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WP5.2:

Combination of MAR and adjusted conventional treatment processes for an Integrated Water Resources Management

Deliverable 5.2.2:

Preliminary report on data of all inorganic substances and physicochemical parameters listed in the Indian and German Drinking Water Standards from surface water and groundwater at the 3 (+1) field sites

Report, May 2008

KOMPETENZZENTRUM Wasser Berlin

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Freie Universität Berlin

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Colophon

Title
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Preliminary report on data of all inorganic substances and physicochemical parameters listed in the Indian and German Drinking Water Standards from surface water and groundwater at the 3 (+1) field sites

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This report is:
PU = Public

Summary

The intention of the work package 5.2 is to analyze the function and relevance of managed aquifer recharge (MAR) techniques with a main focus on Riverbank Filtration (RBF) to enable sustainable water resources management, especially in developing or newly industrialized countries. For this aim three RBF sites in Delhi were equipped with groundwater observation wells and sampled monthly for determination of surface and groundwater quality. This report includes information of more than 150 samples from surface- and groundwater, which were analyzed for a broad series of chemical and physicochemical parameters. For each sample, physicochemical parameters were determined in situ (pH, T, ORP, EC, DO) along with alkalinity, nitrite, ammonia and hydrogensulphide content by the Freie Universität Berlin (FUB) and the Indian Institute of Technology, Delhi (IITD). Additionally, water samples were collected and prepared under appropriate conditions for analysis of inorganic substances (major ions, heavy metals and other inorganic substances) and stable isotopes at FUB laboratories and microbiological parameters and organic contaminants at IIT laboratories. At FUB, in general all parameters were determined monthly except for some heavy metals for which the analysis is very time consuming and costly. For these metals, three sampling campaigns (monsoon, pre- and postmonsoon) were selected for analysis to get an overview of possible contaminations. Investigations on RBF are being performed at three different field sites within the National Capital Territory of Delhi (NCT), two of them on the banks of River Yamuna (Palla and Nizamuddin) and one of them at it's major tributary in the Delhi stretch, called Najafgarh Drain (Najafgarh). At each of the field sites, at least five piezometers were constructed with varying depths and distances from the surface water. For each field site, groups of piezometers were built, to differentiate surface water and piezometers tapping shallow, medium and deep groundwater. For each parameter distribution and range of the values are shown with boxplots and compared to the German and the Indian drinking water standards. At the Palla field site positive effects during bankfiltration can be observed for several heavy metals like Pb, Al and Cu, while no significant changes or an increase in the concentration can be observed for Fe and Mn, respectively. Other substances like As, NO_2^- and Ammonia decrease during underground passage while no significant changes or an increase in the concentration can be observed for B and F, respectively. Only Fluoride exceeds the threshold for drinking water standard (Indian standard 1.5 mg/l) and must be considered as critical. At the Nizamuddin field site positive effects during bankfiltration can be observed only for one heavy metal (Al), while no significant changes can be observed for Pb and Cu and an increase in the concentration can be observed for Fe and Mn. Other substances like As, F and Ammonia increase during the underground passage while no significant changes or an decrease in the concentration can be observed for B and NO_2^-, respectively. At this field site elevated concentrations of several substances like As, Fe, Mn, F and NH4 will make a post-treatment necessary. At the Najafgarh field site the main constraints is the high salinity of the groundwater and the seasonal disavailability of fresh surface water. Due to the high mineralization of the groundwater a possible RBF site must be situated very close to the drain with shallow filter screens in order to obtain a high share of bank filtrate. The design and the potential capabilities of RBF facilities are currently subject to ongoing work and cannot evaluated finally. The sampling campaigns carried out so far are very useful to evaluate i) the seasonal changes in the surface

water and ii) the depth dependent changes of the ambient groundwater. It needs to be taken into account that nitrogen species will promote the occurrence of problematic substances like ammonia, nitrite or nitrate due to a load with untreated sewage. Fluoride is expected to be no problematic substance.

Preface

This report provides an overview on the water analysis performed during the studies on River Bank Filtration in Delhi, India within WP 5.2 of TECHNEAU integrated Project. It is a follow-up, based on report D 5.2.1, that includes a description of the motivation for research, regional information and detailed specifications on the location and environmental conditions at the field sites and field work performed for the study.

The data presented in the following report includes information of more than 150 samples from surface water and groundwater, which were analyzed for a broad series of chemical and microbiological parameters since December 2006. For each parameter distribution and range of values are shown and compared to drinking water standards.

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Abbreviations and units:

DJB - Delhi Jal Board (Delhi water supplier)

DW - Dug well (traditional shallow, open well with bricked wall)

EC - Electrical Conductivity [S/cm]

Eh - Redoxpotential [mV]

GS - German Standard specification for Drinking water (TrinkwV.)

GW - Groundwater

IS - Indian Standard for Drinking Water (IS 10500)

MAR - Managed Aquifer Recharge

mbgl - Meters below ground level

mg/L - Milligram per liter (1 mg/L = 1 ppm)

NA - Najafgarh Drain (Field site)

NI - Nizamuddin Bridge (Field site)

PA - Palla well Field (Field site)

ppm - Parts per million (1ppm = 1 mg/L)

PZ - Piezometer (observation well)

RBF - Riverbank Filtration

SW - Surface water

TDS - totally dissolved solids [mg/L]

1. Introduction

The intention of work package 5.2 of the TECHNEAU integrated project is to analyze the function and relevance of managed aquifer recharge (MAR) techniques with a main focus on Riverbank Filtration (RBF) to enable sustainable water resources management, especially in developing and newly industrialized countries. Within the study investigations on RBF are being performed at three different field sites in India. All the sites are situated within the National Capital Territory of Delhi (NCT), two of them on the banks of River Yamuna and one of them at it's major tributary in the Delhi stretch, called Najafgarh Drain. At each of the field sites, at least five piezometers were constructed with varying depths and distances from surface water (table 1 – 3). Groundwater sampling campaigns were carried out monthly by the Freie Universität Berlin (FUB) and the Indian Institute of Technology Delhi (IITD). Chemical and microbiological parameters were analyzed, in order to detect contaminants and characterize waters from different sources for detailed hydrogeological investigations.

A general descriptions of the objectives for this study, regional aspects and background work was summarized in TECHNEAU report D.5.2.1. The first report also contains detailed information on geological setting and environmental conditions at the field sites and a specification of sampling procedures.

The aim of this second report is to give an overview of all the substances of content in surface-and groundwater that was surveyed in the field and in the laboratories. For each parameter, the range and distribution are compiled and compared to German and Indian standards for drinking water. Whenever permissible limits are exceeded, the temporal and spatial distributions of the corresponding parameter are analyzed more in detail. An assessment on the potential sources and threats of the identified contaminants is given, with a summary on environmental behavior of the substances (mobility, stability, degradation, sorption, precipitation/dissolution, etc.) with reference to RBF.

2. Approach

2.1. Overview on sampling locations

Monthly sampling campaigns were carried out at three field sites. The three field sites were designed and equipped by the FUB. Between February and May 2007, an additional field site has been introduced on a construction site of the Delhi Metro Rail Corporation Ltd. (DMRC). The piezometers were drilled in cooperation of IIT and DMRC.

These field sites (3+1) present a broad variety of hydrochemical and hydraulic conditions in the surface water and the adjacent aquifer. In the following, a brief summary of the location and environmental conditions is given for each field site, with a data table containing information about the respective sampling points and the share of bankfiltrate. The proportion of bankfiltrate was estimated by using appropriate tracer substances (Cl^-, stable isotopes, temperature) and by analyzing the hydraulic conditions (table 1 – 3). A spatial overview is given in figure 1, more detailed information about the location and setup of the field sites can be found in TECHNEAU report D.5.2.1.

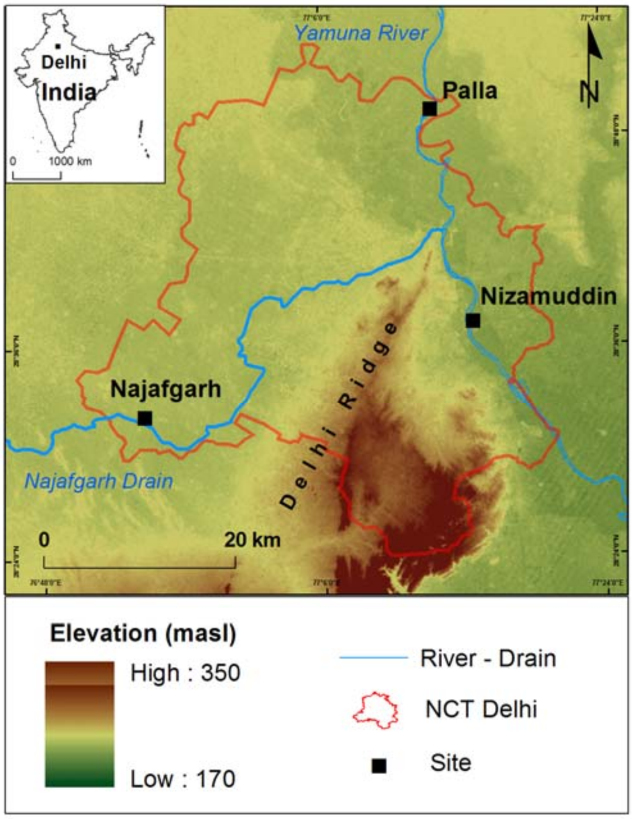

Figure 2 Location map of the three selected field sites with the geomorphology and the main river / drain.

1. Palla Well Field (PA) field site is located in the northern part of Delhi, on a flood plain on the western bank of the Yamuna River upstream of the urbanized parts of Delhi, where the contamination of river water is low. It is surrounded by a field of production wells of the local water supplier (Delhi Jal Board, DJB). Here, the meandering river has shifted its course during the monsoon floods in August 2007, so that the distance between the river and the piezometers has changed significantly.

Table 1 Specification of sampling points at Palla Well Field field site (PA).

Palla Well Field (PA)	Type	Distance from the river		Sampling depth (mbgl)	Share of bank filtrate (estimated)
Sampling point ID		before monsoon 2007	after monsoon 2007		
PA-SW	river	-	-	-	-
PA-PZ-1	piezometer	35 m	~ 200 m	6 - 9	high
PA-PZ-2	piezometer	35 m	~ 200 m	9 - 12	high
PA-PZ-3	piezometer	40 m	~ 200 m	42 – 48	absent
PA-PZ-4	piezometer	30 m	~ 200 m	10.5 –13.5	high
PA-PZ-5	piezometer	60 m	~ 230 m	10.5 – 13.5	high
PA-PZ-6	piezometer	60 m	~ 230 m	17-23	medium
PA-PZ-7	piezometer	80 m	~ 250 m	10-13	high
PA-TW-1	tubewell	75 m	~ 240 m	~ 5 – 54	medium

2. Najafgarh Drain field site (NA) is a channel located in the rural south-western part of the NCT on the Najafgarh Drain in a morphological depression. The region, east of the Delhi Ridge is characterized by relatively warm dry climate and the occurrence of saline groundwater. Gaining-river and loosing-river conditions change during the seasonal cycle (loosing river conditions meaning aquifer recharge during post monsoon season).

Table 2 Specification of sampling points at Najafgarh Drain field site (NA).

Najafgarh Drain (NA) Sampling point ID	Type	Distance from River	Sampling depth [mbgl]	Share of bank filtrate (estimated)
NA-SW	river	-	-	-
NA-PZ-1	piezometer	15 m	3.5 - 9.5 m	low - absent
NA-PZ-2	piezometer	15 m	18 – 24 m	very low - absent
NA-PZ-3	piezometer	15 m	31 – 37 m	absent
NA-PZ-4	piezometer	15 m	7.5 – 13.5 m	low - absent
NA-PZ-5	piezometer	28 m	4 – 10 m	low - absent
NA-DW	dug well	240 m	5 m	absent

3. Nizamuddin Bridge field site (NI) is situated in the urban central part of the city of Delhi, on the eastern bank of Yamuna River. Within this segment in central Delhi, the Yamuna River is highly contaminated by discharge of sewage and industrial wastewaters. Aquifer recharge takes place under "natural" conditions probably due to groundwater abstraction to the east. In November and December 2007, this field site has been upgraded by the construction of additional piezometers in cooperation of IIT Delhi and FUB.

Table 3 Specification of sampling points at Nizamuddin field site (NI).

Nizamuddin Bridge (NI)		Type	Distance from River	Sampling depth [mbgl]	Share of bank filtrate (estimated)
Sampling point ID					
NI-SW		river	-	-	-
NI -PZ-1		piezometer	50 m	4 – 7 m	high
NI -PZ-2		piezometer	50 m	7 – 13 m	medium
NI -PZ-3		piezometer	50 m	31 – 37 m	absent
NI -PZ-4		piezometer	90 m	6.5 – 9.5 m	high
NI -PZ-5		piezometer	50 m	6 – 9 m	high
Upgrading Nov/Dec 2007	NI-PZ-2a	piezometer	2 m	2.6 – 3.4 m	high
	NI-PZ-2b	piezometer	3.5 m	2 – 2.8 m	high
	NI-PZ-2c	piezometer	5 m	3.1 – 3.9 m	high

4. DMRC field site is located on the Yamuna river in central Delhi, about 2 km upstream the NI-field site, so environmental conditions are similar to field site number 2. The construction of the additional field site was an initiative of the partners from IIT Delhi, who selected the location and assigned for the drilling. The details concerning well location, well design and stratigraphy have not been transferred completely, so a description of the field site can not be given yet. The seven piezometers at the field site were introduced in the sampling program to achieve additional information about the groundwater conditions at Yamuna in central Delhi. As they were constructed with delay and were not monitored monthly, only one or a few samples are available for each point. The analytical results from the DMRC site are not considered in this report, because the available data is not sufficient for a statistically representative analysis. For further investigations, however, the samples may be useful to compare specific parameters and hydrogeochemical conditions to the very similar field site at Nizamuddin Bridge.

2.2. Sampling Schedules, Parameters and Analysis

Both, surface water and ground water quality at riverbank filtration sites can react highly sensitive to seasonal changes, due to the fluctuations of water levels, flow velocities, mixing proportions, source water quality and other reasons. Besides, seasonal changes in surface water characteristics like the concentration of tracer substances or temperature can often be re-detected in adjacent groundwater and give valuable information on travel times. It has therefore been intended to sample all piezometers on a monthly schedule.

Sampling campaigns have been scheduled monthly, in order to be able to track seasonal peeks. A table of all sampling locations is attached in the appendix, with an indication of the months in which they were sampled.

For each sample, physicochemical parameters were determined in situ (pH, T, ORP, EC, DO) along with alkalinity, nitrite, ammonia and hydrogensulphide content by the FUB and the IIT. Additionally, water samples were collected and prepared under appropriate conditions for analysis of inorganic substances and stable isotopes at the FUB laboratories and microbiological parameters and organic contaminants at the IIT laboratories. At the FUB, in general all parameters were determined monthly except for some heavy metals for which the analysis is very time consuming and costly. For these metals, three sampling campaigns (pre- / post- and monsoon) were selected for analysis to get an overview of possible contaminations.

2.3. Drinking Water Specifications

The aim of WP 5.2 is to identify managed aquifer recharge by RBF as a suitable (pre-) treatment method for drinking water production. Therefore it is necessary, to analyze the range of contamination in the surface water and the purification capacity of riverbank filtration as well as the potential risk of contamination of bank filtrate by chemical interaction or mixing with ambient ground water. To identify the grade of pollution at each sampling point and evaluate the risk for human health, the results of all analyses are compared to drinking water standards. Drinking water standards are developed for different parameters to protect the consumers from any health related risk related to the ingestion of water. For other parameters, they are defined to guarantee an acceptable quality concerning taste and physical properties of potable water for the consumer. Another concern is to protect the water supply infrastructure from damage through corrosion, encrustation, etc. In this report, the German standard (in the following referred to as GS) and the Indian standard (in the following referred to as IS) are taken into account.

GS - German standard for drinking water (GS)

The German standard specifications for drinking water are defined in the "Trinkwasserverordnung" (TrinkwV) as a federal law. Regulations were redefined in the amendments of 2001 (TrinkwV 2001) to implement the European Community legislation of 3 November 1998 on the "quality of water intended for human consumption". The main principle of the TrinkwV is to assure the purity and aesthetics to protect the consumer's health from any harm related to the contamination of water intended for human usage.

IS - Indian standard specifications for drinking water (IS 10500)

In India, the national agency responsible for all matters concerning standardization, certification and quality assurance is the Bureau of Indian Standards (BIS). The Bureau of Indian Standards prescribes the quality of drinking water in its BIS 10500-1991 (reaffirmed 1993) standards, which list physical, chemical and biological quality parameters. For most of the parameters there are two values indicated, a requirement (desirable limit) and a permissible limit which can be tolerated ("limit in the absence of alternate source"). For others, especially the highly toxic parameters, a relaxation of the desirable limit is not permitted.

