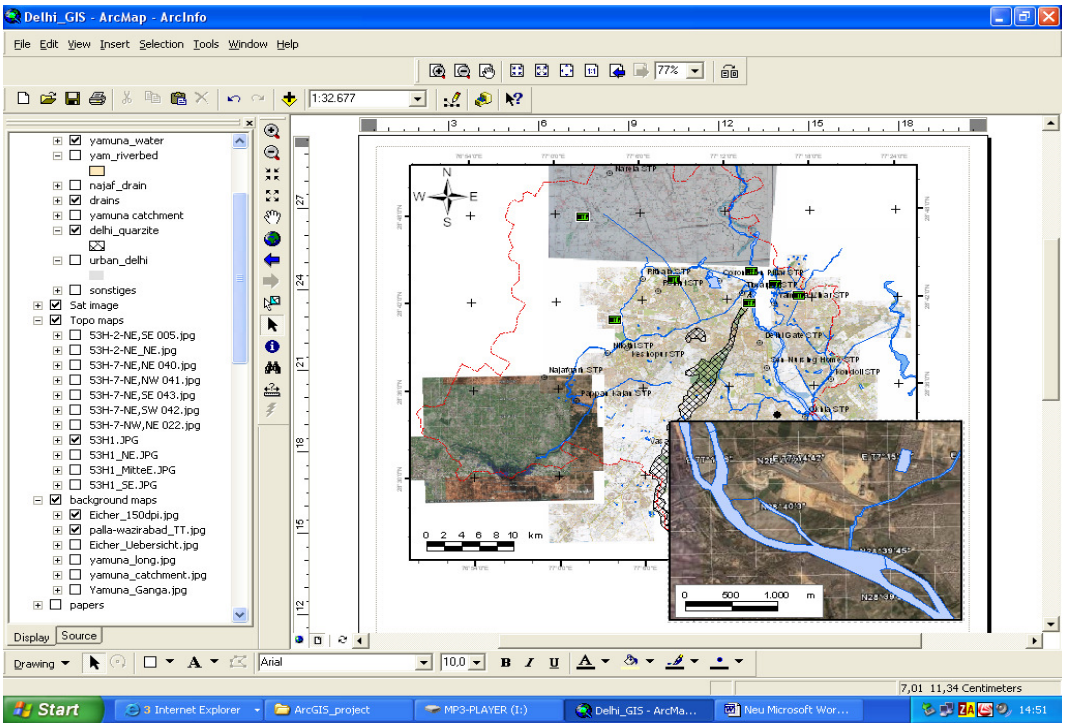


Figure 2.9: „Screenshot“ of the Geographical Information System designed for Delhi Area.

3.0 FIELD SITES

The study of bank filtration processes in Delhi area is based on the detailed investigation of interaction processes between surface water and groundwater at different localities within the NCT. Therefore three places have been selected for the installation of field sites field sites, representing the broad variety of chemical and hydraulic conditions in the river or drains and adjacent aquifer. Besides the surface- and groundwater conditions functional criteria like land use and proprietor or accessibility had to be considered for the selection of suitable field sites. In agreement with local authorities (Central Ground Water Board, Delhi Jal Board, Irrigation and Flood Control Board) the following three places with very distinct site specific attributes have been determined (**Figure 3.1**):

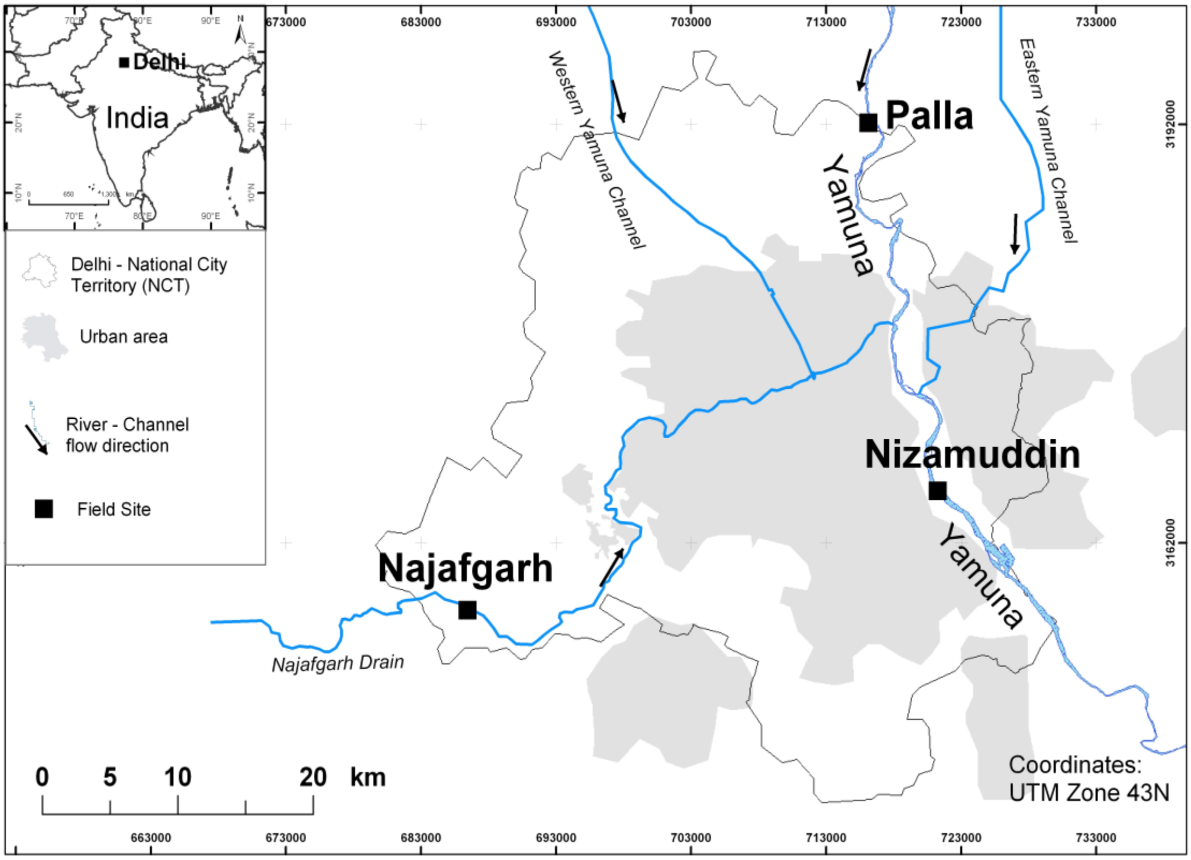


Figure 3.1 Location map of field sites.

