Project Bangla

Safe water for Bangladesh

Rajshahi, September 2nd 2018

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1. Preface

This report contains the analysis and outcomes of a research project performed in Bangladesh as part of the Master's education of five students of the Faculty of Civil Engineering and Geosciences of Delft University of Technology.

The execution of this project would not have been possible without the support of many parties that have been involved. First of all we would like to thank our supervisors Doris van Halem, Annemarie Mink and Julia Gebert for their support and input. We also thank Kajol Annaduzzaman for supervising, giving input and taking care of the group in the field in Bangladesh. Also Federico Trevia helped us many times with his nice and entertaining input and attitude.

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Many thanks to all the inhabitants of Uttar Kazirpara and the other villages for their kind hospitality. Special thanks to the household members of Sirajul family for their cooperation, hospitality and support in establishing the water treatment unit on their property.

Furthermore, we would like to thank all sponsors and funding instances that made it financially possible to perform the project. The funding instances that supported us are: Students4Sustainability, DIMI, StuD and Fundatie van de Vrijvrouwe van Renswoude te Delft and Delft Global Initiative. Moreover IV-Group and Gertjan Medema are generous sponsors of our project.

Last but not least, we would also like to thank the CDM hospital and all the staff for their service when part of the team was suffering from illness. Also Mini deserves special thanks for making us feel like home in Rajshahi.

Overall we have had an amazing time in Bangladesh, experiencing different culture and climate. We are very proud of the work we have delivered and hope that it will contribute to safe water supply to the people of Bangladesh and elsewhere in the world.

ধন্যবাদ (Thank you)

Project Bangla,

Irene Benito Lázaro, Fransje van Oorschot, Rubayat Sobhan, Bart Veenings and Tiemen Wegman


K.S.S

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List of abbreviations

Apps	Mobile applications
As	Arsenic
As(III)	Arsenite
As(V)	Arsenate
DO	Dissolved oxygen
EC	Electrical conductivity
EPRC	Environment & Population Research Centre
Fe	Iron
FOB	Iron oxidizing bacteria
DPHE	Department of Public Health Engineering
GBM	Ganges-Brahmaputra-Meghna Delta
HFO	Iron Hydroxide Flocs
IDW	Inverse Distance Weight
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
MCP	Mobile Crowd Participation
MP	Mega pixel
Mn	Manganese
NH_4^+	Ammonium
NH_3	Ammonia
O_2	Oxygen
ORP	Oxygen reduction potential
RMSE	Root Mean Square Error
SASMIT	Sustainable Arsenic Mitigation
WHO	World Health Organization
XRD	X-ray diffraction
XRF	X-ray fluorescence

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2. Summary

In Bangladesh, groundwater from shallow aquifers is used for communal drinking water supply on a large scale. This water is often polluted by naturally occurring arsenic, causing the largest scale poisoning through drinking water in the world (D. v. Halem, S. Bakker, G. Amy, & J. Van Dijk, 2009). In this report, a highly arsenic affected area in Bangladesh has been investigated. The main objective of this research is to obtain more insight in the three aspects of the DELTAP project: geology, water quality monitoring and safe water supply. It is aimed to analyse the relation between arsenic contamination and the local geology, to monitor the drinking water quality using mobile applications and to design and construct a water treatment unit. An important aspect of this research is to develop a monitoring and maintenance protocol in order to ensure safe water supply in the future.

In the study area, 150 households have been selected and the water quality has been tested. The water quality has been assessed by measuring four chemical parameters and five physical parameters, using simple strip tests and mobile water quality applications. The results of the strip tests have been compared to the results of ICP-MS analysis in order to check the performance of the tests and the mobile apps. The arsenic and iron strip tests showed good performance. However, the manganese and ammonium strip tests did not perform well. Furthermore, no relations between the presence of arsenic and other chemicals have been found. It can be concluded that simple strip tests in combination with mobile applications are a promising tool for water quality monitoring, applying the Mobile Crowd Participation strategy.

Since arsenic in groundwater has a geological origin, the relation between arsenic concentration in the groundwater and geology should be understood distinctly. In order to get a better understanding of this relationship, multiple tools and theories have been investigated and tested. Firstly, a geo information system has been used to map arsenic concentrations that have been obtained from the performed water quality tests. Based on the spatial analysis of the arsenic concentrations, three drillings have been performed: one drilling in a high, medium and low arsenic contaminated area. By use of the SASMIT tool, a link between sediment colour and arsenic contamination has been observed. Furthermore, geomorphological data and satellite images have been used to identify geological features in landscape which could also be linked to arsenic levels. The sediment colour found in drillings is in good accordance with the arsenic levels found in groundwater and thus, proves to be a useful tool to predict arsenic concentrations in the fieldwork area. However, the geological features in the research area are hard to identify and link to the measured arsenic concentrations.

A water treatment unit has been designed and constructed in order to provide safe water to 5 to 10 households. Based on the iron and arsenic concentrations from the ICP-MS results and on practical considerations, a suitable location for the water treatment unit has been selected. The ratio of these parameters is important to remove arsenic from the groundwater efficiently. The water treatment unit is based on oxidation of arsenic along with iron and subsequent filtration with a rapid sand filter. Both chemical and biotic oxidation of arsenic and iron are ensured by setting up a biofilm carrier column before the rapid sand and anthracite filter unit. Finally, a parallel resin column has been installed to remove the residual arsenic. The performance of the water treatment unit has been monitored extensively. The water quality throughout the system varied substantially during the timeline of the project. The produced safe water at the end of the fieldwork did not meet the drinking water standards set by the WHO. Nevertheless, several recommendations have been provided and, in the future, more intensive backwash of the water treatment unit might be the key to produce and distribute safe water.

Overall, a deeper knowledge on arsenic contamination and their effects have been achieved, and the improvement of the Bangladeshis live quality has been attempted.


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3. Introduction

The country of Bangladesh is struggling with large scale poisoning of its population. Groundwater, which is contaminated with natural presence arsenic in large parts of the country, is the main source of drinking water for a substantial part of the Bangladeshi population. Long term exposure to arsenic contaminated drinking water causes arsenicosis. This is a collective name for several diseases among which cancer of the skin, lungs, urinary bladder and kidneys are included (Smith, Lopipero, Bates, & Steinmaus, 2002; WHO, 2017). The country is situated in the in Ganges-Brahmaputra-Meghna Delta, which is one of the densest populated areas in the world. Dhaka, Bangladesh's capital, houses millions of people. Rapid ongoing urbanisation of the delta puts severe stress on the availability of clean and safe drinking water. Many attempts to tackle this problem have been done by several organisations. However, an effective solution has not yet been found.

The DELTAP project, an inter-faculty project at Delft University of Technology in collaboration with foreign partners, aims to develop an integrative approach for small scaled piped water supply in India and Bangladesh, tackling arsenic poisoning through drinking water. The project focusses on four parts of the water quality problem in India and Bangladesh. It is aimed to select a smart source from where water would be supplied to the people. Human centred design is very important in this study to ensure that the provided solutions are being accepted by its end-users. Furthermore, the end-users are of special importance because active participation in monitoring the drinking water quality by the local people is desired. Figure 1 shows the four main pillars of the DELTAP project and their inter-linkages.

Project Bangla is an educational project and is part of the DELTAP project. The team consists of five master students of the faculty of Civil Engineering and Geosciences at Delft University of Technology. This project is executed in a rural area close to the city of Rajshahi in Bangladesh. The geology is studied in order to obtain more insight in the pillar 'smart source selection'. The second part of this study focusses on monitoring the water quality through a mobile application, enabling active participation by the drinking water end-users. The third aim is to design and construct a pilot water treatment unit to produce safe drinking water.

In this report the findings of Project Bangla are presented. It has been formulated based on literature study, laboratory testing, several fieldwork campaigns ranging from water quality testing to geological fieldwork, implementation of a small-scale water supply system and data analysis.

The report is based on three different topics: geology, water quality monitoring and water treatment unit design. In the chapters of this report a differentiation between these three subjects is made. The overall structure of the report is as follows: firstly a general theoretical background will be provided to understand the contents of the report in Chapter 4. Secondly the research goals are outlined in Chapter 5 and a thorough explanation of all methods that have been used for data gathering and water filter design is given in Chapter 6. Thereafter, in Chapter 7 the results of the fieldwork and implementation of the water treatment unit are shown and discussed. Moreover, a general discussion is provided in Chapter 8 and conclusions and recommendations about the findings of this study and a project evaluation are presented in Chapters 9 and 10.

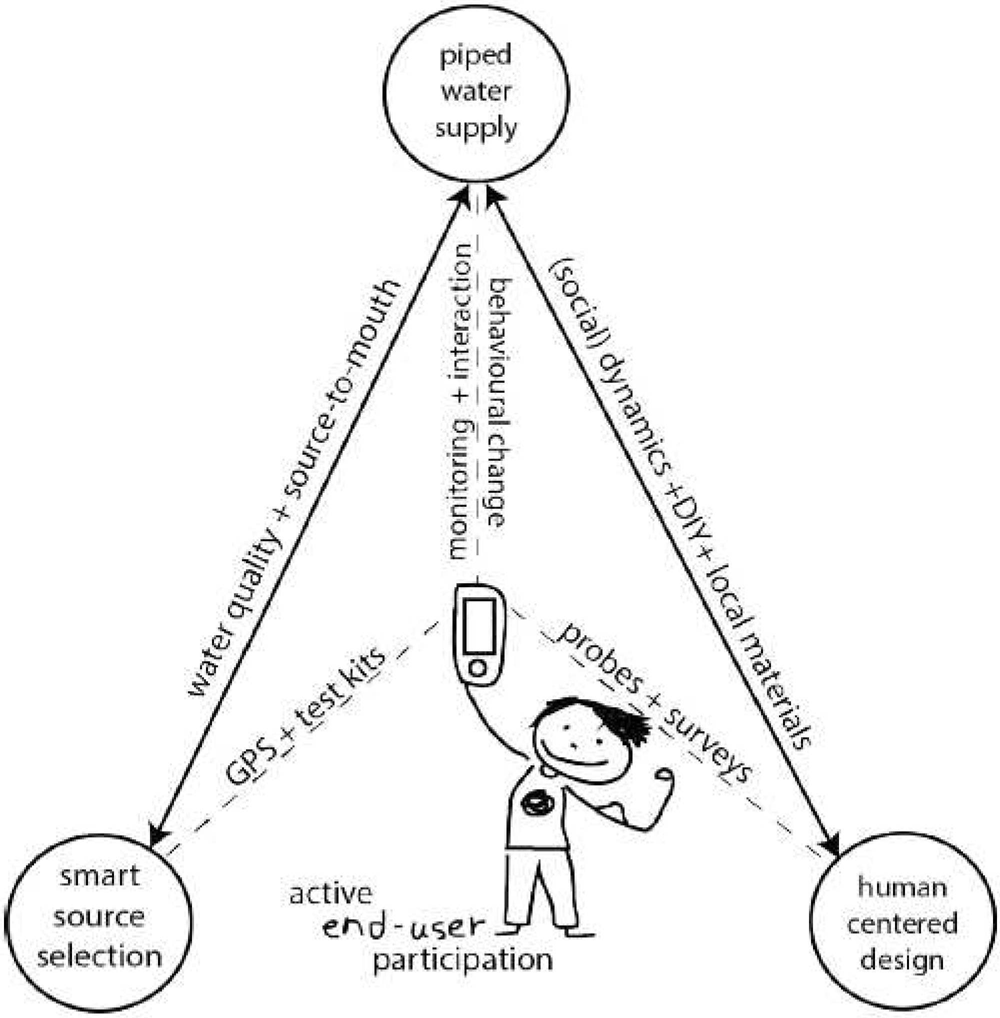


Figure 1. The pillars of the DELTAP project and their inter-linkages

4. Theoretical background

In this section the theoretical background of this study is reported. First, the geology of Bangladesh as a delta-country is studied. Afterwards, the background of water quality monitoring and of the filter are presented.

4.1 Geology

In this section a theoretical framework for understanding the geology of the fieldwork area is provided. First, the geological Ganges-Brahmaputra-Meghna delta is outlined briefly. In the subsequent sections, the explanation will narrow down to the local geology, morphology and finally focus on the relationship between local geology and arsenic concentrations in groundwater.

4.1.1 Geological setting Ganges-Brahmaputra-Meghna delta

The Ganges-Brahmaputra-Meghna (GBM) delta is the largest delta of the world and is located in the Bengal Basin (Islam, 2016) . The delta covers nearly the entire country of Bangladesh and parts of India as well. The formation of the Bengal Basin began during mid-Oligocene when the Asian and Indian continental plates started to collide. A major uplift of the Himalayas was underway by the mid-Miocene. Along the front of the mountain belt a subsiding region started to form the Himalayan foredeep. This foredeep became a repository of clastic sediments that erode from the evolving mountain belt. The Bengal basin evolved from the further subsiding Himalayan foredeep (Allison, 1998). Currently the sedimentological processes are still ongoing.

As the name suggests, the GBM delta is mainly fed with sediments by three rivers. The Ganges river flows through the Indian-Tibetan border and enters the delta plain from the northwest after meandering across the central Indian plateau. The Brahmaputra river enters Bangladesh from the Himalayas in the north. It has a steeper gradient and a braided character. The two rivers merge in central Bangladesh from where the combined rivers flow another 150 km southwards to debouch in the Bay of Bengal. The smaller Meghna river joins the combined river south of Bangladesh's capital Dhaka (Allison, Khan, Goodbred Jr, & Kuehl, 2003).

Approximately 70% of the sediment load carried by the combined Ganges-Brahmaputra river is silt. The sand fraction contributes another 10% to the sediment load. The sand and clay mineralogy of the sediment by the two rivers is rather distinct. The Ganges sediment is relatively enriched in smectite whereas the Brahmaputra sediment contains more illite, kaolinite and chlorite. Furthermore, the sand fraction of the Brahmaputra sediment is generally coarser than that of the Ganges. It also contains more mica and carbonate minerals (Allison et al., 2003).

During Quaternary era, sediment deposition and erosion patterns in the delta system were mainly controlled by climatic factors and sea-level changes (Umitsu, 1993). The Holocene deposits differ in thickness from approximately 15 metres at the edges of the Bengal Basin to 90 metres in the deepest part (Allison et al., 2003). In Bangladesh most tube wells used for daily use are so-called shallow tube wells. These are installed at depths less than 100 metres, however often between ~30 to ~60 metres (Hossain et al., 2017). Therefore, Holocene and late Pleistocene sediments are of most interest for this research. In Figure 2 an overview of geological units in Bangladesh is shown. The fieldwork area is indicated by a red dot. This figure is adapted from BGS and DPHE (2001).

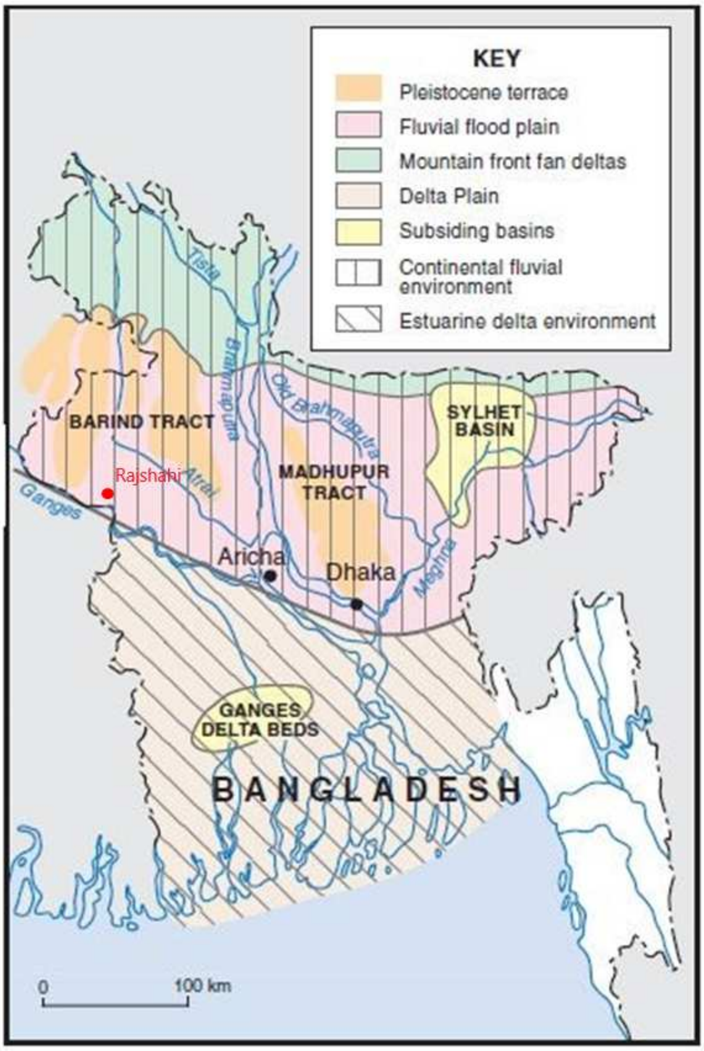


Figure 2 Ganges-Brahmaputra-Meghna delta system. Adapted from BGS and DPHE (2001)

4.1.2 Geological setting of the fieldwork area

The Rajshahi area, where this research area is performed, is located on the Barind tract. This area borders the Ganges (or Padma) river in the south. Furthermore, the area is divided into two distinctive geomorphological units: an elevated area containing mainly Pleistocene sediments, and the floodplains. In Figure 2, it can be appreciated that the fieldwork area is located on alluvial floodplains. As a result, the geology will be dominated by alluvial deposits. Alterations of alluvial sand, silt and clay deposits are expected to be present in the research area (BGS & DPHE, 2001). Borehole data, that was gathered by BGS & DPHE approximately 50 km away from the fieldwork area, also indicates alluvial sediments. Sandy aquifers alternate with silty or clayey aquitards. Comparable soil profiles are expected in the fieldwork area.

4.1.3 Geohydrological setting and effect on Arsenic contamination

To study the geohydrology in Bangladesh an aquifer model containing 4 layers is commonly used. This model consists of an Upper aquitard, Upper Shallow aquifer, lower aquitard and a lower shallow aquifer. The corresponding thicknesses are: 5-25 meter, 20-40 meter, 2-10 meter, 25-60 meter (EPC/MMP, 1991). The deep aquifer is not included in this model. Moreover, for this research the deep aquifer is not of interest because there are no tested tube wells penetrating this layer. All sampled tube wells are more than 25 meters deep and therefore, it is assumed that they are located in the upper shallow aquifer. According to the 4-layer model, the geology of this layer consists of medium to fine sands. The general specifications of this aquifer are a transmissivity between <500 and 1000 m^2/day, based on a map with transmissivity values (BGS & DPHE, 2001).

Effect on Arsenic Contamination

As it has been previously mentioned, the aquitard in the region where the research is conducted contains a thick impermeable clay-silt layer, resulting in a relative small recharge by infiltration. This contrasts with the 4-layer model where the upper aquitard contains more silt and fine sands (BGS & DPHE, 2001; Jahan et al., 2007). During the monsoon period, the groundwater level reaches almost the ground surface. Then there is sufficient recharge to the upper aquitard mostly via the big rivers (BGS & DPHE, 2001).

Groundwater head differences (0.01-1 m km^{-1}) are small across the country of Bangladesh. These, in combination with a low transmissivity and a relatively thick aquifer result in a low groundwater flow and low flushing occurs. According to (BGS & DPHE, 2001), Table 1 has been compiled. Following the low groundwater flow and therefore, the slow flushing, could be an important factor in the high arsenic concentrations in the water.

Table 1. Effects on Arsenic Contamination

Low arsenic	**High arsenic**
Coarse sands in fluvial areas	Low recharge
Relatively high hydraulic conductivity, medium porosity	Low hydraulic conductivity
Present or historical high groundwater gradients	Present or historical low groundwater gradients
Relatively rapid flushing 2,000-10,000 years per pore volume	Slow flushing 50,000 – 200,000 years per pore volume
Sediments greater than 10,000 years old	Low groundwater flow rates

4.1.4 Sources of arsenic in groundwater

Arsenic contamination can end up in several ways in the groundwater. Both, natural (geogenic) as well as human (anthropogenic) sources are known for being the source of arsenic in groundwater. The widespread presence of arsenic in the groundwater can however, only be explained by assuming a geological origin (besides arsenic contamination around mines among others). (Raschid-Sally, 2000). There are two hypotheses that are globally most accepted and that describe the source of arsenic in the GBM delta and other places in the world (Fazal, Kawachi, & Ichion, 2001). Both hypotheses will be addressed briefly below.

Pyrite oxidation hypothesis

The pyrite oxidation hypothesis assumes an anthropogenic cause of the arsenic release to the groundwater. Due to increasing agriculture and irrigation the phreatic surface is lowered artificially. Saturated zones change to unsaturated zones causing reducing environment to change to an oxidizing environment. Arsenopyrite (FeAsS), naturally present in the soil, in the unsaturated zone oxidizes and forms iron hydroxide. In turn the iron hydroxide reduces during the next recharge of groundwater and arsenic is released. Other oxidizing agents such as nitrate can also cause the sulphide minerals to oxidize (Fazal et al., 2001). This hypothesis is however not consistent with observations made in Bangladesh.

Oxy-hydroxide reduction hypothesis

The alternative explanation is the oxy-hydroxide hypothesis. Several versions of this theory are opted by scientists. Below the most general version is explained.

The oxy-hydroxide hypothesis assumes that arsenic is present naturally in Quaternary alluvial sediments. Sediment grains contain iron hydroxide or manganese oxides to which arsenic is adsorbed. Iron oxyhydroxide is known for its ability to adsorb arsenic under oxidizing conditions and release arsenic under reducing conditions.

Arsenic in its primary form, e.g. arsenopyrite (FeAsS), arsenic-micas and arsenic-containing coals (Dowling, Poreda, Basu, Peters, & Aggarwal, 2002), weather from Himalayan geological units and are transported and deposited in mainly alluvial settings in the GBM-delta (Fendorf, Michael, & van Geen, 2010). In the Quaternary era several glaciations and deglaciations happened causing water level fluctuations. During glaciation, water levels decrease and cause oxidizing circumstances. Due to oxidation arsenic is released from its primary form. Iron oxyhydroxide, and in lesser degree manganese oxides, are present on sediment grains in the form of coatings (Raschid-Sally, 2000) and are able to adsorb arsenic.

Redox conditions start to change again during times of deglaciation and because of burial of the arsenic-containing sediments. Conditions become more reducing over time and arsenic is released slowly (Raschid-Sally, 2000). Conditions become much more reducing when the minerals are in contact with organic rich sediment (e.g. clay plugs, see Section 4.1.6) through migrating pore water.

Other factors, besides redox state, that play a role in arsenic (and metal and metalloid mobility in general) are pH, sorbent nature of the soil (grain size, mineralogy and organic matter content), concentration of ligands, water flow and presence of plant roots (Violante, Cozzolino, Perelomov, Caporale, & Pigna, 2010).

Under oxidizing conditions, arsenic in groundwater predominantly occurs as arsenic (V), also called arsenate. Under more reducing conditions arsenic (III), or arsenite, is more dominantly present. Under natural conditions both forms can occur simultaneously (D. Halem, S. Bakker, G. Amy, & J. Van Dijk, 2009). The local circumstances determine the ratio in which the two forms are present in groundwater. In Figure 3 a conceptual model posed by Violante et al. (2010) is depicted.

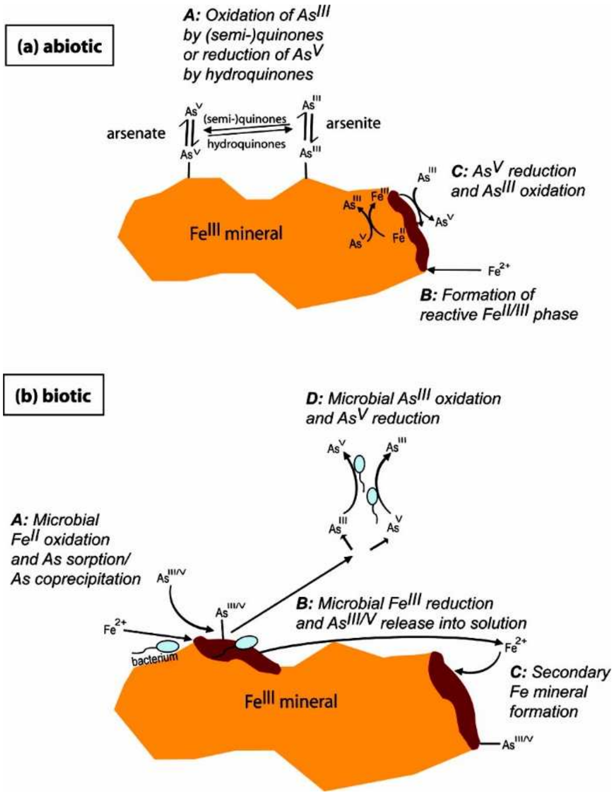


Figure 3. Conceptual model showing As interaction of Fe-oxyhydroxide mineral (Violante et al., 2010)

4.1.5 Sediment colour

As mentioned before, the redox state of the sediment plays an important role in arsenic release. A result of redox state is colour change of the sediment. Hossain et al. (2014) developed a colour tool for local tube well drillers to distinguish between safe and unsafe aquifers in terms of arsenic concentrations. By relating the sediment colour to a redox state, a good assessment of the risk of arsenic contamination in an aquifer can be made. This tool will also be used during the geological fieldwork. In Figure 4 an overview is shown and in Figure 5 the tool itself is provided.

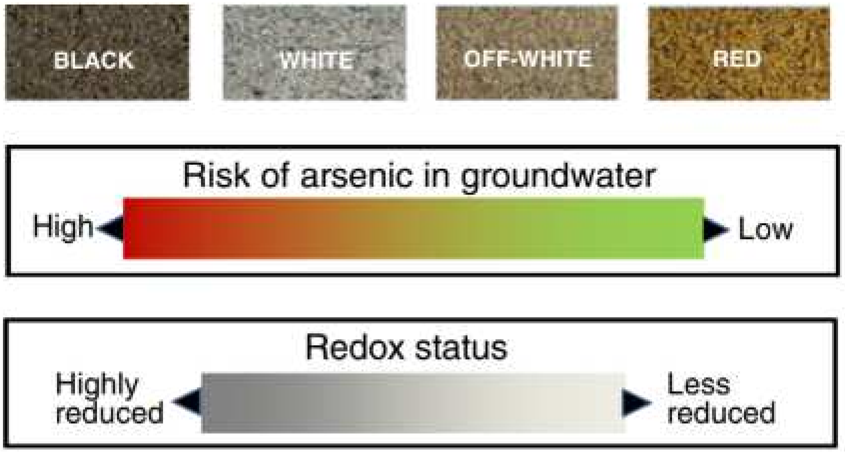


Figure 4. Four sediment colours and corresponding risks of As contamination and redox state (Hossain et al., 2014)

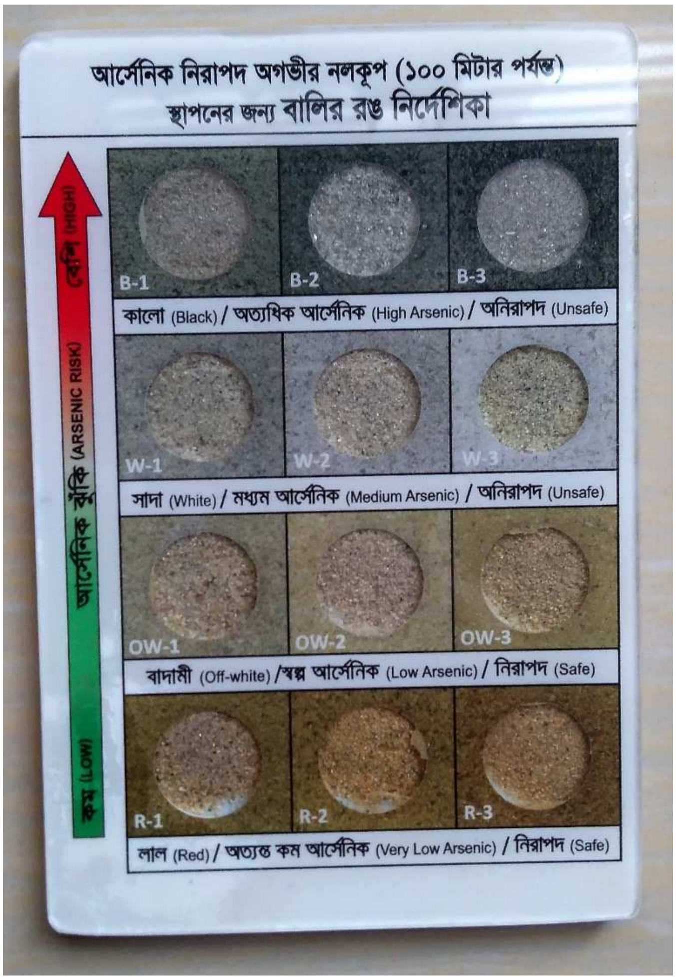


Figure 5. SASMIT colour tool

4.1.6 Arsenic concentrations and geological features

As mentioned before, an important source of arsenic in groundwater, according to the oxy-hydroxide hypothesis, is Holocene and Pleistocene fluvial and deltaic sediment. Shallow-depth meandering river deposits form the dominant geo-morphological setting of arsenic polluted areas (Donselaar, Bhatt, & Ghosh, 2017). Sandy point-bar structures with adjacent clay plugs (clay filled oxbow lakes) form the suitable redox conditions for arsenic release to the groundwater. Analysis of lithofacies by Donselaar et al. (2017) in combination with arsenic concentration data shows that the low-permeable clay plugs have high organic matter content and the point-bar sands high but variable arsenic concentrations. The clay plugs and deeper anoxic parts of the oxbow lake, have been identified as the location of reactive organic matter and microbial activity that causes reduction of iron oxy-hydroxide and releases arsenic. In Figure 6 the model formulated by Donselaar et al. (2017) is shown.

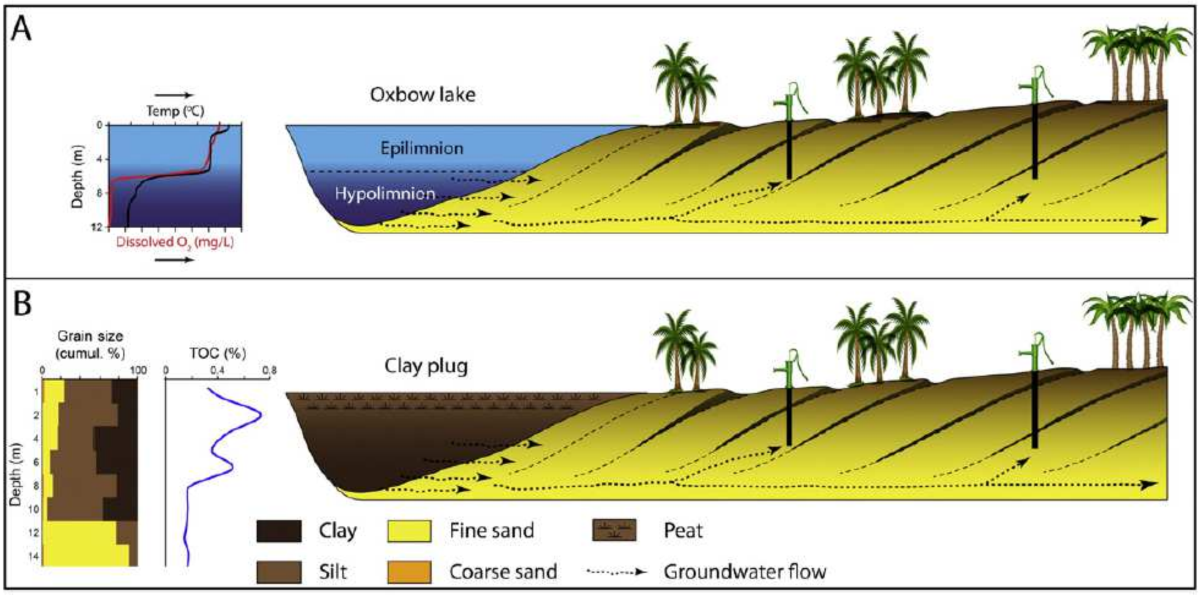


Figure 6. Generic geological model for the release of arsenic by juxtaposition of clay plug and point bar. A: Temperature and oxygen stratification in oxbow lake. B: Clay infill of the oxbow (Donselaar et al., 2017)

4.2 Water quality monitoring

Because the presence of arsenic and other chemical compounds in the groundwater is not stable, it is important to monitor the water quality regularly. In this project the concept of 'Mobile Crowd Participation', later referred to as MCP, is applied to set-up a monitoring plan for the water quality. In this section, the background information of water quality monitoring through MCP is explained.

4.2.1 Mobile Crowd Participation

Mobile Crowd Participation (MCP) is a strategy to involve local communities in the water supply system through smartphones applications. In the research presented in this report, end-users of the water supply system are responsible for the maintenance and monitoring of their own system. MCP forms the basis for this communal responsibility. Mobile applications (apps) are used for end-user interaction, water quality analyses and payment. There are three factors of success to apply MCP: smartphone ownership and internet access, the availability of a useful application, usable and desirable for the end-users (Mink, Hoque, Khanam, & Van Halem, Submitted for publication).