2.4. Statistical treatment of data

For this preliminary interpretation of the data, representative datasets were selected and analyzed with SPSS software. The data is presented in Box-and-Whisker plots (also referred to asbox plots), which give a quick overview on the range and distribution of values for each parameter and make it easy to compare different datasets and to spot differences in distributions, because the overall spread and quartiles are immediately apparent.

An example for a Box-and-Whisker plot is given in figure 1. The diagram shows the range of non-outlier values on a line with an upper and lower limit. On that line, a limits of the box mark the third quartile (75%-percentile: 75 % of the values lie below this score) and first quartile (25%-percentile), the median (50%-percentile) is indicated separately by a line within the box. The box length is the called interquartile range (IQR). Cases with values between 1.5 and 3 IQR lengths from the upper or lower edge of the box are marked as outliers (symbol: circle), cases with values more than 3 IQR lengths from the upper or lower edge of the box are marked as extreme cases (symbol: star). For this report, tolerance limits from standard specifications for drinking water are marked in the plots with arrow symbols. Arrows indicating the German standard's limit (GS) are directed to the right and those indicating the Indian standard limits (IS) are directed to the left.

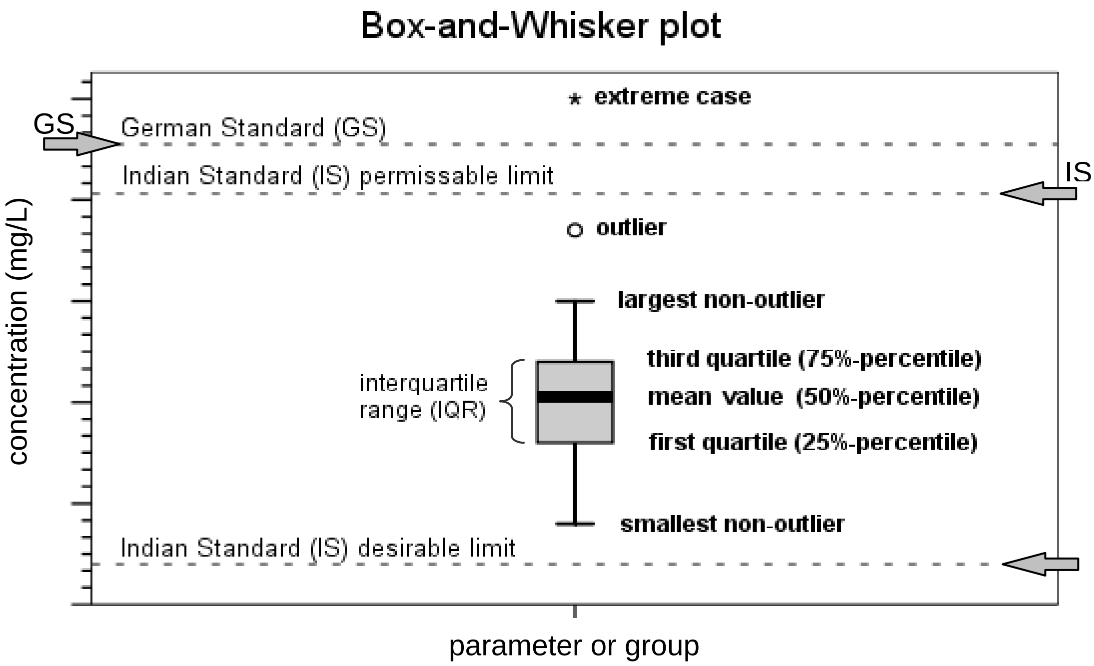

Figure 3 Example of a Box-and-Whisker plot and marks for national tolerance limits.

Detection limits for all parameters are summarized in the appendix. In many samples, the concentration of a specific parameter is below the detectable limit so instead of a quantitative value it is marked as "bdl" (below detection limit) in the database. For many statistical methods, it is necessary to have a quantitative value for each case, so a substitution of these fields by a number was necessary. The substitution of "bdl"-fields by the detection limit value leads to an overestimation and a substitution by zero leads to an underestimation of the parameter. Thus for these fields it is common practice to use the half of the detection limit value for a simple substitution in statistical analysis (DVWG 1999). After applying this, it was possible to plot the dataset in box plots and on logarithmical scales. It is important to remember, however, that in many cases the minimum values in the plots are not to be interpreted as realistic concentrations. Due to the huge amount of samples and parameters it does not make sense, to display every singe value or to distinguish all single sampling locations. For each field site, groups of piezometers were built, to differentiate surface water and piezometers tapping shallow groundwater in three groups:

1. Shallow piezometers with considerably higher amounts of bank filtrate and higher risk of anthropogenic contamination.
2. Piezometers at medium depths with a lower share of bank filtrate or anthropogenic influence or representing mixing of shallow and deep groundwater.
3. Deeper groundwater without bank filtrate or notable influence from anthropogenic contamination.

3. Results

3.1. Physicochemical Parameters

During the sampling campaign, pH value, electrical conductivity (EC), redox-potential (ORP), dissolved oxygen (DO) and water temperature (T) were monitored in situ. Limits for EC/TDS and pH values are defined in the GS and IS drinking water standards and can be compared to the results from the sampling campaigns within this chapter. ORP, DO and T are the controlling parameters for many (bio-)chemical processes within natural waters, but as they are not directly health relevant and limits are not defined, they are not considered within this report.

pH value

Mathematically, the pH value is the negative logarithm with the basis 10 of the concentration of the hydrogen-ion (proton). According to WHO (2004) guidelines the pH has no direct impact on human health, but is considered one of the most important operational water quality parameters. It controls the solubility and hydrochemical parameters (?) of a series of chemical parameters. Values at the different sampling points at each field site are shown in figure 2.

The GS therefore prescribes a pH in the range between 6.5 and 8.5. The IS does not permit values lower than 6.5 or higher than 9.5 because "beyond this range the water will effect the mucous membrane and / or water supply system". Figure 2 shows the distribution of pH values at the different sampling points.

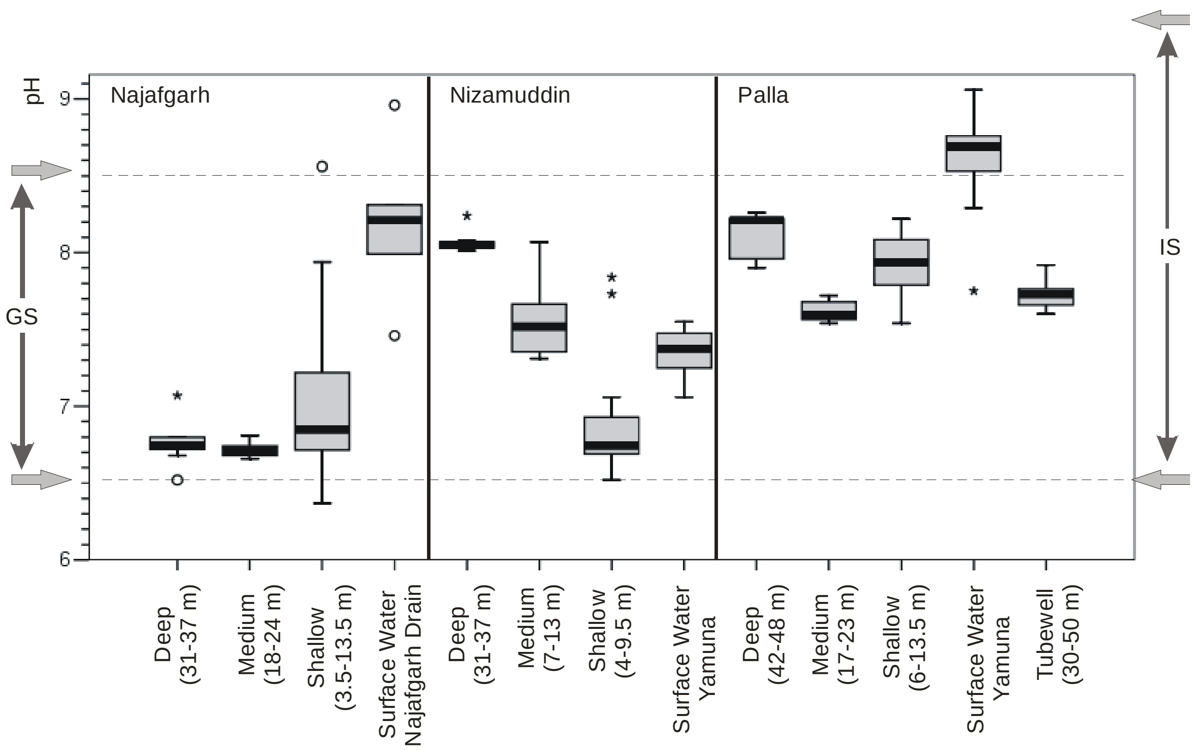

Figure 4 pH values at the three field sites and tolerance limits of drinking water standards.

Except from a few outliers, the values generally remain within GS limits. IS limits are only exceeded by the water of the Yamuna River at Palla field site, where the surface water remains in equilibrium with the atmospheric CO_2 pressure and is relatively free of contaminants and dissolved salts. At Palla field site, increased CO_2 fugacity in the subsoil and aquifer leads to higher concentrations of HCO_3 and lower pH values.

Electrical Conductivity (EC) and Totally Dissolved Solids (TDS)

The electrical conductivity of water is a function of the concentration of dissolved ions, so it is closely related with the TDS value. It comprises the solute of inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and small amounts of organic matter that are dissolved in water (WHO 2004). In groundwaters, the major part of the ions originates from natural sources (solution of salts, water- rock interactions, mixing etc.) or anthropogenic sources like seepage of agricultural runoff or urban wastewater. In practice EC can be measured in field easily and TDS values are sometimes calculated from EC values by a simple multiplication with a conversation factor (f):

$$\text{TDS (mg/L)} = \text{EC } (\mu\text{S/cm at } 25°\text{C}) * f$$

For a more scientific approach it has to be considered that the conversation factor depends on the ionic composition i.e. the ratios between different ions. Varying conversation factors are in use (0.5, 0.6, 0.65, …), which produce specific errors for different water types. To avoid these errors, in this study TDS will be calculated as the actual evaporation residue from the sum of concentrations of all major ions according to Freeze and Cherry (1979):

$$\text{TDS(mg/L)} = [Ca] + [Mg] + [Na] + [Fe] + [NH_4] + [Cl] + [SO_4] + [NO_3] + [HCO_3]/2$$

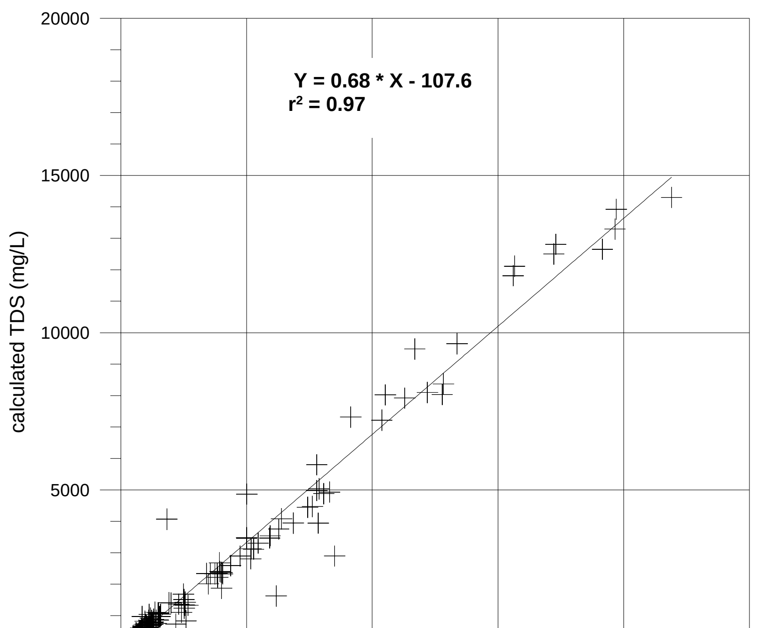

Figure 5: TDS vs. EC with regression line.

According to the WHO (2004) guideline there is no relevant data on "possible health effects associated with the ingestion of TDS". Nevertheless, high contents of dissolved solids in water will create a salty or unpleasant taste, as well as extremely low concentrations of TDS may have a flat, insipid taste.

The GS does not regulate TDS in drinking water but prescribes EC values to be below 2500 µS/cm. In the IS, there is no regulation for EC, but a limitation for totally dissolved solids (TDS) instead, with a desirable limit of 500 mg/L and a permissible limit of 2000 mg/L. According to the regression line (figure 3) the TDS limits in the IS were divided by 0.68 and then compared with the GS in figure 4.

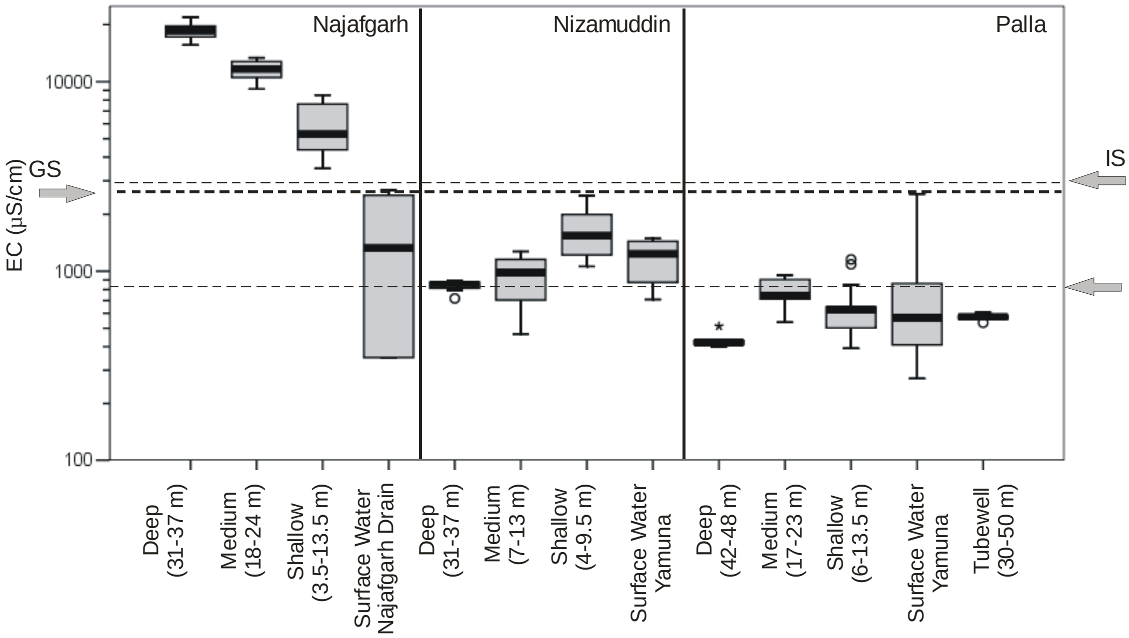

Figure 6: Distribution of electrical conductivity at the three field sites and tolerance limits of drinking water standards.

3.2. Inorganic Ions

3.2.1. Reliability check

The amount of positive ions and complexes with consideration of their valency and the amount of negative ions and complexes must be equal. The hydrochemical analysis of the major ions, given in mg/L, were transformed to mmol(eq)/L [(meq/L)] and the electrical balance was calculated according to (DVWK 1992):

$$\text{balance}(\%) = \frac{\sum \text{Cations} - \sum \text{Anions}}{\left(\sum \text{Cations} + \sum \text{Anions}\right) \cdot 0.5} \cdot 100 \qquad \text{(eq. 3.1)}$$

Analyses higher than 5% according to equation 3.1 were considered as failed. Figure 5 shows all measured samples (n = 181), 12% (n=22) of the samples are out of the tolerance limit and therefore not used for further calculations. Previous to exclusion the, samples with an ion balance greater than 5 % were measured two times to exclude analytical errors.

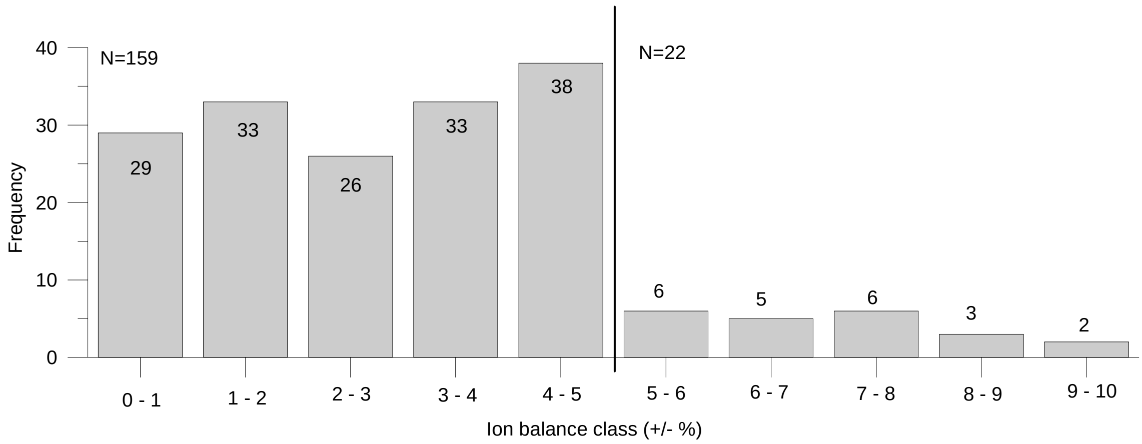

Figure 7 Electrical balances vs. frequency of measured samples.