1. **Palla Field Site** is located on the flood plain on the western bank of river Yamuna, upstream the rural parts of Delhi. Contamination of River Water and adjacent groundwater is relatively low, so that Delhi Jal Board is able to run a huge number of Wells for drinking water production.

2. **Najafgarh Field Site** is situated in the rural southwestern parts of the NCT on the at the Najafgarh Drain. Contamination but also flow in the drain are relatively low and groundwater is highly affected by salinisation.

3. At **Nizamuddin Bridge Field Site** on the eastern bank of River Yamuna in urban central Delhi, where River Water is highly affected by all type of contamination associated to an industrialized and fast growing Mega City with low ecological standards.

At each of the field sites several piezometers (ground water observation wells) have been drilled to have a close, detailed look to the geological and hydrogeological settings. Drilling is important for both getting a rough idea of aquifer composition and local geological strata as well as for construction of piezometers for groundwater monitoring.

The amount and design of piezometers to be drilled was based on the following concept: At least three piezometers in a triangular shape are essential for determination of groundwater surface slope and subsequent calculation of flow direction and hydraulic gradient. These piezometers may be constructed in relatively shallow groundwater, which is expected to be most influenced by interaction with surface water. For being able to analyze the interaction processes between shallow and deeper groundwater, at least one piezometer should tap a deeper horizon of aquifer and another piezometer should be installed in an intermediate level. In areas of high risk of salinisation, where saline water is covered by a limited horizon of sweet ground water, the filter screen of the deep piezometer should tap saline water whereas the intermediate should be installed in the saline water ground water interface. In this case multi level observation points can indicate fluctuation of saline water – sweet water interface and mixing of end members (**Figure 3.2**).

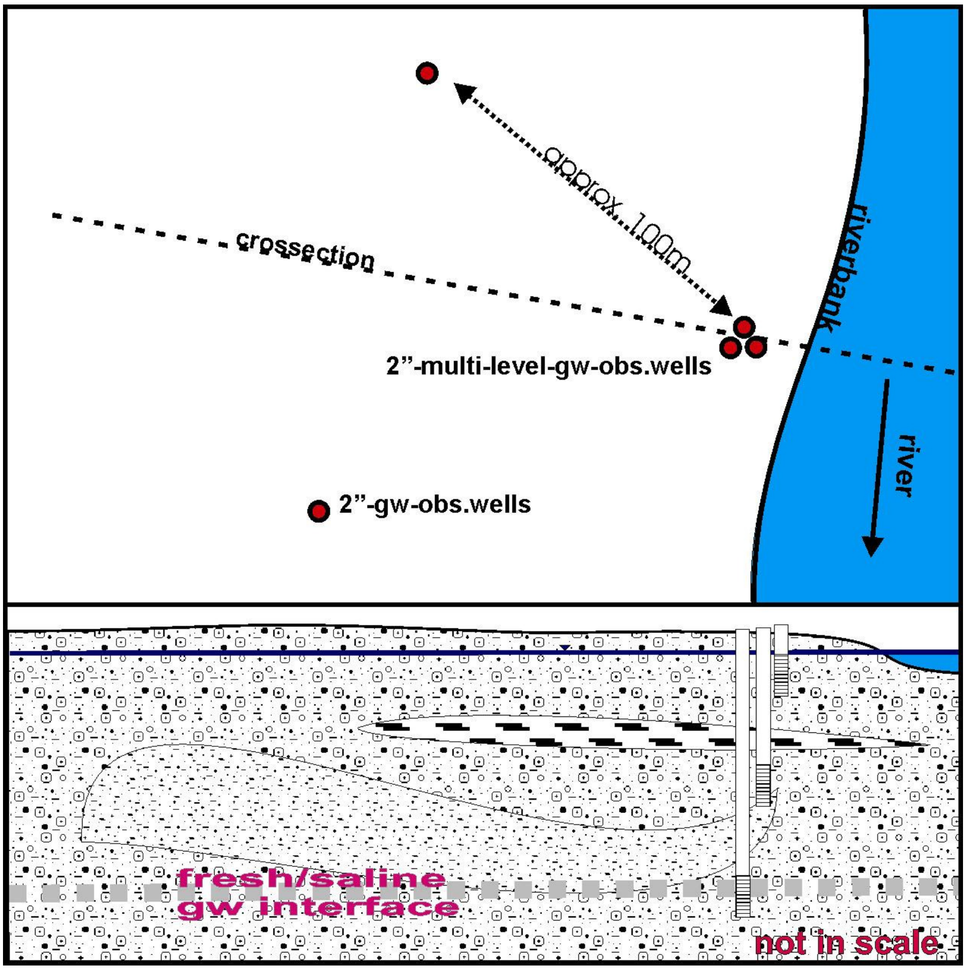


Figure 3.2 General piezometer setup.

After evaluation of available information and interpretation of own experience during drilling and sampling campaigns, a detailed prescription of the site specific conditions can be given as follows:

3.1 PALLA

The Palla Field Site is located within the well field of Delhi Jal Board that stretches on the western bank of river Yamuna from the northern outskirts of urban Delhi until Haryana border over a total length of about ten kilometres. The floodplain is bordered by a dike that has been built in a distance of 0.5 – 2 km from the actual course of River Yamuna to protect the hinterland from flooding. Most of the wells of Delhi Jal Board are built next to the road on top of this dike or on one of the side roads that branch of towards the river. The place for construction of the field site lies about 3 km west of the village Palla. The piezometers have been constructed right in between the river and a tube well of Delhi Jal Board (DJB old number: 18; DJB new number: 30, here PA-TW) (**Figure 3.3**).