Smartphone use in Bangladesh is increasing rapidly and possession of smartphones is therefore not a limitation in the implementation of MCP. In 2017, 85 million people, which is half of the Bangladeshi population, was subscribed to the mobile market. This amount is expected to increase the coming years. Also the use of smartphones is rapidly increasing. In 2017, 31 % of the Bengali people possessed a smartphone which is expected to increase to 75% in 2025 (GSMA, 2018).

A useful mobile application is needed to apply the MCP strategy. The research presented in this report focusses on water quality analyses and therefore only a water quality application will be used. In the DELTAP project it is aimed to use different existing mobile applications for different purposes. 'Whatsapp' is the most common application for communication and the 'AKVO water quality app' is available for water quality monitoring. Furthermore, payment applications already exist and could be applied in this project.

The third success-factor of MCP is user acceptance. Previous fieldwork studies in India and Bangladesh have shown that end-users are willing to participate in the water quality monitoring using smartphones (Mink et al., Submitted for publication).

Water quality application

As mentioned above, the 'AKVO water quality app' is a mobile application available for water quality monitoring. AKVO is a Dutch company that has developed a mobile application for water quality tests. There are two applications available: 'AKVO Caddisfly' and 'AKVO Flow'. 'AKVO Flow' is a mobile survey application in which questionnaires can be uploaded that contain all the relevant information for water quality monitoring. 'AKVO Caddisfly' is an app to perform water quality analyses. These analyses are based on water quality strip tests. Using strip tests is a fast and easy method to determine different water quality parameters. However, the reliability of the results is questionable. Strip test results are based on colour change of a test strip after contact with the water sample. The AKVO Caddisfly application makes use of photography to determine the colour and thus the concentration of the studied chemical compound. The test strip is placed on a colour card and after calibration for the present light conditions, the colour of the strip and the colour card are compared to determine the concentration. An example of the use of the AKVO Caddisfly application for the iron strip test is depicted in Figure 7.

For water quality monitoring, both applications are used. In the survey of 'AKVO Flow', general information about, for example, the location and the weather conditions are addressed. In this survey, 'AKVO Caddisfly' can be called when water quality tests need to be performed. By using the two apps, all relevant information can be obtained and uploaded to a central database.

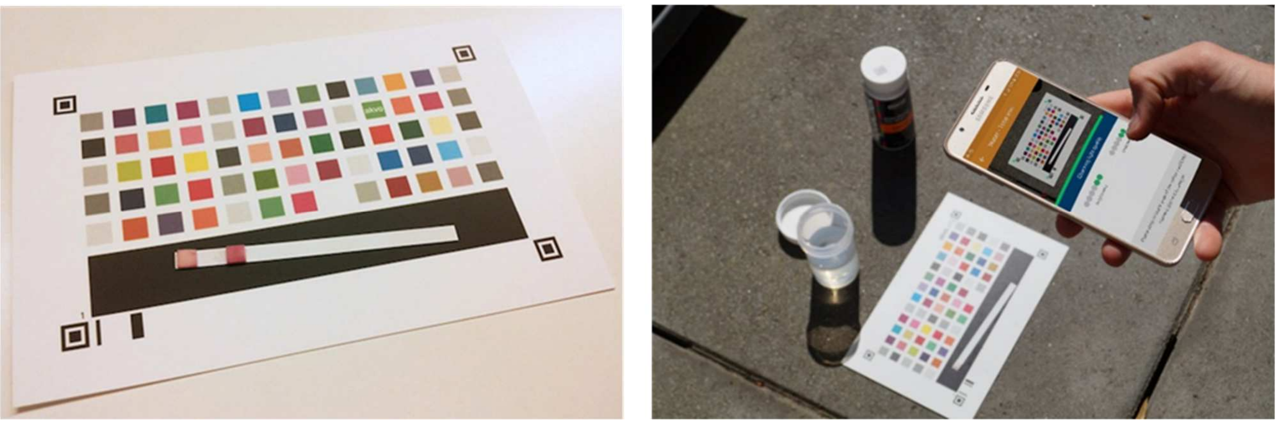


Figure 7. Left: Colour card used for AKVO Caddisfly; Right: Example of a strip test with the AKVO Caddisfly app

4.2.2 Relevant water quality parameters

Since the 1970s the source for drinking water in Bangladesh has rapidly shifted from mainly surface water to mainly groundwater through the installation of tube wells. Groundwater is free of microorganisms and therefore, it is considered as a safe source (Smith, Lingas, & Rahman, 2000). In Table 2, the most relevant parameters for the water quality of the groundwater in Bangladesh are depicted. There are three different purposes for the development of water quality standards: health, aesthetic and operational (Dunea, 2018).

Health standards are developed in order to keep the concentrations below acceptable levels considering the health of the users. Aesthetic or organoleptic standards are not related to health but to people's experience of drinking the water. It is not desired that the water has a metallic taste, brownish colour or odour. Lastly, operational standards are developed to keep the water treatment system in good operation and to keep sufficient water quality (Dunea, 2018).

In Table 2, the health standards developed by WHO and Bangladesh for the different parameters are depicted. Furthermore, the main effects of the parameters on the water quality are mentioned (Dunea, 2018).

The main components in the Bangladeshi groundwater will be further explained in the next sections. Four elements are of special relevance in drinking water. The most important health threat is formed by arsenic, a metal dissolved in the groundwater which has severe long-term health effects. Manganese is a compound present in high concentrations in the groundwater as well. The third relevant chemical is iron, which does not form a direct health threat. However, high concentrations of iron lead to a brownish colour and a metallic taste of the drinking water which is undesirable. The last compound that needs special attention is ammonium. Ammonium concentrations should be limited for both organoleptic and health reasons. Moreover, the physical parameters that are important for the drinking water quality are also addressed.

Table 2: Relevant parameters in groundwater used for drinking water (WHO Guidelines, **(DPHE, 2018))*

Parameter	**WHO standard (mg/L) ***	**Bangladesh standard (mg/L) ****	**Main effect**
Arsenic (As)	0.01	0.05	Skin diseases/cancer
Iron (Fe)	-	0.3-1.0	Colour and taste
Manganese (Mn)	0.4	0.1	Colour and taste
Ammonium (NH_4)	-	0.5	Odour and taste
pH	6.5 - 8.5		Taste
DO	-	6.0	Taste and corrosion
ORP	Not mentioned	-	
EC	Not mentioned	-	

Arsenic

As mentioned before, arsenic can lead to health issues in case of long-term exposure. According to the WHO standard, the concentrations of arsenic in the drinking water should be below 10 µg/L. But if the WHO rule that 'no substance may have a higher life-time risk of more than 1 in 100 000' is applied to arsenic, their standard would not suffice. The guideline of 10 µg/L is set from an economic or engineering point of view. However, reducing the acceptable concentration of arsenic to 1 µg/L would comply the health risks recommended and is technically feasible. The Bangladeshi standard of 50 µg/L is, considering the health risks related to arsenic, too elevated (D. v. Halem et al., 2009).

Iron

Iron is the second most abundant metal present in the earth's crust. In nature, iron is often found in the form of oxides. The main reason why iron should be removed from the drinking water is because of organoleptic properties. In drinking water, concentrations of iron below 0.3 mg/L are unnoticeable and concentrations of iron between 0.3 and 3 mg/L are still acceptable. Above 3 mg/L, the water gets a metallic taste which is undesirable. Staining of laundry and plumbing may already happen at concentrations above 0.3 mg/L (WHO, 2017). Iron concentrations in the groundwater usually vary from 0.5 to 10 mg/L so treatment is necessary to meet people's expectations of the drinking water.

There are no known health hazards associated with iron intake through drinking water. The main iron ingestion by humans is not via water but via food and it is an essential element for a healthy life (WHO, 2017). Because there are no health issues related to iron, the WHO did not set a standard for drinking water. However, the Bangladeshi standard is set to 0.3-1.0 mg/L (DPHE, 2018).

Manganese

Manganese concentrations should be limited in the drinking water for both aesthetic and health reasons. In surface waters, the concentrations of manganese are rather low compared to the groundwater in which reducing conditions favour the manganese levels. At concentrations higher than 0.1 mg/L manganese gives an undesirable taste to water and it can stain plumbing fixtures and laundry. The standard of the WHO is set to 0.4 mg/L because higher levels could lead to health issues. The Bangladeshi standard is set to 0.1 mg/L (WHO, 2017).

The exposure to manganese by drinking water is much lower than the exposure by food. Manganese deficiency hardly ever occurs because of its presence in many common food product. Overexposure to manganese could have severe health effects such as neurotoxicity (WHO, 2017).

Ammonium

Ammonium is the dissolved form (NH_4^+) of ammonia (NH_3). Its presence in the groundwater is mainly due to fertilizers used in agriculture and animal feed production. The organoleptic properties of ammonium are important for the water quality. Studies have shown a threshold odour concentration of approximately 1.5 mg/L and a taste threshold of 35 mg/L (WHO, 2017).

Groundwater levels of ammonium are usually below 0.2 mg/L. However, areas rich in humid substances or iron and forests could contain levels up to 3 mg/L. In contrast to the groundwater, surface water concentrations are maximum 12 mg/L (WHO, 2017).

Elevated levels of ammonium cause undesirable taste and odour of the water. Moreover, high levels of ammonium in the groundwater could indicate faecal contamination. The concentrations of ammonium found in drinking water do not have direct impact on human health (WHO, 2017). Therefore, the WHO did not set a standard for acceptable ammonium concentrations in drinking water. The Bangladeshi government has set a standard of maximum 0.5 mg/L ammonium in the drinking water (DPHE, 2018).

Salinity

High salinity levels of the groundwater could occur in a delta country like Bangladesh. Studies have shown that the intake of salt through drinking water exceeds the standards in large parts of the country (A. E. Khan et al., 2011). Climate change will probably even increase the salt intrusion from the Bay of Bengal. The WHO has not provided limits on the salinity of drinking water, except a taste-concern with sodium levels larger than 0.2 g/L.

However, high salinity levels could have adverse health effects (A. E. Khan et al.). A study in the south-western coast of Bangladesh has examined the relation between salinity and health issues. High salinity rates of the drinking water are considered as the cause for large numbers of pregnant women being diagnosed with pre-eclampsia, eclampsia and hyper tension (A. Khan, Mojumder, Kovats, & Vineis).

This project focusses on the Rajshahi division, a region in the north-east of Bangladesh where salinity is most probably not a relevant parameter.

pH

According to WHO (2017), a pH value of 6.5 or higher is recommended for drinking water to prevent corrosion. Although a pH value larger than 8.0 would be disadvantageous in the treatment and disinfection of drinking water with chlorine. Therefore, pH values ranging between 6.5 and 8.5 usually indicate good water quality and are typical for most of the basins of the world (Oyem, Oyem, & Ezeweali, 2014)

Electrical conductivity

EC refers to the electrical conductivity of the water solution. The amount of electricity that can pass through water is influenced by how many ions are dissolved in the water. An indication of ionic nutrient present in water can be obtained from the EC. Nevertheless, EC does not provide information about the exact part per million of ions present in the solution (Oyem et al., 2014). The WHO does not have any guideline regarding EC values for drinking water quality (WHO, 2017).

Dissolved oxygen

Dissolved oxygen (DO) refers to the volume of oxygen that is contained in the water. A high DO level in a drinking water is positive because larger DO implies better taste of the water. However, higher DO level can accelerate the corrosion in the pipe system. The amount of DO in water is dependent on the temperature, salinity and pressure. The higher the temperature, the less the amount of oxygen is dissolved (APECWater, 2018) . There is no health-related target for DO in water in accordance with WHO (2017).

Oxygen reduction potential

The oxygen reduction potential is a measure of the cleanliness of the water and its ability to breakdown the contaminants (OzoneSolutionsInc., 2018). It has a range of -2000 to +2000 millivolts(mV). The negative sign represents the water is in reducing state and the positive sign represents that the water is in oxidizing state. ORP is based on dissolved oxygen amount. More contaminants in the water results in less dissolved oxygen level as the organics present in water consuming more oxygen hence lower ORP level. The WHO does not have any guideline regarding ORP values for drinking water quality (WHO, 2017).

4.2.3 End-user monitoring

In this study it is aimed to set-up a water quality testing protocol for the end-users of the water supply system. Based on the results of this literature study, it can be concluded that there are four main chemical water quality parameters that need to be tested regularly. First, arsenic is the most important chemical due to its severe health effects. Secondly, manganese concentrations should be monitored well because high manganese levels could result in both negative organoleptic and negative health effects. Next, iron is an essential element to test. Elevated iron levels lead to a metallic taste and a brownish colour of the drinking water. Lastly, ammonium concentrations are of interest because it could indicate faecal contamination.

Different test kits of different prices and user-friendliness are available to test the water quality using mobile applications. Therefore, a proper selection of the test kits needs to be made. The arsenic test kit is expensive compared to the other test kits, it costs 0.80 to 1.80 euro per strip test. Iron strip tests in contrary only cost 0.30 to 0.50 euro. Another disadvantage of the arsenic strip test is that arsenic gas is released, which could be harmful for health. It is thus, not desirable for the end-users to use the arsenic test kit for regular water quality testing. Possible relations between the presence of arsenic and other chemicals such as iron and ammonium could be a key in the water quality monitoring. Literature studies have shown that relations between arsenic and iron and ammonium exist.

As follows from Section 4.1, iron and arsenic co-exist in the groundwater. A research of Dowling et al. (2002) studied the composition of 68 groundwater samples in the Bengal Basin. Figure 8 (left) shows that the relations found between arsenic and iron and ammonium are weak when considering all the groundwater samples. Even though the correlation is weak, due to the fact that locations with high iron concentrations have low arsenic concentrations, iron could still be used as an indicator for the presence of arsenic in the groundwater. If locations would have low iron and high arsenic, iron cannot be used as indicator for arsenic because this is harmful for health. However, this does not hold for arsenic and ammonium as Figure 8 shows that high arsenic concentrations are found with low ammonium concentrations. However, if only the arsenic contaminated wells are considered, the relations are stronger as shown on the right in Figure 8.

In a study of Harvey et al.(2002), 54 monitoring wells have been analysed in the south of Bangladesh. The results indicate that the release of iron and arsenic from sediments are correlated (r^2=0.64) for different depths. Furthermore, the presence of ammonium and arsenic show a similar pattern over the depth (Harvey et al., 2002).

In this research, groundwater samples will be taken and will indicate if relations between arsenic and other elements are present in order to make water quality monitoring through MCP more reachable.

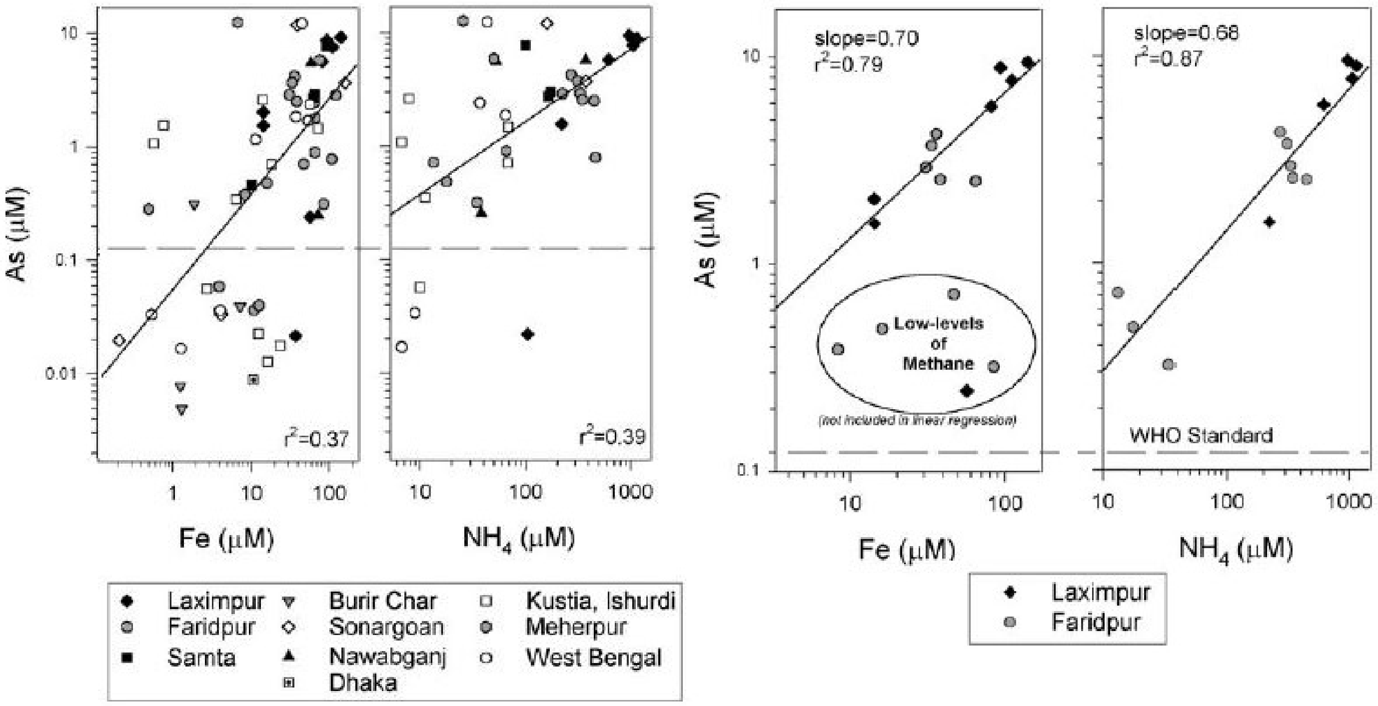


Figure 8. Left: Dissolved As versus Fe and NH4 for all studied tube wells in the Bengal Basin, Right: Dissolved As versus Fe and NH4 for the arsenic contaminated wells (Dowling et al., 2002)

4.3 Water treatment unit

Arsenic poisoning through drinking water is one of the major health concerns in Bangladesh. About half of the population of Bangladesh, almost 80 million people, is affected by the contaminated water from the hand pumps. This number is based on the threshold value of arsenic concentrations of 50 μg/L. According to the (WHO, 2017), arsenic concentration of the drinking water should not exceed 10 μg/L.

Previous studies and research show a variety of techniques to remove arsenic from the groundwater. Oxidation and precipitation, coagulation and coprecipitation, sorption and membrane techniques are the main treatment processes that can remove arsenic from water effectively. However, these removal techniques require high capital cost, operation and maintenance cost and the cost related to treat the brine.

The oxidation state of arsenic is crucial to remove arsenic more effectively. Arsenic (V) can be removed with the help of basic filtration techniques more easily than arsenic (III). The oxidation of arsenic (III) to arsenic (V) can be done with external strong oxidizing agents or with the help of microorganisms (Lytle, Chen, Sorg, Phillips, & French, 2007)

Gude, Rietveld, and van Halem (2018) observed that the biological arsenic (III) oxidation quickly developed in rapid sand filter columns fed with arsenic contaminated water. Therefore, if the micro-organisms growth can be enhanced, the removal of arsenic can be accelerated.

Moreover, the presence of iron can play an important role in removing the arsenic. With the presence of oxygen, iron (II) can be oxidized into iron (III) and make flocs. Arsenic (V) can get adsorbed with the iron (III) flocs and removed with subsequent filtration. However, the disadvantage of this process is that the removal of arsenic is dependent on the availability of iron in the water (Gude et al., 2018).

5. Research objectives

As mentioned in Chapter 3, the main objective of this research is to obtain more insight in three aspects of the DELTAP project: geology, water quality monitoring and safe water supply. Based on literature study and laboratory work, the research goals of the fieldwork conducted in Bangladesh are defined and explained in this chapter.

Geology is the most important source of arsenic contamination of the groundwater. This study aims to obtain a better insight in the relation between arsenic contamination and geology and finally use this knowledge to appoint safe sources of groundwater in the future. This insight is obtained through two different research objectives. First, the purpose is to find relations between geomorphological structures in the landscape and arsenic contamination and link this to the spatial distribution of arsenic concentrations in the groundwater. Secondly, the goal is to relate soil properties to arsenic concentrations in the groundwater.

Monitoring the water quality through mobile applications, applying the Mobile Crowd Participation strategy, is the second main objective of this research. In this study, it is aimed to analyse the performance of the simple water quality tests on which the mobile apps base their results. Furthermore, the research focusses on possible relations between arsenic and other chemicals. The main goal is to set-up a drinking water monitoring procedure for the operator of the water treatment unit.

The third research objective is to design and build a water treatment unit that provides safe drinking water. First, it is aimed to find a suitable location for the construction of the water treatment unit. Once the water treatment unit is built, the study will focus on its performance by extensive monitoring. Moreover, the purpose is to provide recommendations for future work on the water treatment unit. Finally, it is aimed to write an elaborated manual to make sure the system is monitored and maintained well after this research has finished.

SUPER
75
MOTOX

6. Methodology

This research is conducted in three different phases. First, background literature of the three different project aspects has been presented. The results of this study are explained in Chapter 0. Secondly, the preliminary work on the water treatment and on water quality monitoring has been performed before the fieldwork, in the laboratory at TU Delft. The findings in the literature review and in the laboratory are used to set-up a plan for the fieldwork conducted in Bangladesh. This fieldwork consists of three different parts. The aim of the geological fieldwork is to analyse the relationship between arsenic and the geology. The water treatment fieldwork has the objective of constructing a water treatment unit. Besides, the water quality fieldwork focusses on the present water quality in the study area. The methodology of this project is explained in this section.

6.1 Location of the research

The research of this project is conducted in the Rajshahi division, Paba Upazila, Harian Union, Bangladesh. The city of Rajshahi is located along the river Ganges, bordering India. Figure 10 depicts further detail on the location of the study area.

The village selected for this research is close to the city of Rajshahi. Uttar Kazirpara is a small village with approximately 600 people organized in 200 households. Different reasons have played a role in the selection of Uttar Kazirpara as main location of this project. First, previous research has shown that the villagers are extremely affected by arsenic contamination. Approximately 80 households have tube wells with arsenic concentrations above 200 µg/L. Because of the previous research conducted in this village, the inhabitants are conscious about the arsenic contamination. Therefore, their motivation to get a safe water source is enormous, which helps in the implementation. Lastly, practical considerations played a role in the location choice. Uttar Kazirpara is close to Rajshahi city and therefore, it is easily accessible for the researchers. A map of the village is showed in Figure 9.

The income of the people in this village is mainly from agriculture. The village is a residential area with few commercial activities. There are two small tea stalls. Two mosques form a central community point in the village. Several ponds in the village are used for recreation, bathing and laundry purposes.

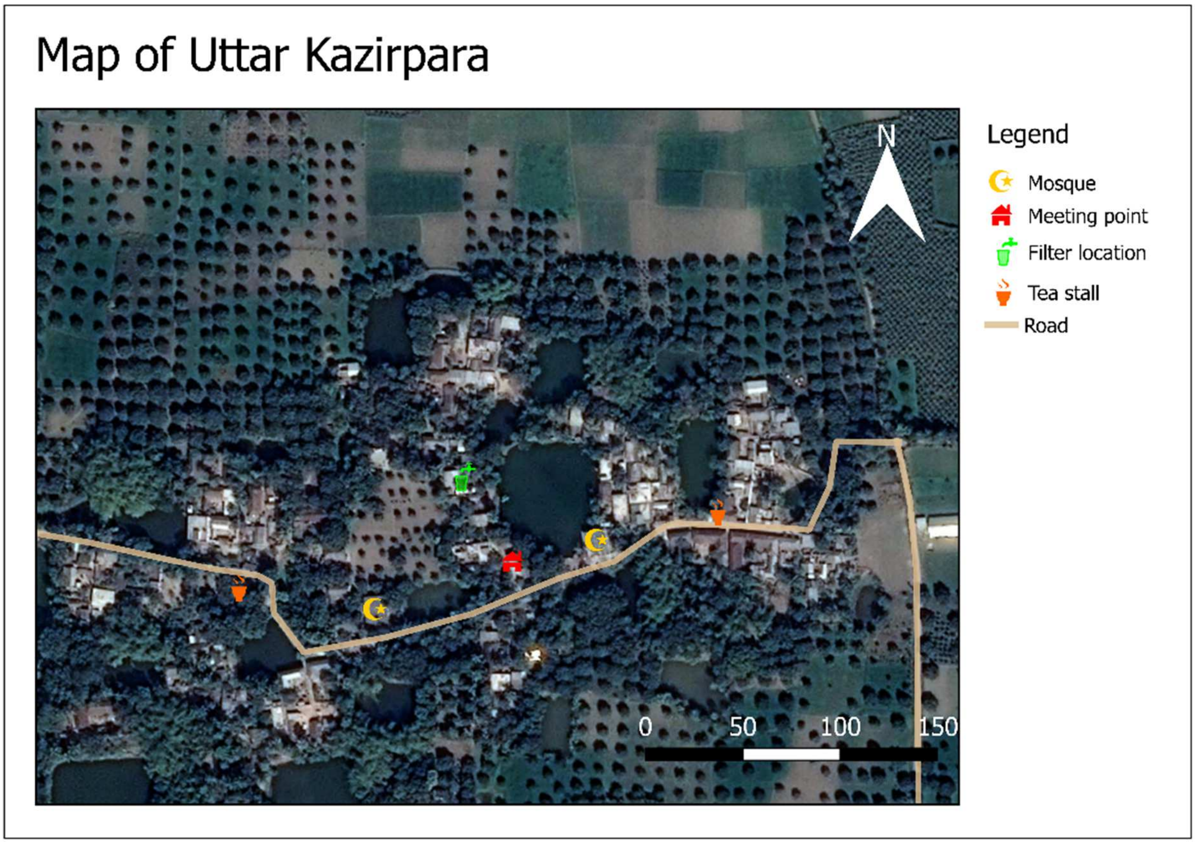


Figure 9. Map of Uttar Kazirpara

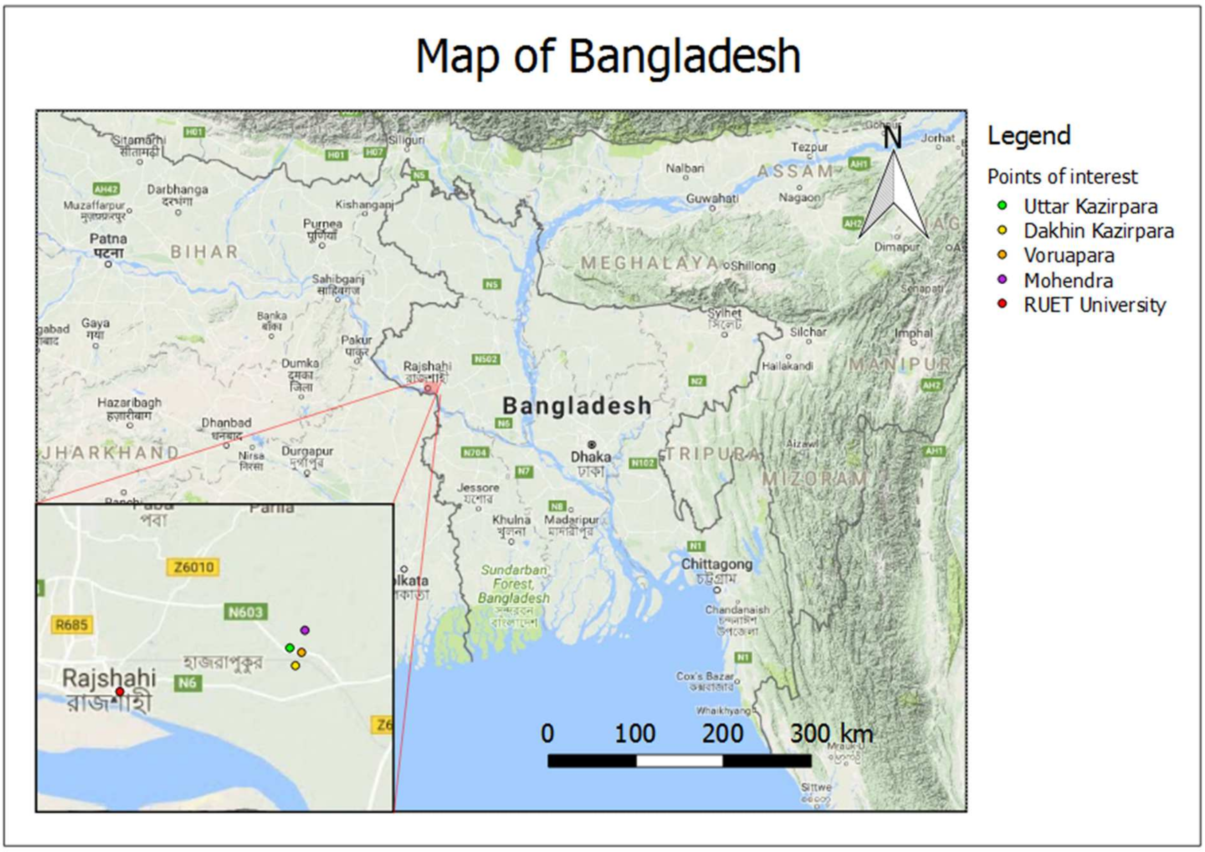


Figure 10. Map of Bangladesh

6.2 Geological fieldwork

The geology of the project area is of large importance for the arsenic release in the groundwater. In this study it is aimed to understand and formulate a relationship between geology and arsenic concentrations in groundwater. The geological fieldwork consists of four different parts, namely: reconnaissance survey, water quality fieldwork, spatial analysis and lastly drilling fieldwork.

6.2.1 Reconnaissance survey

First, a reconnaissance survey is performed. It is aimed to create a map of the project area in which the main facilities of the village are depicted. Besides, the properties of the top-soil at different locations in the village are analysed to understand the geology of the Bengali countryside better. Furthermore, observations relating to geomorphological features are mapped. This is done by looking at satellite images, digital elevation data and field observations. Moreover, a total of 10 soil samples are taken on different locations in the villages Uttar Kazirpara and Voruapara. The samples are collected from approximately 30 cm depth.

6.2.2 Water quality fieldwork

Secondly, the results of the water quality fieldwork, explained in Section 6.3, are used for a geological analysis of the project area. Based on the results of the water quality fieldwork, a map can be compiled that contains all data points and the corresponding concentrations of arsenic. Multiple parameters that have been tested in the water quality fieldwork are examined. However, there is mostly focus on arsenic concentrations since arsenic forms the major health threat.

6.2.3 Spatial analysis

To determine the exact locations to perform the drillings, a spatial analysis of the water quality of the tube wells is performed. For this analysis a geographical information system is used. The software used is QGIS version 2.18.

For determining the drilling locations, only total arsenic is used. The total arsenic concentrations are retrieved via ICP-MS analysis at TU Delft. This is explained in detail in Section 6.3.4.

The spatial distribution of arsenic is visualized according to the GPS coordinates of the corresponding sampling points. The GPS coordinates of the tube wells are retrieved via the application GPS Essentials. The accuracy of this app is five feet.

An interpolation of the arsenic concentration is conducted for the area covering the village of Uttar Kazirpara, since this study mainly focusses on this area. If the results show that there are no sufficient suitable places for drilling, the area will be enlarged eastwards towards the village of Voruapara.

For this kind of data analysis the inverse distance weight (IDW) interpolation is the most common method, since arsenic contamination is expected to be driven by the variation of the local geological conditions (Esri, 2018). The IDW interpolation looks at data points in a radius around the interpolated grid cell. The closer a data point is located, the higher its weight is in calculating the value for the grid cell. The power parameter used for the interpolation is by default 2. The amount of points used for each grid cell are default 12. The results of this interpolation can be found in Section 7.1.2.

6.2.4 Drilling fieldwork

The next step is the execution of the “drilling fieldwork”. In total three drillings are carried out. The drillings are executed by percussion drilling performed by local drillers, a method that normally is used for the installation of tube wells. Every five feet a sample is taken. As a result, the resolution of the drillings is low, and the samples are disturbed. From the drillings soil profiles are compiled. These soil profiles are however, not continuous. Since samples are taken every five feet, thin soil layers can be overlooked. Nevertheless, for the purpose of the geological research the resolution is assumed to be sufficient. NEN-EN-ISO 14688-1+A1+C11:2016 is used as a guideline for the classification of the soil samples. Furthermore, the SASMIT colour tool is used to determine the risk of arsenic contamination in aquifers, see Section 4.1.5 for more details. Soil samples are taken to do laboratory testing. These samples will be analysed later by use of XRD and XRF analysis to compare the mineral and elemental contents of the soil of the different drillings.

In Appendix I the protocol for the drilling fieldwork is shown. Based on the combined results of the reconnaissance survey and the water quality fieldwork the location of the drillings is decided. Practical issues should also be taken into account, e.g. whether or not the local drillers can reach the location, whether or not the landowner allows the drilling, whether or not there are plant roots bothering the drillers, among others.

One of the drillings is located in an area where high arsenic concentrations have been measured in the tube well water. Another drilling is in a medium-arsenic-contaminated area, and the last drilling in an arsenic-safe area. The reason chosen for this spread is to be able to check differences in the aquifer concentrations and concentrations found in the tube well water. Moreover, the mineral and chemical element contents can be compared after the XRD and XRF analysis.

As a result of all data gathering and analysis, an extensive dataset is created. One of the outcomes of the geological related part of the research is this dataset. Furthermore, there is an attempt to understand and formulate a relationship between geology and arsenic concentrations in groundwater.

6.3 Water quality fieldwork

This section will explain the methodology used in order to collect water quality data of 150 tube wells in the four research villages: Uttar Kazirpara, Dakhin Kazirpara, Mohendra and Voruapara. The water quality fieldwork focusses on well depth and head measurements, water sample analysis in the laboratory and water quality strip tests. All data is collected using mobile applications on smartphones.