3.2.2. Major Ions

In this section the major ions are evaluated according to their relation to the German standard of drinking water (GS) and the Indian standard (IS). Figure 6 shows the distribution of major ion concentrations in box plots on a logarithmical scale for all sampling points. The arrows mark the limit of the GS (right directed) and Indian IS-10500 (left directed; lower arrow = desirable limit, upper arrow = permissible limit).

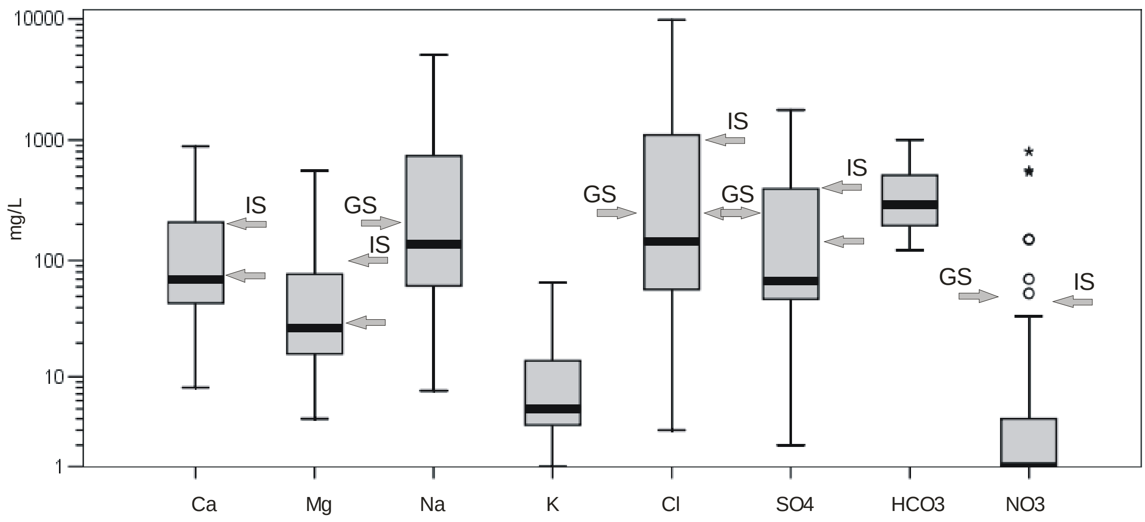

Figure 8	Major ions vs. concentration of all samples. Arrows indicate the drinking water standards for India (IS) and Germany (GS).

For potassium (K) and there is no standard, neither in the GS nor in the IS-10500 and for hydrogen carbonate (HCO_3) a limit is defined indirectly by the alkalinity specification of the IS. Maximum concentrations for all other parameters are limited in one of the specifications. The box plots show that median values for each parameter lie below the desirable and permissible limits, indicating that more than 50 % of the samples can be regarded suitable for drinking water supply. However, except for Magnesium (Mg) at least 25% of the values for each parameter exceed the permissible limits. Potassium and chloride concentrations reach values of up to 20 times the permissible contents. Nitrate limits are exceeded by a few outliers, which may reach values 10 times higher than the permissible limit.

To get a better understanding of the spatial distribution of "problematic parameters", plots for each parameter and field site where concentrations exceeded the drinking water threshold are given in the following,.

<u>Alkalinity / Hydrogen Carbonate</u>

The concepts of alkalinity (acid-neutralizing capacity) and acidity (base neutralizing capacity) are extremely important in characterizing the chemical status of natural waters. The alkalinity and acidity of a solution is always defined with respect to the pH. All samples have pH values below 9, and due to the distribution equilibrium, HCO_3-becomes the dominant carbonate specie. The concentration of carbonate species is detected by a titration with HCl, to measure the buffering capacity of water against changes in pH. The indicator methyl orange was used to detect the pH endpoints. Since the alkalinity of natural water changes very fast when it comes in contact with the atmosphere this parameter was detected in the field. The alkalinity values of the ground waters from the three field sites therefore approximately correspond to the HCO_3 concentrations shown in figure 7.

In the GS, there is no regulation regarding hydrogen carbonate or alkalinity, but the IS does not permit alkalinity values to exceed a desirable limit of 200 mg/L or a permissible limit of 600 mg/L, respectively, because “beyond this limit taste becomes unpleasant”.

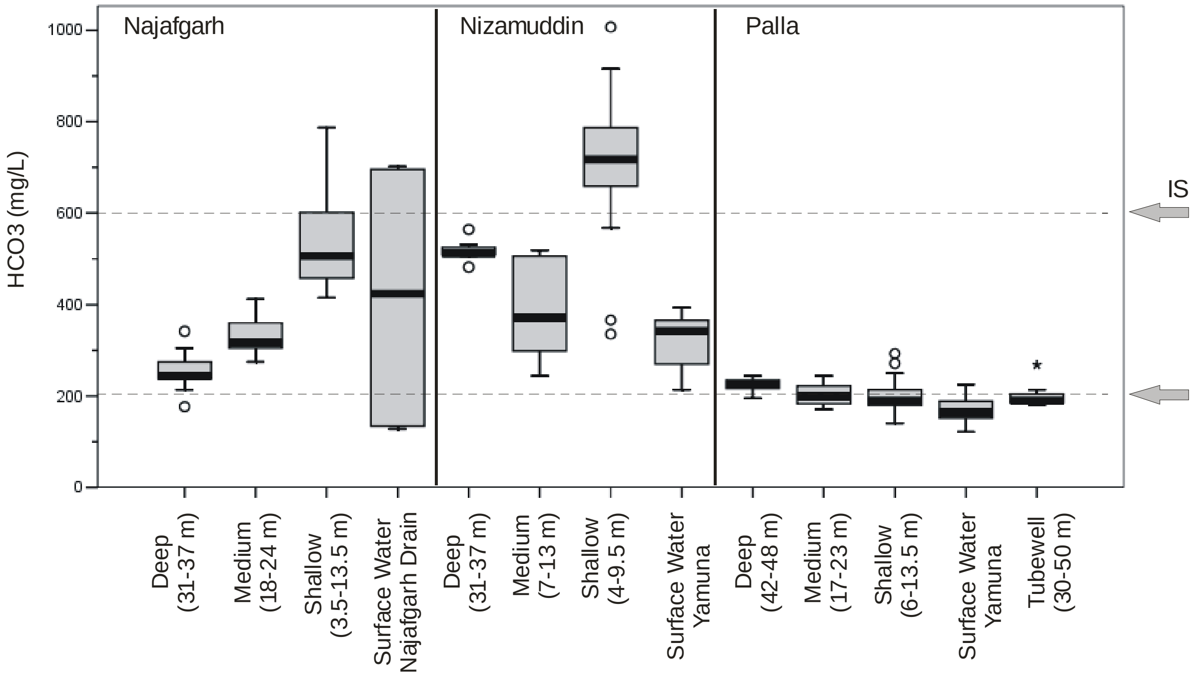

Figure 9 Distribution of hydrogen carbonate concentrations at the three field sites and tolerance limits of drinking water standards

Calcium

For calcium only an Indian standard exists. The desirable limit is at 75 mg/L and can be relaxed up to 200 mg/L. Only in Palla the Ca values are always below the IS and therefore suitable for drinking water. The high mineralization at Najafgarh drain leads to a high content in all alkaline and earth alkaline elements.

At Nizamuddin Bridge, the composition of river water and groundwater differ in their content of Mg (Figure 9), Ca (Figure 8) and HCO_3^-, indicating ongoing carbonate dissolution in the shallow and medium part of the aquifer.

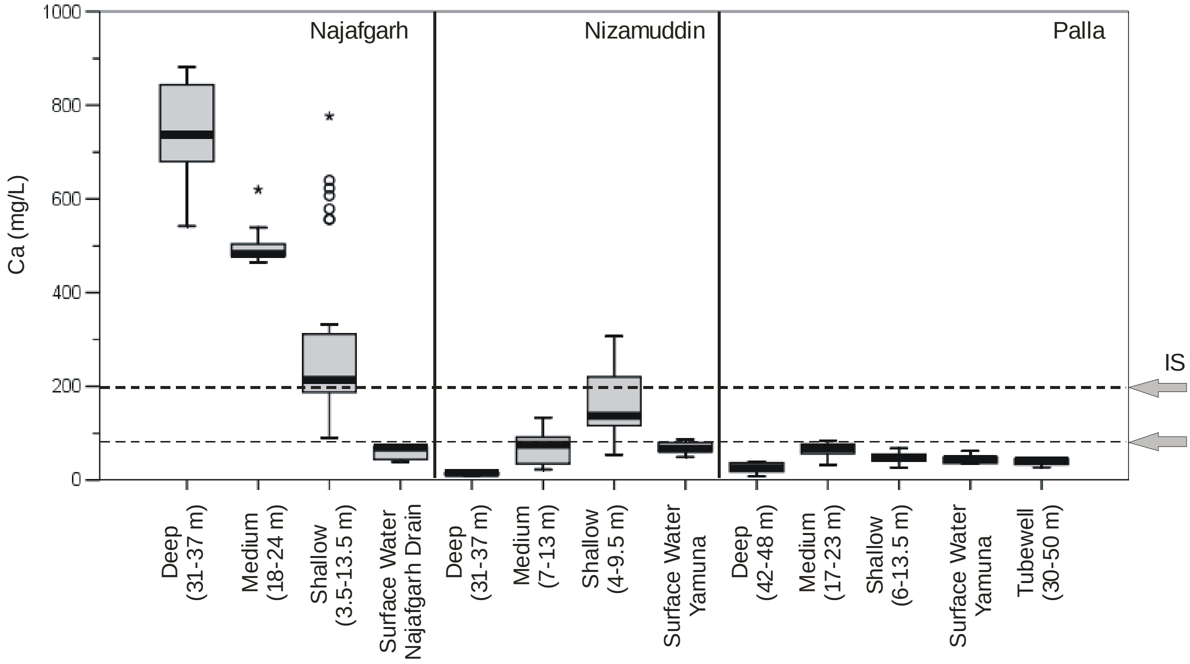

Figure 10 Distribution of calcium concentrations at the three field sites and tolerance limits of drinking water standards.

<u>Magnesium</u>

For magnesium only an Indian standard exists. The desirable limit is at 30 mg/L and can be relaxed up to 100 mg/L. The distribution of Mg at the different field sites is similar to that of Ca (Figure 10) and can be related to the same processes (see above).

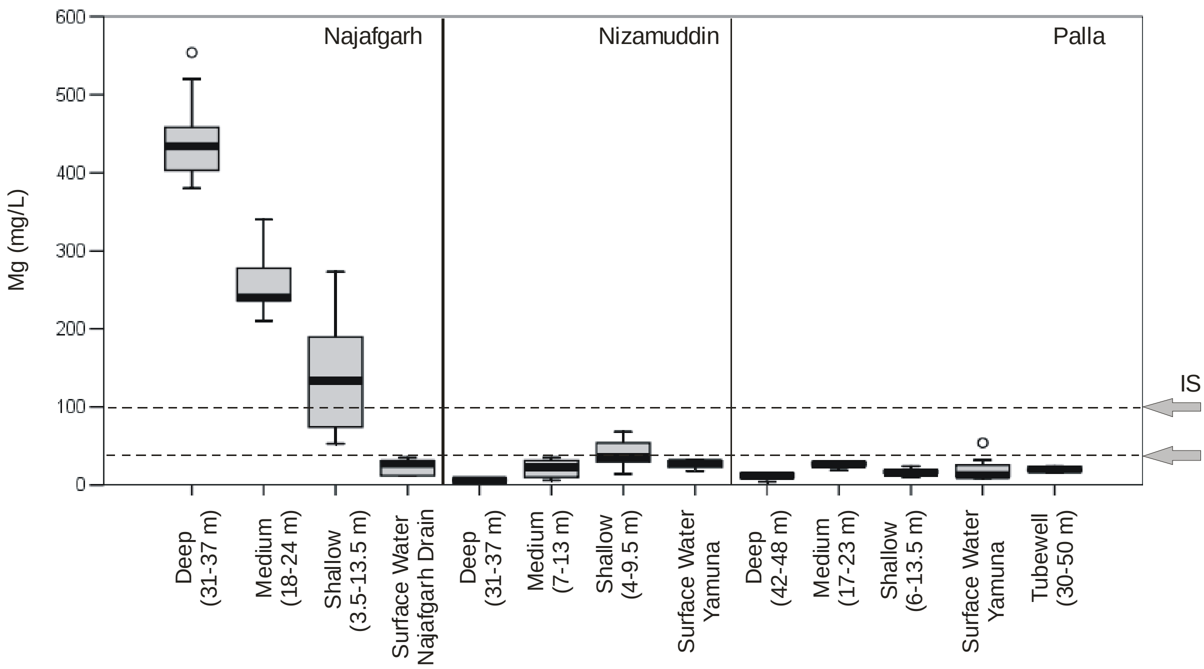

Figure 11 Distribution of magnesium concentrations at the three field sites and tolerance limits of drinking water standards.

Sodium

For sodium only a German standard exists at a limit of 200 mg/L, which can be detected by a salty taste. This is more an aesthetic objective than of health concerns, because sodium is not toxic (Figure 11).

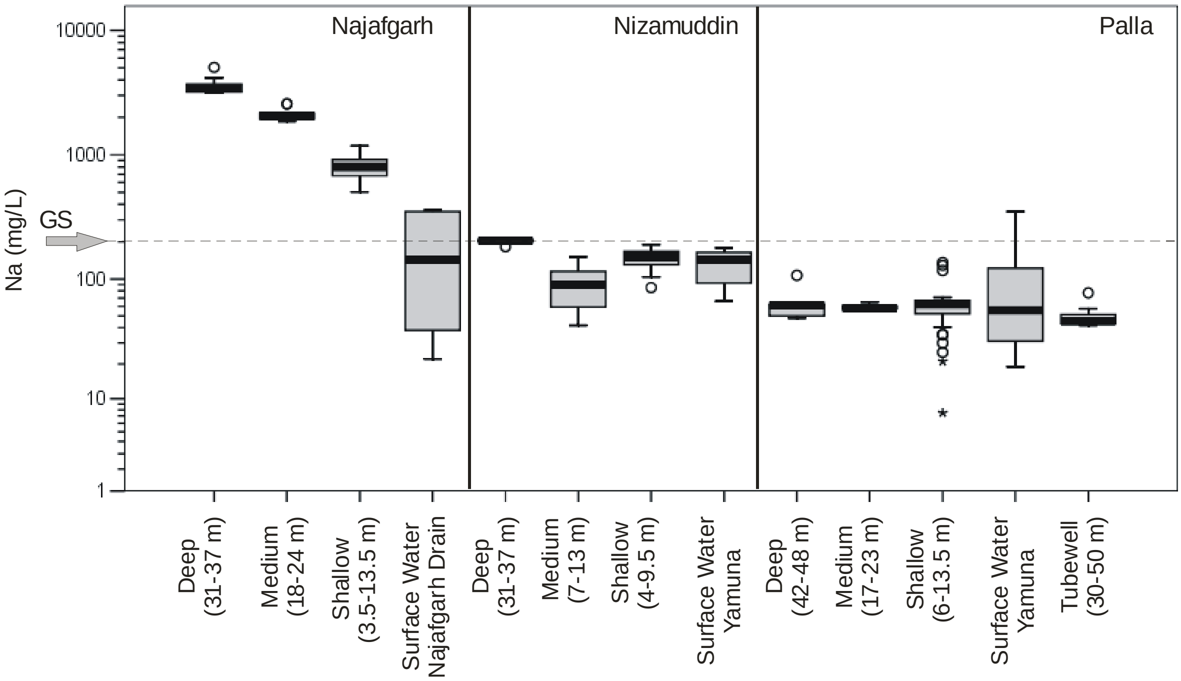

Figure 12 Distribution of sodium concentrations at the three field sites and tolerance limits of drinking water standards.

Chloride

For chloride a drinking water standards exist for the GS at 250 mg/L and for the IS at 250 mg/L which can be extended up 1000 mg/L.