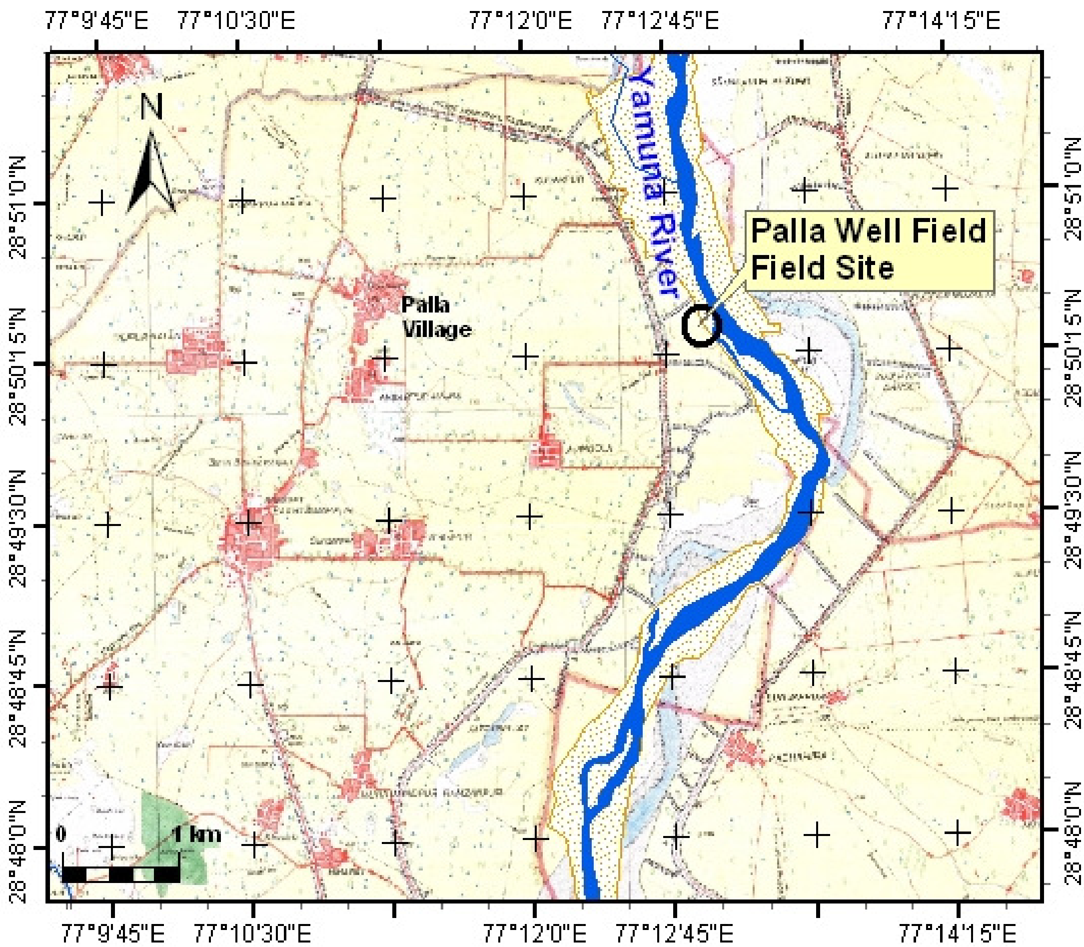


Figure 3.3 Palla field site

Morphologically the floodplain lies as a relatively plain terrace between the dike in the west and the slope of the riverbed in the east. The land is being used intensively by the farmers of the surrounding villages for cultivation of different kind of crops like turnip or even rice. Within one year the course of the river seems to be relatively stable, meandering only within the slopes of the riverbed, with shifting sand banks and high fluctuations of water level throughout the seasons. According to the statements of Central Ground Water Board officials a major flood event, setting the entire floodplain area under water has not occurred for at least 5 to 10 years.

Anyway, oxbow lake structures within the floodplain and comparison of satellite images and maps of different ages show that locally the riverbed has shifted several hundred meters throughout the last decades. Being located upstream of the inflow of urban Delhi and it's sewage canals, quality of river water is still relatively good.
The Geology of the floodplain and surroundings is dominated by sandy Yamuna river deposits which have built up the younger alluvium, covering the entire area with a thickness of several tens of meters. These sediments have been deposited upon a series of several hundreds of meters of Older Alluvium, which is predominately composed of fine sand, silt and clay. Ground water level is reported to be found only a few metres below ground level. Saline and brackish ground waters that occur in deeper wells are covered by a horizon of some tens of meters of sweet water in the floodplain area. Anyway, salinisation seems to be a major problem all around in the backlands of floodplain area. Chemical analysis of water from two exploratory wells in the floodplain are reported to show all parameters to be within the stipulated drinking water standards but the presence of faecal coliforms makes adequate disinfection necessary (Economic Survey of Delhi 2001/2002, DWSSP 2004).

3.2 NAJAFGARH

The second field site is located in the South West district of the National Capital Territory of Delhi, approximately 10 km south-western of Najafgarh Village (**Figure 3.4**). It has been placed on the dike that had been built on the northern side of the drain to protect the back lands from flooding. The site can be reached over the small road in top of the dike and lies some 150 meters east from the bridge over Najafgarh Drain where the major road is connecting the villages of Ujwah / Jhulijhuli and Raota. At this segment, the drain is being divided into two parallel channels. The point of divide is situated some four kilometres upstream where the drain is dammed on a weir before it enters Delhi territory from Haryana.