6.3.1 Fieldwork location

The water quality fieldwork is performed in four villages, all close by the research village Uttar Kazirpara. In order to get a general overview of the water quality of the present tube wells, it is aimed to spread the data collection points as much as possible. Most of the measurement points are collected in Uttar Kazirpara. The tube wells were selected based on spreading of the tube wells. In the other villages, the exact location of the data collection mainly had a social basis due to the fact that some households were very interested in the water quality of their tube well. Dakhin Kazirpara is very close to Uttar Kazirpara but the tube well water has low arsenic contamination. It approximately has 600 people organised over 200 households. Voruapara and Mohendra are located further from Uttar Kazirpara than Dakhin Kazirpara. In these villages some households are affected with arsenic and others not. The map in Figure 11 shows all the tested tube wells in the study area.

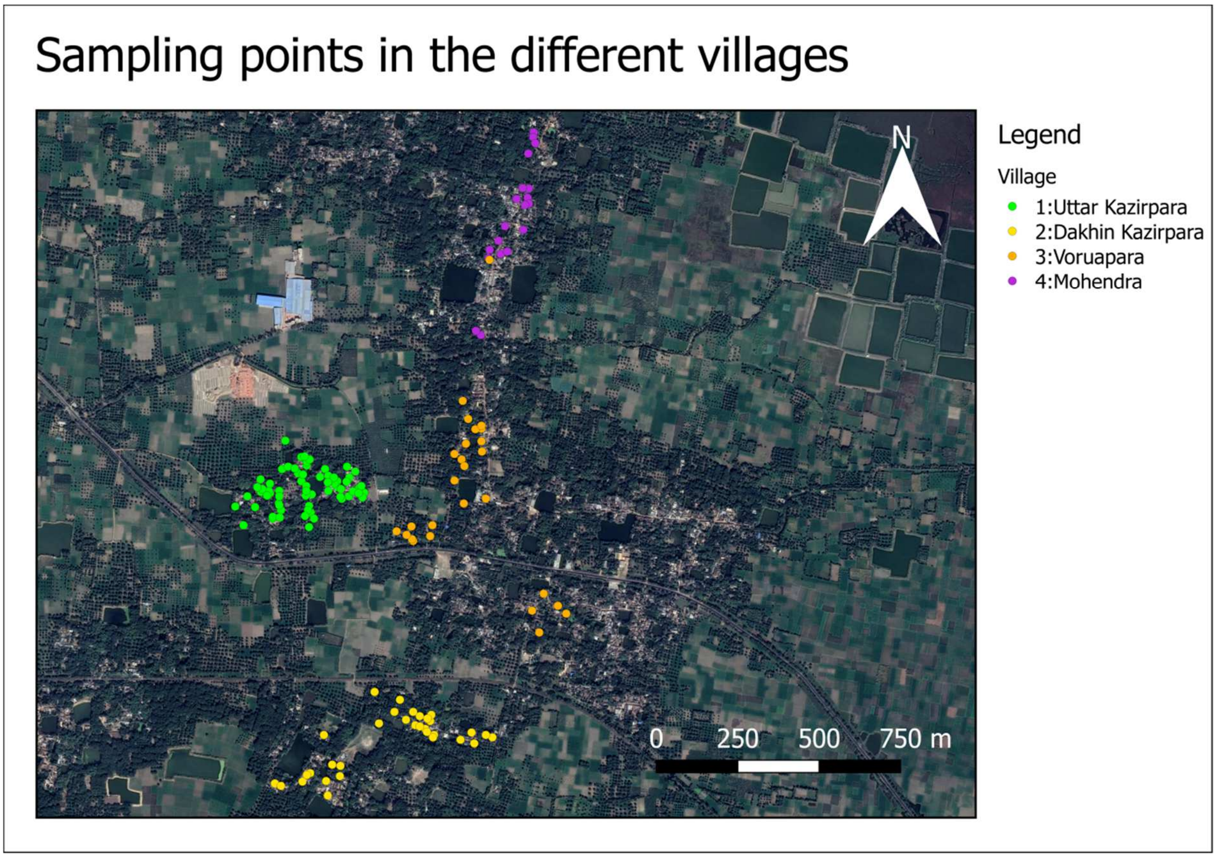


Figure 11. Map of sampling points per village

6.3.2 Data collection through smartphones

As explained before, the smartphone applications of AKVO are available for water quality testing. In this fieldwork, all the data will be collected through smartphones. Six different smartphones of local and global brands are used to collect the data, the specifications of these phones are shown in Table 3. AKVO Caddisfly makes use of photography. Therefore, the camera quality of the phone could influence the results. Besides, the android version of the phone is of importance for the use of the applications. The results of the different smartphones are compared in this study.

Table 3. Smartphone specifications

Phone brand	Phone type	Android version	Camera resolution
Motorola	Moto G2	6.0	8MP
Asus	Zenfone C Z007 ZC451CG	4.4.2	5MP
Motorola	Moto G5 Plus	7.0	12MP
Samsung	Galaxy J7	6.0.1	13 MP
Huawei	Y6 Prime	8.0	13 MP
Oppo	A71	7.1	13 MP

Both ‘AKVO Flow’ and ‘AKVO Caddisfly’ are installed on all the smartphones. In ‘AKVO Flow’ a survey has been set-up which contains all the relevant information for each measurement point. In this survey, ‘AKVO Caddisfly’ is included when water quality tests need to be performed. Not all de strip tests used in this study are available in ‘AKVO Caddisfly’. Therefore, some of the results are only based on visual interpretation of the colour change of the test strip. The results of the tests that are available in ‘AKVO Caddisfly’ are both obtained through visual interpretation and by the application in order to verify the performance of the application.

The survey in ‘AKVO Flow’ consists of the following elements:

Basic information

- Observation ID
- GPS Location
- Village name
- Well depth
- Water head
- Picture of the drinking water source
- Weather conditions
- ICP-MS sample collection
- Ammonium sample collection

Multimeter tests

- Electrical conductivity (µS/cm)
- Water temperature (degrees Celcius)
- Hardness (mg/L)
- Turbidity (TDS)
- pH

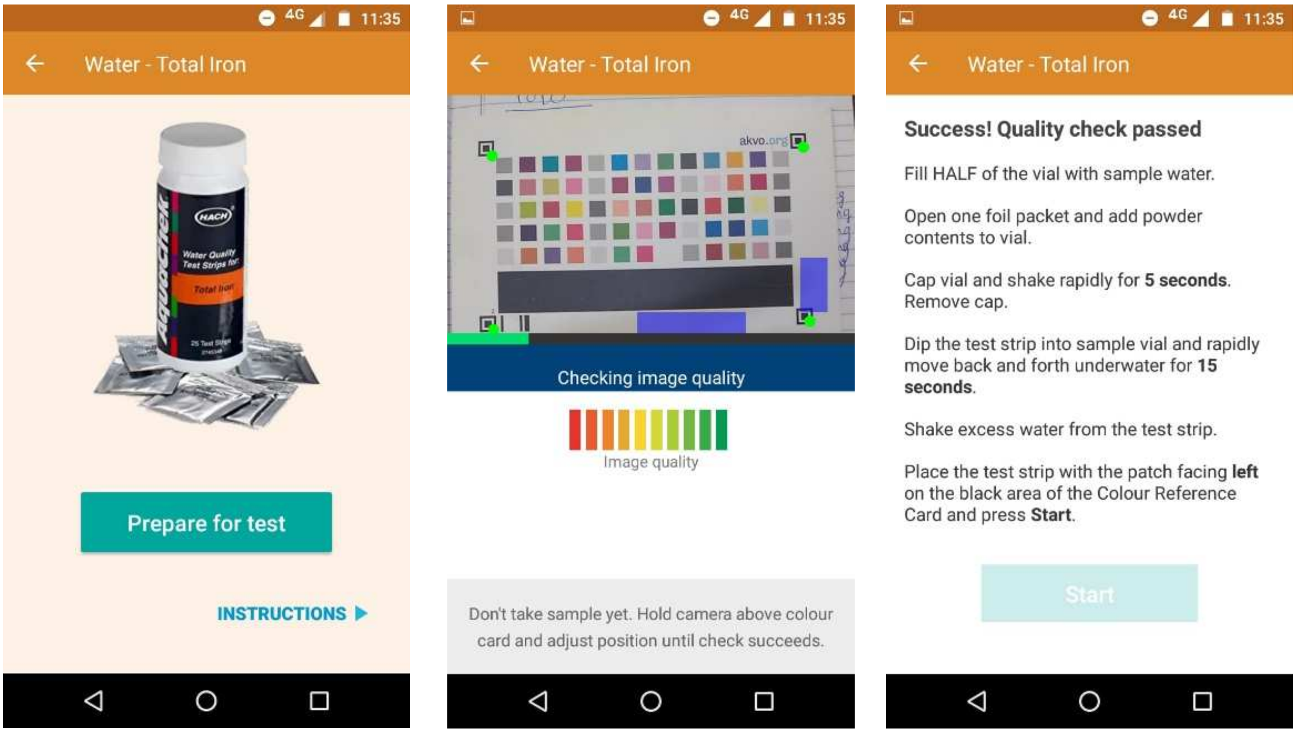
Strip tests

- Name of research phone
- Hach Iron test visual, picture of test strip and Caddisfly
- Quantofix Iron test visual, picture of test strip and Caddisfly
- Quantofix Arsenic test visual, picture of test strip and Caddisfly
- MQuant Manganese test visual and picture of test strip
- Macherey Nagel Ammonium test visual and picture of test strip

PhotoFlex cell test

- Ammonium cell test concentration
- Numbers of hours passed since sample collection

Figure 12 shows three steps of the ‘AKVO Caddisfly’ application. This example shows the Hach Total Iron test. First, the colour card needs to be calibrated. Next, the instructions of the test are provided and when finished, the strip can be placed on the colour card and the concentration will be measured.



Don't take sample yet. Hold camera above colour card and adjust position until check succeeds.

Success! Quality check passed

Fill HALF of the vial with sample water.

Open one foil packet and add powder contents to vial.

Cap vial and shake rapidly for **5 seconds**. Remove cap.

Dip the test strip into sample vial and rapidly move back and forth underwater for **15 seconds**.

Shake excess water from the test strip.

Place the test strip with the patch facing **left** on the black area of the Colour Reference Card and press **Start**.

Figure 12. AKVO Caddisfly for the Hach Total Iron test

6.3.3 Well depth and hydraulic head measurement

In order to relate concentrations of different chemical compounds in the groundwater to the geology, it is important to know the source of the groundwater. In other words, in which aquifer the well, from which the water is withdrawn, is screened. In order to approximate this, the depth of each tube well that has been tested. Two local plumbers are hired to dismantle every tube well. The depth of the tube well is determined by lowering a rope with small weights fixed to the lower end of the rope. When the rope does not go any lower, the length of the rope is measured by use of a measuring tape. The accuracy of the depth measurement is approximately one foot (0.305 metres) since the unit of the measuring tape is feet.

The head measurement is executed by use of measuring tape with a so-called acoustic clock attached to the measuring tape. The accuracy of the head measurement is approximately 0.1 metres. There are no elevation reference points present in the research area. It is therefore, difficult to determine the actual accuracy of the hydraulic head data. A valid assumption is that every tube well that has been tested is at equal elevation ± 1 foot (0.305 metres).

6.3.4 Water sampling

At every tube well, two water samples are taken to conduct laboratory measurements. One sample is taken for ICP-MS (Inductively Coupled Plasma Mass Spectrometry) analysis in the laboratory at the department of Civil Engineering at TU Delft. The ICP-MS apparatus is capable of detecting and measuring very low concentrations of several metals and non-metals. The results are compared to the results obtained with the strip tests. The second sample is taken for determination of ammonium concentration by the aid of a photo-spectrometry device.

Both samples are taken by using a 15 mL syringe which is rinsed twice before use with tube well water. This is done to avoid contamination of the sample. A filter (Chromafil® Xtra PES-45/25) with a pore size of 45 µm of the brand Macherey-Nagel has been attached to the syringe to filter the water. The filter is used to filter out any solid particles that can influence the ICP-MS and photo-spectrometry results. The sample bottles that are used for the ICP-MS samples are acidified before use. The sample bottle is filled up with tube well water to have a total sample of 10 mL. The acidification is necessary for preservation of the water sample. All chemical compounds that are tested will remain dissolved when the samples are acidified, and the sample will thus not change in terms of concentration of chemical compounds.

The sample bottles that are used for the ammonium measurement are also rinsed twice. The bottle is filled completely leaving no space for air. This is also done for preservation of the sample. The samples for ammonium measurement are stored maximally 8 hours before testing. When stored for a longer time or when in contact with oxygen, the ammonium concentration can change due to oxidation reactions.

6.3.5 Water quality field-tests

The water quality tests that are performed in the field are described in this section. The fieldwork is divided into three parts: multimeter measurements, strip tests and photoflex measurements.

Multimeter

The multimeter is a sensor with which several water quality parameters can be measured. Two different types of sensors are used in this study: Tracer PockeTester and WTW Multi3430 with different probes.
The parameters determined in this research are: Electrical conductivity, water temperature, hardness, turbidity and pH.

These parameters are determining for the general quality of the water from the tube well. The pH and the temperature of the water influence the performance of some strip tests that will be performed in this research. The electrical conductivity is a measure for the number of dissolved elements such as arsenic and iron. Hardness is a measure for the concentration calcium and magnesium, this parameter is mainly of importance for operation of the system. Turbidity is a measure for the amount of small particles, not visible for the eye.

Strip tests

The different strip tests that are used to study the water quality are described in the paragraphs below.

pH

Besides the pH measurement with the multimeter, the acidity of the water sample is also determined using a strip test. The Hach pH test is used in this fieldwork. This test has a colour range from 4 to 9 with steps of 1. The procedure of this test kit is described below.

1. Dip a strip into water and remove immediately.
2. Hold the strip level for 15 seconds. Do not shake excess water from the test strip.
3. Compare the pH test pad to the colour chart on the bottle. Estimate results if the colour on the test pad falls between two colour blocks.

Arsenic

The arsenic concentration of the water from the tube wells is determined using the Quantofix Arsen 10 test kit. This test kit contains test strips and three different reagents. Figure 13. Quantofix Arsen 10 test procedureshows the procedure of the Quantofix Arsen 10 test. The concentration measured with this test kit ranges from 0 to 0.5 mg/L $As^{3+/5+}$. The colour range is as follows:

0 – 0.01 – 0.025 – 0.05 – 0.1 – 0.5 mg/L

The results are obtained by both visual interpretation of the test strip and by the AKVO Caddisfly application. The detailed procedure of the Quantofix Arsen 10 test can be found in Appendix III.

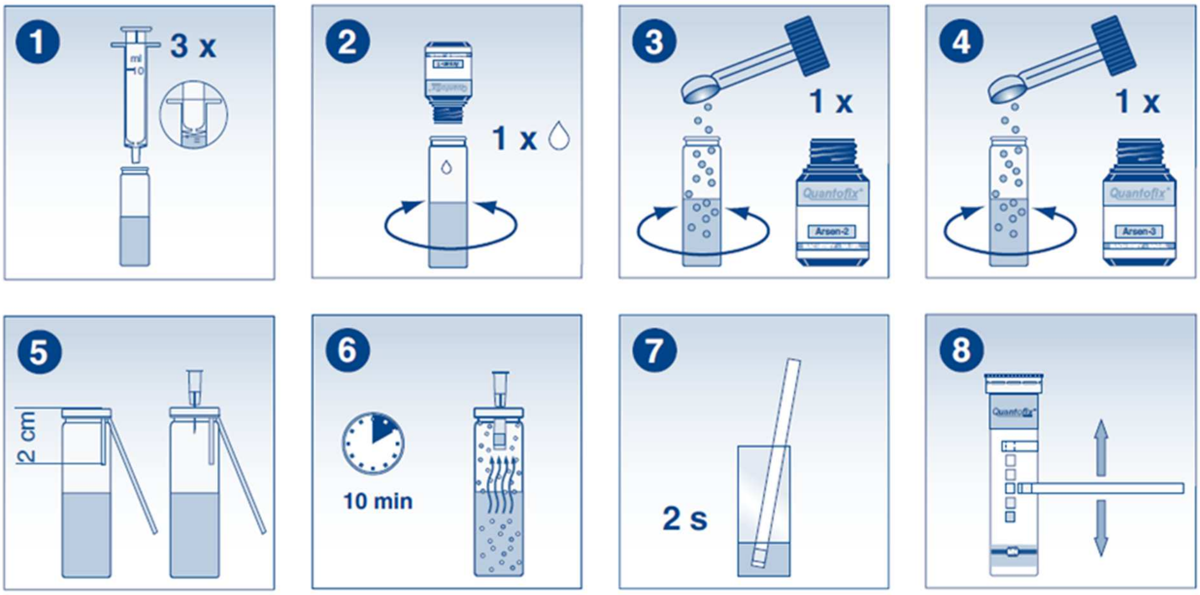


Figure 13. Quantofix Arsen 10 test procedure

Iron

The iron concentration of the water from the tube wells is determined using two different test kits: Hach Total Iron and Quantofix Total Iron 100.

The Hach Total Iron test kit contains a vial, test strips and a reagents powder. The colour range of the Hach Total Iron test is 0 to 5 mg/L with the following steps:

0 – 0.15 – 0.3 – 0.6 – 1 – 2 – 5 mg/L

The procedure of this test kit is as follows:

1. Fill half of the vial with sample water
2. Open one foil packet and add powder contents to vial
3. Cap vial and shake rapidly for 5 seconds. Remove cap
4. Dip the test strip into sample vial and rapidly move back and forth underwater for 15 seconds
5. Shake excess water from the test strip
6. Determine the concentration visually and with 'AKVO Caddisfly'

The Quantofix Total Iron 100 test kit uses test strips that directly change colour after contact with the water. The pH of the sample should be within 1 and 7 and the measured range is 0 to 100 mg/L Fe2+/Fe3+. The colour range of this test strip is as follows:

0 – 2 – 5 – 10 – 25 – 50 – 100 mg/L

Figure 14. Quantofix total iron 100 test procedure shows visually the procedure of the Quantofix Total Iron 100 test.

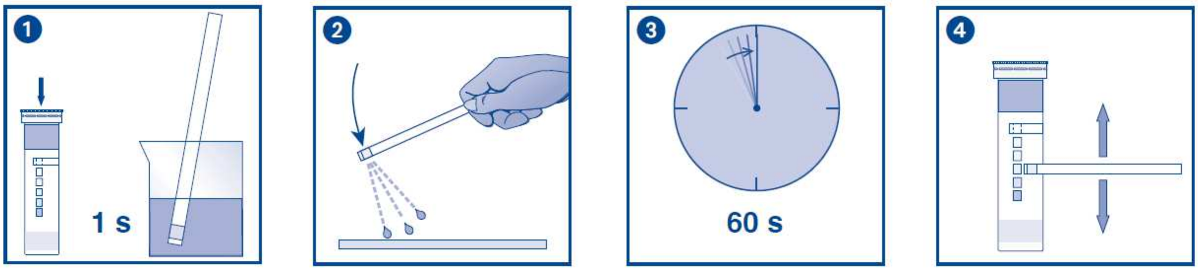


Figure 14. Quantofix total iron 100 test procedure

Both iron strip tests are performed in the field. The results are obtained by visual interpretation of the test strip and by the AKVO Caddisfly application. The complete information manual of the Hach Total Iron and the Quantofix Total Iron 100 test kits can be found in Appendix I

Manganese

The concentration of manganese in the tube well water is determined using the MQuant Manganese Test. This test kit contains test strip and two reagents. A visual test procedure can be found in Figure 15. Concentrations in the range of 0 to 100 mg/L can be determined. The colour range is as follows:

0 – 2 – 5 – 20 – 50 – 100 mg/L

The results are obtained by visual interpretation of the colour of the test strip, compared to the colour chart on the bottle. To get accurate results from this strip test, the pH of the water must be within the range 1 to 7. Moreover, the temperature of the water should be between 10 and 25 ℃. If the pH measurement shows a value larger than 7, one drop of hydrochloric acid is added to the sample. The detailed manual of the MQuant Manganese Test can be found in Appendix V.

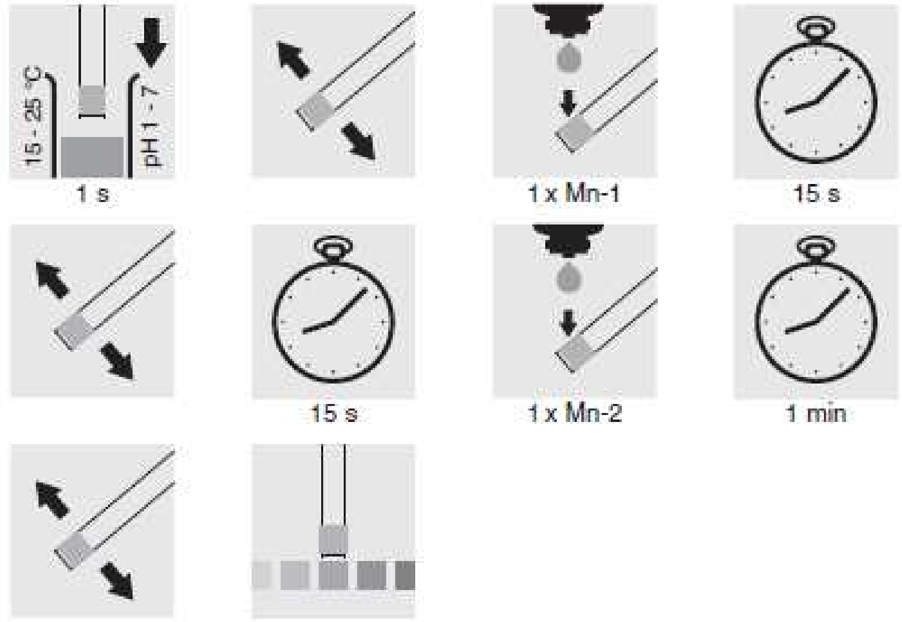


Figure 15. MQuant Manganese test procedure

Ammonium

The Macherey Nagel Ammonia Test is used to determine the ammonium concentration in the water sample. This test contains a test strip that changes colour after immersion in the water. Figure 16 shows the procedure of this test strip visually and the colour ranges of the test. The concentration is directly determined by comparing the colour of the test strip with the colour chart on the bottle. The detailed procedure for the Macherey Nagel Ammonia Test can be found in Appendix VI.

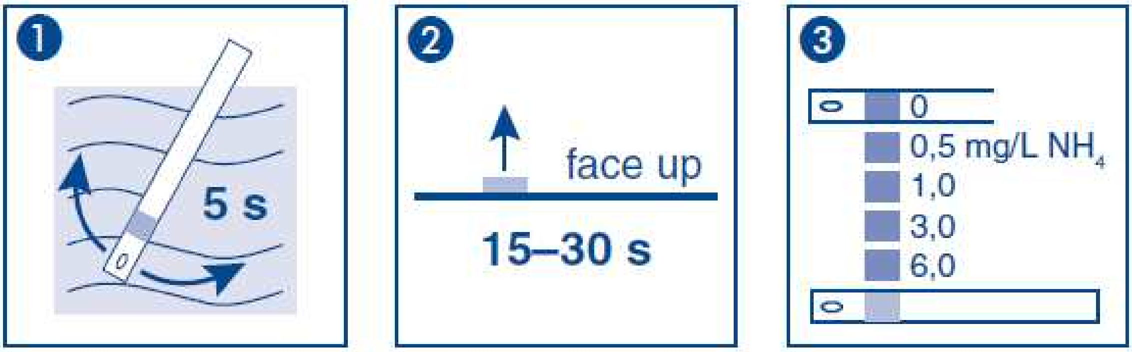
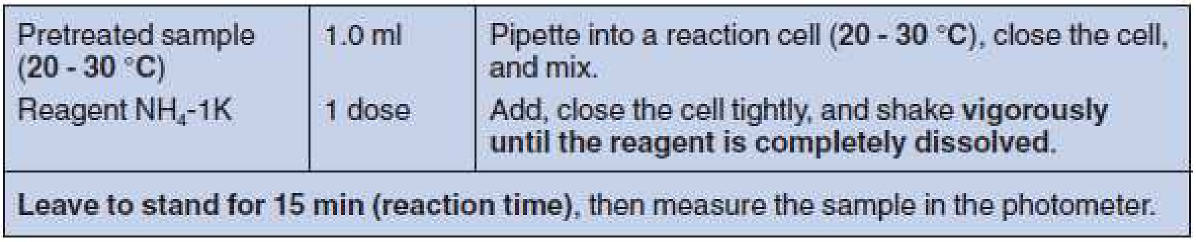


Figure 16. Macherey Nagel Ammonia test procedure

PhotoFlex

As ammonium is not a chemical element, the concentration cannot be determined with the ICP-MS. Therefore, the Spectroquant Ammonium Cell Test is used to verify the results of the test strips. This test kit is used in combination with the PhotoFlex STD colorimeter. Samples from the field are taken and in the end of the day the Spectroquant Ammonium Cell test is performed. The test contains a reagents powder and reagents fluid. After adding 1 mL of the sample to the fluid, the powder is added and 15 minutes later the concentration of ammonium in the sample can be determined by photometry with the PhotoFlex meter. Figure 17 shows the procedure of the ammonium cell test. The measured ammonium concentration ranges from 0.26 to 10.30 mg/L. The information manual of this test kit can be found in Appendix VII.



Pretreated sample (**20 - 30 °C**)	1.0 ml	Pipette into a reaction cell (**20 - 30 °C**), close the cell, and mix.
Reagent NH_4-1K	1 dose	Add, close the cell tightly, and shake **vigorously until the reagent is completely dissolved.**
Leave to stand for 15 min (reaction time), then measure the sample in the photometer.		

Figure 17. Procedure of the Spectroquant Ammonium Cell Test

6.3.6 Fieldwork protocol

As mentioned before, the data collection is performed in four different villages in the Rajshahi district in Bangladesh. A detailed protocol for the water quality tests can be found in Appendix II. All the data is collected using the AKVO Flow survey installed on the smartphones. The results are saved on the mobile phones and uploaded to a database.

6.4 Water treatment unit fieldwork

This section will explain the methodology used in order to build a water treatment unit in Uttar Kazirpara. The water treatment unit fieldwork focusses on the construction of the unit as well as on the sample collection, the monitoring of the water quality in different points of the water treatment unit and the maintenance of the filters afterwards.

6.4.1 Reconnaissance survey

Uttar Kazirpara has been chosen as the area for the field work carried out in this project due to the reasons mentioned in Section 6.1. In order to place the filter that will treat the ground water and produce safe drinking water, an appropriate location that fulfils several requirements must be chosen in this village.

Previous research has been carried out in Uttar Kazirpara, in which the water quality of several tube wells was analysed. The first condition that must be achieved when looking for a location of the water treatment unit is related to the chemical components of the water in the tube well. The arsenic concentrations found in this research in the village were excessively large, in some cases reaching more than 1000 μg/L. From all the data obtained from those tube wells, only six points contained iron concentrations larger than 3.5 mg/L. Iron concentrations of those dimensions are required due to the fact that enough iron must couple with the arsenic to form flocs that can be removed by rapid filtration (for further understanding about arsenic removal with iron see Section 6.4.2).

The second condition the location must fulfil is related to its physical properties. In Bangladesh, electricity is scarce and unstable, with daily shortcuts that can have long duration. Therefore, an important characteristic of the water treatment unit designed is that it should require the least electricity possible, to prevent supply issues. In order to avoid the use of an extra pump, the groundwater tank must be placed on a height of around four meters to be able to filter the water through water head differences. To place the groundwater tank in such a height, two options can be considered. Constructing a platform for the tank or install it in the roof of a building. The construction of a platform is time and money consuming. For that reason, finding an appropriate roof of a building is considered as a better alternative. Nevertheless, due to the large weight of the groundwater tank, a building with a concrete and robust structure that can handle large loads is necessary.

Lastly, after visiting Uttar Kazirpara, the construction of the water treatment unit in a private household has been considered as the best option, due to the social culture of the village. Therefore, a household eager to have the filter in its property and share the safe water produced there with the rest of the community must be found.

From the six data points mentioned above that had enough iron concentrations, only one household was spacious enough and had a concrete roof capable of bearing the necessary loads. At the same time, that household was cooperative and interested in the water treatment unit. Furthermore, that household is really well known and appreciated by the inhabitants of Uttar Kazirpara, which makes it easy for the community to collect the safe water.

6.4.2 Water treatment unit design

The water treatment unit designed is based on the concept of oxidation of arsenic and iron and its subsequent filtration. In the following section the general description and functioning of the treatment unit are described.

General description of the water treatment unit

Uttar Kazirpara is a village largely affected by arsenic, that has led to arsenicosis in many of its inhabitants. As mentioned before, long-term exposure to arsenic can cause health issues that can produce death in the most severe cases (D. v. Halem et al., 2009; Smith et al., 2000). In order to minimise the problems caused by this element in the water, a water treatment unit has been designed to fulfil a total water consumption of 50 L/day/capita for 5 to 10 households, considering that each household comprises around 5 persons. Note that this is a theoretical estimation and that depending on the usage of the water by the household the amount of people supplied will vary. If the community decides to use the treated water only for drinking purposes, more people can be benefited from the safe water.

The aim of the water treatment unit built in Uttar Kazirpara is to supply safe water fulfilling the European drinking water standard of 10 µg/L arsenic concentration (D. v. Halem et al., 2009; WHO, 2017).

General functioning of the water treatment unit

Figure 18 shows a diagram of the water treatment unit functioning. First, the groundwater is pumped from the tube well up to the groundwater tank located on the roof of a building with a height of around four meters. From the groundwater tank, the water flows towards the biocarriers column through a dripping system, in order to aerate the water and increase its oxygen concentration and enhance the iron oxidation from iron (II) to iron (III).

In the biocarriers column, the water flows downwards. Here, the arsenic oxidizing bacteria can grow with the help of the large specific surface of the biocarriers, and therefore, arsenic (III) can be oxidised to arsenic (V), which can be removed after coupling with iron (III) through the anthracite and sand filter.

From the outlet of the biocarriers column, the water flows to the sand and anthracite column through water head difference. The water has a downward displacement, first going through the anthracite and afterwards through the sand.

After the sand and anthracite filter, the remaining arsenic (V) is removed with the ion exchange resin.

The safe water is stored in a reservoir tank, from which it will be supplied to the community of Uttar Kazirpara.

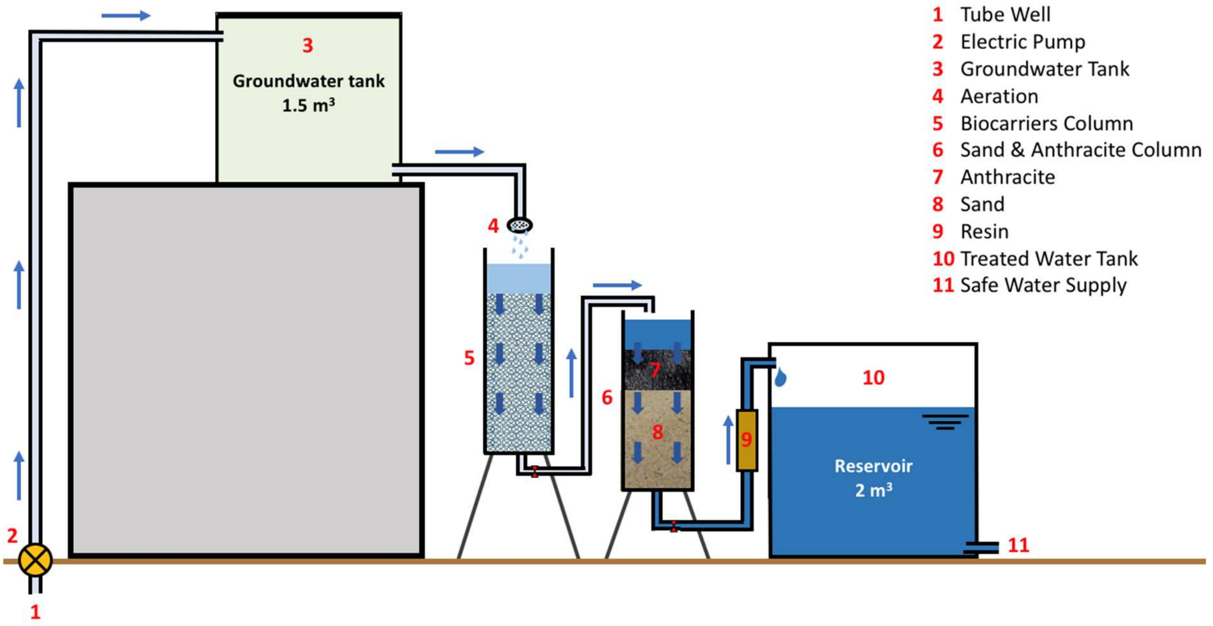


Figure 18. Scheme of the components of the water treatment unit

Backwash functioning of the water treatment unit

Figure 19 shows a scheme of the backwash functioning for the biocarriers column as well as for the sand and anthracite column.

In order to unclog the biocarriers, the sand and the anthracite, backwash is needed. The water from the groundwater tank is used to backwash, taking advantage of the gravity flow to produce the necessary flow rate to expand the biocarriers, sand and anthracite beds. Because the use of the least electrical dependent devices is of great importance in Bangladesh due to the frequent shortcuts, the gravity flow induced by the water head difference between the groundwater tank and the biocarriers column is a good resource for backwash.