Chloride concentrations below 250 mg/L cannot be tasted by humans, above this limit the water will taste brackish or salty. Only in Nizamuddin the Cl content is below the threshold. In Palla only the Yamuna River exceeds the limit sometimes. In Najafgarh the groundwater bears always Cl concentrations above the threshold. The drain shows a broad variation because it is acting in the rainy season as flood drainage. During this period the Cl content is low (~ 100 mg/L) while in the dry season the drain will be getting successively saltier (Figure 12).

Excessive chloride concentrations increase rates of corrosion of metals in the distribution system, depending on the alkalinity of the water. This can lead to increased concentrations of metals in the supply. Depending on pH and alkalinity, hardness above about 200 mg/L can result in scale deposition, particularly on heating.

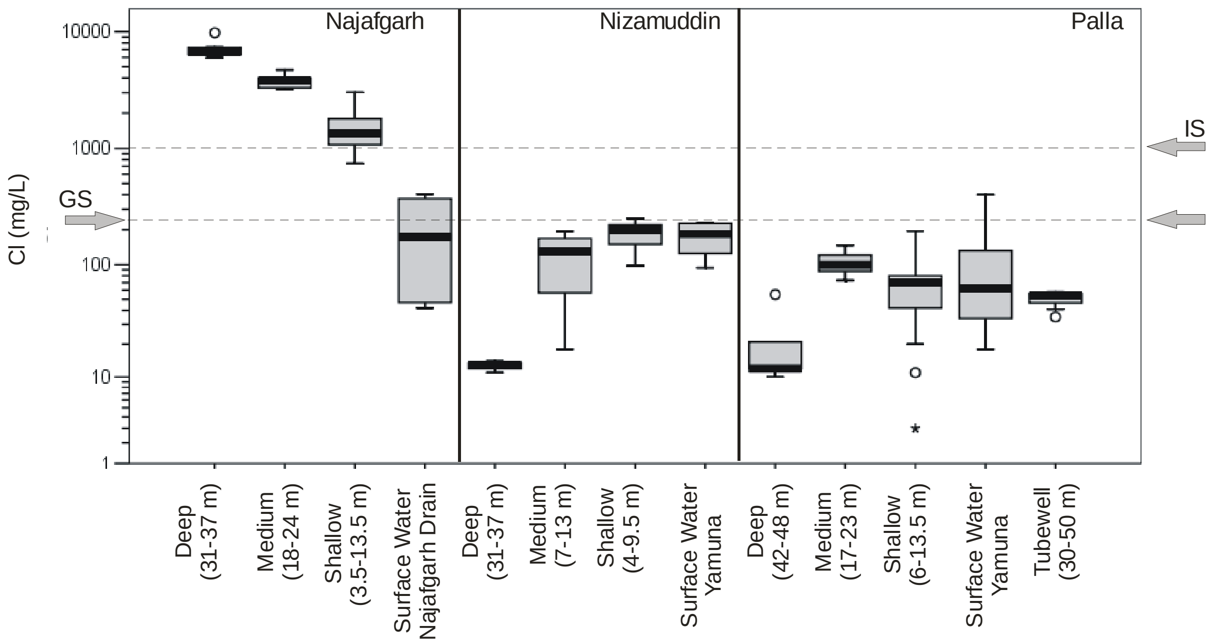

Figure 13 Distribution of chloride concentrations at the three field sites and tolerance limits of drinking water standards.

Sulfate

For sulfate a drinking water standards exist for the GS at 240 mg/L and for the IS at 150 mg/L and can be extended up 400 mg/L. The presence of sulfate in drinking water above 150 mg/L may result in noticeable taste. The taste threshold concentration, however, depends on the associated metals present in the water. High levels of sulfate may be associated with calcium, which is a major component of scale in boilers and heat exchangers. In addition, sulfate can be converted into sulfide by some anaerobic bacteria creating odour problems and potentially greatly accelerating corrosion (Figure 13).

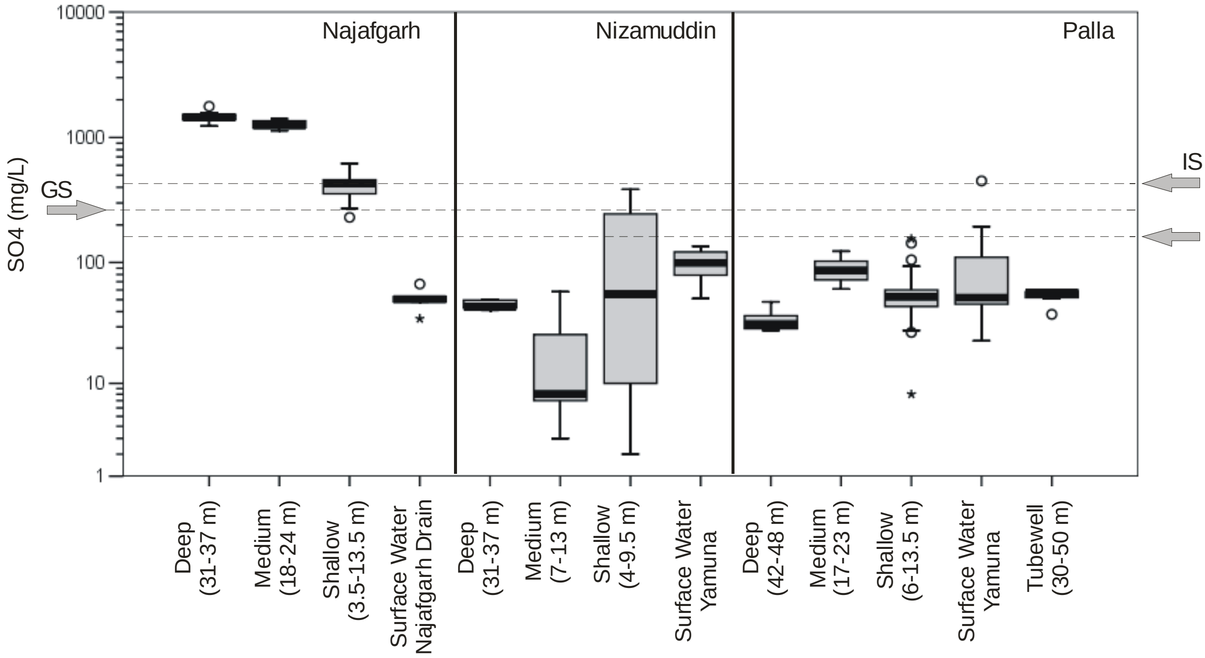

Figure 14 Distribution of sulphate concentrations at the three field sites and tolerance limits of drinking water standards.

<u>Nitrate</u>

For nitrate a drinking water standards exist for the GS at 50 mg/L and for the IS at 45 mg/L and no relaxation is allowed.

Nitrate as a species of the nitrogen cycle occurrs in natural groundwater but in high concentrations it can be regarded as a contaminant due to its harmful biological effects. According to the WHO (2004) guideline it is especially dangerous for infants, because in their stomach it can be reduced to nitrite and cause the "blue-baby syndrome". High concentrations have also been reported to be a risk factor in developing gastric an intestinal cancer. The main source of nitrate pollution in the groundwater results from agriculture.

According to Datta (1997) nitrate contamination of groundwater in Delhi is generally associated with agricultural activities, but domestic sewage, industrial waste, livestock feeding operations and septic tanks, etc. are additional point sources. The extent to which each of these sources adds to the nitrate problem in the Delhi area is unknown.

In groundwater that is oxidizing (e.g. Palla), NO_3^- is the stable form of dissolved nitrogen. It moves with the groundwater and experiences no chemical transformation and little, or no, retardation (Freeze and Cherry 1979). Therefore the decrease of nitrate from the surface water to the tubewell is due to a dilution effect with deep, nitrate free ambient groundwater.

In ground- or surface water that is highly reducing (e.g. Nizamuddin), NO_3^- is not stable and will be transformed to ammonia. In the highly reactive shallow groundwater nitrate can be transformed to ammonia (NH_4^+) by microbiological reduction. Here a slight increase in NO_3^- towards depth can be observed (Figure 14).

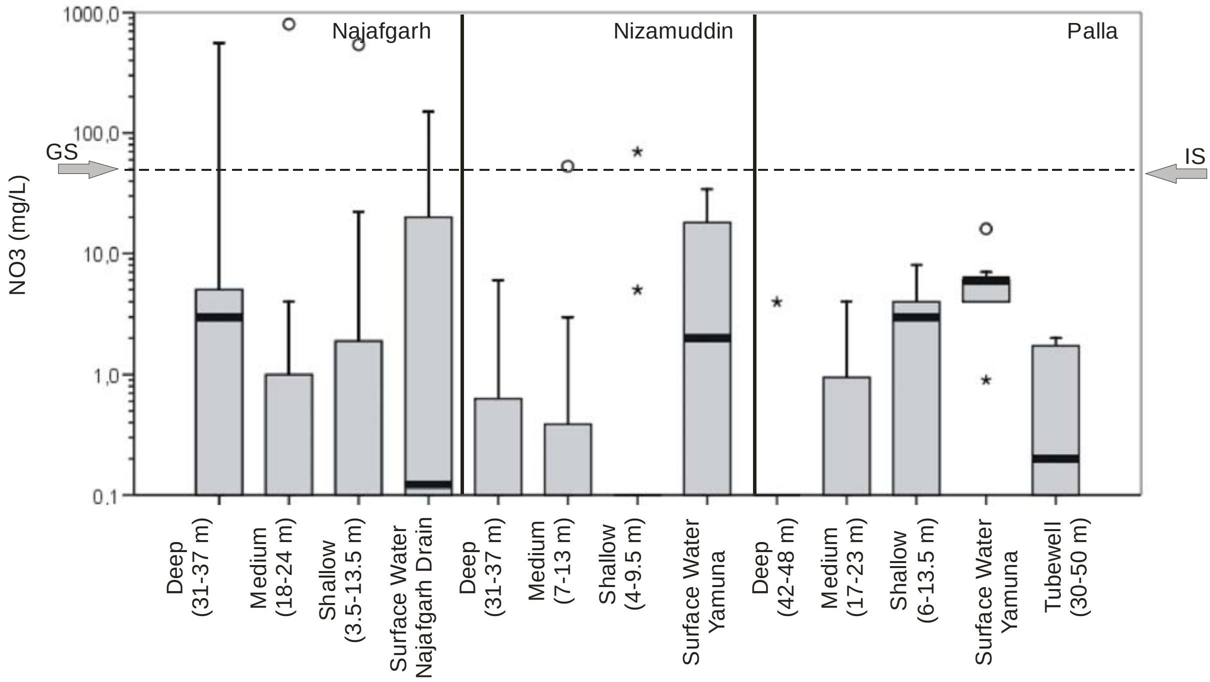

Figure 15 Distribution of nitrate concentrations at the three field sites and tolerance limits of drinking water standards.

3.2.3. Heavy Metals

There are different definitions for the term "heavy metal" which have no scientific basis in common. In technically usage, the group generally includes metals with a high density, while medically it can include all kind of toxic metals and semi-metals. Sometimes arsenic is listed as a heavy metal, but it is in fact a metalloid, and will therefore be included in the following chapter.

Table 4 Overview on the results of heavy metal analysis compared to drinking water standards..

	Results compared to drinking water standards:
Iron (Fe)	Many samples exceed IS and GS limits.
Manganese (Mn)	
Aluminium (Al)	Most samples are below IS and GS limits.
Lead (Pb)	All samples are below IS, few samples exceed GS limits.
Copper (Cu)	All samples below permissible limits, few exceed IS desirable limits.
Zinc (Zn)	
Nickel (Ni)	All samples remain below IS and GS limits.
Chromium (Cr)	
Mercury (Hg)	Below GS and IS and below detection limit in all samples
Cadmium (Cd)	
Molybdenum (Mo)	No limits defined in IS or GS (not considered to be health relevant in drinking water).
Cobalt (Co)	
Antimony (Sb)	

The monitoring of heavy metals includes 13 parameters (table 4). Some of them can be considered as critical, whereas others are not of any health concern whereas others are below IS and/or GS (table 4). Whenever drinking water permissible limits for one heavy metal are exceeded in surface- or groundwater, this parameter is described separately with an overview on the concentrations at each sampling point within this chapter.

<u>Aluminium</u>

There is little indication that orally ingested aluminum is acutely toxic to humans. In the IS, it is mentioned, that cumulative effect is reported to cause dementia and in the WHO guidelines it is mentioned that the exposure has been hypothesized a risk factor for the development or acceleration of Alzheimer disease. Anyhow, the contribution of drinking-water to the total oral exposure to aluminum is low compared to the intake from foods, particularly those containing aluminium compounds used as food additives. Due to the widespread use of aluminium salts as coagulants in water treatment it can often be found in increased concentrations in treated water (WHO 2004).

The IS desirable limit for aluminium is at 0.03 mg/L, whereas for the IS permissible limit and GS the indicated value is 0.2 mg/L.

Figure 15 shows that high aluminium concentrations are not a problem in the majority of the samples, but the limits can be exceeded at all the three field sites. Concentrations in surface water are highest at Nizamuddin, possibly due to the content of treated wastewater. The high Al content in the deep groundwater in Palla is of geogenic origin and may be attributed to Kaolinite or Gibbsite minerals.

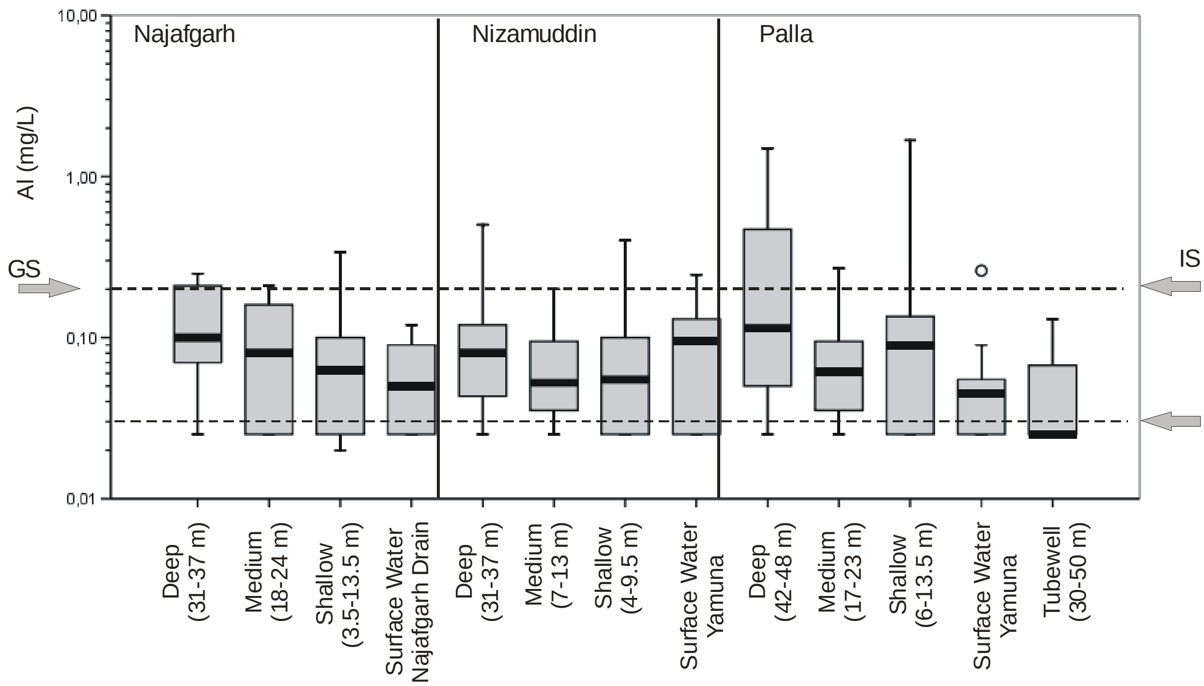

Figure 16 Distribution of aluminium concentrations at the three field sites and tolerance limits of drinking water standards

Copper:

In the WHO (2004) guidelines, copper is described as both, an essential element for human nutrition and a drinking-water contaminant. The sources for human exposure are food but also drinking water, however, the concentrations in the source water are generally low and increase in the distribution system, especially those with an acid pH or high-carbonate waters with an alkaline pH. High concentrations of copper in drinking water should be avoided to prevent gastrointestinal effects and "provide an adequate margin of safety in populations with normal copper homeostasis" (WHO 2004).

In the IS the desirable limit for copper is defined at 0.05 mg/L but can be exceeded up to 1.5 mg/L (permissible limit), with the justification that beyond these limits it can cause an "astringent taste, discoloration and corrosion of pipes, fitting and utensils". The GS is set at 2 mg/L.

Figure 16 illustrates, that copper concentrations in the sampled waters are no threat to public health: the concentrations off all samples are at least 10 times lower than the GS limit and IS permissible limit and only some outliers exceed the IS desirable limit. Since all samples plot below the IS threshold this parameter is considered as not problematic.