Before 1886, when the Najafgarh Drain has been excavated by the British to reclaim fertile land, there has been only a series of ditches. From the so called Najafgarh Jheel (Najafgarh Lake) which has once spread over an area of estimated 88 sq miles today only remains a small surface water reservoir lake (The Times Of India, 11.09.2006). It is situated approximately 5 km downstream of the field site location at the Delhi- Haryana border in the southernmost section of the Najafgarh Drain, at the

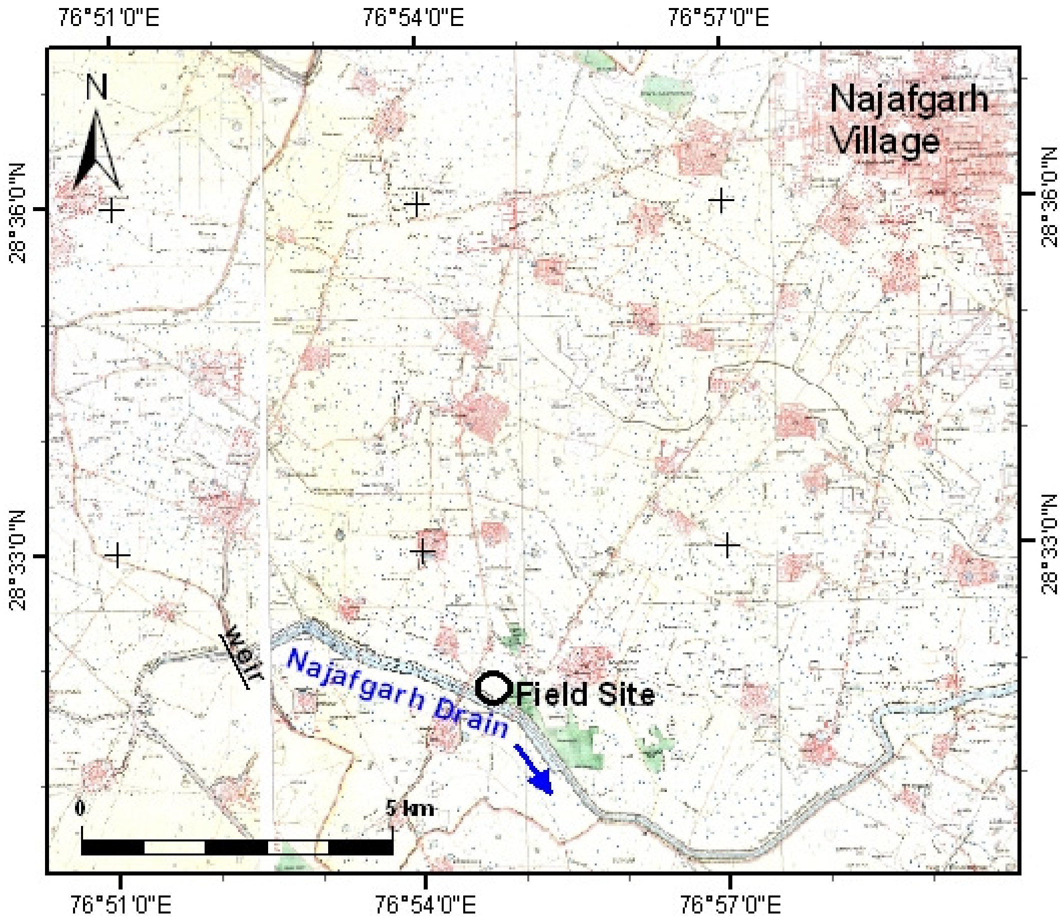


Figure 3.4 Najafgarh Drain field site.

inflow of the channel originating from Gurgaon water treatment plant.

Morphologically, the region presents a wide open depression, separated from the course of the river Yamuna by the Delhi Quarzitic Ridge. The landscape is characterized by a wide open plain surface, which is used for agriculture by the farmers of the small villages spread around the area. Central Ground Water Board reports that borehole data shows that Geology of the whole area is dominated by alternate fluvial and Aeolian bands distributed sporadically. Sediments are described as mostly silt with medium to fine sand and clay (SHEKHAR 2006). Regional maps published by CGWB [http://www.rainwaterharvesting.org/index_files/water_level_fluct.htm] and by KUMAR et al (2006) show that groundwater level in the area has to be expected at about 5 m below ground level at an absolute level of about 205 mNN with a flow direction in a north-eastern direction. Regarding ground water quality, salinization is most concerning in the area, with EC values measured as high as 37,820 µS/cm (BHAWNA & RAMANATHAN, n.d.). Maps published by SHEKHAR (2006) show that inside the Najafgarh depression freshwater of more than 10 m of thickness is only found in small freshwater pockets stretching along the drain and its tributary.

3.3 NIZAMUDDIN

The location for the third field site is situated in the urban central part of the city of Delhi, on the eastern bank of River Yamuna, about 100 meters upstream (i.e. north) of Nizamuddin Bridge. Piezometers have been built right beside the river, on a sandy bank of about 50 to 200 meters of width (**Figure 3.5**). This bank presented itself as a muddy field at the end of monsoon season in late August of 2006. Some 30 meters upstream of the field site, there was a small lake of about 100 meters of diameter within the bank, which was connected to the river through a natural channel. By the end of October of 2006 anyway the terrain had dried up and was ploughed up by local farmers for agricultural use. The only thing left from the lake was a small isolated waterhole (about 50 m of diameter) in the centre of a muddy depression. Most probably the bank has been at least partly flooded during July/August of 2006 thus it might be covered under water again during proximate monsoonal events.
Landwards, the bank is separated by a slope of only a few meters height from a superior flood plain terrace in the back land, which is another 2 km wide. As this terrace has not been flooded for many years, it is permanently being used for agriculture and market-gardens. Recently some outlying terrains have been dammed up for urban development measures. Within this area, Delhi Jal Board is operating some large Ranney Wells (radial collector wells with multiple horizontal screen laterals) and recently a number of tubewells have been constructed. The field site has been placed in a straight line right in between two of the Ranney wells and the river. The first Ranney well lies in a distance of about 1100 m from the river the second one is only some 400 m away from the river is currently not being operated due to high ammonia contents in groundwater, but kept as a reserve for potential bottlenecks in water production. According to the maps published by KUMAR (2006), upper sediments within the area are composed of Yamuna sand, silt and clay with

gravel. Groundwater level should be found only a few meters below surface and flow is expected to be directed towards the east. Salinisation is not known to be a major threat on groundwater quality this area, but problems with ammonia show that infiltration of highly contaminated river water may have a clear negative impact. Within this segment in Central Delhi, River Yamuna is highly contaminated by discharge of sewage and industrial wastewaters. Quite alarming is comtamination with pathogens and organic pollutants in wastewater (KUMAR 2002, WALIA & MEHRA 1998, AGARWAL et al 2006) but also concentrations of heavy metal load in river sediment (SINGH 2001).