A valve is installed on the pipe that connects the groundwater tank and the aeration system. An elastic tube is connected to that valve only when the backwash is needed. Therefore, the same valve is used for the biocarriers and for the sand and anthracite backwash.

The water on the biocarriers column and anthracite and sand column flows upwards. This water is evacuated from the columns through the backwash outlet, that has the function of overflow under normal functioning conditions. This backwash outlet has a siphon shape to prevent that air comes in and keeps the water from being expelled.

The water used for the backwash is then directed to a water body.

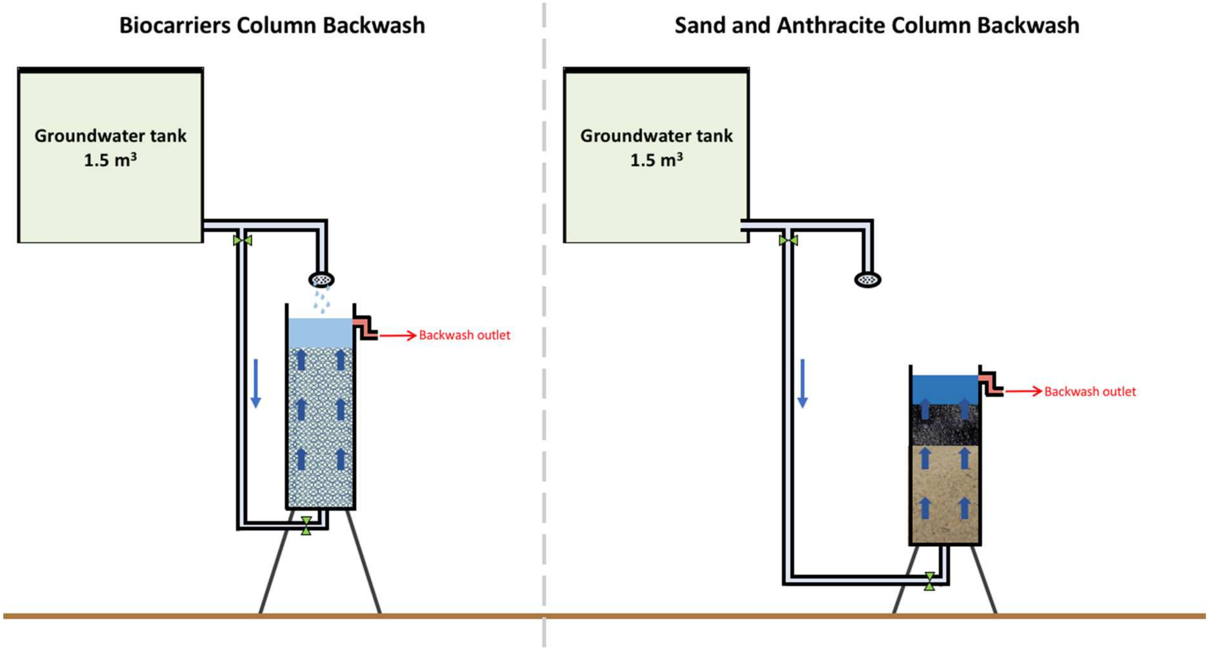


Figure 19. Backwash diagram of the biocarriers column and of the sand and anthracite column

Preliminary design

The main components of the water treatment unit are elaborated in the following part along with the theoretical background.

Water tanks

For the storage of the groundwater and the treated water, SERA water tanks are used. Those tanks are extensively used for water storage in Bangladesh and are produced by the local company RFL.

The reason why this brand has been chosen for the water treatment unit is because RFL is the only company that produces water tanks with three layers. For our project the use of a three-layer tank is of special importance due to its capability to protect water from sunlight heat (PRAN-RFLCenter, 2018). Bangladesh has a warm and humid climate. Therefore, keeping the water as cold as possible is a priority to prevent the growth of hazardous bacteria. Furthermore, the temperature at which the water is supplied is of importance for the acceptance by the end users.

SERA tanks are also characterised by fittings, which are in-moulded with brass inserts which are rust-free and ready to use with threaded PVC or GI pipes, as well as for their easy cleaning and their antibacterial additive to prevent bacteria growth (PRAN-RFLCenter, 2018).

Figure 20. Image of a typical water tank used in Bangladesh (PRAN-RFLCenter, 2018)

The groundwater tank located on the roof of a building has a capacity of 1500L and a height and diameter of 1.42 m and 3.8 m respectively.

The treated water tank is situated at street level and has a capacity of 2000L and a height and diameter of 1.5 m and 4.25 m respectively.

Notice that the groundwater tank has smaller dimensions than the safe water. The groundwater tank should be refilled once a day to prevent the water from remaining in the tank for long time, which could enhance water quality problems. Every time the groundwater tank is refilled, the water must overflow during 5 to 10 minutes to clean all the iron accumulated at the bottom of the tank. On the other hand, the water stored in the safe water tank is fresh and continuously running. Therefore, the tank can be larger because no water quality risks exist.

Aeration

Anaerobic or anoxic groundwater contains iron (II) and the oxidation of iron (II) to iron (III) is governed by the presence of O_2. After oxidation, iron (III) immediately reacts with hydroxide ion which is readily available in groundwater due to dissociation of water molecule. Through this reaction, Iron Hydroxide flocs (HFO) are formed and adsorb arsenic (V), which enhances the removal of arsenic both in the bio carrier and in the sand and anthracite column. In order to enhance the oxidation of iron, the water before reaching the column of biocarriers needs to be aerated. However, some of the iron in the water is already oxidised in the tank due to the residence time of the water in the groundwater tank and the presence of minimal dissolved oxygen. Biotic oxidation of iron also occurs in the tank in the presence of Iron oxidizing Bacteria (FOB).

Biocarriers column

In the range of neutral pH (6.5-7.5), arsenite (H_3AsO_3), which is predominant in the reducing environment is uncharged and difficult to remove with surface adsorption processes. In an oxidizing environment, arsenate ($HAsO_4^{2-}$) prevails and is comparatively easy to remove because it has negative charge and can be adsorbed with HFO flocs during iron removal. However, due to slow oxidation process both species can co-occur (D. v. Halem et al., 2009). Nevertheless, the biotic oxidation of arsenic (III) also occurs within this oxidation process. In order to enhance the oxidation process and the contact time between HFO and arsenic (V), a plastic biofilm carriers column is installed. As a result, greater adsorption of arsenic (V) can be achieved which in turn increases the removal of arsenic from the water.

Figure 21. Biofilm carriers

Figure 21 shows the type of biofilms used in water treatment. In the biofilm carrier, iron (II) oxidizes to iron (III) along with the arsenic conversion from the arsenite to arsenate.

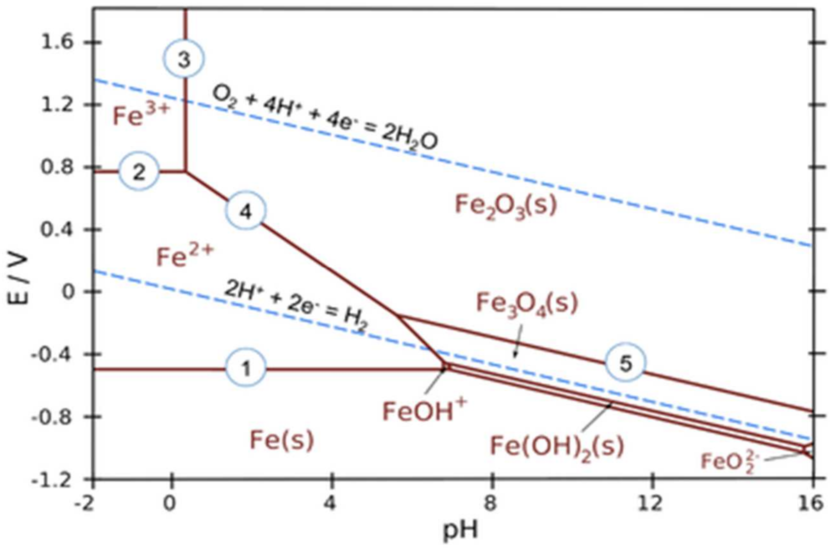


Figure 22. Pourbaix diagram for different speciation of iron at different pH (chem.libretext.com, 2018)

The more in-depth facts about iron oxidation can be obtained from the Pourbaix diagram of iron speciation at different pH. From this diagram, it is evident that the dominant species in neutral pH (6.5-7.5) are iron (II) species. Aeration is needed to convert it to iron (III) species which can from flocs and can be removed by subsequent filtration.

$Fe^{2+} \longrightarrow Fe^{3+} + e^-$

Both the chemical and biotic oxidation of arsenic is given below,

$As^{3+} \longrightarrow As^{5+} + 2e^-$

Sand and anthracite column

To remove dissolved iron (Fe), manganese (Mn), ammonium (NH4) and partially arsenic, the conventional procedure to treat groundwater is aeration and then rapid sand filtration (Gude et al., 2018). Depending on the operational parameters such as supernatant water level, velocity of the filtration, dissolved oxygen concentration and pH, in the bed of sand filter, iron (II) can be oxidized and form flocs of iron (III). Previous studies show that arsenic (III) also oxidizes within the top layer of the filter column. The main idea of this technique is to remove the arsenic together with the iron flocs in the sand column.

Nevertheless, depending on the supernatant water level, the final removal of arsenic can be affected. A constant supply of arsenic (V) and HFO is needed to remove the arsenic completely. A biofilm carrier column ensures that iron in the water is thoroughly oxidized through a higher surface area and the adsorption of arsenic (V) is enhanced. Afterwards, arsenic can be subsequently filtered by the sand column.

To avoid frequent clogging and backwash, an anthracite layer with a higher filter bed opening is chosen on top of the sand layer. In the deeper layer of sand only the filtration occurs which removes the iron flocs together with arsenic.

Another reason to use an anthracite layer is to prevent filter material loss during backwashing. Smaller sand grains can be washed away during backwashing. Anthracite protects those, due to its higher grain size and lower unit density.

Figure 23. Sand (left) and anthracite (right) as filtration medium (IndiaMart, 2018)

Resin

As a final safety barrier to remove arsenic, the treated water is passed through a resin column. The resin adsorbs the remaining arsenic (V) in the treated water and at the end the water only contains arsenic (III) that was not oxidized. The main working principal of the resin is ion exchange, which is a reversible process between a solid and a liquid in which no permanent exchange of the structure occurs. A strong base anion exchange resin, Amberlite® IRA-400 chloride form is used as resin which is previously used to remove heavy metals from the water (Mustafa, Ahmad, Naeem, Shah, & Waseem, 2010). The chloride in the resin exchanges with As(V) and releases chloride ions, which can be easily regenerated by NaCl solution and demineralized water.

The exchanger reaction occurring in the resin column is the following:

$$2RCl + AsO_5^{2-} \leftrightarrow R_2AsO_4 + 2Cl^-$$

In Table 4 the characteristics of Amberlite® IRA-400 chloride resin form are summarized.

Table 4. Main characteristics of the resin (Sigma-Aldrich, 2018)

	Properties
Parameter	60 °C max. temp.
	77 °C max. temp.
Cross-linkage	8%
Moisture	40-47%
Matrix	Styrene/divinylbenzene (gel)
Matrix Active Group	Quaternary ammonium functional group
Particle Size	20-25 mesh
	600-750 μm
Operating pH	0 - 14
Capacity	1.4 meq/mL by wetted bed volume

The regeneration of resin is required when this one is saturated. The process to regenerate the resin is the following: For 500 gr of resin, 200 gr of sodium Chloride (NaCl) salt must be mixed with one litre of demineralized water. Then the resin must be kept in the solution for 24 hours. Afterwards it can be used again.

6.4.3 Water quality sampling and testing

In order to check and observe the proper functioning of the water treatment unit, 11 sampling and testing points are selected. In the following section, the methods of sampling as well as the physical and chemical parameters testing procedure are described. In each sampling point, the following physical and chemical parameters are tested.

Chemical properties testing

To check the proper functioning of the water treatment unit on site, several tests have been performed. In each of the sampling points, total arsenic, arsenic (III) and iron are measured.

For both, onsite testing with strips and TU Delft ICP-MS testing, three types of samples must be prepared. Table 5 shows the elements tested for each water sample. The chemical parameters have been tested once a week for 4 weeks.

Table 5. Sampling method and name of the elements to be tested

Water Type	**Elements tested**
Raw Water	Only sample taken, no onsite testing
Water passed through 0.45 μm filter	Tested for total As and Fe
Water passed through 0.45 μm filter and resin	Tested for As (III)

When water passes through the 0.45 µm filter, iron flocs are removed from the water as well as the arsenic (V) adsorbed in the iron. By testing this water sample, the total arsenic concentration and the amount of iron diluted in the water can be determined. The total arsenic consists of unoxidized arsenic (III) and arsenic (V) which has been oxidized but not yet attached to the flocs.

When the 0.45 µm filtered water passes through the resin, the remaining oxidized arsenic (V) is adsorbed by the resin, and only arsenic (III) can be measured. By deducting this concentration from the total arsenic, the amount of oxidized arsenic (V) can be determined, which gives an indication of the rate of arsenic oxidation.

Physical properties testing

The following physical properties at each of the sampling points are determined with the multimeter. The physical properties measured by the multimeter are electrical conductivity (EC), potential of hydrogen (pH), dissolved oxygen (DO) and oxygen reduction potential (ORP): Electrical conductivity gives an indication of the turbidity and salt content of the water; potential of hydrogen provides the measurements of the acidity or alkalinity of the water; dissolved oxygen measures the amount of dissolved oxygen that is capable of oxidizing iron and arsenic; and oxygen reduction potential shows whether the water is in an oxidizing (+) or reducing (-) state.

The physical properties are tested every day in the first week to have a thorough understanding of the filtration processes. Afterwards the parameters are tested twice a week for three weeks.

Measurement tools

In the following section the details of the measurement tools used for the determination of both, physical and chemical parameters are described.

Arsenator

Arsenator is used to determine arsenic concentrations with lab accuracy, but in the field. The kit contains all the items required to perform accurate and reliable determination of arsenic concentration in the field. Figure 24 shows the main components of the arsenator, and Figure 25 depicts an arsenator.

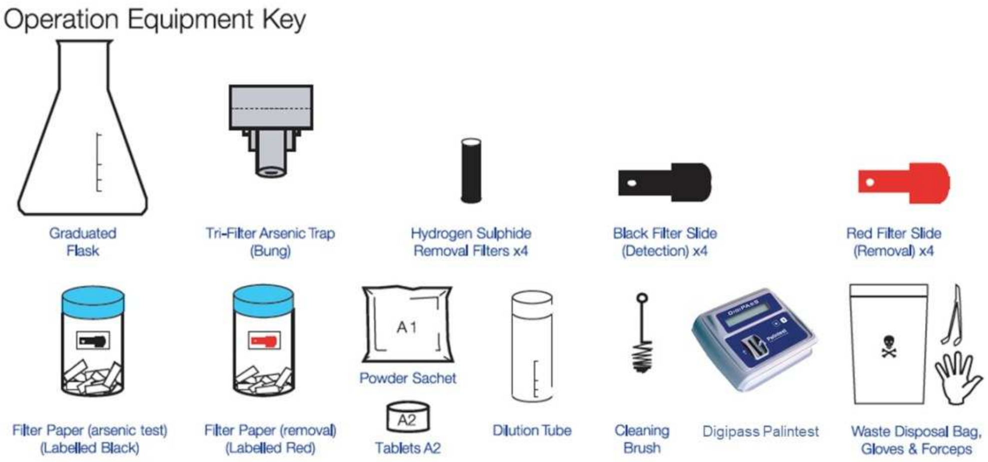


Figure 24. Operation equipment of the arsenator

Figure 25. Arsenator (DirectIndustry, 2018)

The kit uses the Gutzeit method by which the system is converts all the arsenic in the sample to arsine gas and detects the gas produced quantitatively using a unique three stage filter.

First, the three-layer filter for arsine gas must be calibrated with the digital arsenator device. Afterwards, a 50ml water sample must be prepared and mixed with an A1 powder sachet. The detection and removal filter slides have to be prepared by inserting their corresponding filters. Later on the tri-filter arsenic trap can be prepared, inserting both filter slides in the tri-filter. Then, the A2 tablet reagent has to be dropped into the sample bottle and the trap must be closed in order to avoid gas release from the reagent reaction. The total reaction time is twenty minutes and the hydrogen sulphide filters are used to adsorb hydrogen sulphide gas released during that reaction time.

Once the reaction is complete the concentration of arsenic is quickly assessed using a colour chart for levels in excess of 100 µg/l arsenic or the DigiPass instrument for good accuracy in the 2 – 100 µg/l arsenic range.

In the manual attached to this report, the detailed procedure of the arsenator is provided.

Arsenic test kit

The arsenic concentrations of more than 100 µg/l are tested with arsenic kit. The testing procedure has been described in Section 6.3.5. The arsenic kit is faster than the arsenator. Therefore, when high arsenic concentrations are expected, the test can be performed directly with the arsenic kit instead of using the arsenator.

Iron Test Kit

The iron concentration is measured with the Hach Total Iron test kit. The testing procedure is further elaborated in Section 6.3.5. Notice that the Hach Total Iron test kit has been chosen instead of also mentioned Quantofix Total Iron 100, because low iron concentrations of less than 5mg/L are expected.

Amberlite-Chloride resin

The Amberlite Chloride Resin has been used to remove arsenic (V) from the water sample. See Table 4 for more physical characteristics of the resin. A syringe is filled with the resin and the water is passed through that syringe.

Multimeter

The multimeter is used to measure DO, EC ORP and pH. Four different probes for each of the physical parameters have been connected to the multimeters. Each probe should be calibrated with their respective multimeter. Figure 26 shows the WTW Multi3430 multimeters and the probes used for this study.

Figure 26. WTW Multi3430 multimeter

ICP-MS

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is used to accurately determine the concentration of arsenic, iron and other elements at the TU Delft laboratory as explained in Section 6.3.4.

Sampling points

In order to test take the samples that will lately be analysed in TU Delft and to perform the water quality tests, 11 sampling points have been defined throughout the water treatment unit. Each of the sampling points is located in a strategic position that represents the locations at which the water quality might be different throughout the system. Therefore, there is a sampling point after every new element on the water treatment chain. Figure 27 depicts each of the sampling points of the water treatment unit.

The detailed explanation of the sampling procedure at each sampling point is described below.

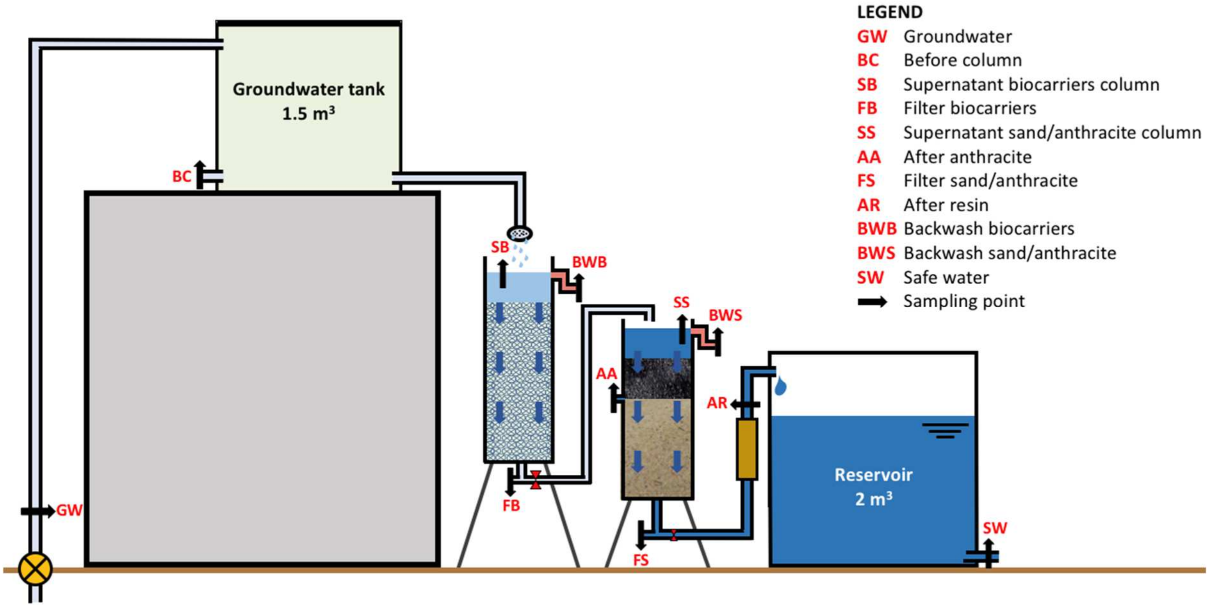


Figure 27. Diagram of the 11 sampling points of the water treatment unit.

Groundwater (GW)

The groundwater sampling is measured to know the physical and chemical parameters of the groundwater. Nevertheless, because those values are less relevant than what actually occurs with the water quality in the filter itself, they are measured once every two weeks.

Before column (BC)

The water sampling and test of the water entering the biocarriers column must be done in the outlet of the groundwater tank. It cannot be done collecting the water from the dripping system because then aeration is already occurring, and the actual properties of the water are modified.

Supernatant biocarriers (SB)

The biocarriers float due to the light weight of the biocarriers and hence, the supernatant in the biocarriers column does not only contain water but biocarriers as well. Therefore, in order to obtain the actual physical parameters of the supernatant water of the biocarriers column, the EC meter proves need to be inserted inside the biocarriers column carefully. Besides, to measure the arsenic and iron concentrations, a syringe can be inserted into the biocarriers and water can be extracted to be tested later.

Notice that when the measurements and sampling are done the water level of the supernatant should always be the same to obtain relevant data.

Filter biocarriers (FB)

To take samples and measure the physical and chemical parameters of the water after the biocarriers column, the valve that connects the biocarriers column with the sand column must be closed to avoid the reduction of the supernatant of the biocarriers, and the valve used for backwash and sampling must be open. Furthermore, to avoid also the reduction of the supernatant of the biocarriers column, the valve open for sampling must have a flow rate equal to the incoming water to the biocarriers.

In order to keep the residence time of the water flowing downwards the biocarriers column, the water head must be maintained. Therefore, the tube connected to the sampling valve must be elevated up to the water head.

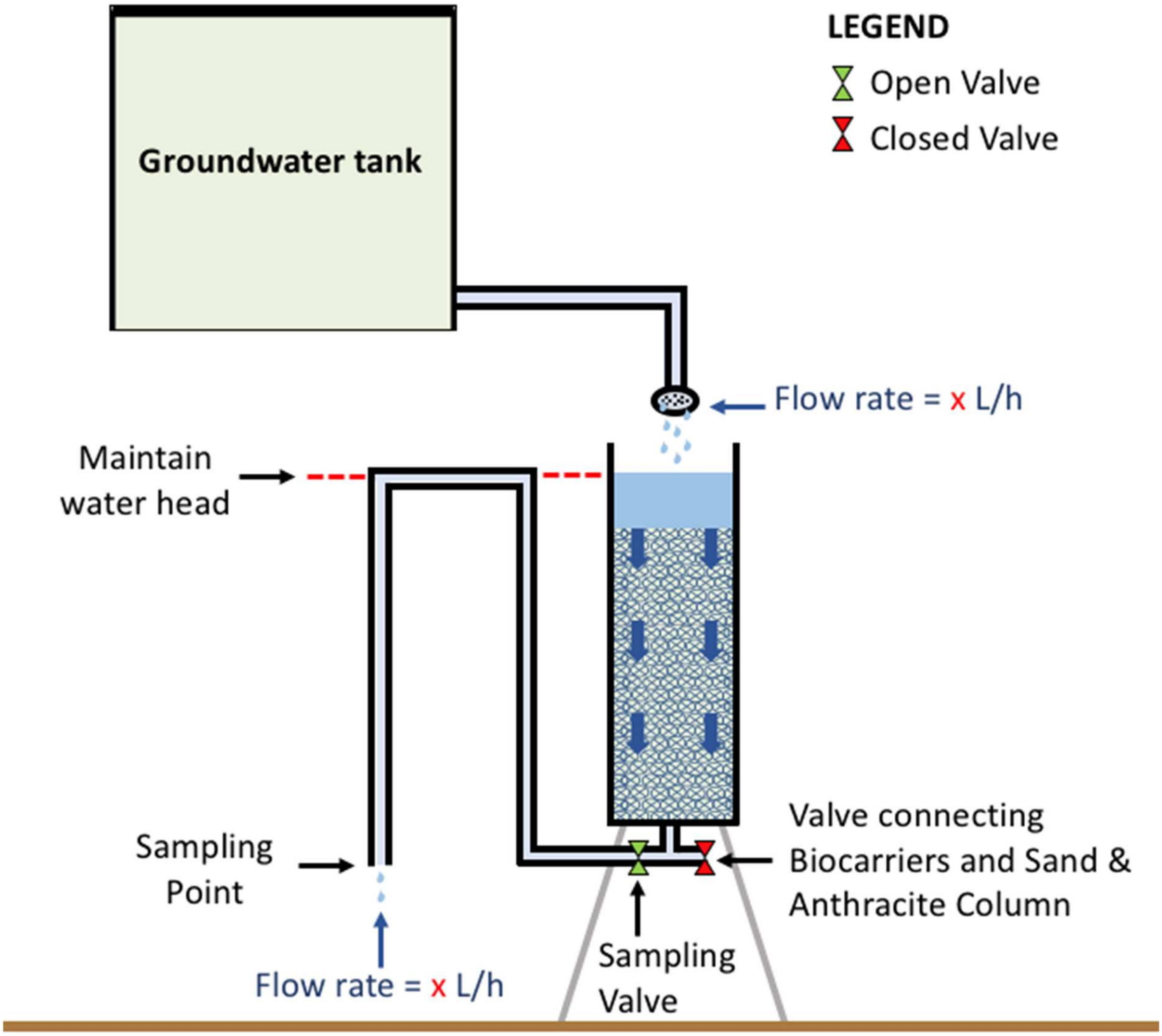


Figure 28. Filter biocarriers sampling point remarks

Supernatant sand and anthracite column (SS)

To measure the physical parameters of the supernatant water, the EC meters must be inserted inside the supernatant without touching the anthracite. To measure the arsenic and iron concentrations, the water is extracted with a syringe and can be tested later on.

Notice that when the measurements and sampling are done the water level of the supernatant should always be the same to obtain relevant data.

After anthracite (AA)

To take samples and measure the physical and chemical parameters of the water after passing through the anthracite filter, the valve located between the anthracite and sand layers must be opened.

In order to keep the residence time of the water flowing downwards the sand and anthracite column, the water head must be maintained. Therefore, the tube connected to the sampling valve must be elevated up to the water head.

Furthermore, to avoid the reduction of the supernatant of the column, the valve open for sampling must have a flow rate equal to the incoming water from the biocarriers column to the sand and anthracite column.

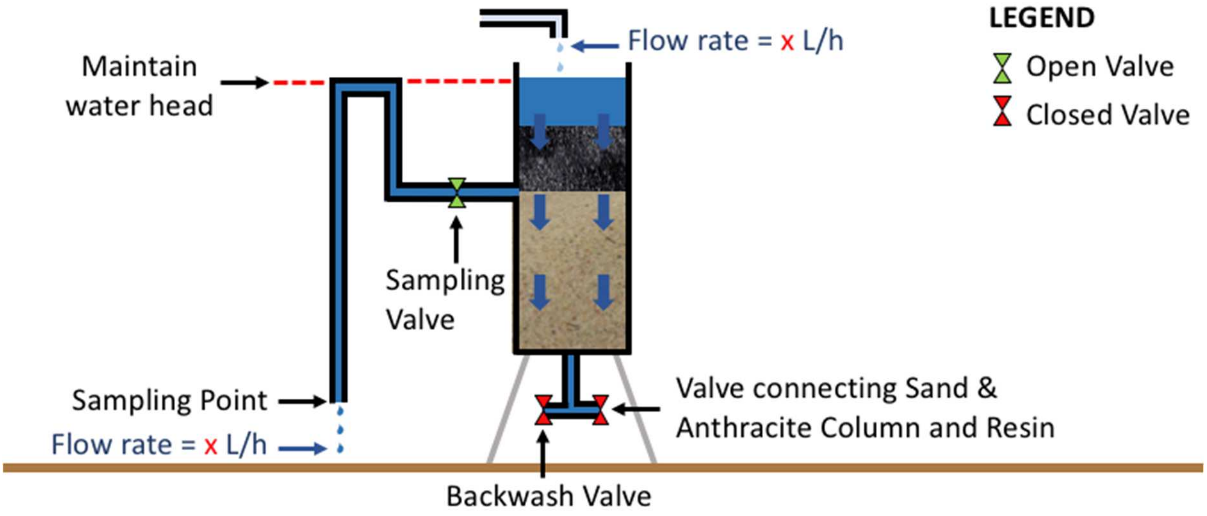


Figure 29. After anthracite sampling point remarks

Because the last stages of the filter provide important information about the final water quality that will be supplied to the consumers, it is necessary to keep track of how the arsenic and iron change. Therefore, the arsenic and iron concentrations are measured during every field visit in the after-anthracite location.

Filter sand and anthracite (FS)

To take samples and measure the physical and chemical parameters of the water after the sand and anthracite column, the valve that connects the column with the resin must be closed to avoid the reduction of the supernatant of the sand and anthracite. On the other hand, the valve used for backwash and sampling must be open. Furthermore, to avoid also the reduction of the supernatant, the valve open for sampling must have a flow rate equal to the incoming water to the sand and anthracite column.

In order to keep the residence time of the water flowing downwards the column, the water head must be maintained. Therefore, the tube connected to the sampling valve must be elevated up to the water head.

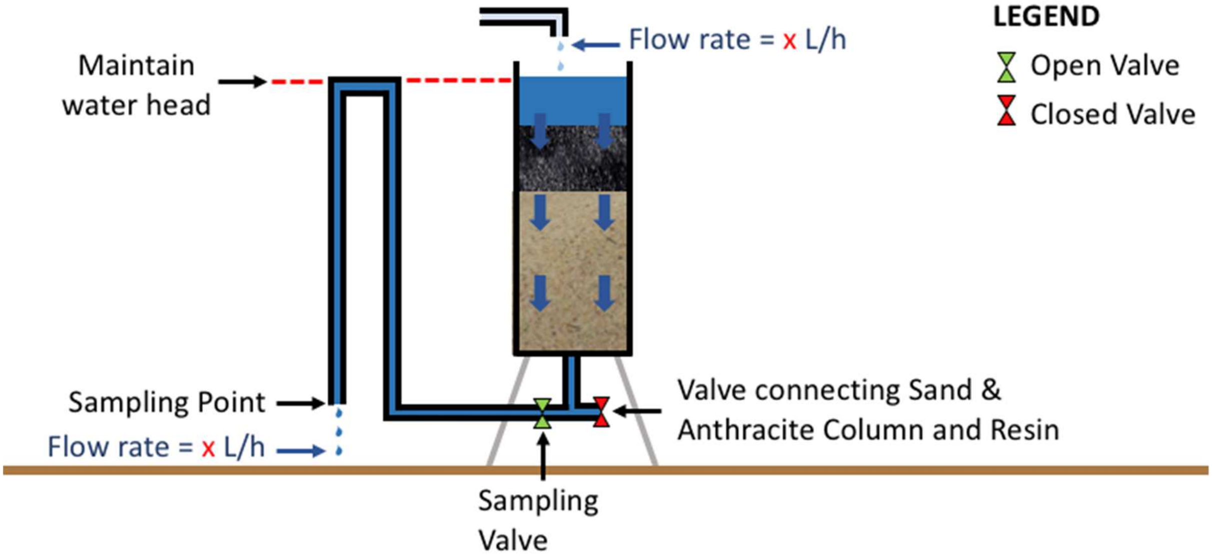


Figure 30. Filter sand and anthracite sampling point remarks

Because the last stages of the filter provide important information about the final water quality that will be supplied to the consumers, it is necessary to keep track of how the arsenic and iron change. Therefore, the arsenic and iron concentrations are measured during every field visit in the filter sand and anthracite location.

After resin (AR)

Because the last stages of the filter provide important information about the final water quality that will be supplied to the consumers, it is necessary to keep track of how the arsenic and iron change. Therefore, the arsenic and iron concentrations are measured during every field visit in the filter sand and anthracite location.

Backwash biocarriers (BWB) and backwash sand and anthracite (BWS)

The backwash must be done twice a week or when is necessary. The increase of the supernatant will indicate the clogging of the biocarriers column and therefore, the need of backwash.

Every time backwash is done, the physical and chemical parameters of the water from outlet of the backwash must analysed and samples must be taken.

Furthermore, notice that when backwash is carried out, the water characteristics of the water treatment unit will change. Therefore, the backwash should be done after the samples and tests have been performed in all the other sampling points. After one day the conditions of the water will be back to normal and the tests and sampling will provide appropriate results.

Safe water (SW)

The safe water sampling is not being done during the sampling period. Only when there is complete certainty that the water filtered is safe and will be provided to the consumers that water will not be tested.

6.4.4 Operator

Distributing drinking water to the community requires a safe and an optimally performing water treatment set-up. In order to ensure the quality of the filtered water, an operator is necessary to maintain and monitor the water. This operator should have authority and a certain skillset to fulfil his task.