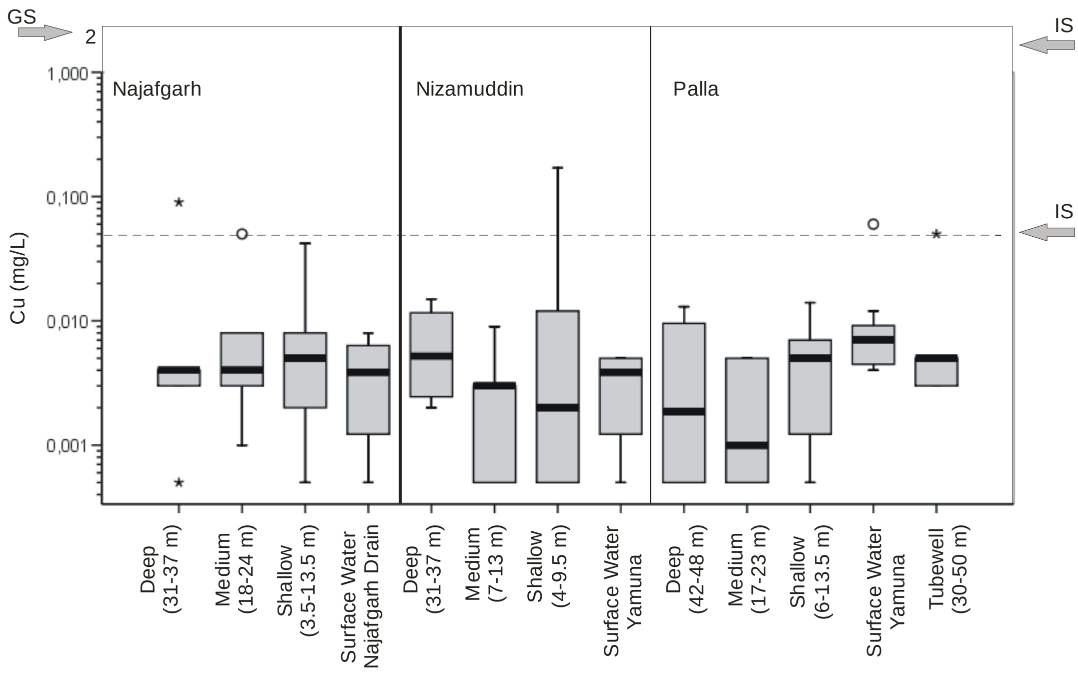

Figure 17 Distribution of copper concentrations at the three field sites and tolerance limits of drinking water standards.

Lead

The WHO (2004) describes lead as a cumulative poison that is especially dangerous to infants, children up to 6 years and pregnant women. It is considered to be toxic to both the central and peripheral nervous systems and may amongst others cause neurological and carcinogenic effects even at very low concentrations of exposure. Concentrations observed in raw water for drinking water are generally low (< 5 mg/L) but may increase significantly before it reaches the consumer in old buildings with plumbing and fittings containing lead.

The GS and IS prescribes limit at 0.01 mg/L and 0.05 mg/L with no relaxation permitted, because of the toxicity of lead. Except of one water sample from Palla field site, all of the samples had values below the IS. In Palla an equilibration effect can be observed by comparing the high load of Pb in the surface water samples with the low concentration of the tubewell samples.

The GS is exceeded by the water of the Yamuna river at Palla and Nizamuddin field site and at several piezometers even at Najafgarh drain. However, all median values lie clearly below 0.01 ppm. In summary in Palla the tubewell samples all lie below the desirable limit of the GS and therefore Pb is considered as a non problematic substance while in Nizamuddin the Pb content must be addressed to post-treatment (Figure 17).

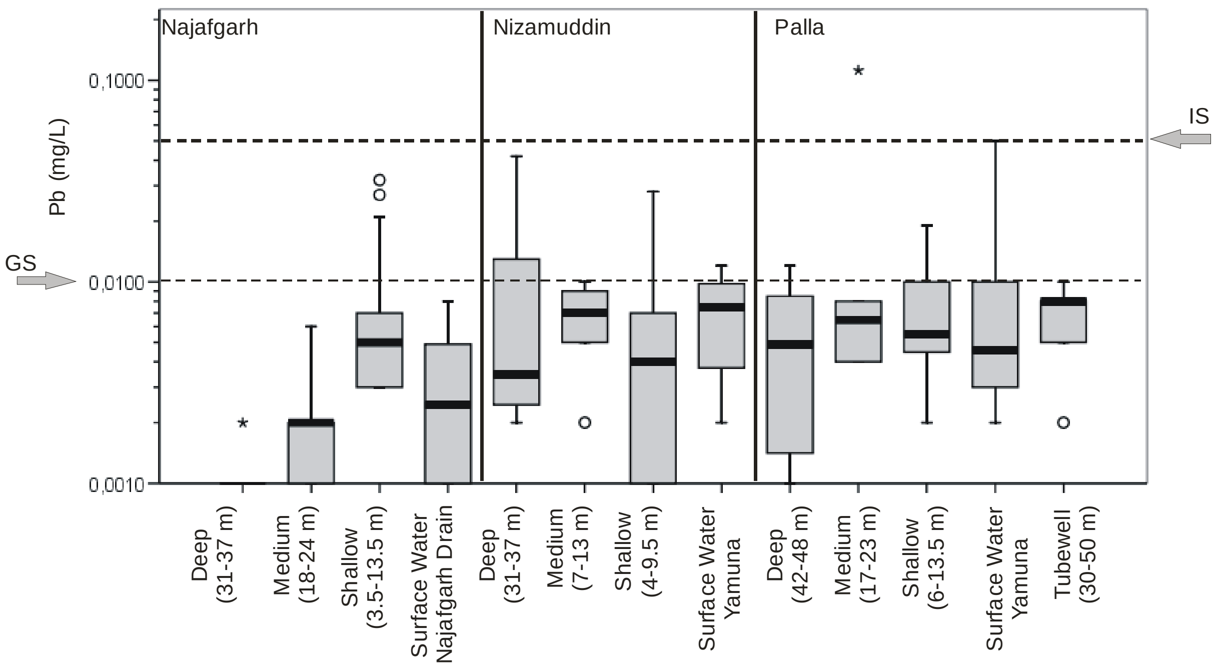

Figure 18 Distribution of lead concentrations at the three field sites and tolerance limits of drinking water standards.

Iron

Iron is one of the most abundant metals in the earth's crust, and an essential element for humans and animals. It is described as a non toxic element, but some drinking water specifications suggest a precaution against storage of excessive iron in the body. In practice, aesthetic considerations have more importance, because reduced Fe2+ can be oxidized in the supply system and precipitate in form of oxides/hydroxides. Thus excessive iron may affect the appearance and taste of the water and cause for example iron stains in the laundry and other plumbing fixtures.

The GS therefore has a limit of 0.2 mg/L that can be extended up to 0.5 mg/L for small scale water supply structures with capacities below 1000 m³ per year. The IS desirable limit is 0.3 mg/L and may not be extended to more than 1 mg/L (permissible limit) to avoid "adverse affects on domestic uses and water supply structures". Figure 18 demonstrates that these values are exceeded at all sampling locations.

The median concentrations in the surface water are generally lower than in the adjacent groundwater. If one compares the Palla surface water with the tubewell no significant change in the distribution range can be observed. This is attributed to mixing processes with deep groundwater and to dissolution and precipitation processes in the aquifer. In summary the tubewell samples all lie within the permissible range of the IS and since Fe is not of health concern it can be considered as a non problematic substance at this site.

Anoxic waters at Nizamuddin Bridge lead to very high concentrations of iron and manganese. At Najafgarh drain the contents are higher in the shallow wells, possibly due to a lower solubility of iron in saline waters.

However, high iron concentrations can commonly be found in drinking water production wells all over the world, but are easily treatable by aeration and subsequent filtration.

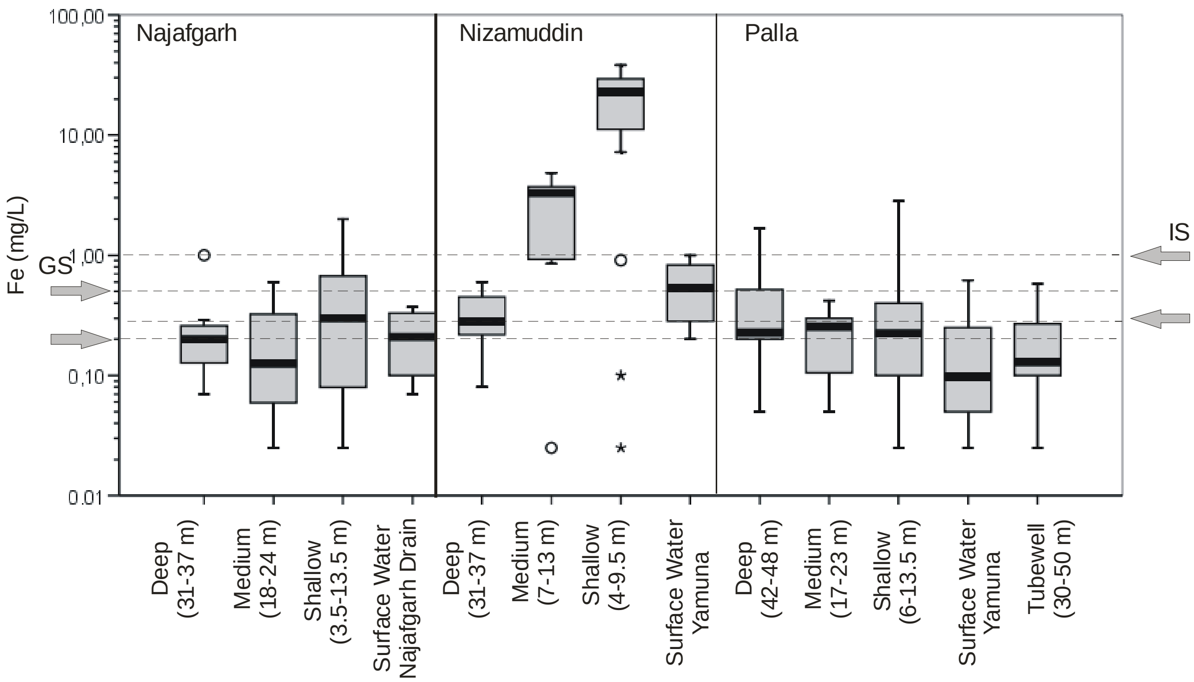

Figure 19 Distribution of iron concentrations at the three field sites and tolerance limits of drinking water standards.

Manganese

Manganese is abundant in many natural waters and an important nutrient occurring in many food sources. According to the WHO (2004) guidelines, health effects for humans and animals was reported from both deficiency and overexposure of manganese at very high levels. The geochemistry of Mn is similar to iron so higher concentrations of the ion occur particularly in anaerobic or low oxidation conditions. The occurrence in drinking water is not expected to be of public health concern but may have negative effects on taste and appearance.

The GS is limit is defined at 0.05 mg/L but concentrations may exceed up to 0.2 mg/L in small scale systems supplying less than 1000 m³ per year. In the IS, the tolerance limits are at 0.1 mg/L (desired) and 0.3 mg/L (required).

The distribution of manganese at the different field sites (Figure 19) is similar to that of iron (Figure 18). The GS limit of 0.05 mg/L is exceeded by almost all samples, except those from surface water at Palla and Najafgarh field sites, the tubewell at Palla and a few outliers from the shallow tubewells at Najafgarh drain. Except from the deep well at Nizamuddin bridge, all groundwater samples have manganese contents above IS limit of 0.1 mg/L and at Nizamuddin Bridge and Najafgarh Drain 75 percent of the samples of each well even exceed the 0.3 mg/L permissible limit.

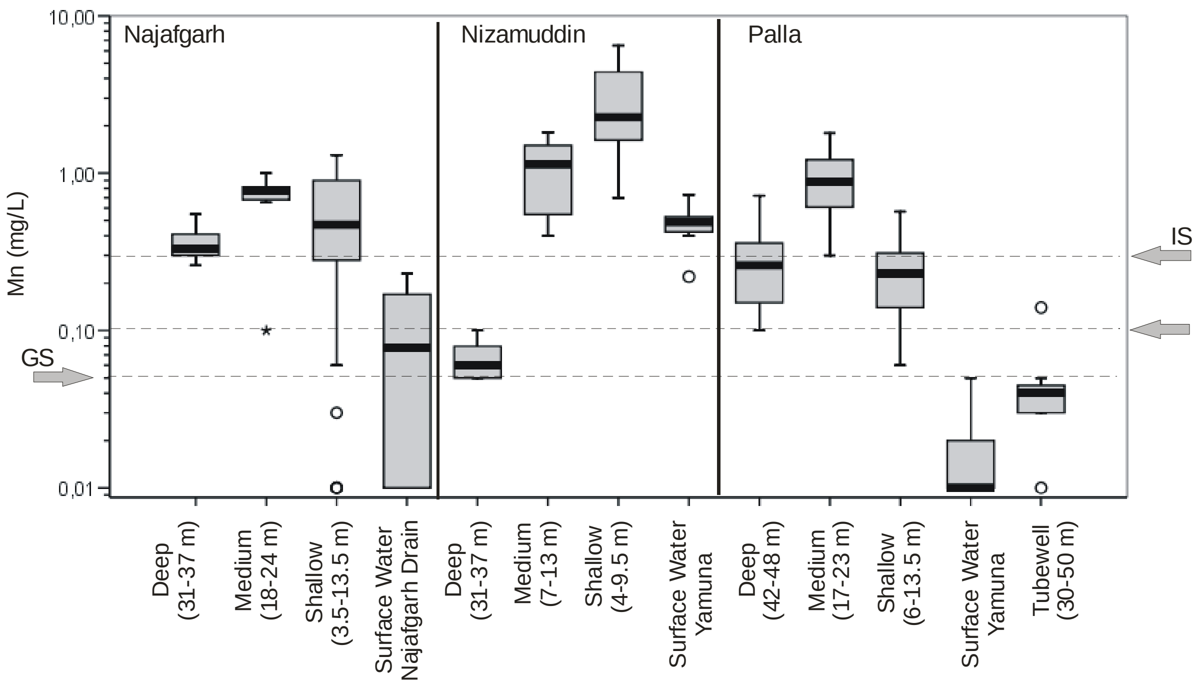

Figure 20 Distribution of manganese concentrations at the three field sites and tolerance limits of drinking water standards.

3.2.4. Other inorganic trace substances

Apart from the heavy metals, eleven additional elements were analyzed because of their toxicity or scientific importance for hydrogeochemical investigations (table 5). For some parameters, permissible limits are defined in IS and/or GS, whereas the majority of the parameters are not considered to be health relevance in drinking water, so no limits are defined in the IS and GS. Whenever drinking water permissible limits for one element are exceeded in surface- or groundwater, this parameter is described separately with an overview on the concentrations at each sampling point within this chapter.

Table 5 Overview on the results of heavy metal analysis compared to drinking water standards.

	Results compared to drinking water standards:
Arsenic (As)	IS and GS limits are exceeded in many samples.
Fluoride (F)	
Nitrite (NO_2)	Many samples exceed IS and GS limits.
Ammonia (NH_4)	
Boron (B)	Most samples are below IS and GS limits.
Hydrogensulfide (HS)	No limits defined in IS or GS (not considered health relevant in drinking water).
Silicon (Si)	
Strontium (Sr)	
Barium (Ba)	
Lithium (Li)	
Phosphate (PO_4)	

<u>Fluoride</u>

In many parts of the world food seems to be the primary source of fluoride but in some regions the intake through drinking water is much more important due a local abundance in the groundwater. A deficiency in fluoride may cause dental caries, bone demineralization or even osteoporosis, so some countries prefer add fluoride to drinking water or provide cooking salt enriched with the anion. In other regions, it can occur in drinking water in such abundance, that it is a serious concern to public health with epidemic dimensions. The excess fluoride may lead to painful skeleton deformations termed fluorosis which it is a common disease threatening millions of people in India. In the Himalayan foreland, excess fluoride is essentially derived from weathering with salts and sedimentary fluoride-bearing minerals are the primary sources (Jacks et al 2000).

The IS recommends to keep fluoride as low as possible and has its desirable limit at 1,0 mg/L and its permissible limit at 1,5 mg/L which is also the GS maximum tolerance value. Figure 19 shows the distribution of fluoride at the sampling points.

A study of Datta et al (1996) indicates that almost 50% of Delhi area is affected by fluoride contamination beyond the limit of 1.5 mg/L. The highest concentrations of F can be found in the deep groundwater. The origin of F is basically leaching from minerals in the sediments.

Our investigations show that the concentrations in the tubewell and the medium groundwater in Nizamuddin are above the GS and IS threshold and therefore should be subject to possible post-treatment.