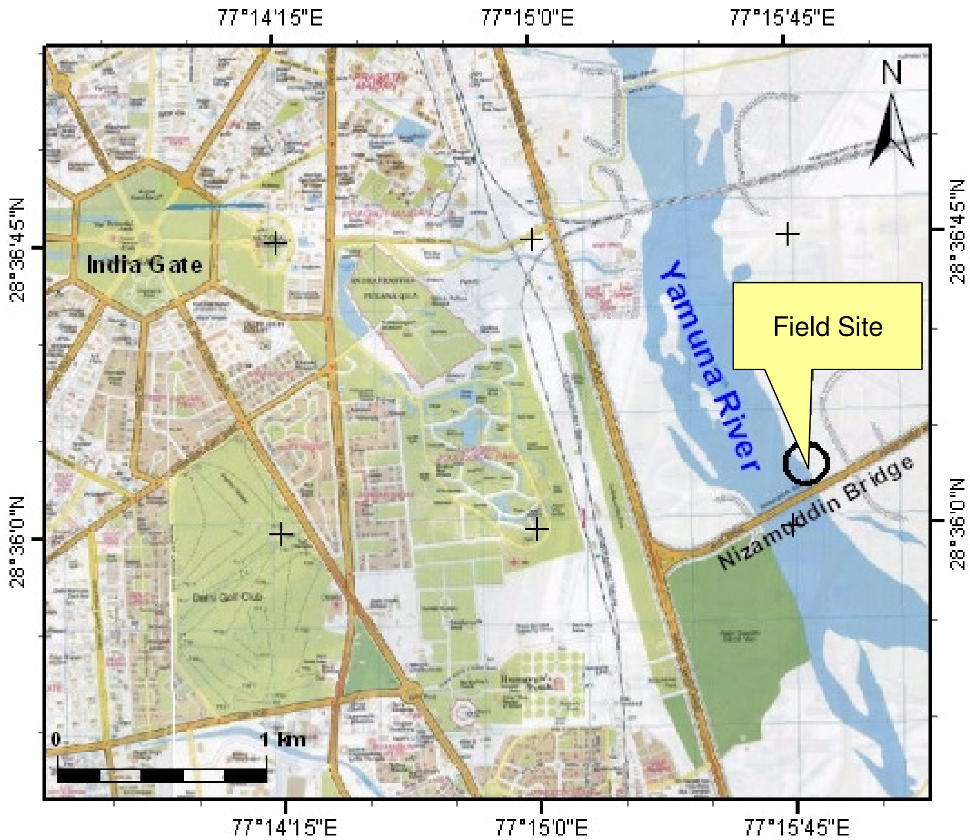


Figure 3.5 Nizamuddin Bridge field site.

4 Field work

4.1 Drilling campaigns

Two drilling campaigns were carried out at the 3 selected sites (Palla, Najafgarh and Nizamuddin) between September and November 2006. The unconsolidated sediment was drilled by two simple methods:

Hand-auger drilling (manual)

The cutting tool (known as the auger head) rotated to cut into the ground, and then withdrawn to remove the excavated material. The first few meters were drilled as shown in **Photo 1** until the groundwater level was reached. Afterwards a rig was installed (**Photo 2**) and the procedure was repeated until the required depth was reached. Boreholes drilled according to this method were not backfilled with filter gravel. Only shallow piezometers at the Palla field site were drilled manually.

Photo 1 Manual drilling at Palla.

Photo 2 Rig for manual drilling and assemblage.

Rotary drilling with flush

A drill-pipe and a bit rotated to cut the rock. Water with drilling mud is pumped down the drill-pipe to flush out the debris (**Photo 3**). This method is used for all of the piezometer in Najafgarh and Nizamuddin, and only for the deep and medium boreholes in Palla. The bits diameter was 8“ and the borehole was backfilled with filter gravel (**Photo 4**) and mud.

Foto 3 Rig for rotary drilling

Foto 4 Backfilling with pea gravel

Due to technical and logistical problems the spatial distribution of the piezometers at the field sites may differ from the proposed concept described in section 3.

Palla

In Palla 7 piezometers have been drilled. Due to a collapsed borehole at the multilevel position, the deep borehole (PA-PZ-3) was shifted about 7 m to the NW (parallel to the river). The piezometer PA-PZ-7 was constructed to detect the influence of groundwater from the hinterland. The exact piezometer setup is shown in **Figure 4.1**. The assembly for each piezometer and the well is shown in appendix, figure a1-a8.