Preferably the operator should be from the area around the village of Uttar Kazirpara. The reason for this condition is that therefore, the operator is familiar with local culture and has knowledge of the resources available in the area. Furthermore, if the operator lives near Uttar Kazirpara, it can be more accessible for the village people in case of emergency. Moreover, the operator should be a man, because women are unfortunately not equally treated in Bangladesh and hence, a woman would not have enough authority to manage and operate the system. Because the operator has to deal with different kinds of people, and sometimes difficult situations, this person needs a certain status and to be trusted among the people.

Since the operator does not require a fulltime job, it is preferable that this will be a student. In this way there will not be any conflicts with other jobs, and the chosen operator will have more knowledge than non-educated people in the village. Furthermore, students are respected and trusted in Bangladesh, and hence, their educated status will increase the authority of the operator as well as his credibility among the local people.

Moreover, the operator should be able to communicate with employees and students of the DELTAP project. Therefore, it is essential that his English proficiency is sufficient. The treatment design is rather complicated and asks for some engineering and chemical insight. Additionally, the set-up will require the necessary maintenance and reparations. From this perspective the operator would preferably have a scientific or engineering background. Also the operator should be aware of the arsenic contamination problem. The knowledge about the importance of this problem could make it more easily for the operator to defend the necessity of the water treatment unit.

Putting all of the requirements together, the operator is preferably a science or engineering student from Rajshahi University or RUET. The student should preferably be familiar with the arsenic problem in his area. Furthermore, he should have a strong personality to deal with the villagers.

HD
6

7. Results

In this chapter the results of all data gathering activities are shown, explained and discussed. A distinction between geology, water quality and water filter has been made. These topics are addressed in separate sections.

7.1 Geology

In this section the results obtained by the execution of the geological fieldwork will be presented and discussed. First the reconnaissance survey will be addressed. Secondly the spatial analysis is outlined and discussed. Lastly the results of the drilling fieldwork are presented and a connection between the separate parts is provided.

7.1.1 Reconnaissance survey

In order to validate that the geomorphological setting of the fieldwork area is actually as is explained in Chapter 0, a reconnaissance survey has been conducted.

The four villages that comprise the fieldwork area are located in a rural area with much agricultural activity. The agricultural activity is a combination of small-scale agriculture of multiple crops for own use and the cultivation of sugar cane on larger scale. A large sugar cane factory is located near the fieldwork area. The factory provides directly and indirectly work and income for many of the inhabitants of the area. Crops that are observed in the field are amongst others: rice, jute, eggplant and cucumber. Fruits are also cultivated; mango and banana trees are observed in the field. Mango trees are often located on the so-called silvopasture.

A remarkable observation is the fact that the villages are slightly elevated compared to the surrounding agricultural fields. The elevation difference is approximately 0.5 to 2 metres. This could indicate a sand ridge as a result of a point bar. Sandy point bars are less or not prone to compaction while the surrounding clay is, causing a relief in the landscape. This phenomena is observed more often (Donselaar et al., 2017). Other observations that could indicate sand bars in the landscape could however not be distinguished in satellite images or in digital elevation data. Figure 31 shows a satellite image of the area. Nevertheless, another option is artificial heightening. This is observed for many of the roads in the area. For larger areas it is though, doubtful if this is the case.

As part of the reconnaissance survey, ten soil samples have been collected in and around the villages Uttar Kazirpara and Voruapara. All samples contained a clay fraction. For 8 out of 10 samples the principal fraction was clay. Two samples did not have clay as principal fraction but sand and silt. Both samples were taken in Uttar Kazirpara. In some of the samples, remnants of shells and snails have been found. This is a clear indication of deltaic sediments. One of the soil samples is shown in Figure 32.

As it can be seen in Figure 31, the direct surroundings of the village of Uttar Kazirpara do not show any oxbow lake features. The dark vegetated band situated north east of Uttar Kazirpara could possibly be classified as an oxbow lake. This possible filled-in oxbow lake is however located rather far from the area of interest and thus assumed not to be relevant for the research. A more detailed investigation has therefore not been conducted.

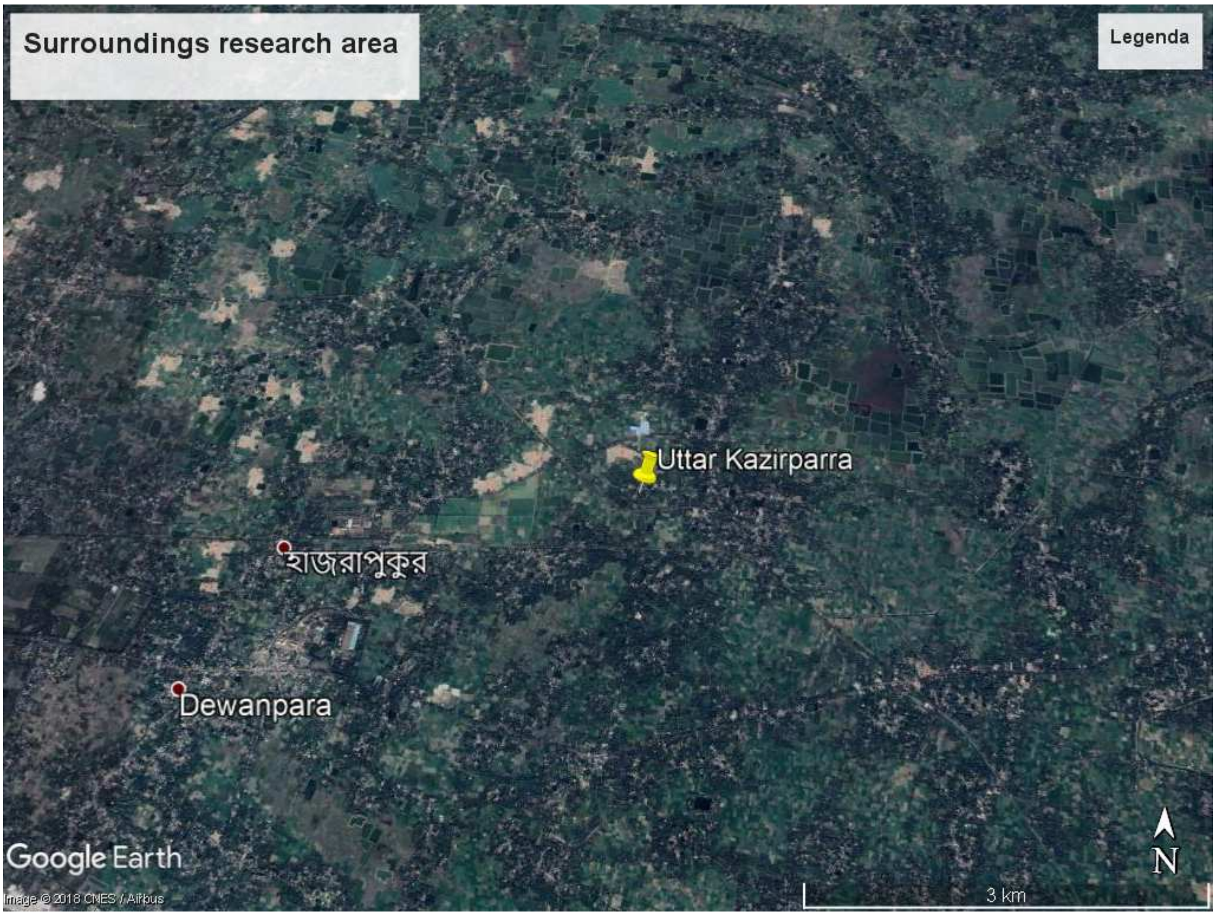


Figure 31. Google Earth Pro image of the surroundings of Uttar Kazirpara

Figure 32. Soil sample containing clay, a small shell fraction is visible

7.1.2 Spatial analysis water quality parameters

Performing a spatial analysis gives more insight in spatial distribution of the water quality parameters. The water quality parameters are mostly influenced by the geological characteristics and the local environmental conditions (Raschid-Sally, 2000). The water quality parameters are retrieved from the water quality fieldwork of Section 6.3. While situated on an alluvial floodplain, the research area is located in a dynamic geological setting, resulting in a dynamic spatial distribution of the different water quality parameters. First, the arsenic distribution is analysed. Afterwards, the iron, manganese and ammonium are studied. Finally, the observed spatial patterns are described.

To visualize the arsenic concentration, the according concentrations are plotted at their GPS location and visualized in Figure 33. The data has been checked on reliability and the outliers in terms of GPS-location are corrected by the use of GPS coordinates retrieved from the AKVO Flow application.

The step size that has been used for the concentrations of the water quality parameters (and thus indicated in the legends of the figures), are in accordance with the step size that is indicated on the strip tests. See Section 6.3.

From Figure 33, it can be seen that the highest arsenic concentrations are situated in Uttar Kazirpara with a maximum value of 1124 µg/L, see Table 6. The arsenic distribution in Uttar Kazirpara will be described in more detail later. The tube wells of the villages Dakhin Kazirpara and Mohendra contain less arsenic. However, contaminated wells are still present. The latter mentioned villages are both divided in a part of high arsenic and a part of low arsenic pollution.

Table 6: Water quality parameters per village

Village name	Uttar Kazirpara	Dakhin Kazirpara	Voruapara	Mohendra
Samples	68	33	27	20
Average Arsenic (mg/L)	0.20	0.03	0.05	0.02
Maximum Arsenic (mg/L)	1.12	0.26	0.17	0.13
Average Iron (mg/L)	2.57	1.49	3.07	0.81
Maximum Iron (mg/L)	10.69	9.84	10.53	5.52
Average Manganese (mg/L)	0.42	1.06	0.64	1.45
Maximum Manganese (mg/L)	1.46	1.61	1.51	2.03
Average Ammonium (mg/L)	1.55	0.81	0.86	0.62
Maximum Ammonium (mg/L)	2.65	1.69	3.01	1.22

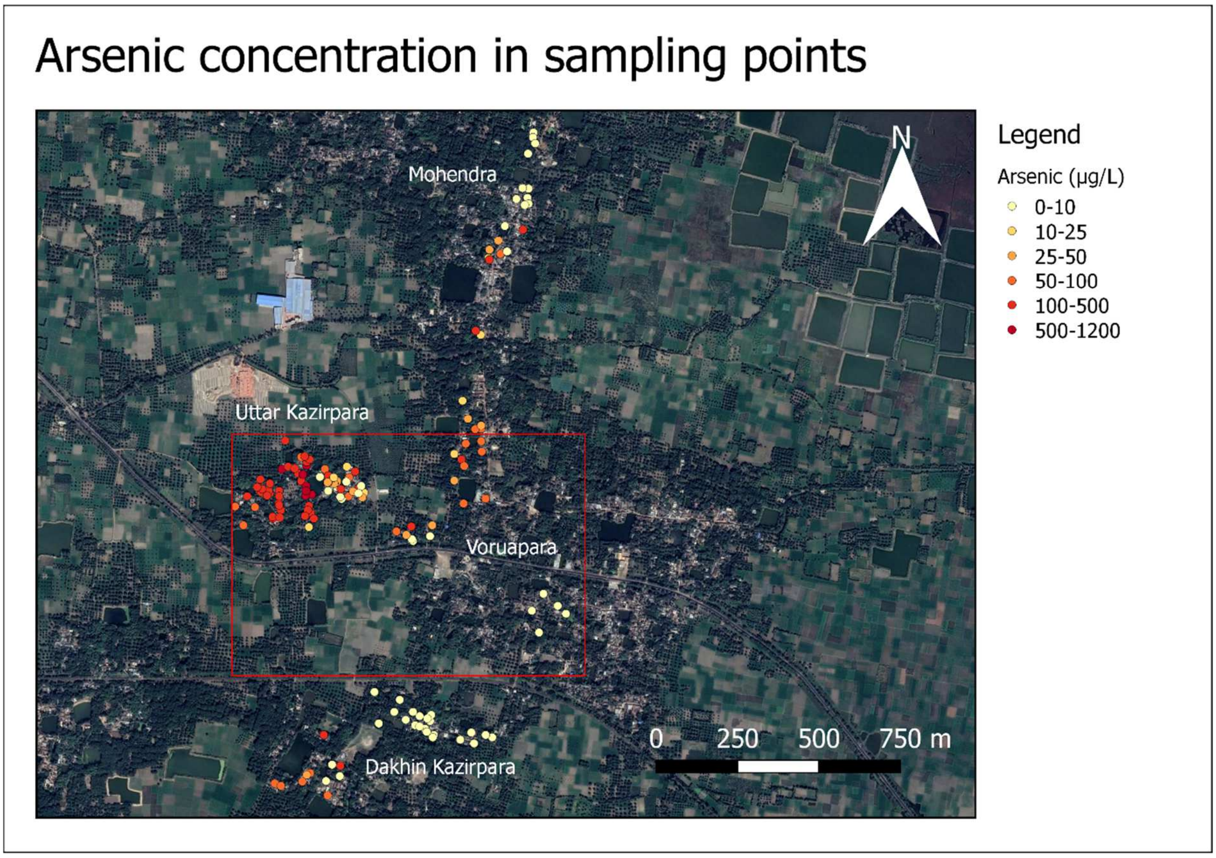


Figure 33: Arsenic Concentration in sampling points

Since this project is mainly focused on Uttar Kazirpara, the arsenic distribution is studied more in detail here. An interpolation map is created for Uttar Kazirpara. The results of the interpolation are shown in Figure 34. QGIS is used to obtain the interpolation as explained in Section 6.2.3. The figure shows different levels of arsenic pollution in the village of Uttar Kazirpara and a part of Voruapara. Highest arsenic values are clustered in the north western corner of the map and create a small area with high interpolated arsenic concentration. In the eastern part of Uttar Kazirpara, an inhomogeneous distribution of arsenic is found. Nevertheless, the highest values in this area are not as high as in the western part. Arsenic safe tube wells and highly contaminated tube wells exist next to each other.

According to the interpolation result, a gradient from high arsenic concentration towards low arsenic concentration is situated along a northwest-southeast line. The interpolation map is a first approximation of the arsenic distribution because a big part of the interpolated area does not contain any points. Furthermore, the distributions of sampling points are not homogenously in the entire area.

However, the interpolation map is used as a tool to determine were the drillings should be located. The drilling locations have been chosen on well-defined parts of the area where a high density of sampling points surround the drilling sites. Therefore, it is very likely that the drillings have been performed in a high, medium and almost not polluted part of the aquifer. The locations are displayed in Figure 34 and Table 7.

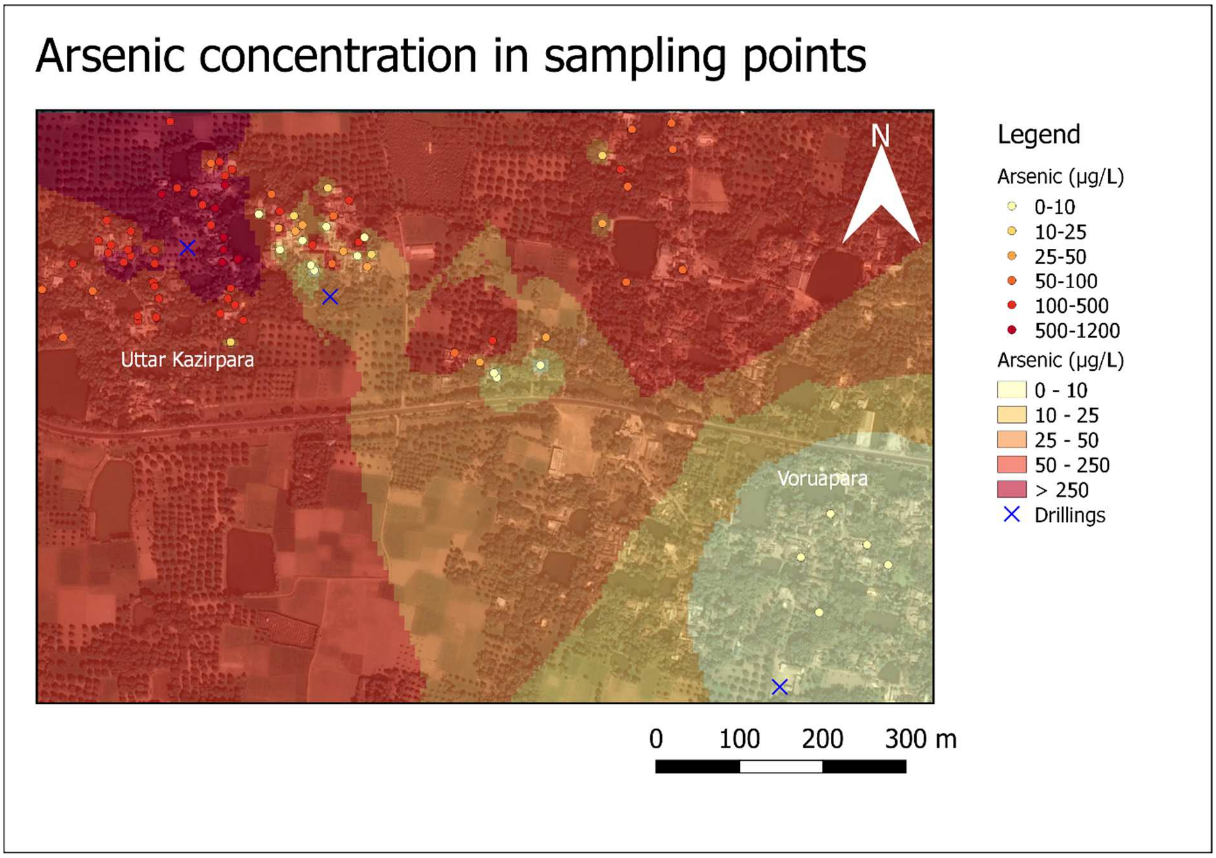


Figure 34: Interpolation of arsenic concentration and drilling locations

Table 7. GPS-coordinates drilling locations

	latitude	longitude
drilling-1	N24°22'51.38"	E88°42'10.35"
drilling-2	N24°22'48.95"	E88°42'15.58"
drilling-3	N24°22'33.67"	O88°42'35.63"

An iron concentration map is created using the same method as has been used to create the map showing arsenic concentration. The spatial distribution of iron is shown in Figure 35. From this figure it is observable that the iron concentrations are especially high in Voruapara and Uttar Kazirpara, also Dakhin Kazirpara and Mohendra contain areas with higher amounts of iron, as can be seen as well in Table 6.

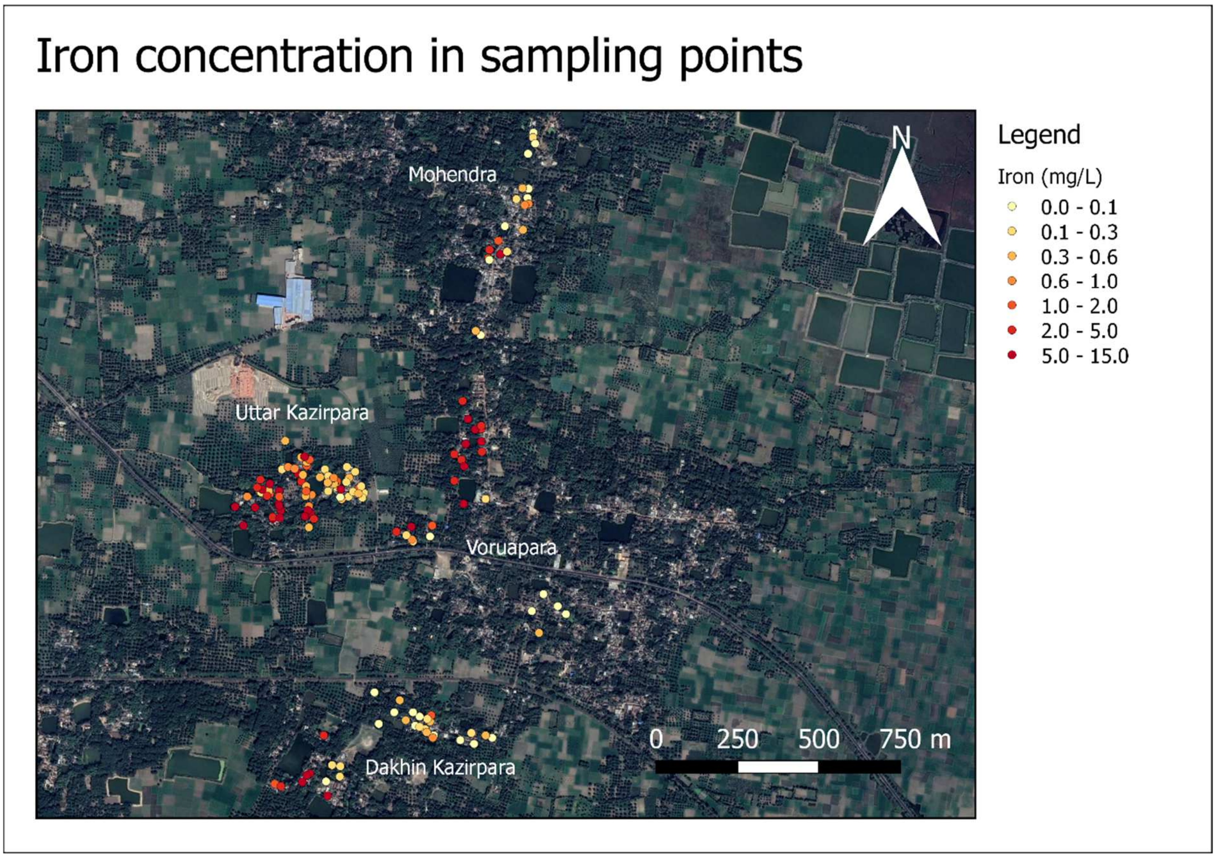


Figure 35: Iron Concentration in sampling points

Furthermore, a manganese concentration map is created and depicted in Figure 36. In contrast to the concentrations of arsenic, the manganese concentrations are low in the villages Uttar Kazirpara and Voruapara. On the other hand, there are high concentrations in the villages Dakhin Kazirpara and Mohendra.

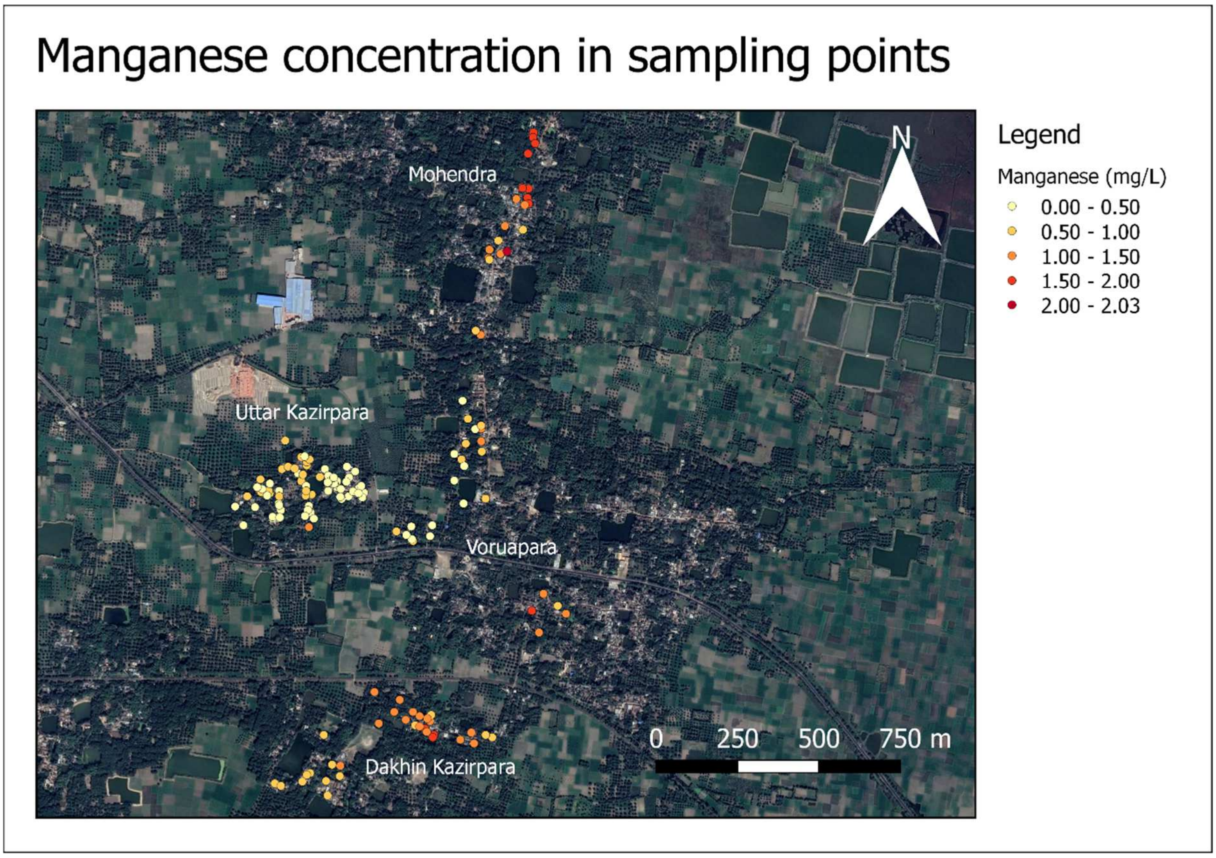


Figure 36: Manganese Concentration in sampling points

Besides arsenic, iron and manganesen, also an ammonium concentration map has been created which can be found in Figure 37. It is notable that the ammonium concentration is relatively high in Uttar Kazirpara. The information from Table 6 confirms the graphical display. The average ammonium concentration is indeed around 2 times higher in Uttar Kazirpara than in the surrounding villages.

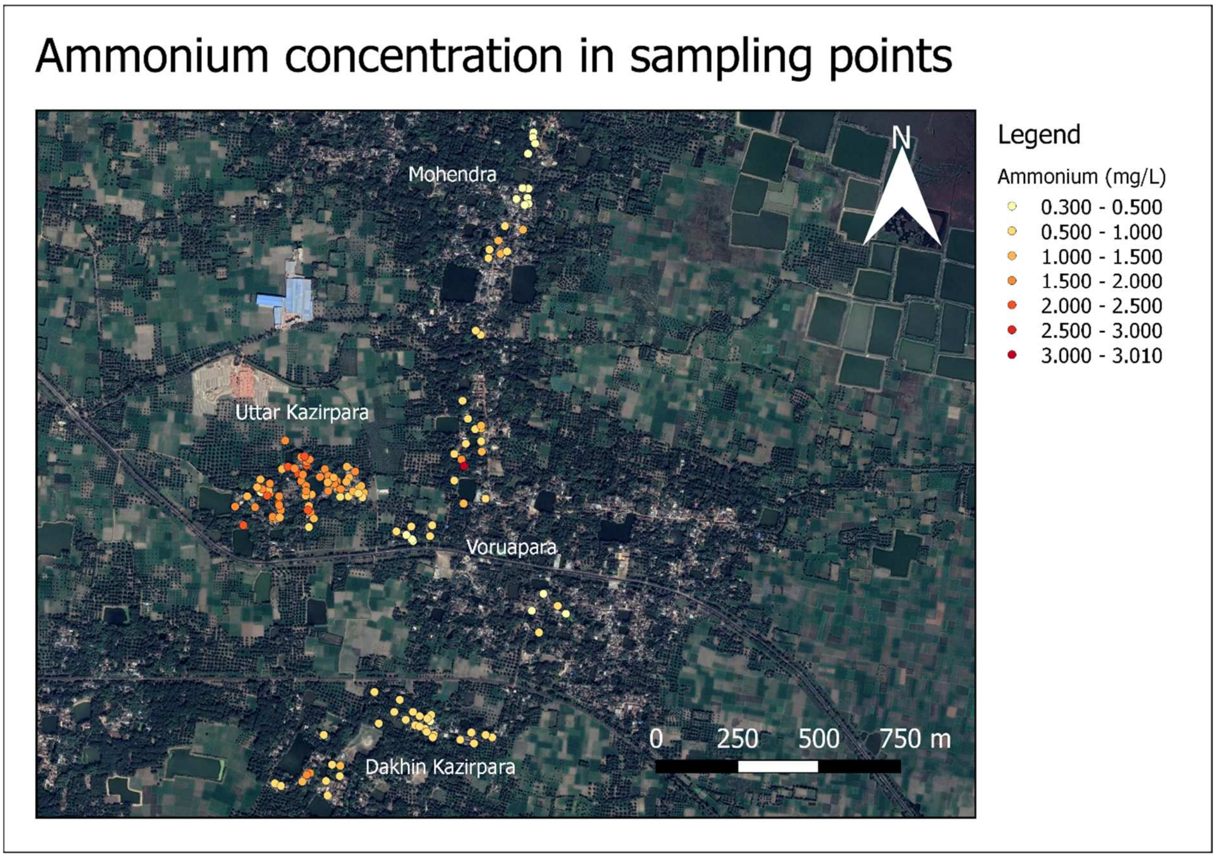


Figure 37: Ammonium Concentration in sampling points

When looking to the different figures of the sampling points, there are some facts that stand out. Firstly, the most striking pattern is that the spatial distribution of arsenic concentrations seems similar to that of iron. On the other hand, the distribution of manganese tends to have an inverse relationship compared to the iron and arsenic distribution. This is contradicting the findings explained later in this report in Section 7.2. From those results, it can namely be concluded that there is no relation between arsenic and iron nor between arsenic and manganese concentrations. A possible explanation of the apparent spatial distribution is the scale that has been used. An increasing step size scale has been used for the spatial analysis which could result in a distorted image of the relationships. For the analysis of the water quality data in Section 7.2 a homogenous scale has been used, this gives a less distorted result.

7.1.3 Drilling

As mentioned before, a total of three drillings have been executed. In Figure 34 the locations of the drillings are shown. Drilling-1 is executed in highly arsenic contaminated area, drilling-2 in a moderately contaminated area and drilling-3 in an arsenic safe area. The distances between drilling-1 and drilling-2 and between drilling-2 and drilling-3 are 200 metres and 800 metres respectively. The drillings are more or less located on a straight line.

The intended XRD and XRF analysis of the soil samples that are taken during drilling could not be executed. The reasons for this are unforeseen circumstances and limited budget. Nevertheless, the XRD and SRF analysis might be executed in the Netherlands after finishing the project in Bangladesh. The results will however, not be presented in this report.

General soil profile

A first observation that can be done from the soil profiles, is that for all three locations the top layer consists mainly of alternating clay and silt, probably deposited in floodplain environment. This is in accordance with the expected geology explained in the Chapter 0. The thickness of this layer differs however between 25 (drilling-1) and 65 feet (drilling-3) and thus, is not homogenous. The large thickness difference of 40 feet is remarkable. This high variability within approximately one kilometre indicates rapidly shifting depositional environments during the time of deposition. The finding of shell remnants during the reconnaissance survey and during drilling-2 could indicate a marine depositional setting. More likely it is of lacustrine origin or transport towards the floodplain by a flooding event during the time of deposition. The shell remnants could also be the result of human intervention (e.g. application of shells as a source of lime for agriculture) since all shell remnants were found at less than 3 metres depth.

Furthermore, a rather homogenous aquifer is present in the three profiles. The thickness of the aquifer ranges between 100 to 120 feet. The aquifer is interrupted by clay layers of maximum 1.5 metres in drilling-1 and drilling-2. The aquifer consists mainly of medium to coarse grained sand. The coarse-grained character of the aquifer sand indicates a rather fast flowing river system such as a braided river. In particular, the depth ranges from 110 to 130 feet (in which the majority of the tube wells are screened) contain coarse grained sand. In the profile of drilling-1 a coarsening upward sequence can be distinguished: The scale is however very large (25 feet). Throughout the whole aquifer, rather large minerals are observed (up to 2mm), in all the three profiles. The most observed minerals are quartz, feldspar and mica. These observations are made with the naked eye. In Figure 38 a close-up of the aquifer sand is shown in which some minerals are present. In the picture a five-Bangladeshi-taka coin is shown for scale. The diameter of this coin is 26.8 mm.

The aquifer is bordered at the bottom by a hard clay layer. The depth of this clay layer is rather consistent for the three drillings. It is located at a depth between 155 to 165 feet. The transition is rather abrupt from coarse sand to clay. The top of the clay layer is characterised by a mix of coarse sand and hard clay. The clay that is encountered is stiff and contains little angular clumps (<2mm) of very stiff clay in a matrix of slightly less stiff clay. The three soil profiles compiled after the drillings are shown in Figure 39. The interpretation of the soil profiles is shown in Figure 40.

Due to disturbed sampling technique it is not possible to compile a continuous core. As a result, lamination, ripples and other subtle structures cannot be distinguished in the soil profile. Classification of different lithofacies units is therefore difficult. Furthermore, the determination of the depth is not really accurate. There is a lag between the drill bit being at a certain depth and the moment that the soil sample reaches the surface. The accuracy is estimated to be one foot.