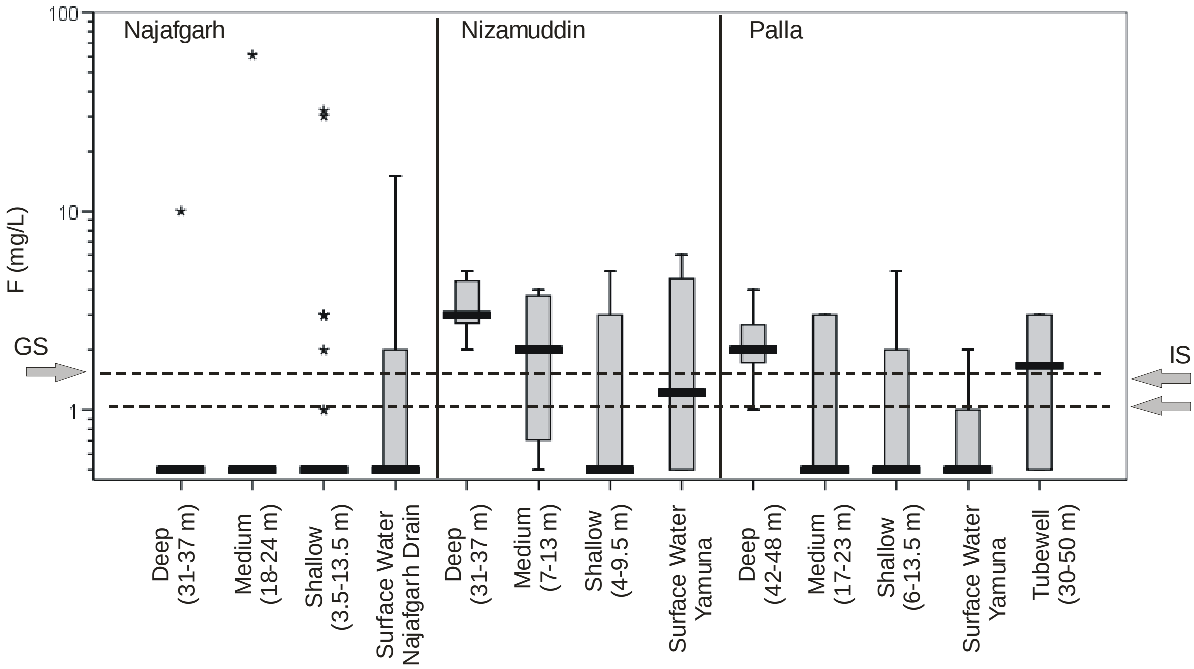

Figure 21 Distribution of fluoride concentrations at the three field sites and tolerance limits of drinking water standards.

<u>Arsenic</u>

In Bangladesh and other countries (i.e. Vietnam) millions of people are affected by arsenic contamination of drinking water. Investigations particularly over the last years have shown that the health risk is based on the presence of arsenic in the groundwater. Values of the lethal dose of arsenic for human beings range from 0.1 - 0.3 g per 70 kg body weight (HOLLEMAN AND WIBERG, 1990). Epidemiological studies demonstrated doubtlessly the carcinogenicity of arsenic. Typical symptoms of arsenic poisoning are: diaphoresis, muscle spasms, nausea, vomiting, abdominal pain, garlic odour to the breath, diarrhea, anuria, dehydration, hypertension, cardiovascular collapse, aplastic anemia and death (WHO 2004).

The weathering of arsenic bearing minerals in the Himalayan mountains is considered to be the source of As. The median in the Yamuna river samples of the Palla field site and the Nizamuddin field is very similar and can be considered as the current background contamination. In environments where dissolved oxygen occurs the principle attenuation mechanism is adsorption on Fe(III)-oxides and hydroxides. Therefore, high concentrations of arsenic occur in strongly reducing aquifer. The driving agent for the reduction is organic matter. Since only minor organic matter is present in the Palla aquifer As mobilization plays no important role. In Palla e.g. the median of the tubewell samples lies below the current background contamination. In an anoxic environment arsenic may be derived as a result of desorption and reductive dissolution of the surface reactive mineral phases (Fe(III)-oxides and hydroxides) down-gradient from the river. This can be observed at the Nizamuddin field site. Here, the total content of As increases with depth and distance from the river in the upper aquifer and reaches maximum concentrations of 0.08 mg/L in the depth of approx. 8 m below surface level. Here, arsenic must be considered as a problematic substance since it exceeds the IS (Figure 20).

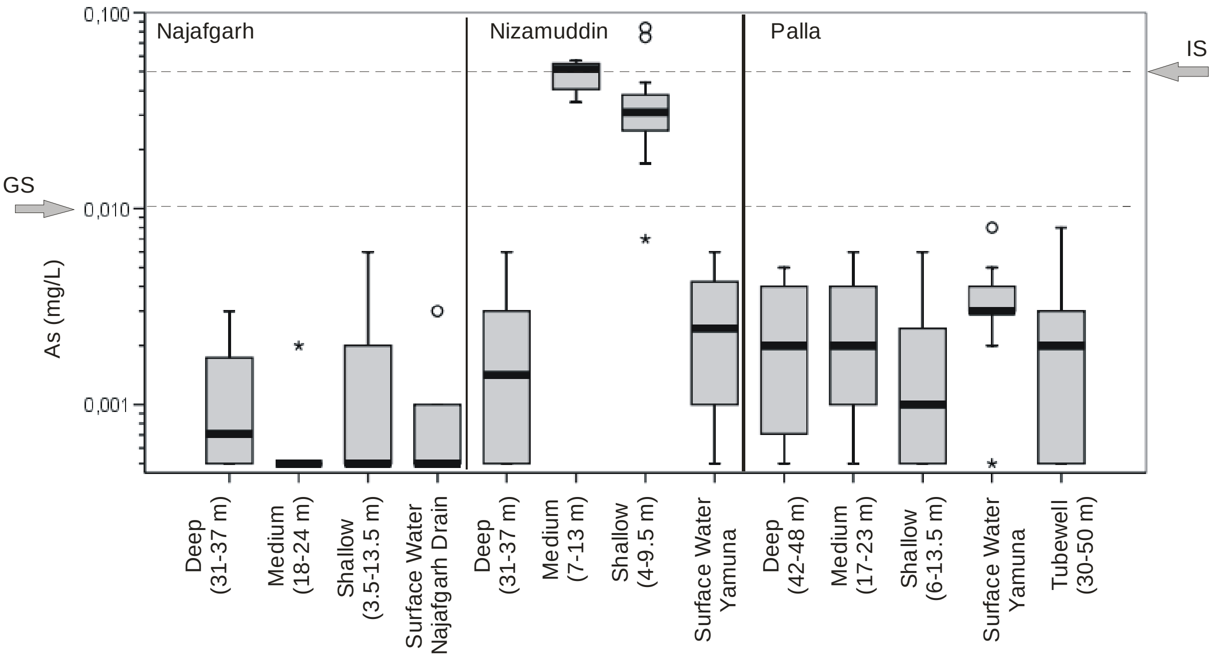

Figure 22 Distribution of arsenic concentrations at the three field sites and tolerance limits of drinking water standards.

Ammonia

Naturally, ammonia as NH4 is formed as a product of the decomposition of proteins, but where it occurs in high concentrations in the water cycle, it is usually an indicator for untreated sewage, agricultural runoff or landfill leakage. It appears in anaerobic water because in the presence of oxygen it can be converted to nitrite (see below) and in a second step to nitrate by microbiological oxidation (nitrification). As a major component of the metabolism of mammals the tolerance of humans to ammonia is quite high, so in the WHO (2004) guidelines ammonia in drinking water is described as being not of immediate health relevance. It is described as an undesired component, however, because "ammonia can compromise disinfection efficiency, result in nitrite formation in distribution systems, cause the failure of filters for the removal of manganese and cause taste and odor problems" (WHO 2004).

The IS includes no specification on ammonia in drinking water and the GS limits the maximum concentration to 0.5 mg/L but allows values up to 30 mg/L in case of a geogenetic source (Figure 21).

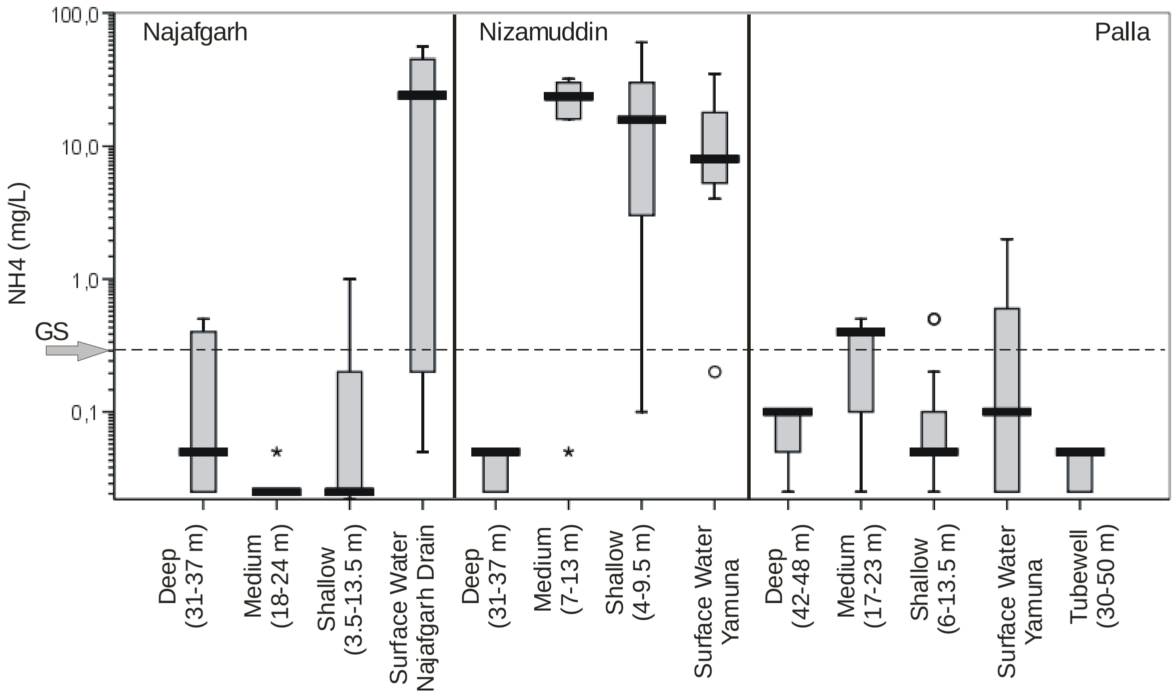

Figure 23 Distribution of ammonia concentrations at the three field sites and tolerance limits of drinking water standards.

Nitrite

Nitrite is a part of the natural nitrogen-cycle and can be formed through microbiological activity either by the reduction of nitrate under anaerobic conditions or by the oxidation of ammonia (see above), which may also occur in the distribution system. Nitrite is toxic especially to infants ("blue baby syndrome"), because it can oxidize haemoglobin to methaemoglobin, which is unable to transport oxygen around the body (WHO 2004).

In the IS there is no limit defined for nitrite concentrations but the GS, does not permit nitrite concentration above 0.5 mg/L in drinking water and prescribes that concentrations should not exceed 0.1 mg/L at the outlet of water works. For this study, the 0.1 mg/L limit for water works was defined as the relevant value. In the surface water it is exceeded by more than 25 % of the samples from Nizamuddin Bridge field site and 75 % or more of the samples from the Yamuna river at Palla and Najafgarh Drain. In the groundwater, concentrations are significantly lower: At Palla nitrite decreases with depth so that the deep piezometer is almost free of nitrite, whereas in the medium depth some samples are above 0.1 mg/L and in the shallow piezometers more than 25 % of the samples exceed the limit. Nitrite values in the anoxic groundwater at Nizamuddin bridge are clearly below the limit and at Najafgarh Drain less than 25 % of the samples from shallow groundwater have contain more than 0.1 mg/L of nitrite (Figure 22).

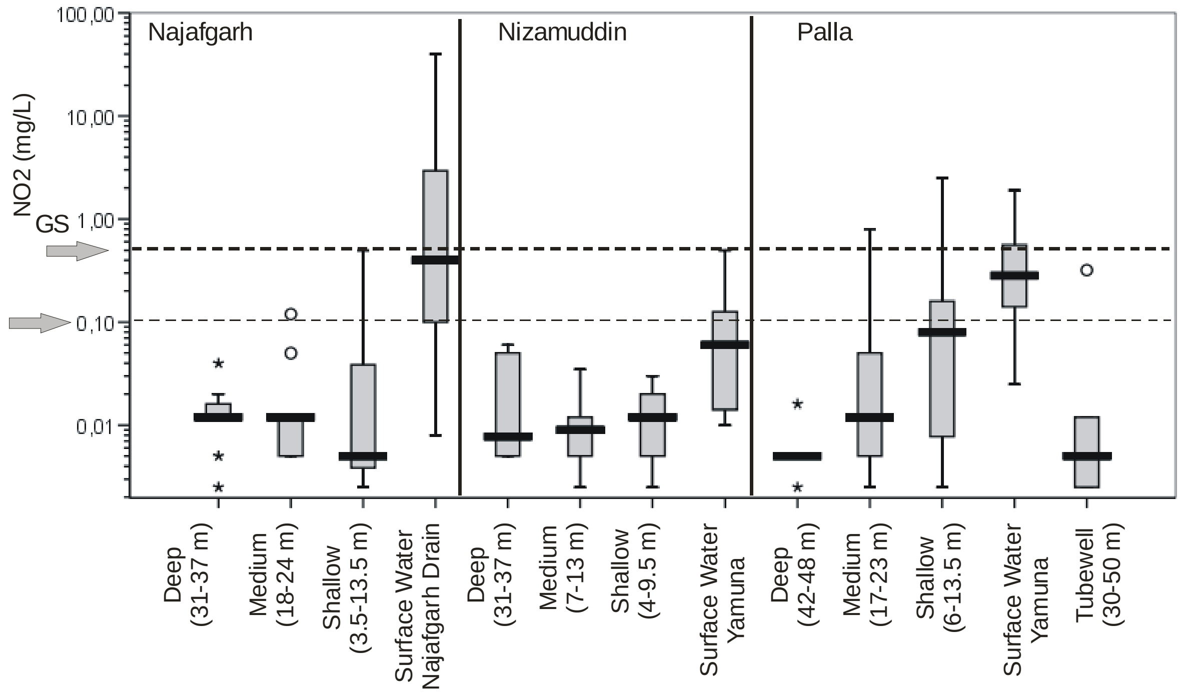

Figure 24 Distribution of nitrite concentrations at the three field sites and tolerance limits of drinking water standards.

Boron

Boron naturally occurs in groundwater but due to its use in several industries and in some detergents, it often indicates anthropogenic influence especially in surface waters.

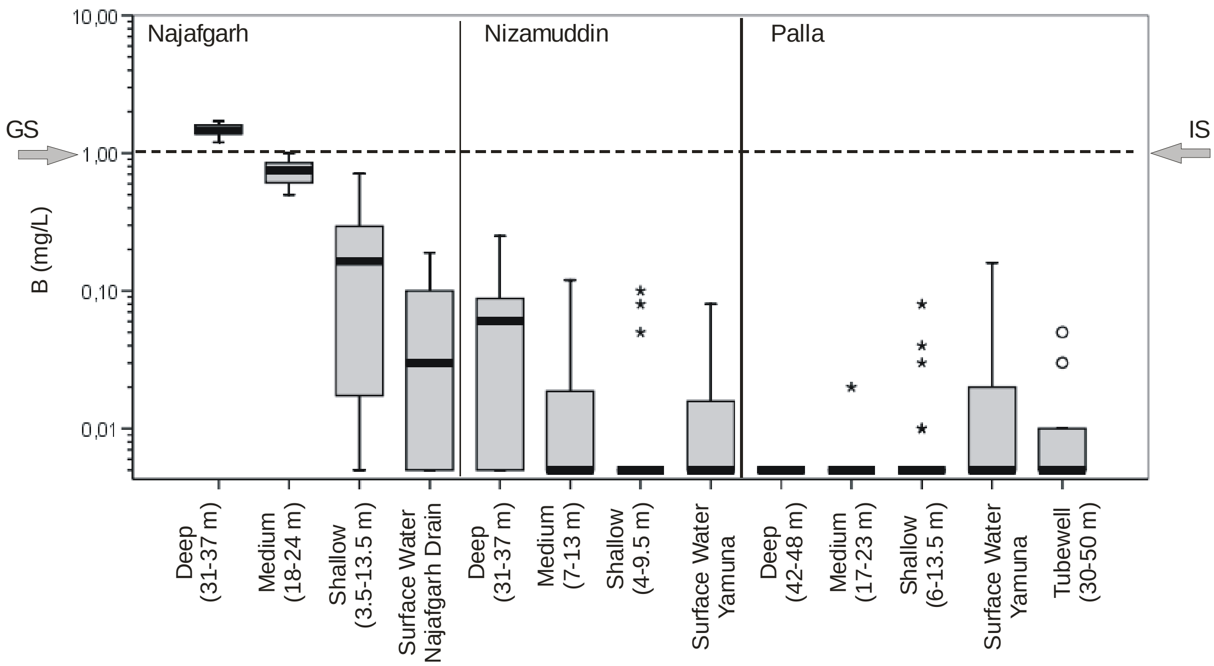

Figure 25 Distribution of boron concentrations at the three field sites and tolerance limits of drinking water standards.