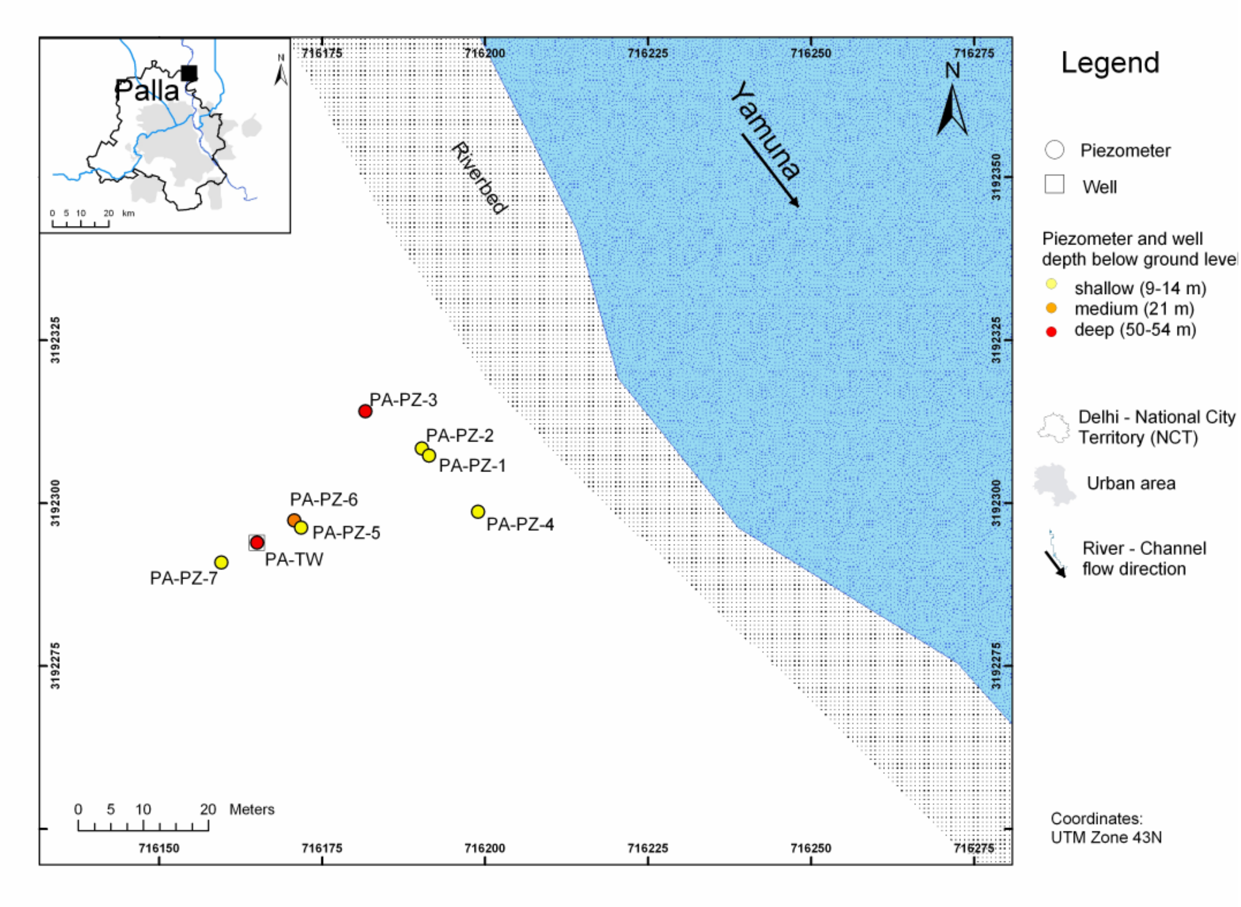


Figure 4.1 Piezometer setup in Palla.

Najafgarh

In Najafgarh 5 piezometers have been drilled and the exact piezometer setup is very close to the proposed concept (**Figure 4.2)**. The assembly for each piezometer is shown in appendix, figure a9-a13.

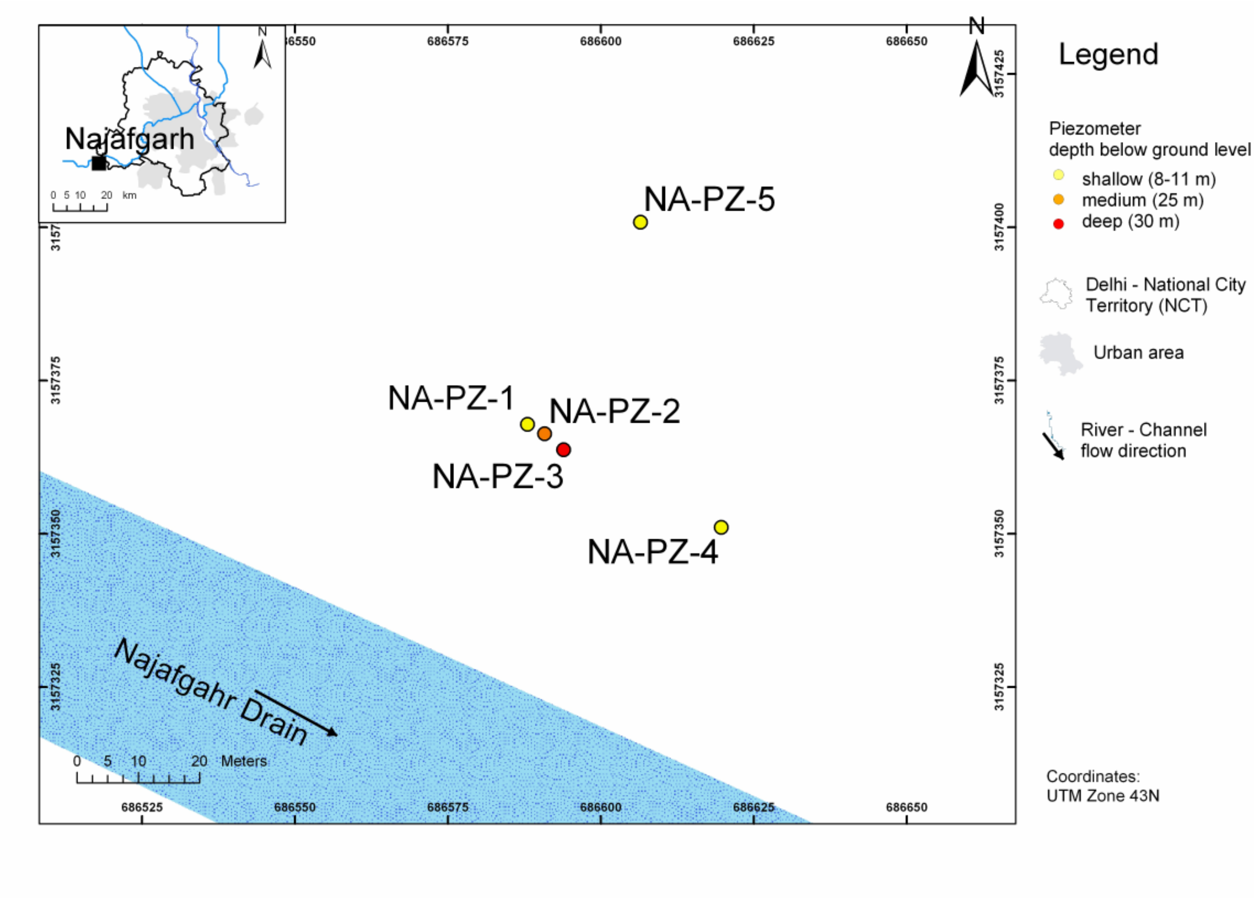


Figure 4.2 Piezometer setup in Najafgarh.

Nizamuddin

In Nizamuddin 5 piezometers have been drilled. Due to a problem with a farmer the piezometer PA-PZ-5 is only about 5 m away from the multilevel piezometers. The assembly for each piezometer is shown in appendix, figure a14-a18.