Figure 38. Close-up of a soil sample (drilling-2 130 ft. depth)

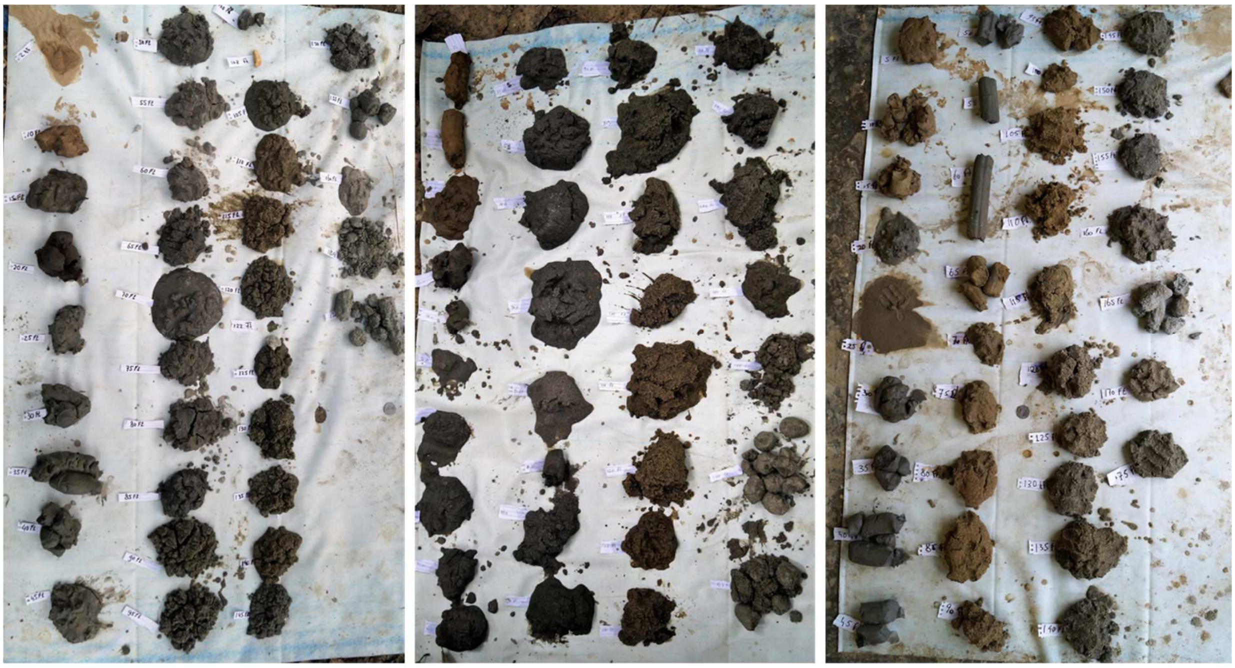


Figure 39. From left to right: soil profiles of drilling-1, drilling-2 and drilling-3

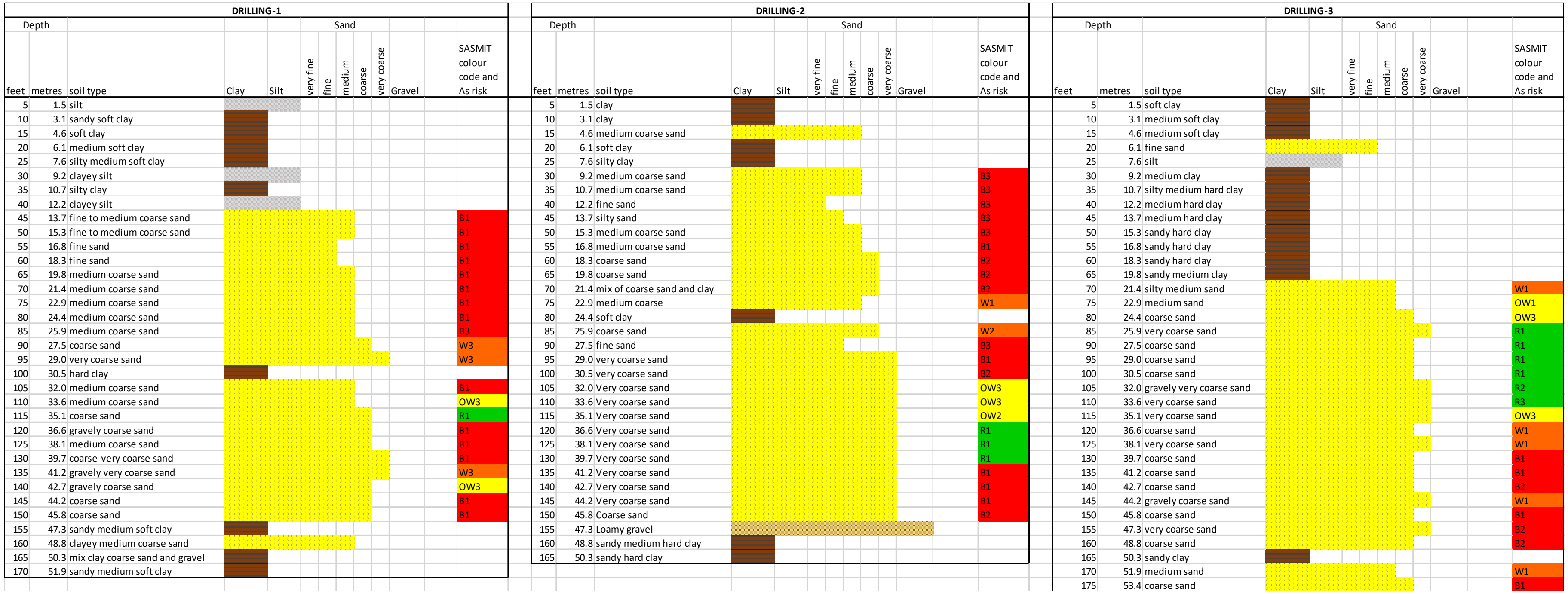
SASMIT results

As it has been explained in the Section 6.2.4, the SASMIT tool (Hossain et al., 2014; Hossain et al., 2017) has been used as a guideline during the drillings to identify the arsenic risk of the encountered aquifers.

As mentioned earlier, the risk of As contamination is the lowest when the aquifer sand has a reddish colour. In Figure 39, an increase in red-coloured soil samples can be seen from drilling-1 to drilling-3, (for pictures in higher resolution see Appendix XIAppendix). This becomes however, more clear when looking at the soil profiles compiles in Excel, which are depicted in Figure 40. A clear difference between the drillings can be seen in terms of arsenic contamination risk. This means that the theory by Hossain et al. (2017) is correct for the research area.

A remarkable result is the depth of the safe aquifer interval in drilling-3 (arsenic-safe area). The safe aquifer interval is namely between 85 and 110 feet depth, while the majority of the tube wells are screened slightly deeper. The eight nearest tubes are screened at 116 feet depth on average. Probably, the significant part of the water withdrawn by the well originates from the aquifer above the well screen due to the drawdown and therefore, the water is mainly originated from the safe part of the aquifer. Also, most well screens are 15 feet long, according to the local plumber. Consequently, the top of the well screen is inside the safe aquifer.

During the execution of the drillings it became clear that soil colour determination by using the SASMIT colour tool is not as easy as it seems. It is very difficult to distinguish between the different colour shades. Two independent assessments of the colour sometimes resulted in classification in different colour shades. This was however in the minority of the assessments. Another difficulty has been the difference between moist and dry soil. The SASMIT tool contains really dry sand (see Figure 5) while literature says (Hossain et al., 2017) that an assessment has to be made when the soil is at natural moist conditions.



DRILLING-1

Depth					Sand					
feet	metres	soil type	Clay	Silt	very fine	fine	medium	coarse	very coarse	Gravel	SASMIT colour code and As risk
5	1.5	silt	▒	▒							
10	3.1	sandy soft clay	🟫								
15	4.6	soft clay	🟫								
20	6.1	medium soft clay	🟫								
25	7.6	silty medium soft clay	🟫								
30	9.2	clayey silt	▒	▒							
35	10.7	silty clay	🟫								
40	12.2	clayey silt	▒	▒							
45	13.7	fine to medium coarse sand	🟨	🟨	🟨	🟨	🟨				🟥 B1
50	15.3	fine to medium coarse sand	🟨	🟨	🟨	🟨	🟨				🟥 B1
55	16.8	fine sand	🟨	🟨	🟨	🟨					🟥 B1
60	18.3	fine sand	🟨	🟨	🟨	🟨					🟥 B1
65	19.8	medium coarse sand	🟨	🟨	🟨	🟨	🟨				🟥 B1
70	21.4	medium coarse sand	🟨	🟨	🟨	🟨	🟨				🟥 B1
75	22.9	medium coarse sand	🟨	🟨	🟨	🟨	🟨				🟥 B1
80	24.4	medium coarse sand	🟨	🟨	🟨	🟨	🟨				🟥 B1
85	25.9	medium coarse sand	🟨	🟨	🟨	🟨	🟨				🟥 B3
90	27.5	coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟧 W3
95	29.0	very coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟧 W3
100	30.5	hard clay	🟫								
105	32.0	medium coarse sand	🟨	🟨	🟨	🟨	🟨				🟥 B1
110	33.6	medium coarse sand	🟨	🟨	🟨	🟨	🟨				🟨 OW3
115	35.1	coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟩 R1
120	36.6	gravely coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟥 B1
125	38.1	medium coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟥 B1
130	39.7	coarse-very coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟥 B1
135	41.2	gravely very coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟧 W3
140	42.7	gravely coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟨 OW3
145	44.2	coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟥 B1
150	45.8	coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟥 B1
155	47.3	sandy medium soft clay	🟫								
160	48.8	clayey medium coarse sand	🟨	🟨	🟨	🟨	🟨				
165	50.3	mix clay coarse sand and gravel	🟫								
170	51.9	sandy medium soft clay	🟫								

DRILLING-2

Depth					Sand					
feet	metres	soil type	Clay	Silt	very fine	fine	medium	coarse	very coarse	Gravel	SASMIT colour code and As risk
5	1.5	clay	🟫								
10	3.1	clay	🟫								
15	4.6	medium coarse sand	🟨	🟨	🟨	🟨	🟨				
20	6.1	soft clay	🟫								
25	7.6	silty clay	🟫								
30	9.2	medium coarse sand	🟨	🟨	🟨	🟨	🟨				🟥 B3
35	10.7	medium coarse sand	🟨	🟨	🟨	🟨	🟨				🟥 B3
40	12.2	fine sand	🟨	🟨	🟨						🟥 B3
45	13.7	silty sand	🟨	🟨	🟨	🟨					🟥 B3
50	15.3	medium coarse sand	🟨	🟨	🟨	🟨	🟨				🟥 B3
55	16.8	medium coarse sand	🟨	🟨	🟨	🟨	🟨				🟥 B1
60	18.3	coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟥 B2
65	19.8	coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟥 B2
70	21.4	mix of coarse sand and clay	🟨	🟨	🟨	🟨	🟨	🟨			🟥 B2
75	22.9	medium coarse	🟨	🟨	🟨	🟨	🟨				🟧 W1
80	24.4	soft clay	🟫								
85	25.9	coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟧 W2
90	27.5	fine sand	🟨	🟨	🟨	🟨					🟥 B3
95	29.0	very coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟥 B1
100	30.5	very coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟥 B2
105	32.0	Very coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟨 OW3
110	33.6	Very coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟨 OW3
115	35.1	Very coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟨 OW2
120	36.6	Very coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟩 R1
125	38.1	Very coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟩 R1
130	39.7	Very coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟩 R1
135	41.2	Very coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟥 B1
140	42.7	Very coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟥 B1
145	44.2	Very coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟥 B1
150	45.8	Coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟥 B2
155	47.3	Loamy gravel	▨	▨	▨	▨	▨	▨	▨	▨	
160	48.8	sandy medium hard clay	🟫								
165	50.3	sandy hard clay	🟫								

DRILLING-3

Depth					Sand					
feet	metres	soil type	Clay	Silt	very fine	fine	medium	coarse	very coarse	Gravel	SASMIT colour code and As risk
5	1.5	soft clay	🟫								
10	3.1	medium soft clay	🟫								
15	4.6	medium soft clay	🟫								
20	6.1	fine sand	🟨	🟨	🟨	🟨					
25	7.6	silt	▒	▒							
30	9.2	medium clay	🟫								
35	10.7	silty medium hard clay	🟫								
40	12.2	medium hard clay	🟫								
45	13.7	medium hard clay	🟫								
50	15.3	sandy hard clay	🟫								
55	16.8	sandy hard clay	🟫								
60	18.3	sandy hard clay	🟫								
65	19.8	sandy medium clay	🟫								
70	21.4	silty medium sand	🟨	🟨	🟨	🟨	🟨				🟧 W1
75	22.9	medium sand	🟨	🟨	🟨	🟨	🟨				🟨 OW1
80	24.4	coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟨 OW3
85	25.9	very coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟩 R1
90	27.5	coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟩 R1
95	29.0	coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟩 R1
100	30.5	coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟩 R1
105	32.0	gravely very coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟩 R2
110	33.6	very coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟩 R3
115	35.1	very coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟨 OW3
120	36.6	coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟧 W1
125	38.1	very coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟧 W1
130	39.7	coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟥 B1
135	41.2	coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟥 B1
140	42.7	coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟥 B2
145	44.2	gravely coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟧 W1
150	45.8	coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟥 B1
155	47.3	very coarse sand	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟥 B2
160	48.8	coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟥 B2
165	50.3	sandy clay	🟫								
170	51.9	medium sand	🟨	🟨	🟨	🟨	🟨				🟧 W1
175	53.4	coarse sand	🟨	🟨	🟨	🟨	🟨	🟨			🟥 B1

Figure 40. Soil profiles of the three drillings. SASMIT column: red=very high As risk, orange=high As risk, yellow=moderate As risk and green=low As risk

7.2 Water quality fieldwork

The results of the water quality fieldwork will be reported in this section. In total 149 tube wells have been tested for which different parameters and different testing methods are analysed. However, one sample taken broke before it was analysed with the ICP-MS. Therefore, this data point (155) is excluded from the analysis. The results of the ICP-MS are considered as the baseline. The results of the strip tests for arsenic, iron and manganese are compared to this baseline to study the performance of the test kits. In the case of ammonium and pH, the cell test and the multimeter results are considered as the baseline. All the results of the ICP-MS can be found in Appendix VIII.

7.2.1 Statistics

In order to analyse the performance of the different testing methods, two statistical methods have been applied. First, outliers are excluded from the analysis. In this study, an outlier is defined as a data point that has an absolute difference between the two tests more than 1.5 interquartile ranges (IQRs) above the third quartile (Q3) or below the first quartile (Q1). Q1 and Q3 represent the median of respectively the lower and the upper half of the dataset. The IQR is then $\mathrm{Q3} - \mathrm{Q1}$. Data points with absolute differences between the executed tests which exceed $\mathrm{Q3} + 1.5 * \mathrm{IQR}$ and which are lower than $\mathrm{Q1} - 1.5 * \mathrm{IQR}$ are considered as outliers and excluded from the analysis.

To analyse the performance of the different strip tests compared to its baseline, the Root Mean Squared Error (RMSE) is determined. The following equation applies in which C_{strip} and $C_{baseline}$ are respectively the concentration found with the strip test and with the baseline test. N is the amount of data points.

$$RMSE = \sqrt{\frac{\sum\left(C_{strip} - C_{baseline}\right)^2}{N}}$$

In order to compare the RMSE of different strip tests, the normalized RMSE is determined. This is done by dividing the RMSE with the testing range of the strip test.

7.2.2 Physical parameters

The pH, electrical conductivity and temperature of the tube well water are determined during the fieldwork. The hardness and turbidity have not been measured in the field for many data points because the multimeters did not provide good results.

The pH measured with the multimeter varies between 5.48 and 7.88. The strip test however shows pH values from 7 to 9. No outliers have been excluded from the analysis. Comparing the two methods, a RMSE of 1.04 is found and a normalized RMSE of 0.52. Considering the fact that pH ranges from 6.5 to 8.5 in drinking water, this error is very large and not acceptable.

The differences found between the two methods could be due to different reasons. Firstly, it is probable that one of the multimeters was broken during the last days of measurements. The strip test results stay constant on these days while the multimeter results drop suddenly to 6 or even lower. The tests on these days should be performed again to prove this hypothesis. Secondly, the strip test result is difficult to determine due to fast colour changes after the 15 seconds of waiting. Moreover, the colour scale is too rough to differentiate decimal numbers which are relevant for values between 6 and 9.

The electrical conductivity of the groundwater varies from 0.475 µS/cm to 1.382 µS/cm with an average of 0.760 µS/cm.

The average temperature of the tube well water is 28.5℃, varying from 24.8℃ to 33℃. As mentioned in Section 6.3.5, the water temperature should be between 10℃ and 25℃ for the MQuant manganese strip test. This condition is thus not satisfied.

7.2.3 Arsenic

The concentrations of arsenic found with the Quantofix Arsen test are compared with the results of the ICP-MS. The strip test has only been interpreted visually because the ‘AKVO Caddisfly’ app did not show results for the Quantofix Arsen test due to an update of the app.

The maximum concentration of arsenic found with the ICP-MS is 1123 μg/L. 94 of the analysed tube wells contain arsenic concentrations that exceed the WHO standard of 10 μg/L. Figure 33 depicts a map with the spatial variation of the arsenic levels found in the villages.

The strip test has a test range from 0 to 500 μg/L. Therefore, test strips for all tube wells with arsenic levels above 500 μg/L show a value of maximum 500 μg/L. A value of 500 μg/L with the strip test, while the actual value is larger indicates therefore good performance of the strip test. The following steps are taken to analyse the performance of the Quantofix Arsen test.

1. All the arsenic concentrations larger than 500 μg/L according to the ICP-MS are set to 500 μg/L because the test strip cannot indicate more than 500 μg/L.
2. The outliers are determined using the statistical outlier method described before and are excluded from the dataset.
3. The arsenic concentrations measured with the strip test are plotted against the arsenic concentrations measured with the ICP-MS, excluding all the outliers.
4. The RMSE is determined as a measure of the performance of the strip test.
5. The RMSE is normalized according to the test range of the strip test (500 μg/L).

The results of the performance of the Quantofix Arsen 10 Test are depicted in Figure 41. A RMSE value of 22.6 μg/L is found which indicates good performance when considering a testing range from 0 to 500 μg/L. The normalized RMSE value is equal to 0.045. The figure shows that the strip tests indicates concentrations both above and below the ICP-MS concentration. However, for concentrations lower than 100 μg/L, the strip test indicates lower values than the ICP-MS. It is remarkable that for 48 of the 54 tube wells that meet the WHO standard, the strip test indicates zero arsenic while the ICP-MS shows values varying between 0.1 and 10 μg/L.

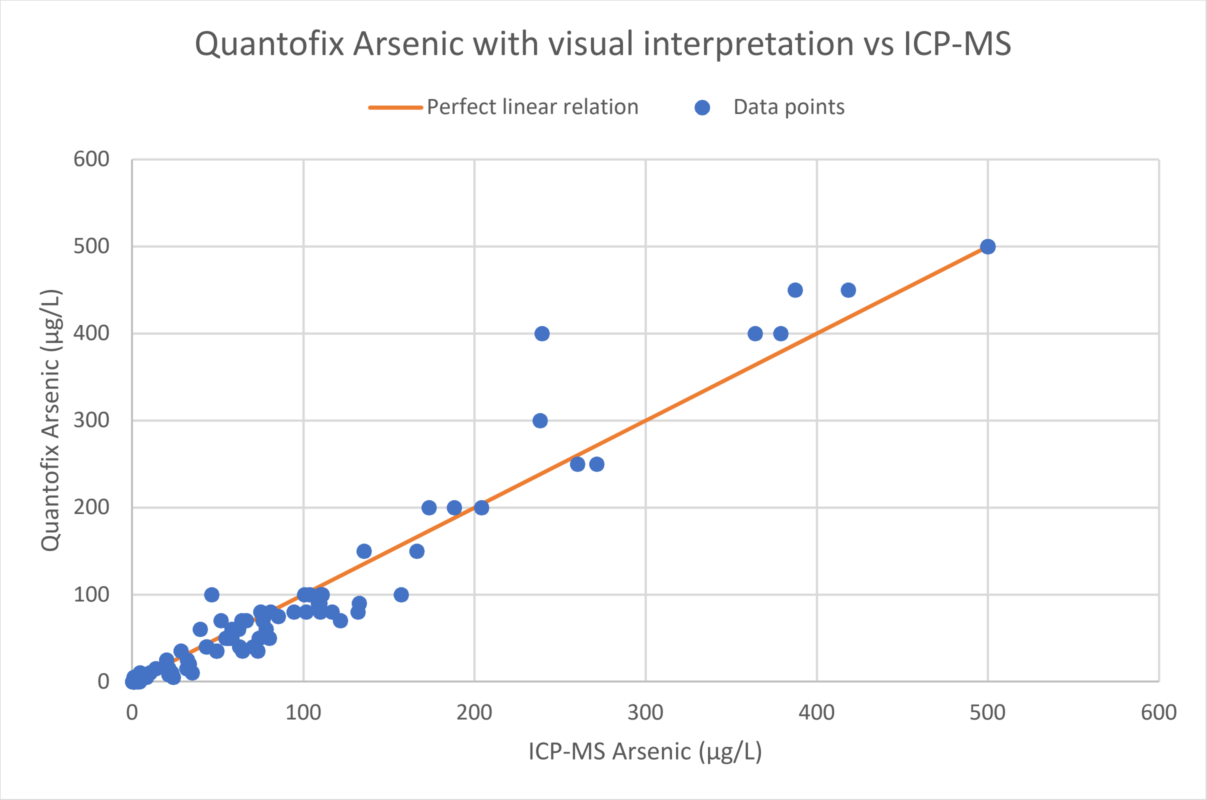


Figure 41. Performance of the Quantofix Arsen 10 strip test using visual interpretation

In the analysis performed, 20 data points have been excluded due to too large deviations from the arsenic concentration measured with the ICP-MS. The strip test results of data points 10 and 55 both indicate zero arsenic while the ICP-MS shows respectively 605 µg/L and 126 µg/L. Probably the arsenic test was not performed correctly for these two data points.

For 11 data points (4, 13, 22, 23, 29, 34, 65, 67, 75, 77, 88), the strip tests indicate arsenic levels around 100 µg/L below the ICP-MS result. On the other hand, for 7 data points (2, 3, 9, 17, 32, 74, 92), the strip test indicates arsenic levels around 100 µg/L above the ICP-MS result. Those deviating results mainly occur around concentrations from 100 µg/L to 500 µg/L. A reason for these deviations could be that the arsenic test has one step in the colour range from 100 µg/L to 500 µg/L. This makes it difficult to determine the colour and thus the concentration in between. Furthermore, it is remarkable that most of these reading errors occurred in the data points collected on the first days. On the first days, the highest arsenic levels have been measured. As the deviating results mainly occurred at higher arsenic levels, this could be the reason why the data of the first days is more erroneous. Another reason could be that on these days, the students did not have much experience yet in reading the test strip, resulting in larger errors.

In order to study what went wrong in the tests of the data points mentioned above, the pictures taken of the test strip compared to the colour range are analysed. The test strip of data point 3, 4 and 9 is very dry. A dry test strip is always darker than a wet test strip. It is probable that the student did not immerse the test strip in distilled water for 2 seconds after performing the test which resulted in a darker test strip and a too high concentration.

For data point 65, 74 and 75, the visual interpretation of the student was incorrect. The concentration of data point 92 is probably reported incorrectly in the app as the picture shows a very different concentration than the result in the data set collected with the app. The other deviating data points mentioned above are probably a result of incorrect execution of the test, as the reported concentration matches with the colour of the test strip.

7.2.4 Iron

The iron levels in the studied tube wells are determined using two different strip tests and the ICP-MS. The results of the strip tests are obtained through the 'AKVO Caddisfly' app and through visual interpretation of the test strip. The iron concentrations found with the ICP-MS vary from 0.04 mg/L to 10.6 mg/L. The WHO has not set a standard to iron concentrations of the drinking water. A value below 0.3 mg/L is however desired because of taste and colour.

Hach Total Iron test

The results of the Hach Total Iron test with the mobile app are compared to the concentrations found with the ICP-MS. The Hach iron test has a testing range from 0 to 5 mg/L. If the result of the test is 5 mg/L, this indicates a concentration of 5 mg/L or larger. The same procedure as explained for the arsenic test is applied to study the performance of the Hach Total Iron test. First, all the iron concentrations larger than 5 mg/L according to the ICP-MS are set to 5 mg/L because the app cannot indicate more than 5 mg/L. After, the outliers are determined and the RMSE indicates the performance of the strip test.

Figure 42 depicts the results of the Hach iron strip test and the ICP-MS. The RMSE for this relation is 0.30 mg/L which indicates a good performance of the strip tests considering the testing range of 0 to 5 mg/L. The normalized RMSE value is 0.06. As the figure shows, the iron concentrations measured with the app are mainly lower than the concentrations measured with the ICP-MS for concentrations. The app shows lower results than the ICP-MS for 121 out of 148 data points.

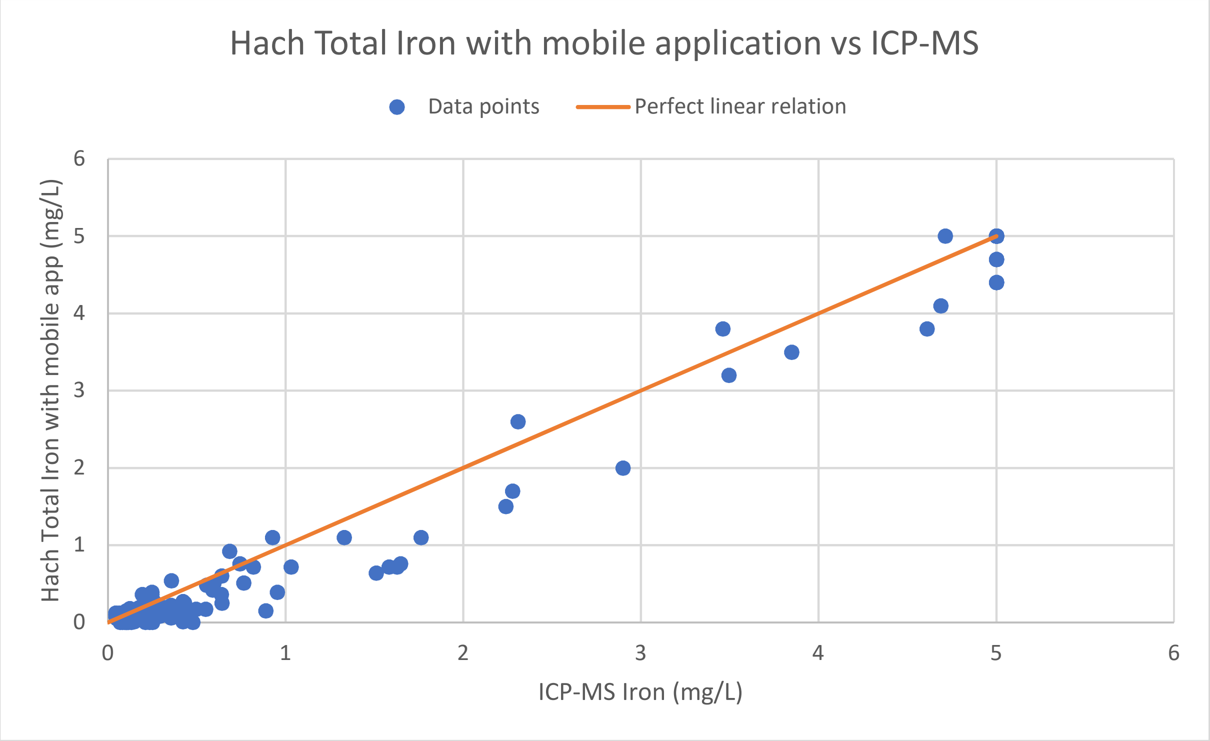


Figure 42. Performance of the Hach Total Iron strip test using 'AKVO Caddisfly'

The outliers found can be divided into three categories. Firstly, data points 15, 20, 22, 54, 95 and 105 show a zero-iron concentration through the app while the ICP-MS results give at least 2 mg/L. Visual interpretation of these test strips however shows little deviation from the ICP-MS result. For these data points, the ‘AKVO Caddisfly’ did not work properly which could be due to light conditions or a bug in the application.

Secondly, both the app and visual interpretation of the test strip show for data points 29, 65 and 138 an iron concentration of approximately zero while the ICP-MS indicates a concentration of more than 1 mg/L. This problem indicates failure of the entire strip test. The test could have been executed incorrectly resulting in zero result.

Thirdly, data points 32, 72, 75, 88, 115, 117, 118, 120 and 171 have iron concentrations varying from 2.3 mg/L to 5.6 mg/L. The mobile app and visual interpretation both underestimate these values by at least 1.5 mg/L. Since both the app and the visual interpretation are underestimating, the iron test itself probably is erroneous. Due to the fact that this error occurs for many data points with similar concentrations, it is not likely that improper execution of the test is the cause for the error.

The strips have also been analysed through visual interpretation. Comparing these results with the ICP-MS, a RMSE of 0.7 mg/L is found which indicates a worse performance than the mobile application. Outliers are excluded from this analysis following the same method as explained before. Six data points (17, 32, 72, 75, 88, 118) that are excluded are similar to the ones in the third category in the previous section. Also, 77, 104 and 107 are excluded from the analysis. For these three data points, the app indicated a concentration close to the ICP-MS concentration, but the visual interpretation of the test strip resulted in around 2 mg/L instead of the ICP-MS value of around 5 mg/L. The pictures of the test strip compared to the colour range are analysed for these three data points. From this it can be concluded that the visual interpretation of the test strip is not incorrect. As the app gives the correct values and visual interpretation not, light conditions could be the influencing factor. Another reason could be that the strip does not change colour homogeneous which makes visual interpretation more difficult

Quantofix Total Iron 100 test

The Quantofix Total Iron 100 test has a testing range from 0 to 100 mg/L. Therefore, all iron concentrations found in this study can be reached by the test kit. Outliers are determined using the outlier method explained before. The results of the strip test compared to the ICP-MS are depicted in Figure 43. The RMSE for the Quantofix Iron test using the mobile application is 0.67 mg/L, which indicates a good performance. The testing range of the Quantofix Total Iron 100 test is 0 to 100 mg/L. However, in this study only concentrations up to 10 mg/L are found. Therefore, the normalized RMSE is determined by a range of 10 mg/L and is equal to 0.067.

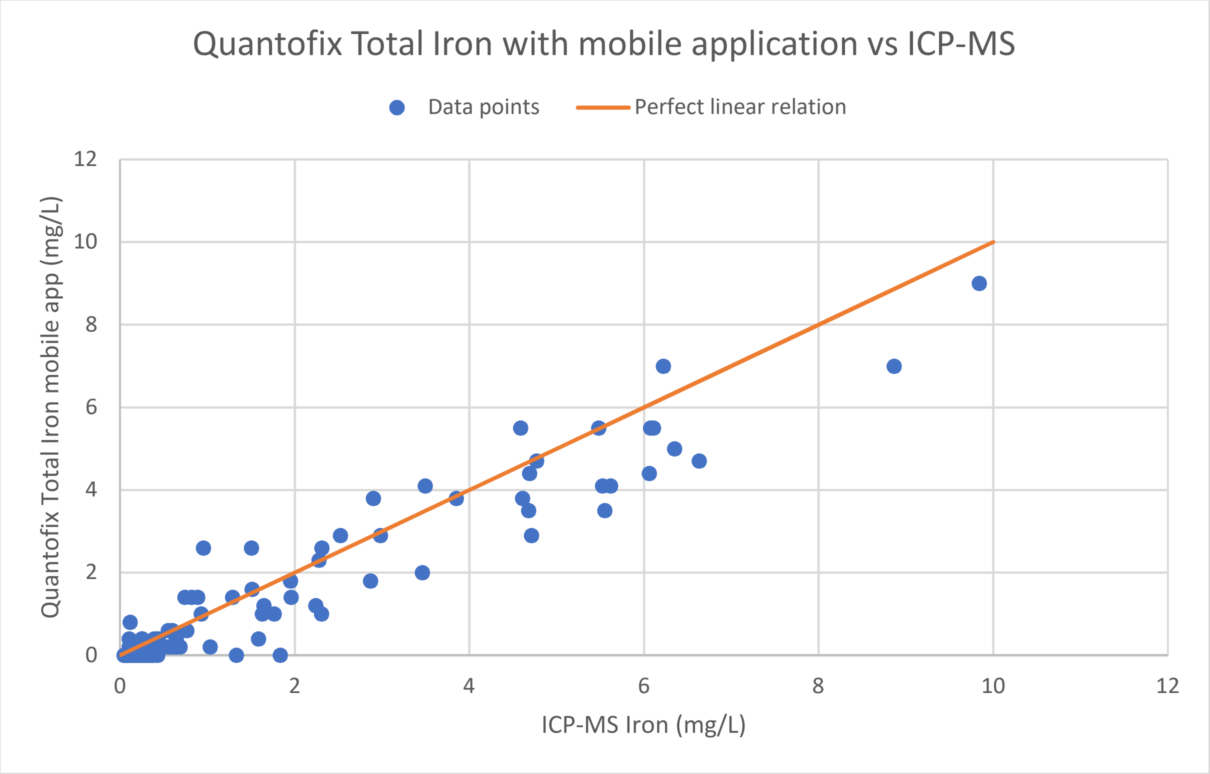


Figure 43. Performance of the Quantofix Iron test with 'AKVO Caddisfly'

The outliers for the Quantofix iron test using the mobile app can be divided into two types. The iron concentrations measured for the first type are for both the app and the visual interpretation too low. The concentrations measured vary from 1.4 mg/L to 5 mg/L, while the ICP-MS results vary from 5.5 mg/L to 10 mg/L. The data points showing this deviation are 9, 13, 58, 83, 88, 95, 110 and 167. For these data points the test kit did not perform well, probably due to improper execution of the test.