Concerning toxicity, the WHO (2004) guideline mentions that it is found in many edible plants on the one hand, but on the other hand oral exposures to laboratory animals have shown some evidence harmful health effects to male reproductive tract.

Both GS and IS give a tolerance limit at 1 mg/L for drinking water, but the IS permits exceeding this value up to 5 mg/L. Boron concentrations plotted in figure 23 are below 1 mg/L at all sampling points except the deep groundwater at Najafgarh Drain field site which is highly enriched in many elements, due to it's high grade of mineralization. Towards the medium and shallow groundwater, boron contents decrease along with totally dissolved solids. Since all samples, except for Najafgarh deep groundwater, plot below the IS/GS threshold this parameter is considered as not problematic.

4. Conclusions

To differentiate between real purification and mixing processes it is necessary to know the proportion of bankfiltrate. Generally the proportion of bankfiltrate decreases towards depth and with distance from the river and it is dependent on the hydraulic connections of the river to the aquifer. In natural systems the proportion of bankfiltrate is changes with time. Therefore, it rather makes sense to give average than absolute values. The estimations on bank filtration share given above (tab 1-3) refer to the current field site conditions. Construction of appropriate RBF facilities will increase the proportion of bankfiltrate.

<u>Summary for the Palla field site:</u>

The tubewell in Palla is gaining approx. 60% of bankfiltrate. We attribute the change of the parameters therefore to 40% on pure mixing with the ambient groundwater and to 60% on the bankfiltration capacities. The seasonal influence on the share of bankfiltrate is subject to modifications, since not all data is analysed yet. Positive effects during bankfiltration can be observed for several heavy metal like Pb, Al and Cu, while no significant changes or an increase in the concentration can be observed for Fe and Mn, respectively. Other substances like As, NO_2^- and Ammonia are decreased during the underground passage while no significant changes or an increase in the concentration can be observed for B and F, respectively. Only fluoride exceeds the threshold for drinking water standard and must be considered as critical.

<u>Summary for the Nizamuddin Bridge field site:</u>

Positive effects during bankfiltration can be observed only for Al while no significant changes can be observed for Pb and Cu and an increase in the concentration can be observed for Fe and Mn. Other substances like As, F and Ammonia are increased during the underground passage while no significant changes or an decrease in the concentration can be observed for B and NO_2^-, respectively. At this field site elevated concentrations of several substances will like As, Fe, Mn, F and NH4 will make a post-treatment necessary.

Summary for the Najafgarh Drain field site:

The main constraints at this field site are the high salinity of the groundwater and the seasonal availability of fresh surface water. Due to the high mineralization of the groundwater a possible RBF site must be situated very close to the drain with shallow filter screens in order to obtain a high share of less mineralized bank filtrate. The design and the potential capabilities of RBF facilities are currently subject to ongoing work and cannot be evaluated finally. The sampling campaigns carried out so far are very useful to evaluate i) the seasonal changes in the surface water and ii) the depth dependent changes of the ambient groundwater. It needs to be taken into account that nitrogen species will promote the occurrence of problematic substances like ammonia, nitrite or nitrate due to a load with untreated sewage. Fluoride is expected to be no problematic substance.

However, the complete dataset is not yet available because some check measurements, plausibility control of the data and statistical evaluation are still in progress. Therefore, the information provided within this report does not represent the definite outcome and is still subject to modifications and amendments.

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Appendix

		2006		2007											2008			
		Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
		FUB	FUB	FUB	FUB+ IIT	FUB+ IIT	IIT	FUB+ IIT	IIT	FUB+ IIT	IIT	FUB+ IIT	IIT	FUB+ IIT	FUB+ IIT	IIT	IIT	FUB
PA	SW	X	X	X	X	X	X	X		X	X	X	X		X	X	X	
	PZ-1	X	X	X	X	X	X	collapsed										
	PZ-2	X	X	X	X	X	X	X	X	X		X			X		X	
	PZ-3	X	X	X	X	X	X	X		X		X				X	X	
	PZ-4	X	X	X	X	X	X	X	X	X	X	X						plugged
	PZ-5	X	X	X	X	X	X	X	X	X	X	X			X	X	X	
	PZ-6	X	X	X	X	X	X	X	X	X	X	X			X		X	
	PZ-7	X	X	X	X	X	X	X	X	X	collapsed							
	TW-1	X	X			X	X	X		X	X	X	X		X	X	X	
	TW-2		X		X	X	X	X				X						
NA	SW	X	X	X	X	X	X	X	X	X	X	X			X	X	X	
	PZ-1	X	X	X	X	X	X	X	X	X	X	X				X	X	
	PZ-2	X	X	X	X	X	X	X	X	X	X	X			X	X	X	
	PZ-3	X	X	X	X	X	X	X	X		X	X				X	X	
	PZ-4	X	X	X	X	X	X	X	X			X						
	PZ-5	X	X	X	X	X	X	X	X			X				X	X	
	DW	X	X	X	X	X		X			X	X			X	X	X	
NI	SW	X	X	X	X	X	X	X		X	X	X	X	X				
	PZ-1	X	X	X	X	X	X		X		inundated	X	sanded up					
	PZ-2	X	X	X	X	X	X	X	X	X	inundated	X	X	X			X	
	PZ-3		X	X	X	X	X	X	X	X	inundated	X	plugged					
	PZ-4		X	X	X	X	X	X	X	X	inundated	collapsed						
	PZ-5	X	X	X	X	X	X	X	X	X	inundated	X						plugged
	PZ-2a	→ drilled in nov. / dec. 2007 →													X		X	
	PZ-2b	→ drilled in nov. / dec. 2007 →													X		X	
	PZ-2c	→ drilled in nov. / dec. 2007 →													X		X	
DMRC	SW								X		X	X			X			
	PZ-1				?			?	X			X						
	PZ-2				?				X									
	PZ-3				?				X			X						
	PZ-4								X									
	PZ-5							?	X		X							
	PZ-6								X		X							
	PZ-7								X		X							

Appendix 1: Overview on sampling locations and sampling schedule (Nov. 2006 to March 2008)

para-meter	det. limit (mg/L)	total	Najafgarh Drain (NA)				Nizamuddin Bridge (NI)				Palla Well Field (PA)				
			NA-de	NA-me	NA-sh	NA-SW	NI-de	NI-me	NI-sh	NI-SW	PA-de	PA-me	PA-sh	PA-SW	PA-TW
pH	-	159	9	9	31	6	7	7	18	8	5	7	32	9	7
EC	-	157	9	9	29	6	7	7	18	8	5	8	33	10	7
Ca	1	159 (0)	9 (0)	9 (0)	31 (0)	6 (0)	7 (0)	7 (0)	18 (0)	8 (0)	6 (0)	8 (0)	33 (0)	10 (0)	7 (0)
Mg	1	159 (0)	9 (0)	9 (0)	31 (0)	6 (0)	7 (0)	7 (0)	18 (0)	8 (0)	6 (0)	8 (0)	33 (0)	10 (0)	7 (0)
Na	1	159 (0)	9 (0)	9 (0)	31 (0)	6 (0)	7 (0)	7 (0)	18 (0)	8 (0)	6 (0)	8 (0)	33 (0)	10 (0)	7 (0)
K	1	159 (0)	9 (0)	9 (0)	31 (0)	6 (0)	7 (0)	7 (0)	18 (0)	8 (0)	6 (0)	8 (0)	33 (0)	10 (0)	7 (0)
Cl	1	159 (0)	9 (0)	9 (0)	31 (0)	6 (0)	7 (0)	7 (0)	18 (0)	8 (0)	6 (0)	8 (0)	33 (0)	10 (0)	7 (0)
SO_4	1	159 (0)	9 (0)	9 (0)	31 (0)	6 (0)	7 (0)	7 (0)	18 (0)	8 (0)	6 (0)	8 (0)	33 (0)	10 (0)	7 (0)
HCO_3	1	159 (0)	9 (0)	9 (0)	31 (0)	6 (0)	7 (0)	7 (0)	18 (0)	8 (0)	6 (0)	8 (0)	33 (0)	10 (0)	7 (0)
NO3	1	159 (82)	9 (3)	9 (5)	31 (21)	6 (3)	7 (4)	7 (5)	18 (16)	8 (3)	6 (5)	8 (5)	33 (9)	10 (0)	7 (3)
Fe	0.02	162 (0)	*9 (0)*	*9 (0)*	*32 (0)*	*6 (0)*	*7 (0)*	*8 (0)*	*18 (0)*	*8 (0)*	*6 (0)*	*8 (0)*	*34 (0)*	*10 (0)*	*7 (0)*
Mn	0.02	162 (12)	*9 (0)*	*9 (0)*	*32 (3)*	*6 (2)*	*7 (0)*	*8 (0)*	*18 (0)*	*8 (0)*	*6 (0)*	*8 (0)*	*34 (0)*	*10 (6)*	*7 (1)*
Al	0.02	162 (55)	9 (2)	9 (4)	32 (10)	6 (2)	7 (2)	8 (2)	18 (8)	8 (3)	6 (1)	8 (2)	34 (11)	10 (4)	7 (4)
Zn	0.01	162 (0)	9 (1)	9 (2)	32 (8)	6 (2)	7 (2)	8 (3)	18 (5)	8 (2)	6 (2)	8 (4)	34 (15)	10 (5)	7 (2)
Pb	0.001	103 (54)	5 (4)	5 (2)	21 (3)	4 (1)	4 (0)	5 (0)	10 (3)	4 (0)	4 (1)	6 (1)	20 (0)	6 (0)	5 (0)
Cu	0.001	100 (0)	*5 (0)*	*5 (0)*	*21 (0)*	*4 (0)*	*4 (0)*	*5 (0)*	*10 (0)*	*4 (0)*	*4 (0)*	*6 (0)*	*20 (0)*	*7 (0)*	*5 (0)*
Ni	0.001	100 (33)	5 (4)	5 (4)	21 (4)	4 (4)	4 (1)	5 (2)	10 (2)	4 (0)	4 (1)	6 (2)	20 (5)	7 (2)	5 (2)
Mo	0.01	51 (47)	3 (3)	3 (3)	11 (10)	2 (2)	3 (1)	3 (3)	5 (5)	2 (2)	3 (2)	3 (3)	9 (9)	2 (2)	2 (2)
Co	0.001	78 (62)	4 (4)	4 (4)	17 (13)	3 (3)	3 (2)	4 (3)	7 (1)	3 (3)	3 (2)	5 (3)	15 (14)	6 (6)	4 (4)
Sb	0.001	50 (30)	3 (2)	3 (3)	11 (6)	2 (2)	3 (2)	3 (1)	5 (2)	2 (1)	2 (1	3 (2)	9 (4)	2 (2)	2 (2)
Cr	0.001	50 (44)	3 (3)	3 (2)	11 (10)	2 (2)	3 (1)	3 (3)	5 (5)	2 (1)	2 (1)	3 (3)	9 (8)	2 (2)	2 (2)
Si	1	156 (0)	7 (0)	8 (0)	29 (0)	6 (0)	7 (0)	7 (0)	17 (0)	7 (0)	7 (0)	8 (0)	36 (0)	9 (0)	8 (0)
Sr	0.05	156 (0)	7 (0)	8 (0)	29 (0)	6 (0)	7 (0)	7 (0)	17 (0)	7 (0)	7 (0)	8 (0)	36 (0)	9 (0)	8 (0)
Ba	0.02	173 (3)	8 (0)	9 (0)	32 (0)	7 (0)	8 (3)	8 (0)	18 (0)	8 (0)	7 (0)	9 (0)	39 (0)	10 (0)	10 (0)
Li	0.02	161 (106)	8 (0)	8 (0)	32 (0)	7 (6)	7 (7)	7 (7)	17 (14)	7 (5)	6 (6)	8 (8)	36 (35)	9 (9)	9 (9)
B	0.01	151 (88)	7 (0)	8 (0)	28 (8)	6 (2)	7 (3)	7 (5)	15 (12)	7 (5)	6 (6)	8 (7)	34 (29)	9 (5)	9 (6)
As	0.001	173 (62)	8 (4)	9 (8)	32 (18)	7 (4)	8 (3)	8 (0)	18 (0)	8 (0)	7 (2)	9 (2)	39 (17)	10 (1)	10 (3)
PO_4	0.02	168 (90)	9 (7)	10 (7)	31 (26)	6 (2)	8 (3)	8 (1)	18 (10)	8 (1)	7 (3)	9 (7)	38 (24)	7 (2)	9 (7)
NO_2	0.005	161 (23)	9 (1)	10 (0)	31 (8)	7 (0)	8 (0)	7 (1)	16 (3)	7 (0)	5 (1)	9 (1)	35 (2)	8 (0)	9 (6)
NH_4	0.05	133 (36)	5 (2)	7 (6)	22 (11)	5 (0)	6 (2)	6 (0)	14 (0)	7 (0)	5 (1)	9 (2)	30 (6)	9 (3)	8 (3)
HS	0.02	86 (57)	6 (4)	8 (7)	17 (11)	3 (2)	5 (4)	5 (1)	11 (2)	5 (2)	4 (2)	3 (3)	12 (12)	3 (3)	4 (4)
F	1	173 (99)	8 (7)	9 (8)	32 (25)	7 (4)	8 (0)	8 (2)	18 (10)	8 (4)	7 (0)	9 (6)	39 (22)	10 (7)	10 (4)
Cd	0.0001	39 (38)	3 (3)	3 (3)	3 (3)	3 (3)	3 (2)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)
Hg	0.005	39 (39)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)

de – deep groundwater, me – medium depth Groundwater; sh – shallow groundwater; SW – surface water.
(Depths in meters below ground levels as indicated in figures 2 - 24)

Appendix 2: Physicochemical and inorganic parameters: Number of samples N per field site and number of analysis below detection limit (in parentheses)

			Ca	Mg	Na	K	Cl	SO_4	NO_3	HCO_3	pH	EC	TDS
Najafgarh Drain (NA)	deep	Mean	748	445	3637	44	7006	1464	80	255	6.8	18310	13551
		Median	737	434	3400	40	6700	1450	3	244	6.7	18610	12850
		Max.	542	380	3160	36	5950	1230	0	177	6.5	15600	11848
		Min.	882	554	5050	65	9785	1770	560	342	7.1	21900	18225
	medium	Mean	505	264	2123	22	3814	1272	90	333	6.7	11577	8257
		Median	482	240	2060	20	3800	1250	0	317	6.7	11690	8052
		Max.	465	210	1860	18	3200	1130	0	275	6.7	9140	7232
		Min.	620	340	2575	40	4700	1410	800	412	6.8	13370	9676
	shallow	Mean	299	135	807	7	1528	415	21	545	7.0	5797	3485
		Median	213	134	802	3	1350	430	0	506	6.9	5280	3392
		Max.	90	53	505	2	740	230	0	415	6.4	3480	1873
		Min.	777	273	1180	32	3015	620	540	787	8.6	8500	5801
	SW	Mean	61	24	195	17	217	51	28	418	8.2	1518	802
		Median	70	28	201	16	220	51	0	424	8.2	1608	852
		Max.	39	12	22	3	42	35	0	128	7.5	349	218
		Min.	71	35	360	32	404	67	150	702	9.0	2670	1321
Nizamuddin Bridge (NI)	deep	Mean	14	6	202	2	13	46	1	518	8.1	834	542
		Median	15	6	204	2	13	44	0	513	8.1	847	539
		Max.	9	4	182	2	11	41	0	482	8.0	719	527
		Min.	19	8	210	2	14	50	6	564	8.2	894	568
	medium	Mean	69	21	90	13	117	20	8	392	7.6	932	533
		Median	76	23	90	14	130	8	0	372	7.5	985	528
		Max.	22	6	42	1	18	3	0	244	7.3	467	225
		Min.	133	35	151	18	194	58	53	519	8.1	1274	808
	shallow	Mean	153	40	148	13	187	113	4	712	6.9	1637	1013
		Median	137	36	152	13	198	56	0	717	6.7	1538	945
		Max.	54	14	85	11	98	2	0	336	6.5	1062	536
		Min.	307	68	189	20	250	385	70	1007	7.8	2510	1660
	SW	Mean	69	27	131	16	175	99	9	320	7.4	1166	685
		Median	67	28	144	17	185	100	2	342	7.4	1237	733
		Max.	49	18	66	10	94	51	0	214	7.1	711	441
		Min.	87	32	178	20	230	135	34	394	7.6	1487	878
Palla Well Field (PA)	deep	Mean	26	12	65	4	20	34	1	224	8.1	435	273
		Median	26	12	61	4	12	32	0	226	8.2	420	263
		Max.	8	4	48	3	10	28	0	195	7.9	398	242
		Min.	39	16	107	4	55	48	4	244	8.3	513	321
	medium	Mean	65	26	59	4	105	88	1	203	7.6	777	450
		Median	68	27	58	4	100	86	0	200	7.6	743	456
		Max.	33	19	56	3	73	61	0	171	7.5	537	334
		Min.	84	30	65	6	147	123	4	244	7.7	953	533
	shallow	Mean	48	17	61	5	67	57	3	199	7.9	618	357
		Median	48	16	62	5	70	53	3	189	7.9	629	358
		Max.	27	10	8	3	3	8	0	140	7.5	391	177
		Min.	68	24	136	7	195	155	8	293	8.2	1155	651
	SW	Mean	44	20	93	7	106	107	6	172	8.6	807	470
		Median	44	13	56	7	64	52	6	165	8.7	568	323
		Max.	35	9	19	4	18	23	1	122	7.8	271	195
		Min.	62	54	350	11	400	450	16	226	9.1	2560	1435
	tubewell	Mean	39	20	51	3	50	54	1	203	7.7	572	320
		Median	41	20	46	3	54	57	0	189	7.7	574	325
		Max.	27	16	42	3	35	38	0	180	7.6	535	267
		Min.	47	24	77	4	58	60	2	268	7.9	606	364
Total		Mean	175	82	553	11	983	285	17	372	7.5	3450	2291
		Median	69	27	136	5	145	67	0	293	7.6	1075	622
		Max.	8	4	8	1	3	2	0	122	6.4	271	177
		Min.	882	554	5050	65	9785	1770	800	1007	9.1	21900	18225

Appendix 3.1 Results of the sampling campaigns: Statistical overview on major ion concentrations.