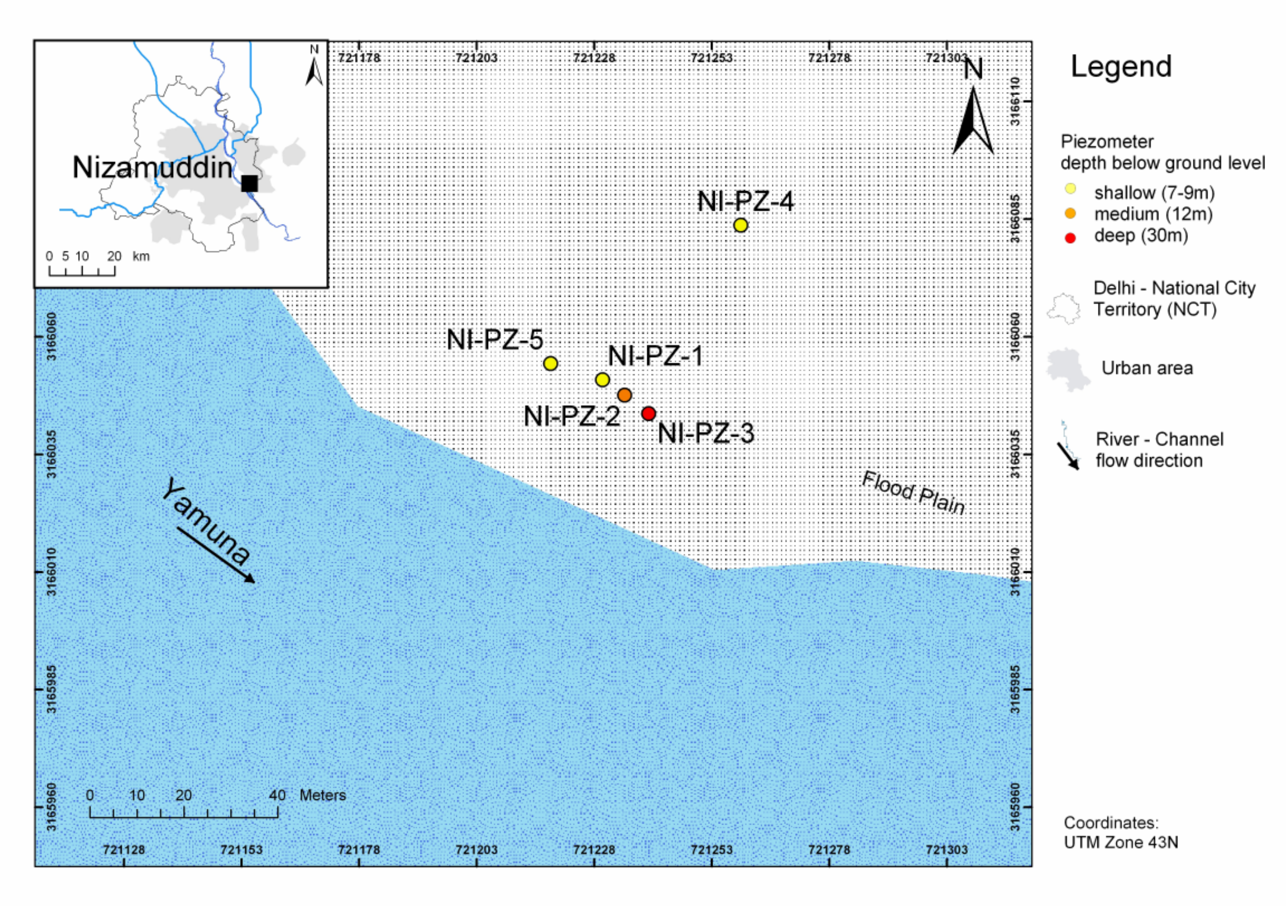


Figure 4.3 Piezometer setup in Nizamuddin.

4.2 Geophysical Logs

Geophysical logs can provide continuous and in-situ data about the delineation of hydrogeologic units and the definition of groundwater quality. Geophysical logs (normal-resistivity, spontaneous-potential) were carried out in November 2006 at the deep piezometer in Nizamuddin. Unfortunately are the results not yet available.

Normal-resistivity log

Records the electrical resistivity of the borehole environment and surrounding rocks and water as measured by variably spaced potential electrodes on the logging probe. The spacing for potential electrodes is 16 inches for short-normal resistivity and 64 inches for long-normal resistivity. Normal-resistivity logs are affected by bed thickness, borehole diameter, and borehole fluid and can only be collected in not assembled boreholes.

Spontaneous-potential log

Records the potentials or voltages developed between the borehole fluid and the surrounding rock and fluids. Spontaneous-potential log can be used in the determination of lithology and water quality.

4.3 Lithological Logs

Lithological logs were made on site with the available drilling samples to provide information about sedimentological aspects such as lithology, stratigraphy, grain size distribution and thickness and also hydraulic properties such as porosity and hydraulic conductivity.

A summary of the field parameters gives **Table 4.1**, where the coefficient of hydraulic conductivity was estimated according to empirical table by Dr. REINSCH.

Table 4.1 Site, stratigraphy, lithology and coefficient of hydraulic conductivity.

No.	Site	Stratigraphic Unit	Lithology Description	depth below ground level [m]	k_f [m/s]
1	Palla	Younger Alluvium	medium to coarse sand with kankar (gravel), mica	0 - ca. 20	5.0e-4 - 8.0e-4
		Older Alluvium	fine to medium sand	ca.20 - 54	1.0e-4 - 1.0e-5
2	Najafgarh	Older Alluvium	silt to fine sand, calcitic matrix	0 - 34	1.0e-6 - 1.0e-5
3	Nizamuddin	Younger Alluvium	medium to coarse sand with kankar (gravel), mica	0 – ca.10	5.0e-4 - 8.0e-4
		Older Alluvium	fine to medium sand	ca.10 - 30	1.0e-4 - 1.0e-5
		Hardrock (Quartzitic Ridge)	quartzite, schist	> 30	Aquiclude

Palla

In this terrain the upper sediments are found to be medium to coarse sand with kankar (carbonate concretions) in gravel size. The high mica content is characteristic for sediments of the younger alluvium unit. The older alluvium was encountered between 18 – 22 m below ground level and is to be found fine to medium sand. The mica content decreased and silt/clay lenses can be found. This fining up in grain size is expressed by a relatively low coefficient of hydraulic conductivity around $1x10^{-4}$ – $1x10^{-5}$.