The second type of outlier shows large deviations for the app, but the visual interpretation is close to the concentration measured with the ICP-MS. The data points that are considered as outliers of the second type are 22, 87, 97, 108, 117, 156 and 161. In this case, the mobile application failed in indicating the iron concentration.

Considering the visual interpretation of the strip test compared to the ICP-MS results, a RMSE of 0.94 mg/L is found which is higher than the results of the mobile app. Data points 9, 13 and 95 show low concentrations compared to the ICP-MS. This overestimation of the ICP-MS results in those data points was also observed when comparing the mobile app results with the ICP-MS. However, 17, 68, 70, 72, 73, 114 and 115 indicate iron concentrations from 7.5 mg/L to 20 mg/L while the ICPMS results vary from 2.5 mg/L to 6.2 mg/L. Analysing the pictures of the test strips, it can be stated that test strips 17 and 68 have been interpreted wrongly. However, the other deviating data points are interpreted correctly. As the app indicates concentrations close to the ICP-MS for these data points, light conditions and inhomogeneous colour change of the strip could be influencing factors.

Another influencing factor for the Quantofix Total Iron 100 test is the pH. As stated in Section 6.3.5, the pH should be in between 1 and 7. This condition is not met, and no acid had been added to the sample before testing. The results could have been negatively influenced by the pH, resulting in lower performance of the strip test.

Comparison Hach and Quantofix

Both the Hach Total Iron test and the Quantofix Total Iron 100 test show good performance. Table 8 shows the normalized RMSE values for both the iron test in order to compare the results. Considering these values, none of the tests is preferred over the other. It is clear that the results obtained with the mobile application are better than the ones obtained through visual interpretation of the test strip.

Table 8. Normalized RMSE values for the iron tests

	Hach	Quantofix
Normalized RMSE app	0.06	0.067
Normalized RMSE visual	0.14	0.094

In **Fout! Verwijzingsbron niet gevonden.**, the outlier data points for both tests are depicted. It can be seen that the Hach test results more often in incorrect outcomes than the Quantofix test, which would indicate that the Quantofix test is more trustable. It is also remarkable that the amount of incorrect data obtained with visual interpretation is half of the amount of incorrect data through the app for the Hach test. This would indicate that a single data point is less reliable using the mobile application than visual interpretation, even though the error with visual interpretation is higher as shown in Table 8.

Hach test incorrect	Hach app incorrect	Hach visual incorrect
29	15	77
32	20	104
65	22	107
72	54	
75	95	
88	105	
115		
117		
118		
120		
138		
171		

Quantofix test incorrect	Quantofix app incorrect	Quantofix visual incorrect
9	22	17
13	87	68
58	97	70
83	108	72
88	117	73
95	156	114
110	161	115
167		

Table 9. Left: Outlier data points of the Hach Total Iron test, Right: Outlier data points of the Quantofix Total Iron 100 test

Smartphone use

The performance of different smartphones used are also analysed. The android version and camera quality could influence the performance of the mobile application. The Asus Zenfone and the Moto G2 are not considered because too few data points are collected with these phones. The relative error between the strip tests and the ICP-MS results for the Huawei, Oppo and Samsung are considered, and the average is determined. Table 10 shows the performance of the different phones compared to each other. The Samsung J7 has the lowest relative error considering the two strip tests and is therefore the best phone to use for ‘AKVO Caddisfly’. The Huawei performs almost similarly to the Samsung, the Oppo however, it shows worse performance.

Table 10. Performance of different smartphones for both iron tests

Phone	#Datapoints	Average relative difference Hach	Average relative difference Quantofix	Sum
Samsung	46	0.39	0.57	0.96
Oppo	39	0.69	0.72	1.41
Huawei	45	0.44	0.65	1.09

7.2.5 Manganese

The presence of manganese in the tube well water is determined by a strip test and by the ICP-MS. Figure 36 shows the spatial variation of the manganese concentration in the studied villages.

The MQuant Manganese strip test is performed and the results are obtained through visual interpretation of the test strip. The concentrations found with the strip test and the ICP-MS respectively vary from 0 to 3 mg/L and from 0 to 2.03 mg/L. The standard of the WHO for manganese in drinking water is set to 0.4 mg/L. 105 out of 148 tube wells exceed this standard.

When analysing the performance of the strip test, no data points are excluded. Figure 44 shows the concentrations found with the strip test versus the ICP-MS. The RMSE is 0.61 mg/L, which is large considering the low manganese concentrations found. The normalized RMSE is equal to 0.20, considering the results range of 0 to 3 mg/L.

The low performance of this strip test is due to its testing range. The MQuant Manganese strip test has a testing range of 0 to 100 mg/L which is too large for the present concentrations in the groundwater. With this strip test it is hard to distinguish between the low values because the colour change is not very sensitive to small changes in concentration. Therefore, the RMSE is relatively large and it is recommended to use a strip test with a smaller testing range.

As mentioned in Section 6.3.5, the manganese strip test should be used at a pH of 1 to 7 and a temperature between 10 and 25 ℃. As the pH of the sample is lowered by addition of acid, the pH condition is met. However, the temperature of the water is almost always higher than 25℃ which could have influenced the performance of the strip test.

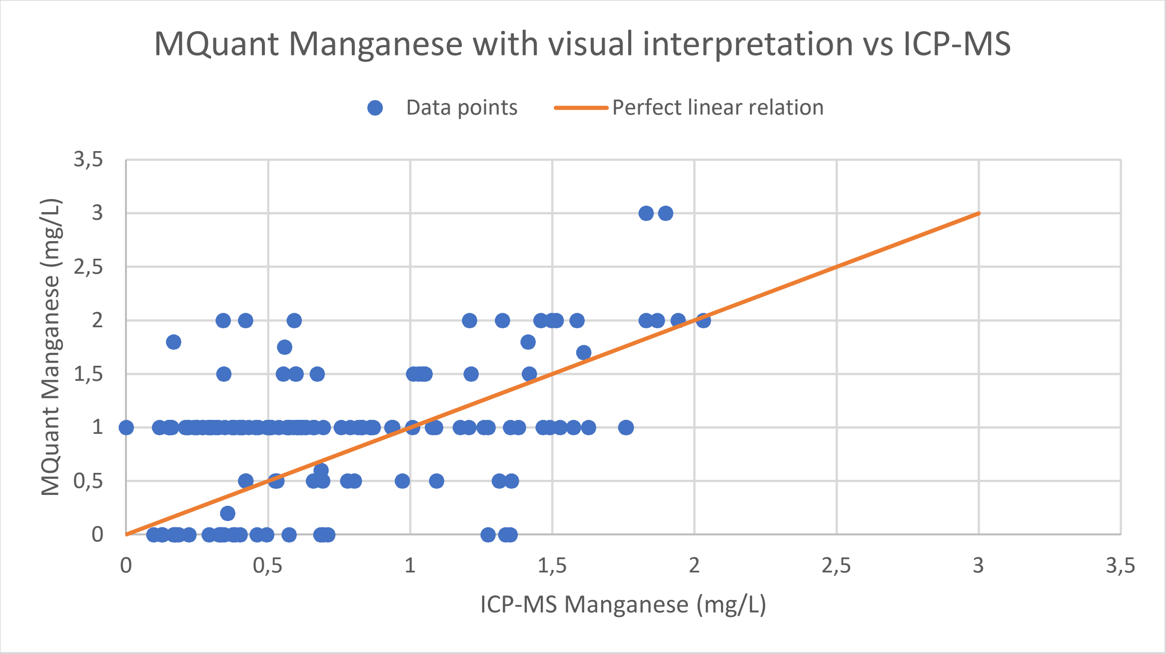


Figure 44. Performance of the Merck Manganese test using visual interpretation

7.2.6 Ammonium

The concentration ammonium in the water is determined with two different methods. The results of the Macherey Nagel Ammonia Test are compared with the results of the PhotoFlex testing the Spectroquant Ammonium Cell Test. The spatial variation of ammonium is depicted in Figure 37. The concentration found with the cell test is considered as correct as this method is more advanced than the strip test. The concentrations measured with the cell test are for 95% of the sampling points higher than the strip test results. The average concentrations measured with the strip test and the cell test are respectively 0.26 mg/L and 1.14 mg/L. Studies have shown a threshold odour concentration of 1.5 mg/L ammonium which is exceeded by 43 out of 149 tube wells.

Comparing the two methods (Figure 45), a RMSE of 1.0 mg/L is found which is large considering the low concentrations. The normalized RMSE is equal to 0.33, considering the result range of 0 to 3 mg/L. There are no outliers excluded from this analysis. The colour code of the strip test was difficult to read which could be the reason for its low performance.

As the cell test is not directly performed in the field, the number of hours could influence the results. The composition of the sample changes over time as oxidation reactions take place if there is air present in the sample. However, the results of this study show that the number of hours passed between sampling and measuring with the PhotoFlex does not influence the error between the tests. However, this is based on the results of the bad performing strip test. Therefore, it is probably not valid in general.

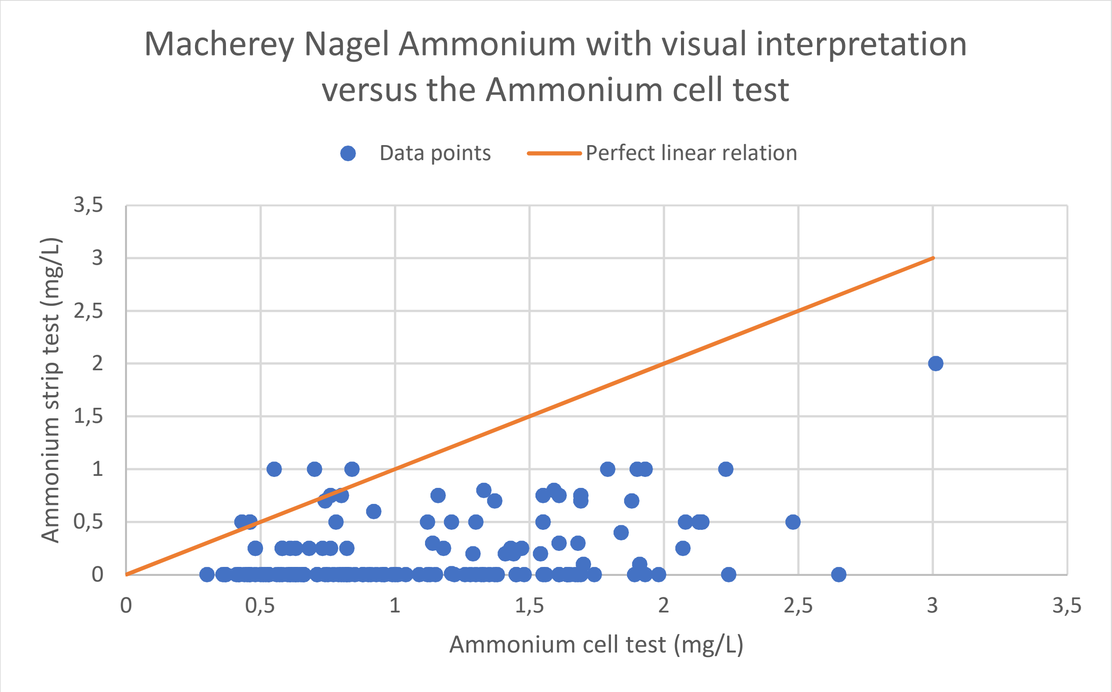


Figure 45. Performance of the Macherey Nagel Ammonium test compared to the Cell test

Summary of strip test results

The results analysed in this section indicate that the arsenic test, the Hach iron test and the Quantofix iron test perform well. However, the pH test, the manganese test and the ammonium test do not show good results. Table 11 shows the normalized RMSE values for all the six different strip tests performed.

Table 11. Performance of different strip tests

Strip test	**Normalized RMSE**
pH	0.52
Quantofix Arsen 10	0.045
Hach Total Iron	0.060
Quantofix Total Iron 100	0.067
MQuant Manganese	0.20
Macherey Nagel Ammonium	0.33

Because of the low performance of the pH, manganese and ammonium test, these three tests are not included in analysing incorrect data points.

Table 12 shows the data points for which it is assumed that the test did not perform well, for arsenic, Hach iron and Quantofix iron. It is remarkable that the tests at data point 88 all indicate strongly deviating results compared to the ICP-MS. This could indicate that either the ICP-MS sample is wrongly taken, or all the three tests are wrongly performed. The data points coloured in blue in Table 12 have two out of three test results considered to be incorrect. Furthermore, for these points both the ICP-MS sample and the performed strip tests could be incorrect. It is recommended to perform the tests and to take samples again for the blue and orange coloured data points in Table 12.

Table 12. Outlier datapoints indicating that the test did not perform well for arsenic, Hach iron and Quantofix iron

Arsenic test incorrect	**Hach test incorrect**	**Quantofix test incorrect**
2	**29**	**9**
3	**32**	**13**
4	**65**	58
9	72	83
13	**75**	**88**
17	**88**	95
22	115	110
23	117	167
29	118	
32	120	
34	138	
65	171	
67		
74		
75		
77		
88		
92		

7.2.7 Relations

Possible relations between arsenic and the other studied elements are analysed based on the ICP-MS data for iron and manganese and on the cell test data for ammonium. Figure 46 shows all the data points for arsenic versus iron, ammonium and manganese. No clear relations can be found from this study between arsenic with iron, ammonium and manganese.

The highest arsenic levels are found with low iron concentrations of around 1 mg/L. All other data points do not show clearly whether the presence of iron and arsenic are related. Ammonium, however, seems to show a slightly increasing trend with higher arsenic levels. The highest arsenic levels show remarkable results and do not follow the weak trend of the other data points. Manganese levels seem to decrease with higher arsenic levels. Data points with concentrations of manganese exceeding 1.3 mg/L, all have arsenic levels around 0 µg/L. However, concentrations between 0 and 1 mg/L of manganese show strongly variable arsenic levels.

It is remarkable that the seven data points with the largest arsenic concentrations have really low iron concentrations. Moreover, for the cases of ammonium and manganese, these data points show noticeable results. It is therefore decided to retake these samples. The concerning data points are depicted in Table 13. With the results of the new samples, the analysis should be performed again and might give other results.

Furthermore, relations between iron and ammonium, iron and manganese and ammonium and manganese do not show conclusive results.

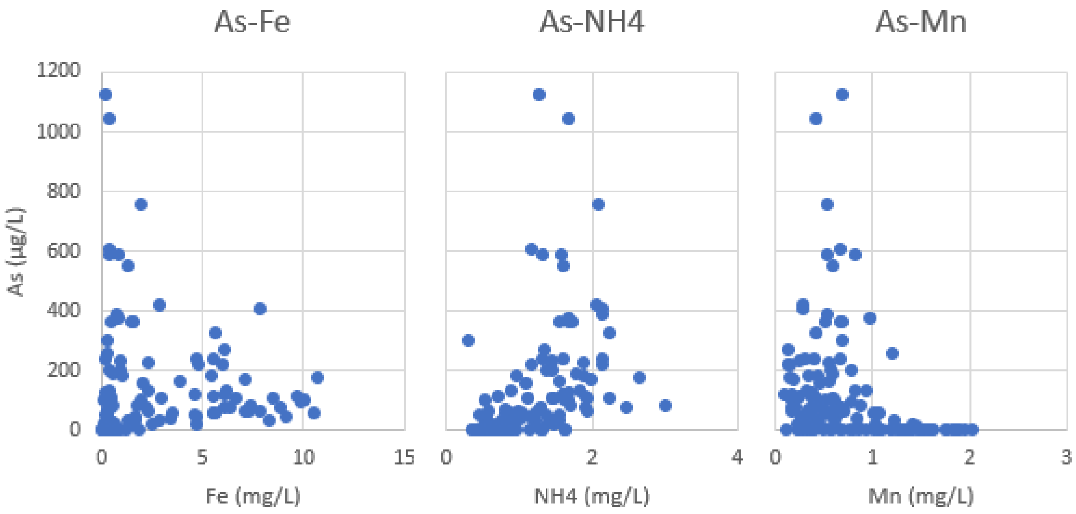


Figure 46. Arsenic concentrations versus iron, ammonium and manganese

Table 13. Samples with high arsenic levels that are retaken for further analysis

ID	Village	As (µg/L)	Fe (mg/L)
5	1:Uttar Kazirpara	586.945	0.808
10	1:Uttar Kazirpara	605.508	0.378
12	1:Uttar Kazirpara	1041.364	0.361
14	1:Uttar Kazirpara	1123.662	0.238
15	1:Uttar Kazirpara	754.883	1.960
18	1:Uttar Kazirpara	588.393	0.356
29	1:Uttar Kazirpara	547.952	1.288
155	2:Dakhin Kazirpara	Sample was broken	Sample was broken

7.2.8 Well depths

According to (BGS & DPHE, 2001) groundwater extracted from deep aquifers (>100m or 330 feet) is supposed to be arsenic-safe. As outlined before, the depths of all tested well depths are measured. As one can see in Figure 47, by far most wells are between 115 and 120 feet deep. No wells deeper than 170 feet are encountered in the field. It is therefore not possible to validate the statement by BGS and DPHE (2001) with the available data. Furthermore, no relation between the well depths and arsenic, iron, manganese and ammonia concentrations have been found. A plot of the data is shown in Figure 48. However, it cannot be concluded that there is no depth trend in the fieldwork area. The data that has been used has a distribution, which makes it hard to analyse the data. There are very few data points which are deeper than 130 feet (10% of the data points). As a result, there is too less data available, specifically too less deep wells, to draw a conclusion about a relationship between depth and arsenic, iron, manganese and ammonium concentrations in the groundwater.

Some difficulties occurred during the execution of the well depth measurements. Some of the tube wells were too old and rusty to dismantle and reassemble again. Also, some of the tube wells were covered with a roof which made it impossible to dismantle the tube well completely. Some households had a submerged electrical water pump, it was impossible to determine the depth of these wells. The owners were asked to indicate the depth, but this was often an approximation. Therefore, the number of useful data points is not equal to the number of tested tube wells.

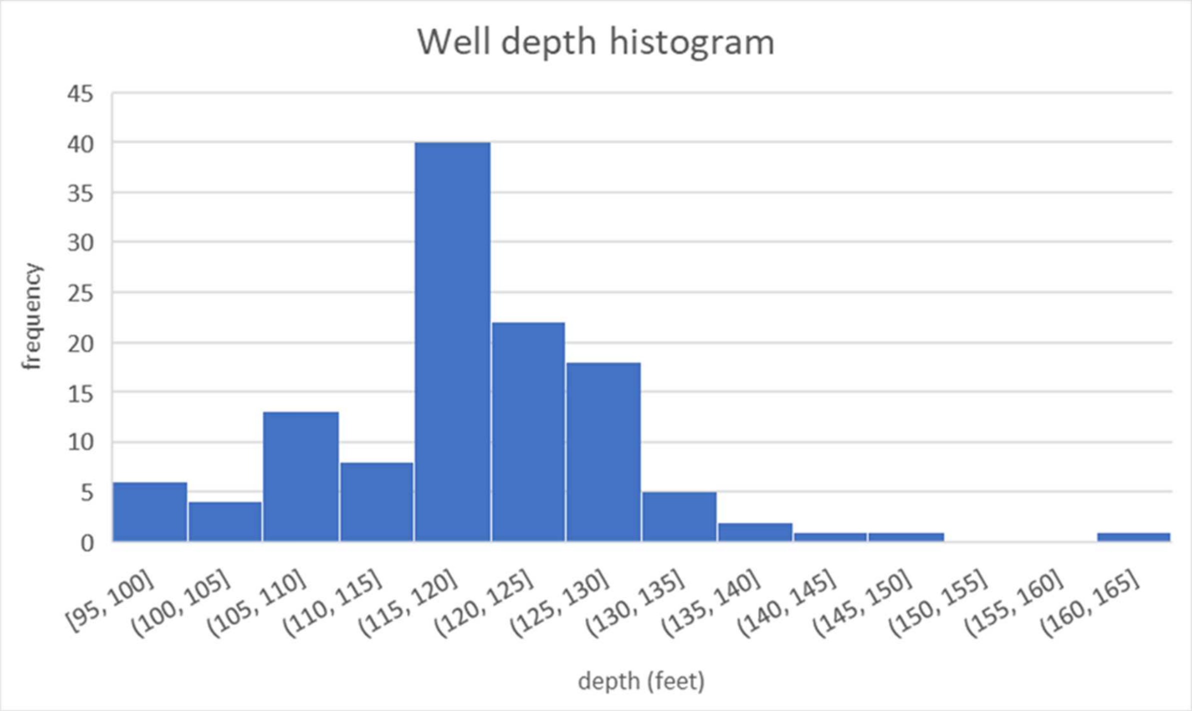


Figure 47. Histogram of well depths

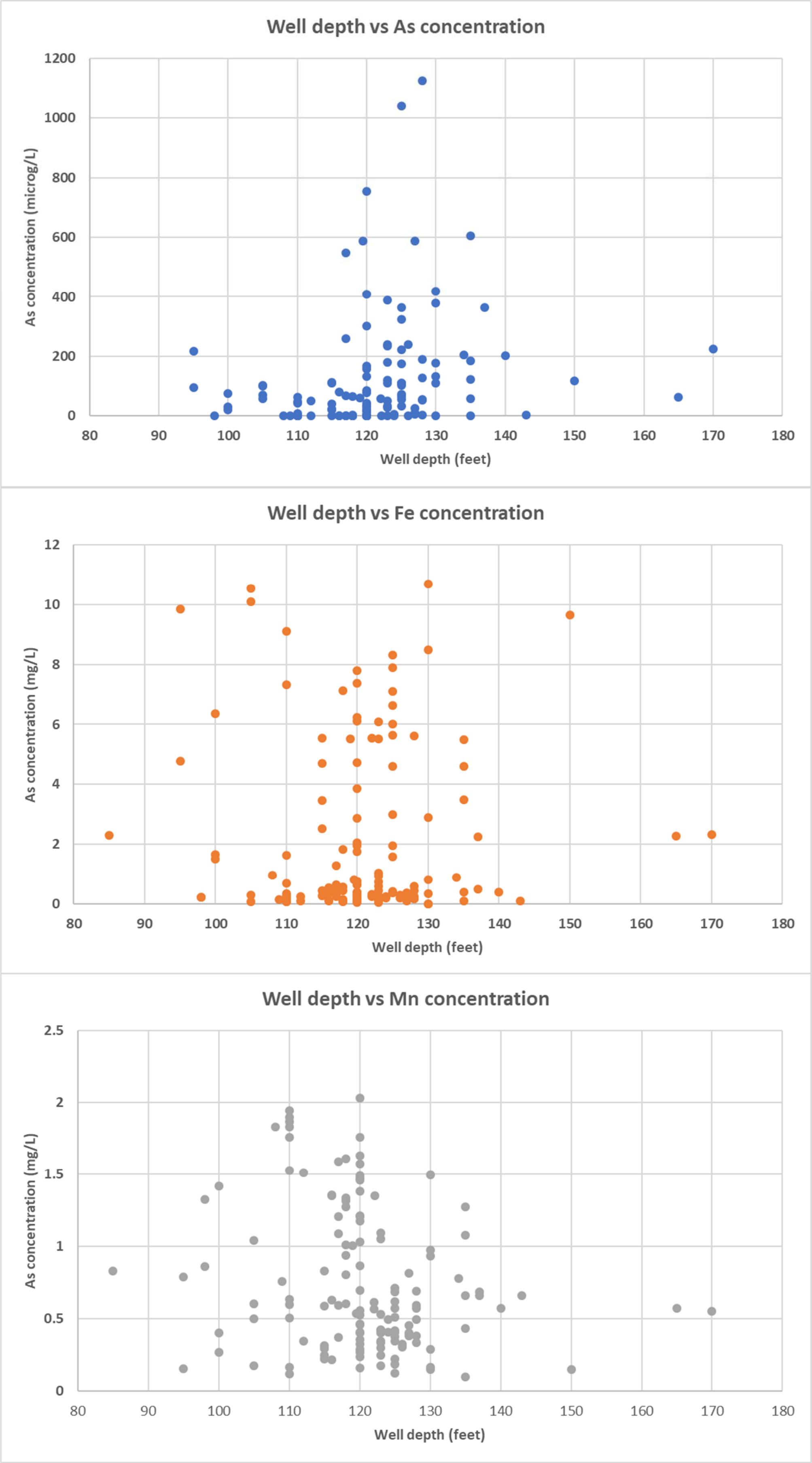


Figure 48. Well depths vs metal concentrations

7.3 Water treatment unit

The results of the constructed filter are explained in this section. First, the final set-up is presented. Secondly, the results of the performed water quality tests are addressed. Lastly, the water quality parameters of the produced safe water are compared to the WHO standards and recommendations about the set-up are provided.

7.3.1 Water treatment unit

This section will show the final construction of the water treatment unit and the general maintenance it needs.

Water treatment unit on site

In this section, the actual design of the water treatment unit in Uttar Kazirpara is presented, showing each part of it.

In this page the set-up of the hand pump and the installed electric pump are presented. The green pipes observed in that image connect the groundwater with the groundwater tank. Furthermore, a tap that provides raw water has been built to be used during the filter testing. Afterwards that tap can be used by the household for non-drinking water purposes. On the other hand, the hand pump is still functioning and can still be used by its owners.

Figure 49. The hand pump and the newly installed electric pump set-up

Figure 50. Groundwater tank image with the view of the sampling point

The previous page shows the groundwater tank that is installed in Uttar Kazirpara. On that picture it is possible to observe the small platform build in order to make the pipe connections and water extraction easier. Otherwise when the sampling was performed, there would be difficulties connecting the soft pipe. The sampling point in the groundwater tank (before the biocarriers column) is also depicted in that image. The valve of the sampling point as well as the soft pink pipe required to perform the sampling are shown.

The image in this page presents the groundwater tank from a different perspective. On the left side of the tank there the pipe has been placed that connects the electric pump and hence, the groundwater, with the groundwater tank. In the middle of the tank, two different pipes can be observed. The vertical one connected to the upper part of the tank, is used as the overflow outlet when the iron is being flushed from the tank. The other pipe, which is attached to the bottom of the groundwater tank, connects the stored groundwater with the aeration system of the water treatment unit. The vertical pipe the diverts from this pipe has been built to release the air from the pipe, which would block the flow of the water. The upper end of that pipe has a bend to prevent rain and other droppings from falling inside the tube.

Figure 51. Groundwater tank with the incoming water pipe on the left side and the outgoing water pipe on the middle of the tank

Figure 52. Aeration system

Figure 53. Biocarriers in the biocarriers column

The previous page depicts the aeration system of the water treatment unit installed in Uttar Kazirpara. A shower head with dripping structure has been installed to enhance the oxidation of iron and arsenic.

The image in this page shows the biocarriers as well as the overflow outlet of the biocarriers column.

The upper picture on the next page shows the sand and anthracite column, the supernatant water and the tube that connects the biocarriers column with the filter column. The backwash outlet can also be observed.

The lower picture on the next page depicts the resin columns in parallel installed at the water treatment unit as final security barrier to produce arsenic free water.

Figure 55.Sand and anthracite column

Figure 54. Resin columns

Figure 56. Set-up of the biocarriers column, the sand and anthracite column and the resin columns

Figure 57. View from the roof of the set-up

The previous page provides an overview of the first filter set-up, with the aeration system and the biocarriers column on the left side, and the sand and anthracite column as well as the resin columns on the right.

In this page the metal roof can be observed that has been constructed to protect the filters from the sun, rain and other droppings.

The following two pages show the set-up of the backwash for the biocarriers column and for the sand and anthracite column. The green tube connects the backwash valve to the columns.

Figure 58. Backwash set-up of the biocarriers column

Figure 59. Backwash set-up of the sand and anthracite column

Safe water production

An adequate flow rate in the aeration system is important to be able to produce enough filtered water and water of good quality. The flow rate of the water treatment unit has been established as 25L/h, which enables to produce 600L/day. Because at the start of the project the aim was to supply around 2000L/day, two more biocarriers columns and two more sand and anthracite columns have been installed to achieve that demand. Nevertheless, in the analysis of the chemical and physical properties of the water, only the first filter set-up unit has been taken into account. More tests and samples were taken on that first set-up than on the others, and therefore more relevant data has been obtained.

Water treatment unit maintenance

After all the tests have been performed, it has been discovered what would be the best maintenance schedule of the water treatment unit to obtain the best drinking water quality.

Regarding the groundwater tank, every time this one is filled, water needs to overflow for around 5 to 10 minutes to get rid of all the iron particles that have sunk to the bottom of the tank. When only the first set-up was installed, this procedure had to be done every two days. Afterwards, when the final water treatment unit with three biocarrier columns and three sand and anthracite columns are build, the iron flush must be done twice a day, which is the necessary frequency to fill the tank to produce 2000L/day safe water.

The biocarriers and sand and anthracite columns require a backwash of at least twice a week. Due to the possible variance in iron and arsenic concentrations in the groundwater throughout the year, this cleaning frequency might vary. Therefore, it is important to keep monitoring the water quality of the filter at least once a week and observe the supernatant level of both columns. An increase in the water level might indicate clogging of the filter and hence, backwash is required.

Furthermore, monitoring the quality of the water after the resin column is relevant to ensure the complete arsenic removal up to the European drinking water standards. Little reduction of arsenic or even increase of arsenic (V) after the resin column indicates a saturation of the ion exchange. When this occurs, the resin must be regenerated with the use of sodium chloride and distilled water.

7.3.2 Changes of the parameters throughout the water treatment unit

The most relevant changes in the physical and chemical parameters of the water tested throughout the water treatment unit are presented in this section. Nevertheless, the entire results of the arsenic, iron and physical parameters tests are provided in Appendix X.

For this prototype, other relevant drinking water parameters such ammonium, manganese and nitrate are not tested because the primary objective of the water treatment unit is to remove arsenic with the presence of iron.

Notice that on the 9th and 10th of August the measurements were done wrongly on the following sampling points: After anthracite, after sand filter and after resin. The water head was not maintained and hence the water tested did not have the necessary residence time to be properly filtered. This mistake might have affected the physical parameters as well as the arsenic and iron concentrations.

In Table 14 below the main events that occurred during the sampling and testing period are presented.

Table 14. Schedule of events regarding the filter

Date	Event
13th of August	Backwash of the biocarriers and sand and anthracite columns.
17th of August	Backwash of the biocarriers and sand and anthracite columns.
19th of August	Installation of the 2 resin columns in parallel and use of new resin that was not saturated.
24th of August	Backwash of the biocarriers and sand and anthracite columns.
27th of August	Complete clean-up of the biocarriers column and strong backwash of the sand and anthracite column, with two backwash inlet points.

Physical parameters

The physical parameters studied are pH, dissolved oxygen (DO), electrical conductivity (EC), oxygen reduction potential (ORP) and temperature. The results of the measurements are presented below.

pH

The pH values obtained with the multimeter are certainly constant throughout the days for each sampling point. Furthermore, the pH is stable throughout the water treatment unit, with barely any changes.

The values of the pH range between 6.8 and 7.5 for all the days and all the sampling points.

The larger pH differences occur after the aeration system of the biocarriers and after the aeration of the sand and anthracite column. Nevertheless, that difference is in the order of one decimal.

Dissolved oxygen

The dissolved oxygen values obtained with the multimeter provide consistent results all the days for most of the sampling points. Nevertheless, the dissolved oxygen concentrations after the sand filter and after the resin column vary substantially throughout the days that it was measured. After the sand filter, values range between 0,1 mg/L on the 17th of August, up to 6,3 mg/L on the 13th of August. After the resin column, values range between 0 mg/L on the 17th of August up to 5,5 mg/L on the 10th of August. The cause of this differences in a certain point throughout the days might be due to not waiting long enough till the dissolved oxygen value on the multimeter was stabilised. Therefore, for further correct measurements enough time should be spent on the dissolved oxygen measurement, up to the stabilization of the concentration in the multimeter.

Electrical conductivity

The electrical conductivity values obtained with the multimeter are substantially constant throughout the days for each sampling point. Furthermore, the EC is stable throughout the water treatment unit, with barely no changes.

The values of the electrical conductivity are around 660 µS/cm in all the sampling point for each day tests were carried out.

Oxygen reduction potential

The oxygen reduction potential values are for most of the sampling points unstable, with different values for every day that ORP was measured. Therefore, few conclusions can be extracted from this physical parameter.

The main remark that can be obtained from the ORP values is that in the groundwater this property is negative due to the anaerobic conditions of the water. In the groundwater tank, when the tank is fully filled the oxygen reduction potential is negative as well, due to the lack of oxygen. Nevertheless, when the tank is not completely filled with water, oxygen is present and hence the oxygen reduction potential has positive values. After aeration oxygen is present in the water and hence, the oxygen reduction potential is positive in all the posterior sampling points.

More accurate devices should be used in order to obtain precise values of the oxygen reduction potential in every sampling point.

Temperature

The temperature in each sampling point varies slightly throughout the water treatment unit and throughout the days. The coldest water is found in the groundwater, with temperatures around 27 ºC. Once the water is in the groundwater tank, the temperature increases. Although the tank has good heat isolation, some warming occurs. In the supernatant water of the biocarriers column, the temperature increases almost one degree compared to the water in the groundwater tank. Nevertheless, the water temperature decreases through the biocarriers column, in some cases up to one degree. There is no pattern on the temperature behaviour in the sand and anthracite column. Some days the temperature increases, whereas on others the temperature decreases slightly. Besides, the final safe water after the resin column has a stable temperature of around 29 – 30 ºC.