			Zn	Al	Pb	Cu	Ni	Mo	Co	Sb	Cr	Mn	Fe	Hg	Cd
Najafgarh Drain (NA)	deep	Mean	0.28	0.12	0.001	0.020	0.001	bdl	bdl	0.001	bdl	0.36	0.28	bdl	bdl
		Median	0.28	0.10	bdl	0.004	bdl	bdl	bdl	bdl	bdl	0.33	0.20	bdl	bdl
		Max.	0.52	0.25	0.002	0.090	0.003	bdl	bdl	0.002	bdl	0.55	1.00	bdl	bdl
		Min.	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.26	0.07	bdl	bdl
	medium	Mean	0.24	0.09	0.002	0.013	0.001	bdl	bdl	bdl	0.001	0.71	0.21	bdl	bdl
		Median	0.13	0.08	0.002	0.004	bdl	bdl	bdl	bdl	bdl	0.78	0.14	bdl	bdl
		Max.	1.00	0.21	0.006	0.050	0.001	bdl	bdl	bdl	0.002	1.00	0.60	bdl	bdl
		Min.	bdl	bdl	bdl	0.001	bdl	bdl	bdl	bdl	bdl	0.10	0.03	bdl	bdl
	shallow	Mean	0.21	0.07	0.008	0.007	0.002	0.005	0.001	0.001	0.001	0.57	0.43	bdl	bdl
		Median	0.16	0.06	0.005	0.005	0.002	bdl	bdl	bdl	bdl	0.47	0.30	bdl	bdl
		Max.	1.46	0.34	0.032	0.042	0.005	0.010	0.002	0.004	0.003	1.30	2.00	bdl	bdl
		Min.	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.03	bdl	bdl
	SW	Mean	0.28	0.06	0.003	0.004	0.011	bdl	bdl	bdl	bdl	0.10	0.22	bdl	bdl
		Median	0.32	0.05	0.003	0.004	0.012	bdl	bdl	bdl	bdl	0.08	0.21	bdl	bdl
		Max.	0.57	0.12	0.008	0.008	0.020	bdl	bdl	bdl	bdl	0.23	0.37	bdl	bdl
		Min.	bdl	bdl	bdl	bdl	0.002	bdl	bdl	bdl	bdl	bdl	0.07	bdl	bdl
Nizamuddin Bridge (NI)	deep	Mean	0.35	0.13	0.013	0.007	0.002	0.010	0.001	0.004	0.001	0.07	0.33	bdl	2E-04
		Median	0.28	0.08	0.004	0.006	0.002	0.010	bdl	bdl	bdl	0.06	0.28	bdl	bdl
		Max.	0.93	0.50	0.042	0.015	0.003	0.015	0.002	0.012	0.003	0.10	0.60	bdl	bdl
		Min.	bdl	bdl	0.002	0.002	bdl	bdl	bdl	bdl	bdl	0.05	0.08	bdl	bdl
	medium	Mean	0.33	0.07	0.007	0.003	0.002	bdl	0.001	0.002	bdl	1.08	2.60	bdl	bdl
		Median	0.32	0.05	0.007	0.003	0.003	bdl	bdl	0.002	bdl	1.16	3.30	bdl	bdl
		Max.	1.26	0.20	0.010	0.009	0.004	bdl	0.002	0.004	bdl	1.82	4.85	bdl	bdl
		Min.	bdl	bdl	0.002	bdl	bdl	bdl	bdl	bdl	bdl	0.40	0.03	bdl	bdl
	shallow	Mean	0.24	0.09	0.007	0.023	0.004	bdl	0.002	0.001	bdl	3.10	19.48	bdl	bdl
		Median	0.22	0.06	0.004	0.002	0.003	bdl	0.002	0.002	bdl	2.28	22.75	bdl	bdl
		Max.	0.75	0.40	0.028	0.170	0.016	bdl	0.004	0.002	bdl	6.46	38.30	bdl	bdl
		Min.	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.70	0.03	bdl	bdl
	SW	Mean	0.32	0.09	0.007	0.003	0.015	bdl	bdl	0.001	0.005	0.48	0.57	bdl	bdl
		Median	0.38	0.10	0.008	0.004	0.015	bdl	bdl	0.001	0.005	0.49	0.54	bdl	bdl
		Max.	0.70	0.25	0.012	0.005	0.017	bdl	bdl	0.001	0.009	0.73	1.00	bdl	bdl
		Min.	bdl	bdl	0.002	bdl	0.012	bdl	bdl	bdl	bdl	0.22	0.20	bdl	bdl
Palla Well Field (PA)	deep	Mean	0.21	0.38	0.006	0.005	0.002	0.007	0.001	0.001	0.001	0.31	0.48	bdl	bdl
		Median	0.20	0.12	0.005	0.004	0.002	bdl	bdl	0.001	0.001	0.26	0.23	bdl	bdl
		Max.	0.44	1.50	0.012	0.013	0.004	0.010	0.002	0.001	0.002	0.72	1.67	bdl	bdl
		Min.	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.10	0.05	bdl	bdl
	medium	Mean	0.16	0.08	0.023	0.002	0.003	bdl	0.002	0.001	bdl	0.94	0.22	bdl	bdl
		Median	0.09	0.06	0.007	0.001	0.002	bdl	bdl	bdl	bdl	0.88	0.26	bdl	bdl
		Max.	0.52	0.27	0.112	0.005	0.006	bdl	0.004	0.002	bdl	1.80	0.42	bdl	bdl
		Min.	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.30	0.05	bdl	bdl
	shallow	Mean	0.24	0.18	0.007	0.005	0.002	bdl	0.001	0.001	0.001	0.24	0.35	bdl	bdl
		Median	0.12	0.09	0.006	0.005	0.002	bdl	bdl	0.001	bdl	0.23	0.23	bdl	bdl
		Max.	1.10	1.68	0.019	0.014	0.006	bdl	0.002	0.002	0.002	0.57	2.82	bdl	bdl
		Min.	bdl	bdl	0.002	bdl	bdl	bdl	bdl	bdl	bdl	0.06	0.03	bdl	bdl
	SW	Mean	0.14	0.06	0.013	0.014	0.002	bdl	bdl	bdl	bdl	0.02	0.19	bdl	bdl
		Median	0.03	0.05	0.005	0.007	0.002	bdl	bdl	bdl	bdl	bdl	0.10	bdl	bdl
		Max.	0.45	0.26	0.050	0.060	0.003	bdl	bdl	bdl	bdl	0.05	0.62	bdl	bdl
		Min.	bdl	bdl	0.002	0.004	bdl	bdl	bdl	bdl	bdl	bdl	0.03	bdl	bdl
	tubewell	Mean	0.13	0.04	0.007	0.013	0.002	0.003	bdl	bdl	bdl	0.05	0.21	bdl	bdl
		Median	0.05	bdl	0.008	0.005	0.002	0.003	bdl	bdl	bdl	0.04	0.13	bdl	bdl
		Max.	0.40	0.13	0.010	0.050	0.005	bdl	bdl	bdl	bdl	0.14	0.58	bdl	bdl
		Min.	bdl	bdl	0.002	0.003	bdl	0.001	bdl	bdl	bdl	bdl	0.03	bdl	bdl
Total		Mean	0.23	0.11	0.008	0.009	0.003	0.005	0.001	0.001	0.001	0.72	2.62	bdl	bdl
		Median	0.21	0.07	0.005	0.004	0.002	bdl	bdl	bdl	bdl	0.33	0.27	bdl	bdl
		Max.	1.46	1.68	0.112	0.170	0.020	0.015	0.004	0.012	0.009	6.46	38.30	bdl	bdl
		Min.	bdl	bdl	bdl	bdl	bdl	0.001	bdl	bdl	bdl	bdl	0.03	bdl	bdl

Appendix 3.2 Results of the sampling campaigns: Statistical overview on heavy metal concentrations.

Site	Depth	Statistic	Sr	Ba	Li	B	NH4	NO2	HS	PO4	F	As	Si	DOC
Najafgarh Drain (NA)	deep	Mean	11.63	0.07	0.95	1.47	0.20	0.015	0.06	0.13	1.7	0.001	11	1.8
		Median	11.60	0.07	0.90	1.46	0.05	0.012	bdl	bdl	bdl	0.001	11	1.8
		Max.	13.70	0.09	1.13	1.70	0.50	0.040	0.25	1.10	10.0	0.003	12	2.5
		Min.	9.94	0.03	0.85	1.20	bdl	bdl	bdl	bdl	bdl	bdl	10	1.2
	medium	Mean	6.96	0.17	0.44	0.74	0.03	0.025	0.01	0.41	7.2	0.001	12	1.8
		Median	6.69	0.10	0.49	0.75	bdl	0.012	bdl	bdl	bdl	bdl	12	1.6
		Max.	9.00	0.90	0.50	1.00	0.05	0.120	0.04	4.00	61.0	0.002	13	3.0
		Min.	6.00	0.02	0.10	0.50	bdl	0.005	bdl	bdl	bdl	bdl	11	1.0
	shallow	Mean	3.07	0.09	0.08	0.21	0.17	0.062	0.02	0.07	2.7	0.001	11	2.6
		Median	2.50	0.09	0.08	0.17	bdl	0.005	bdl	bdl	bdl	bdl	12	2.5
		Max.	11.50	0.13	0.10	0.71	1.00	0.500	0.08	1.60	32.0	0.006	15	5.3
		Min.	0.93	0.04	0.06	bdl	0.01	bdl	bdl	bdl	bdl	bdl	8	1.1
	SW	Mean	0.74	0.07	0.01	0.07	25.05	7.008	0.02	6.27	3.1	0.001	7	6.8
		Median	0.81	0.05	bdl	0.05	24.00	0.400	bdl	4.80	bdl	bdl	10	9.4
		Max.	0.91	0.11	0.02	0.19	56.00	40.000	0.05	15.00	15.0	0.003	11	11.4
		Min.	0.41	0.04	bdl	bdl	0.05	0.008	bdl	bdl	bdl	bdl	bdl	1.3
Nizamuddin Bridge (NI)	deep	Mean	0.12	0.02	0.01	0.07	0.04	0.024	0.03	0.08	3.4	0.002	10	1.1
		Median	0.10	0.03	bdl	0.06	0.05	0.009	bdl	0.05	3.0	0.002	10	0.5
		Max.	0.20	0.04	0.01	0.25	0.05	0.060	0.13	0.25	5.0	0.006	11	5.2
		Min.	0.09	bdl	bdl	bdl	bdl	0.005	bdl	bdl	2.0	bdl	10	0.2
	medium	Mean	0.54	0.21	0.01	0.03	20.93	0.012	0.04	3.19	2.2	0.048	10	3.0
		Median	0.60	0.25	bdl	bdl	23.75	0.009	0.04	2.30	2.0	0.052	10	3.2
		Max.	1.00	0.33	0.01	0.12	32.00	0.035	0.08	7.50	4.0	0.057	11	4.8
		Min.	0.18	0.07	bdl	bdl	0.05	bdl	bdl	bdl	bdl	0.035	8	0.3
	shallow	Mean	0.86	0.29	0.01	0.02	17.46	0.013	0.04	0.15	1.8	0.035	11	6.0
		Median	0.86	0.32	bdl	bdl	15.75	0.012	0.04	bdl	bdl	0.031	11	5.4
		Max.	1.69	0.46	0.02	0.10	60.00	0.030	0.08	2.00	5.0	0.084	15	13.7
		Min.	0.40	0.10	bdl	bdl	0.10	bdl	bdl	bdl	bdl	0.007	10	1.0
	SW	Mean	0.61	0.14	0.01	0.02	12.89	0.126	0.06	2.19	2.6	0.003	7	5.0
		Median	0.65	0.14	bdl	bdl	8.00	0.060	0.06	1.15	1.8	0.003	7	4.9
		Max.	0.76	0.24	0.03	0.08	35.00	0.500	0.16	6.00	6.0	0.006	7	6.4
		Min.	0.40	0.05	bdl	bdl	0.20	0.010	bdl	bdl	bdl	bdl	6	2.5
Palla Well Field (PA)	deep	Mean	0.33	0.08	bdl	bdl	0.08	0.007	0.14	0.04	2.3	0.002	8	2.8
		Median	0.33	0.08	bdl	bdl	0.10	0.005	0.02	0.05	2.0	0.002	8	0.7
		Max.	0.44	0.12	bdl	bdl	0.10	0.016	0.50	0.08	4.0	0.005	9	14.5
		Min.	0.18	0.05	bdl	bdl	bdl	bdl	bdl	bdl	1.0	bdl	6	0.3
	medium	Mean	0.86	0.11	0.01	0.01	0.29	0.108	bdl	0.02	1.3	0.003	10	1.5
		Median	0.85	0.10	bdl	bdl	0.40	0.012	bdl	bdl	bdl	0.002	10	1.4
		Max.	1.00	0.16	0.01	0.02	0.50	0.800	bdl	0.10	3.0	0.006	12	3.4
		Min.	0.70	0.05	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	9	0.2
	shallow	Mean	0.36	0.12	0.01	0.01	0.09	0.207	bdl	0.03	1.4	0.002	4	1.5
		Median	0.34	0.11	bdl	bdl	0.05	0.080	bdl	bdl	bdl	0.001	4	1.2
		Max.	0.62	0.29	0.02	0.08	0.50	2.500	bdl	0.10	5.0	0.006	6	5.4
		Min.	0.15	0.02	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	2	0.3
	SW	Mean	0.35	0.05	0.01	0.03	0.46	0.497	bdl	0.33	0.8	0.003	4	2.3
		Median	0.29	0.05	bdl	bdl	0.10	0.300	bdl	0.40	bdl	0.003	4	2.7
		Max.	0.90	0.08	0.01	0.16	2.00	1.900	bdl	0.66	2.0	0.008	5	3.6
		Min.	0.17	0.03	bdl	bdl	bdl	0.025	bdl	bdl	bdl	bdl	3	0.3
	tubewell	Mean	0.56	0.09	0.01	0.01	0.04	0.041	bdl	0.07	1.7	0.002	9	1.0
		Median	0.60	0.09	bdl	bdl	0.05	0.005	bdl	bdl	1.7	0.002	10	0.9
		Max.	0.70	0.25	0.01	0.05	0.05	0.320	bdl	0.50	3.0	0.008	10	2.5
		Min.	0.36	0.05	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	6	0.2
Total		Mean	1.82	0.12	0.09	0.16	4.52	0.406	0.03	0.57	2.3	0.007	8	2.7
		Median	0.65	0.10	bdl	bdl	0.08	0.012	bdl	bdl	bdl	0.002	10	2.0
		Max.	13.70	0.90	1.13	1.70	60.00	40.000	0.50	15.00	61.0	0.084	15	14.5
		Min.	0.09	bdl	bdl	bdl	0.01	bdl	bdl	bdl	bdl	bdl	bdl	0.2

Appendix 3.3 Results of the sampling campaigns: Statistical overview on concentrations of other inorganic substances.