Najafgarh

In this terrain silt to fine and sporadically medium size sands were found. These sediments were interpreted as alternating fluvial sequences distributed with a high spatial variance in thickness. The coefficient of hydraulic conductivity (kf) ranges between 5x10-4 – 8x10-4 for the younger alluvium unit and between $1x10^{-4}$ – $1x10^{-5}$ for the older alluvium unit.

Nizamuddin

In this terrain the unconsolidated sediments were divided in two units analogous to the Palla field site. At a depth of 30 m below ground level the quartzitic hardrock was encountered. Due to low permeability of the hardrock this unit is considered as a aquiclude.

4.4 Sampling campaigns

The objective of a good sampling campaign should be the collection of a representative sample of the current groundwater over a specified volume of the aquifer. To meet this objective, the sampling equipment, the sampling method, the piezometer construction and sample-handling procedures should not alternate the chemistry of the water sample.

In November 2006 sampling campaigns were carried out at the selected field sites. The samples were taken according to the DVWK 1992 guidelines. The minimum necessary equipment is:

- Steel tape with weight (used for measuring total depth of well)
- Depth-to-water measuring device (light plummet)
- Sampling pump (submersible pump, 12 V DC)
- Power supply (12 V DC accumulator, wire)
- Flow measurement equipment (water meter, stop watch)
- Flow-through cell (with measuring devices described in Appendix,Table 1)
- Decontamination supplies (distilled water, paper tissues)
- Sample bottles (20 ml polypropylene, water proof labels)
- Filtration equipment (cellulose filter, hand vacuum pump)
- Tool boxes (steel boxes with tools)

Water level and total well depth measurements

Photo 5 Measuring setup at a piezometer (flow-through cell, accumulator, light plummet, water meter)

The field measurements of total well depth and depth to water were done from a permanently-marked reference point. This reference point is the top of the iron case of the piezometer (top of piezometer).

The total depth of each piezometer was measured with a weight attached steel tape and documented in Appendix, Figures a1-a19. Additionally, the distance between top of the piezometer and ground surface was measured. The depth to water was measured with a light plummet prior to any other activities at the piezometer.

Static water volume

From the information obtained for casing diameter (here 4“ or 10.16 cm), total well depth and depth-to-water measurements, the volume of water in the well was calculated. This value is a criterion that was used to determine the volume of water to be purged from the well before the sample is collected.

The static water volume was calculated using the following formula:

$$V = \frac{d^2 \pi}{40} \cdot h \qquad \text{(eq.1.0)}$$

where:

V = Volume [L]

r = casing diameter [cm]

h = height of static water [m]

Piezometer purging volumes

In most cases, the groundwater in the piezometer casing can be of a different chemical composition than that in the aquifer. Solutes may be adsorbed or desorbed from the casing material, oxidation may occur, and biological activity is possible. Therefore, the static water within the well must be purged so that water is representative for the aquifer.

The removal of at least 3 piezometer volumes is suggested by many authors and guidelines (e.g. GIBB et al. 1981, WILDE et al. 1998, DVWK 1992) and was applied in this study. The amount of water to be removed was calculated according to eq. 1.0, multiplied by 3 and measured by a flow meter (**Photo 5**).

The number of purging volumes to be removed is based on the stabilization of hydrochemical/-physical parameters such as temperature (T), pH, oxidation-reduction potential (ORP), electrical conductivity (EC), dissolved oxygen (DO) and turbidity. These measurements were taken and recorded in certain time steps until the parameters were stable. The complete field protocol for sampling is shown in Appendix, Table a19.

Sampling procedure

In-situ parameters (pH, T, ORP, EC, DO) were measured with Eutech devices (Appendix, Table a1) in a flow-through cell. The flow-through cell consists of a transparent chamber through which water moves in a constant flow from the bottom to the top. The electrodes measure groundwater that has not yet been in contact with the atmosphere (**Photo 6**).

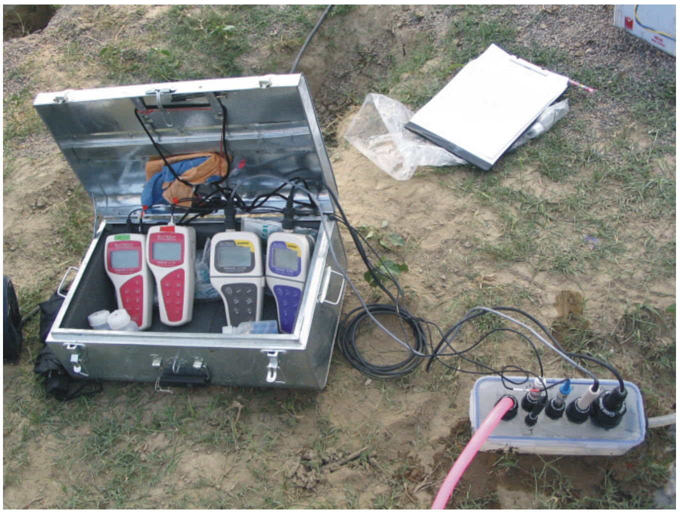


Photo 6 Measuring in-situ paramters on site (flow-through cell, measuring devices in steel box).

After the in-situ parameters were considered as stable the samples were taken and stored in 20 ml polypropylene (PP) bottles with watertight caps. All samples for ion determination were filtered on site with 0.2 mm acetate cellulose filters. The sample for cation measurements was acidified to pH 2 with ultra pure HNO_3 and one bottle of each sample (not acidified) was kept for anion determination. Additionally, one 20 ml PP bottle for each piezometer was taken for stable isotope (δD and δ18O) measurement.

Alcalinity was determined by HCl titration in field for the determination of the HCO3-species using a Merck Acidity test. Nitrite, ammonium and sulphide content were determined on site by colometric tests (Appendix, Table a2).

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