Arsenic

The arsenic concentrations in the water treatment unit were measured with the arsenic test kit when concentrations were larger than 100 μg/L, and with the arsenator when those were below 100 μg/L.

Table 15 to Table 17 present the total arsenic concentrations, the arsenic (III) concentrations and arsenic (V) concentrations for each date and each of the most relevant sampling points. The arsenic concentrations for all the sampling points measured can be found in Appendix X.

Table 15. Total arsenic concentrations

Arsenic concentrations (microg/L) (F) - Total Arsenic						
	Sampling Point					
Date	GW	BC	FB	AA	FS	AR
9/8/18	300	300	200		5	3
10/8/18						
13/8/18		400	200	100	70	0
14/8/18						
15/8/18				150	38	
16/8/18				150	110	53
17/8/18	450	400	200	200	100	63
18/8/18			130		80	70
19/8/18						4
25/8/18				100	100	84
27/8/18	450	250	200	200	200	92|76*
28/8/18		250	200-250	90	75	84|80*
29/8/18		250	100		82	50

*) The left number represents one single resin column and the right number the other resin column during the period the columns were installed in parallel.

Table 16. Arsenic (III) concentrations

Arsenic concentrations (microg/L) (FR) - Arsenic (III)						
	Sampling Point					
Date	GW	BC	FB	AA	FS	AR
9/8/18	200	150	40		9	3
10/8/18						
13/8/18		200	60	25	1	0
14/8/18						
15/8/18				13	5	
16/8/18				3	5	0
17/8/18	400	0	0		8	3
18/8/18			0		3	16
19/8/18						
25/8/18				8	6	13
27/8/18	350	0	0	0	0	0
28/8/18		0.05	0	0	0	0
29/8/18		30	0		3	1

Table 17. Arsenic (V) concentrations

Arsenic concentrations (microg/L) - Arsenic (V)						
	Sampling Point					
Date	GW	BC	FB	AA	FS	AR
9/8/18	100	150	160		-4	0
10/8/18						
13/8/18		200	140	75	69	0
14/8/18						
15/8/18				137	33	
16/8/18				147	105	53
17/8/18	50	400	200	200	92	60
18/8/18			130		77	54
19/8/18						4
25/8/18				92	94	71
27/8/18	100	250	200	200	200	92|76
28/8/18		249.95	200-250	90	75	84|80
29/8/18		220	200-251		79	49

*) The left number represents one single resin column and the right number the other resin column during the period the columns were installed in parallel.

Notice that although arsenic (V) concentrations in each sampling point are measured, it is not possible to find the fraction of the arsenic (V) that is being oxidized and the fraction that is being removed in each element of the water treatment unit.

Groundwater arsenic concentration

The groundwater in the tube well where the water is extracted to be treated by the filter has large arsenic concentrations, of around 400 µg/L according to the onsite strip test. But according to ICP-MS testing report, obtained from the water quality fieldwork (see Appendix VIII) this groundwater source contains 223 µg/L total arsenic. The discrepancy in the arsenic concentration values might be caused by to lack of proper sampling processes. Nevertheless, all the results commented in the water treatment unit consider only strip and arsenator test, and not the ICP-MS data.

Most of the arsenic found in the groundwater is arsenic (III), nevertheless there is few arsenic (V). The arsenic (III) concentration in the groundwater tank is less than the raw groundwater. This reduction occurs due to the oxidation of arsenic (III) into arsenic (V). The 17th of August the arsenic (III) concentration was zero because the groundwater tank was half full, and therefore all the arsenic completely oxidized into arsenic (V).

Arsenic removal through the biocarriers column

When the groundwater is aerated and flows through the biocarriers column, the total arsenic concentration is reduced to half of the arsenic concentration in the groundwater. The arsenic concentration removal produced by the biocarriers is really stable, reducing almost every day that measurements were done 200 µg/L concentrations of total arsenic. This removal can be explained by the fact that the total arsenic was measured after filtering and therefore, all the arsenic flocs coupled with iron had been removed before the tests were performed. Therefore, of the 400 µg/L total arsenic, 200 µg/L had already coupled with iron (III) and formed flocs.

It can be observed that after the backwash performed on the 17th of August, more total arsenic was reduced. The effect of the backwash on the 13th of August cannot be observed in the data, because arsenic was not measured in that sampling point after four days after, when backwash was again required.

Furthermore, large part of the arsenic (III) of the groundwater is oxidized into arsenic (V) because if the presence of the arsenic oxidizing bacteria. This result supports the total arsenic reduction of up to 200 µg/L. Most of the arsenic (III) is oxidized into arsenic (V) and hence, it has coupled with the iron (III), forming flocs that can be removed through filtration.

Arsenic removal through the anthracite bed

The anthracite results are inconclusive due to the lack of relevant data. Only three days (13th, 17th and 27th of August) arsenic concentrations were tested after the biocarriers column and after the anthracite sand bed. Furthermore, the 17th and 27th of August backwash was required and hence, the anthracite did not reduce the arsenic concentration due to the clogging of the filter bed. On the other hand, the 13th of August the anthracite bed was capable to reduce from 200 µg/L to 100 µg/L the arsenic concentrations, besides having a bed of only 20 centimetres.

Furthermore, after the anthracite bed, most of the total arsenic is arsenic (V), which can be coupled with iron and filtered in the sand filter later on.

Due to the decline of the safe water produced by the water treatment unit after the 25th of August, the 27th of August an intensive cleaning of the system was made in order to improve its efficiency. More information on the tests and results of the 27th of August can be found further in this section.

Arsenic removal through the sand bed

The sand bed reduces the total arsenic concentrations with a large variability depending on the measured day. The 13th and 16th of August the removal is only 30 – 40 µg/L. On the other hand, the 15th and 17th of August the arsenic removal exceeds 100 µg/L arsenic. The 25th and 27th of August there was no removal of arsenic through the sand filter.

Besides, the arsenic (III) concentrations also vary throughout the sand bed. The 13th of August the arsenic (III) concentrations reduced by 24 µg/L, whereas the 15th they reduced by 8 µg/L. The 16th of August the data obtained indicates that whereas the arsenic (III) after the anthracite layer was 3 µg/L, after the sand filter the arsenic (III) was 5 µg/L. An error during the arsenic test must have occurred that leads to this result. The 25th of August only 2 µg/L reduced throughout the sand filter bed. On the other hand, the 27th of August all the arsenic was already arsenic (V) and therefore, there was no arsenic (III) in the sand filter.

Most of the total arsenic measured after the sand filter is arsenic (V), which can be adsorbed by the resin column afterwards.

After backwash was performed the 13th and 17th of August, more arsenic removal occurred in the sand bed. Nevertheless, that reduction was not excessively significant, reducing between 20 and 35 μg/L.

After the 17th of August the water leaving the sand filter had large concentrations of total arsenic, most of the times larger than 100 μg/L. Because of those large concentrations and the complete non-removal of arsenic after the 25th of August, the 27th of August it was decided to check more into detail the water treatment unit in each of the sampling points to find the reason for that decline in the filter performance. More information on the tests and results of the 27th of August can be found further in this section.

Arsenic reduction through the ion exchange resin

The potential of the resin column to reduce arsenic shows good effectiveness during the tests of the first weeks. Around 60 μg/L is reduced almost every day measurements were taken. Nevertheless, the 18th of August almost no reduction was produced, and even arsenic (III) increased after the resin column. The release of arsenic (III) by the resin column might indicate that the resin was saturated and hence, its regeneration is needed.

In order to improve the results of the resin, the 19th of August the resin column was replaced by two resin columns in parallel. Resin produces resistance to the water to flow and hence, less water can go through the column. Therefore, placing two resin columns in parallel helps to overcome that flow reduction.

After the replacement of the 19th and the change of the saturated resin by new resin, the arsenic concentration of the water reduced up to the European drinking water standards, with 4 μg/L. However, one week later the results showed almost no arsenic (V) reduction, which might indicate that the resin started to saturate again, due to the high arsenic concentrations after the sand filter.

As it has been mentioned before, due to the decline of the safe water produced by the water treatment unit after the 25th of August, the 27th of August an intensive cleaning of the system was made in order to improve its efficiency. More information on the tests and results of the 27th of August can be found in further in this section.

Iron

The iron concentrations in the water treatment unit were measured with the Hach total iron test. Visual interpretation of the test strip was used to obtain results because the smartphones were not always available in the field.

Table 18 presents the total iron concentrations after filtering, for each date and each of the most relevant sampling points. The iron concentrations for all the sampling points measured can be found in Appendix X.

Table 18. Iron concentrations

Iron concentrations (mg/L) (F)						
	Sampling Point					
Date	GW	BC	FB	AA	FS	AR
9/8/18	1.9	0.84	0.1		0.05	0
10/8/18						
13/8/18		1	0.01	0	0	0
14/8/18						
15/8/18				0.03	0	
16/8/18				0	0	0
17/8/18	1	0	0	0.05	0	0
18/8/18			0		0.02	0
19/8/18						
25/8/18					0	0
27/8/18	1	0	0	0	0	0
28/8/18		0	0	0	0	0
29/8/18		0.21	0	0		0

Iron groundwater concentration

The iron concentrations of the groundwater after performing the Hach total iron test are large, with 1.9 mg/L the 9th of August and 1 mg/L the 17th of August.

The location of the filter was chosen because previous research showed that the groundwater had more than 3.5 mg/L of iron. Nevertheless, the results obtained with the Hach total iron test show that the groundwater has much less iron concentration than expected. The previous research on which the choice of the location was based had different results than the ones obtained now in the same tube well. This difference might be due to the fact that the iron tests were carried out in a different season, and iron concentration in the groundwater might differ throughout the year.

Furthermore, the water quality fieldwork also tested the tube well where the water treatment unit is installed (see Appendix VIII), and the data obtained from the ICP-MS results also provides lower total iron concentrations than the values provided by the previous research. The iron concentration of the ICP-MS in this groundwater source is 2.3 mg/L.

Iron reduction through the filter unit

After the aeration system, the iron concentrations after filtering are almost 0 mg/L for every day in each sampling point.

Those concentrations are 0 mg/L because after aeration all the iron has been oxidized into iron (III) and has formed flocs. When the water was analysed, it was done after filtering the water and hence, the flocs were removed and not included in the test. If the tests would have been done without filtration, probably the iron values would not have been zero at least until after the sand filter, when the iron flocs would have been removed by rapid filtration.

Results of the 27th of August

The 27th of August more comprehensive tests were done. The reason to carry out a detailed check of the water treatment unit was because it stopped working properly and producing arsenic free water. Therefore, in order to find the cause for that deterioration of the unit performance, total arsenic and arsenic (III) were measured in each of the key sampling points, as well as total iron and filtered iron.

Figure 60 provides the results for the tests done in each sampling point.

The first observation that can be done is that because the groundwater tank was not completely full, and the water remained stagnant for a couple of days, both, arsenic as well as iron oxidized into arsenic (V) and iron (III) respectively.

Furthermore, the sand and anthracite column did not remove any arsenic. On the other hand, the resin columns removed more than 100 μg/L. However, that was not enough to reach the European drinking water guidelines.

Besides, all the iron formed flocs after being stored in the groundwater tank. All the iron found in each of the sampling points afterwards is present as flocs. Nevertheless, it can be observed that the total iron concentration in the groundwater tank is less than after the biocarriers column. Therefore, the iron concentration increases after the biocarriers column. When the water flows through the anthracite bed a reduction of the iron occurs, and hence there is removal of the iron flocs by the anthracite. However, through the sand bed the iron concentrations increase, following a similar pattern as the one observed in the biocarriers column.

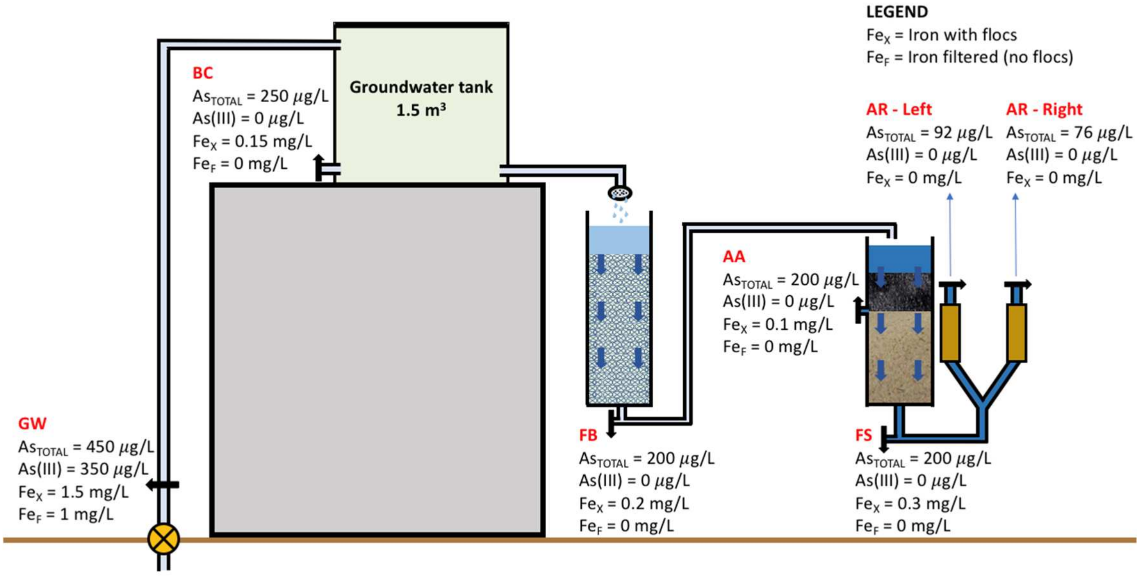


Figure 60. Diagram of the arsenic and iron concentrations in the water treatment unit the 27th of August

Several conclusions can be taken from the results mentioned above. The first conclusion is that the iron concentrations after each column increase with respect to the iron concentrations before the columns. This rise of iron is caused by the clogging of the net at the bottom of each column, which prevents the biocarriers and the sand from leaving the column through the outlet. Therefore, the 27th of August the biocarriers column was emptied and cleaned completely to unclog its bottom. Large amount of iron flocs were observed clogging the entire net and bottom of the column. In order to backwash the sand and anthracite column, an intensive backwash was performed. First, the normal backwash was carried out, together with a backwash through a different valve using an extra pump in order to provide larger flow that could clean the sand and anthracite beds. Afterwards, backwash through the valve located after the anthracite bed was done as well. From these results it has been concluded that the backwash applied until that day had not been enough and a change in the backwash procedure had to be done from then on. More details about recommendations for the improvement of the backwash are provided in Section 7.3.4.

The second conclusion that can be observed when analysing the results of the 27th of August is the fact that there might be enough iron flocs in both, the biocarriers column and the sand and anthracite column to couple with the arsenic (V). Nevertheless, arsenic is not being removed. A reason for this result could be that arsenic and iron do not have enough time to couple in the filter and hence, arsenic (V) is leaving the water treatment unit in a diluted state. Therefore, a solution for this problem could be to increase the residence time of the water in the filter. The 28th of August the flow rate of the water treatment unit was reduced to 8 L/h. Notice that the flow rate established beforehand was calculated taking into account the amount of water that it was wished to supply, and not on the amount of time iron flocs and arsenic require to couple. As far as our knowledge arrives, there are no studies that provide a guidance on the flow rate that is required.

The last conclusion that can be extracted from the tests on the 27th of August is that the resins columns remove large amounts of arsenic (V). Nevertheless, those are not enough to achieve the European drinking water standards because of the high arsenic levels after the sand filter.

Intensive backwash of the biocarriers and the sand and anthracite columns

As it has been mentioned above, the 27th of August a deep cleaning of the columns was made. The figure depicted below provides the results for the tests done in each sampling point the 28th of August.

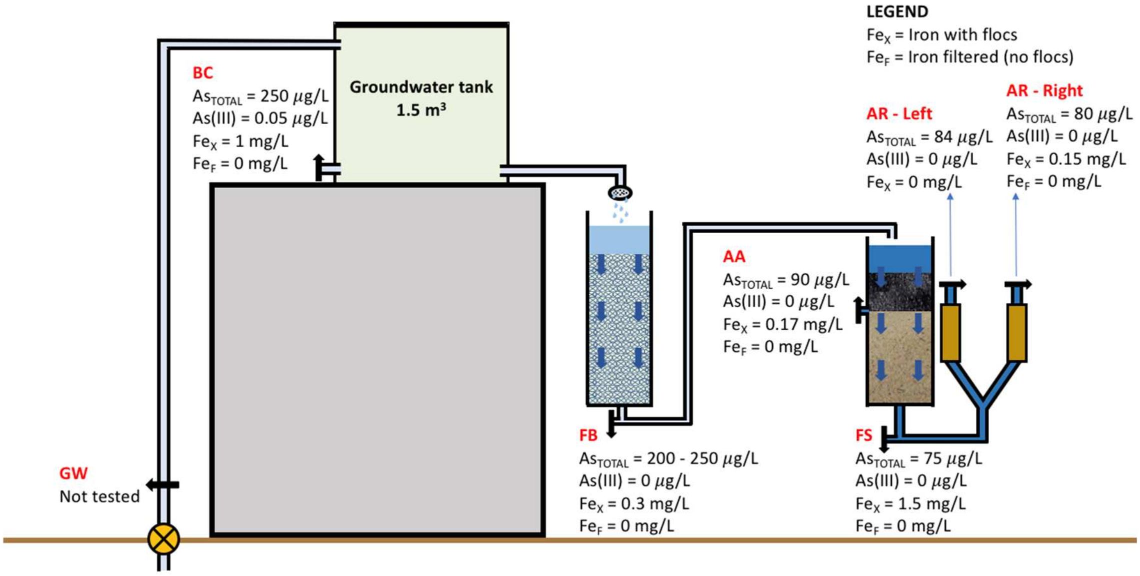


Figure 61.Diagram of the arsenic and iron concentrations in the water treatment unit the 28th of August

The 28th of August the groundwater tank was refilled completely and overflown. In the sampling point before the biocarriers, therefore, it can be observed an increase on the amount of total iron. Nevertheless, iron is still completely oxidized in the tank and in a floc shape. Furthermore, almost all arsenic found is arsenic (V). Therefore, a solution to increase the amount of iron in the biocarriers column and sand and anthracite column would be to reduce the size of the groundwater tank or increase the refill frequency of the tank, so that iron has no time to settle on the bottom of the tank.

After the cleaning of the biocarriers column, there is a slight increase of 0.1mg/L total iron with respect to the 27th of August. The cause of this behaviour change could be the unclogging of the net located at the bottom of the column. After the net is unclogged, more iron flocs can flow to the sand and anthracite column, and hence, more arsenic can couple with the flocs to be removed in the filter. Furthermore, the total iron concentrations reduced throughout the biocarriers column up to 0.7mg/L.

The backwash of the anthracite seems to have worked as well. Before the backwash had been done, no arsenic was removed by anthracite. However, on the 28th of August anthracite removed 110 µg/L.

On the other hand, the sand filter did not improve its performance significantly. Before the backwash no arsenic removal occurred. Afterwards, only 15 µg/L were filtered. Furthermore, iron flocs concentrations throughout the sand filter increased substantially, up to 1.5mg/L after the column. This result might mean that the backwash done the 27th of August was not sufficient for the sand bed and hence, a more intensive backwash might be required.

Besides, the resin performance declined up to the point that more arsenic (V) was released by the resin column than it was released by the sand and anthracite column. Hence, the resin showed variable results throughout the days. Therefore, an analysis of the capacity of the resin might be interesting, to discover how much arsenic concentrations the resin can adsorb before being saturated. Furthermore, the study of the flow behaviour, such as plug flow, inside the resin column would as well provide interesting insight that could improve the performance of the water treatment unit.

Increase of the residence time

As it has been mentioned above, the 28th of August the residence time of the water treatment unit was increased, in order to find out a solution to improve the sand filter performance. A flow rate of 8 L/h was established to analyse whether the arsenic removal increased once the iron and arsenic had more time to couple in the filter.

Figure 62 shows results for the tests done in each sampling point the 29th of August, the day after changing the residence time.

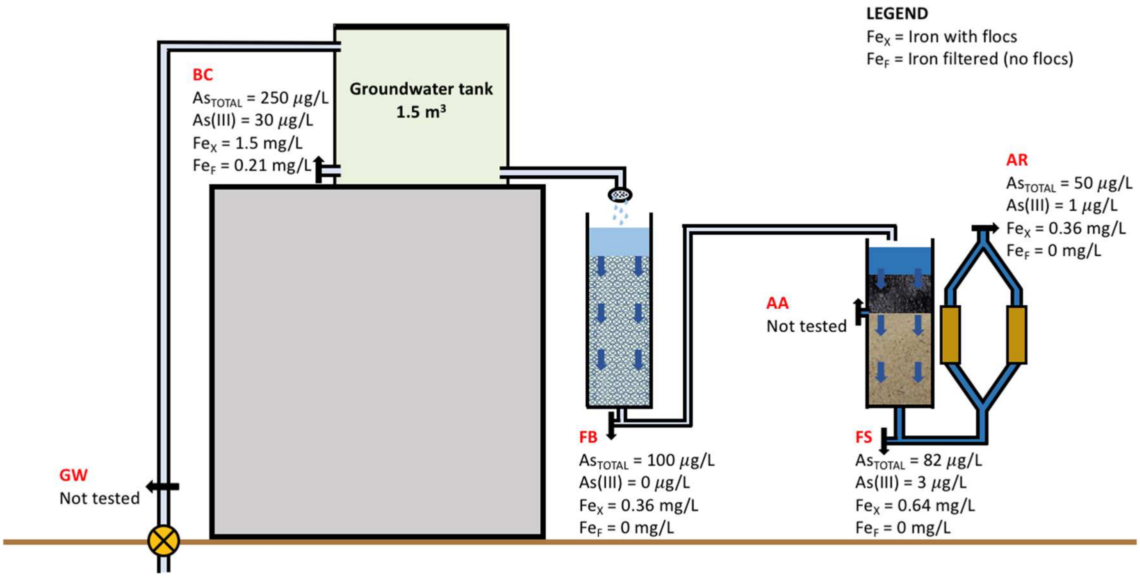


Figure 62. Diagram of the arsenic and iron concentrations in the water treatment unit the 29th of August

The increase of residence time might have had a good effect on the arsenic coupling with iron in the biocarriers column. Between 100 and 150 μg/L more arsenic was coupled with iron on the 29th of August than on the 28th of August. Therefore, the increase in residence time let more time for the arsenic and iron to couple together, and the measure taken was effective. It can also be observed that when comparing total arsenic concentrations and total iron concentrations between the sampling point *Before Column* and the sampling point after *Filter Biocarriers*, both elements reduced substantially, which supports the theory that longer residence time can lead to more iron and arsenic flocculation.

On the other hand, the sand and anthracite filter did not reduce significantly the arsenic concentration, and even iron concentrations increased after the column. This can indicate that the sand filter must still be clogged, and a more intensive backwash is required to improve its performance.

Besides, the resin columns remove on the 29th of August 30 μg/L arsenic. Nevertheless, the previous day more arsenic was released by the resin column than by the sand and anthracite column and therefore if could be concluded that the resin might not be saturated, as it was thought previously. However, this result shows the instability and fluctuation of the resin performance, which requires further studies to evaluate whether there is plug flow inside the column or other possible issues. Further analysis should be done in order to improve and keep constant the resin efficiency.

7.3.3 Comparison of the treated water with the drinking water standards of WHO.

The World Health Organisation has established the *Guidelines for drinking-water quality*. Those guidelines include the health targets drinking water must achieve as well as the safety plans to ensure the safety of drinking water supply. Furthermore, the microbial, chemical, radiological and acceptability aspects drinking water must have are provided as well (WHO, 2017).

Certain parameters have been considered of more relevance in the construction of the water treatment unit and must fulfil the WHO guidelines. Arsenic is hazardous for the health of the villagers and hence, this element has been of large interest in the final drinking water produced in Uttar Kazirpara. Furthermore, iron is an important element for the acceptability. Large concentrations of iron can be tasted in the water and hence, consumers can refuse to drink it. pH is one of the most important operational water quality parameters and therefore, its values must be within the WHO guidelines (WHO, 2017).

Arsenic

The water treatment unit designed in Uttar Kazirpara produced safe arsenic water that fulfilled the WHO drinking water standards during the first days of functioning. Nevertheless, after the 16th of August the arsenic concentrations rose, and only one day the values did not exceed the 10 µg/L, which is the guideline of WHO for arsenic concentrations in drinking water.

Iron

The treated water in Uttar Kazirpara after the resin column in non-filtered conditions contains no iron (iron concentration is 0mg/L). Therefore, all the iron is being removed and no taste or rust-coloured problems occur.

pH

The pH value of the treated water in Uttar Kazirpara is on average 7.3. Therefore, the pH of the water is within the optimal values for drinking water.

Dissolved oxygen

The dissolved oxygen measured in the treated water of Uttar Kazirpara is not stable and has a large range of values. As it has been previously mentioned, this is due to the wrong measurement procedure with the multimeter. Nevertheless, WHO has no health-based guideline recommended. Therefore, dissolved oxygen has not been proven to be hazardous for human health, and any value is acceptable for drinking water.

Electrical conductivity

Electrical conductivity is not mentioned in the *Guidelines for drinking-water quality* of WHO and hence, there are no reference values that indicate whether the electrical conductivity of around 660 µS/cm has a negative effect on the quality of the drinking water.

Oxygen reduction potential

Oxygen reduction potential is not mentioned in the *Guidelines for drinking-water quality* of WHO and hence, there are no reference values that indicate whether the measured ORP values have a negative effect on the quality of the drinking water. Nevertheless, as it has been mentioned before, the values obtained in the field work are not constant and therefore, it is not possible to consider an average or a single value as the actual ORP of the treated water.

Temperature

The average temperature measured in the treated water of Uttar Kazirpara is of 29.5ºC. WHO has no health-based guideline recommended for temperature and therefore, any value is acceptable for drinking water. Nevertheless, it should be noticed that high water temperatures enhance the bacteria growth as well as the chances of taste, odour, colour and corrosion problems (WHO, 2017).

Other water quality parameters

The most relevant properties for the water quality of this project have been analysed on the treated water produced in Uttar Kazirpara as well as in other sampling points of the water treatment unit. Nevertheless, more parameters of importance should be measured.

Among the water quality elements that were not able to be analysed in the field, manganese is of more relevance. The manganese test used in the field did not work properly and hence, could not be used. However, all the samples taken in Uttar Kazirpara are taken to Delft University of Technology to be lately tested. Therefore, the manganese values of the treated water will be obtained once the ICPMS is performed.

Besides, during the sampling stage of the water treatment unit a microbial test was performed, and no microbial community was found in the water.

7.3.4 Future modifications of the water treatment unit

After considering all the results and entire water treatment unit functioning, some recommendations are provided for better performance of the filtration unit.

First of all, the diameters of the backwash valves for both, the biocarrier and the sand and anthracite column should be increased. Nowadays, with the actual valves size it has been observed from the iron and arsenic results that the maximum backwash that can be provided is not enough, and therefore clogging is occurring in both columns. Therefore, larger diameters would help the system to increase the backwash flow and the required fluidization of the bed, especially for the sand and anthracite column. The expansion of the sand layer obtained on the 27th of August is in the order of 3 cm. However, for rapid sand filters the expansion bed should be 10 – 20% of the total bed height (Sincero & Sincero, 2002), which in the case of the water treatment unit in Uttar Kazirpara should be between 6 and 12 cm. Hence, a higher backwash velocity provided by valves with larger diameter can ensure proper cleaning of the filter bed. This improvement of the backwash could enhance the performance of the biocarriers and the sand and anthracite and raise the rate of arsenic and iron removal.

Another option to improve the cleaning of the clogging on the sand and anthracite column would be, instead of changing the valve for the backwash, to replace the column which currently has twenty centimetres diameter, by two columns in parallel, each with ten centimetres diameter. By replacing the single column by two thinner columns the weight of the sand bed would reduce to half and hence, the actual backwash flow rate would be enough to achieve the required bed expansion and completely unclog the filter.

Besides, the analysis of the resin performance should be analysed more in depth, and the placement of the two resin columns in parallel instead of in series should be further studied to observe whether the change of set-up structure would improve the arsenic removal by the resin column.

Moreover, it has been observed on the results that the decrease of the flow rate in the aeration system improves the biofilm carrier column performance. However, the reduction of the water velocity throughout the filter means a reduction in the amount of water supplied. Therefore, a lower flow rate implies less safe water production. Nevertheless, the water supplied might have better quality than the actual treated water.

Regarding the sustainability of the unit, currently there is no system to collect the backwashed water from the columns and the water from the regeneration of the resin. The water is being directed towards a community pond situated on the outside of the household. Nevertheless, this is not an environmentally friendly and healthy measure. Therefore, a suitable system should be developed in order to collect the water and dispose it in a sustainable manner.

According to the final objective of the project to deliver safe water to the community of Uttar Kazirpara, the water treatment unit should run for longer time until the results are stable and comply the WHO standards for drinking water quality. Once this requirement is fulfilled, the water treated by the three separate filtration set-ups must be connected to the safe water tank, to store the water. A tap must be built on a communal area, to be able to distribute the safe water to the people of the village.

Finally, nowadays the total set-up with the three biocarriers and the sand and anthracite columns as well as with the resin columns are already installed. Therefore, the operator should keep up with the monitoring and maintenance of the entire system properly.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8. Discussion

In this chapter the general outcomes of Project Bangla will be discussed. The results of the three parts of the project have been discussed in their corresponding results chapters. First, the conducted water quality fieldwork and the data collection and the possible errors involved will be discussed. Secondly, the potential of the water treatment unit will be addressed.

8.1 Fieldwork and data collection

During fieldwork the conditions are different than in the laboratory since social, cultural and climatic factors have large influence on the execution of the fieldwork. Therefore, fieldwork demands a solid preparation, improvisation and flexibility of the researchers. Two climatic conditions in Bangladesh influencing the fieldwork execution and results are the high temperature and humidity. Most of the used strip tests in the water quality fieldwork were not designed for these conditions which could have led to deviating results.

Proper data collection is absolutely important for conducting scientific research. However mainly social factors have had influence on the process of data collection. It was planned to have spatially homogeneous and random tube well samples in the water quality fieldwork. Nevertheless, plumbers supporting our research arranged the tested households. Since the plumbers were villagers, it is likely that they only selected households they were familiar with. Unfortunately, only the last day of the water quality fieldwork the project team managed to pick locations for the sake of homogeneously and randomness.

Furthermore, the data of the water quality fieldwork was not gathered by the person actually analysing it. In this way, some valuable insights about the fieldwork are easily lost and the data is less trustable. Moreover, it was more challenging to explain and correct gaps and outliers in the dataset. The data collection of the performance of the water treatment unit is also missing some important values at certain days due to different researchers executing the tests in the field.

Also measurement equipment did not always perform as it should. In the water quality fieldwork, the multimeters did not provide realistic results. Moreover, the bad performance of the strip tests used for manganese, ammonium and pH could have been avoided by more laboratory studies. The results of the water treatment unit are mainly obtained with strip tests. Even though this study has proven that these tests perform well, outliers might have occurred, influencing the analysis of the water treatment unit.

Another part of discussion regarding data collection is the quality of the samples taken. In the data analysis of the water quality fieldwork, it is assumed that the ICP-MS results are reliable. However, incorrect sampling could have led to errors in these results and therefore in the final results of this research.

8.2 Water treatment unit location

As mentioned in Section 6.4.1, the location of the water treatment unit was selected on specific criteria. However, after implementation of the system, the location could be reconsidered. For the research purposes of this set-up, the location is suitable. However, a higher iron concentration in the groundwater could probably improve the performance of the filters in removing arsenic.

Another interesting consideration of drinking water distribution is related to the ethical concerns. First, the location of the water treatment unit is inside a household courtyard. Because this is not a communal site, problems could occur with unfair distribution of the water. However, after analysing the behaviour of the household and the relations with other villagers, it is expected that no problems will occur related to social issues once the safe water supply starts. Secondly, it should be ensured that the water produced by this water treatment facility is safe, accepted by its end-users and a good solution for the current drinking water problems in the village. Currently, the produced drinking water is not safe for distribution. It is extremely important to achieve a stable safe water quality to obtain acceptance and trust by DPHE and the end-users. It should be noted that arsenic contamination in Uttar Kazirpara is extremely large. Therefore, a water treatment unit like the one designed in this project could possibly be an effective solution. However, other villages suffer less from arsenic contamination. At these locations it should be considered whether the effort and costs to design a complete water treatment system results in significant improvement of the drinking water quality.

Currently, the water treatment unit is built for research purposes also considering potential drinking water distribution among the villagers. A central tap-point outside the courtyard will be connected to the safe water tank inside the household. The household is located at a central point in the highly contaminated part of village, next to the main pond used for bathing, swimming and cleaning. The nearest safe alternative source in a public place is around 120 meters from the location of the treatment set-up. One could argue that it is close enough to retrieve the safe drinking water. Nonetheless, for the villagers living in the western part of Uttar Kazirpara the nearest safe source is located at around 300 meters. The distance to the safe water source should be limited so that the villagers are eager to make the effort to fetch water from the communal tap. When the water treatment unit is accepted and trusted by the villagers, the willingness to collect the water from the tap will increase leading to higher acceptance for larger distances to collect safe water. There is however one drawback of a communal tap point. From social surveys executed in the village, it could be concluded that many women do not leave their houses. Therefore, it is desired to construct a distribution system in the future to overcome this cultural challenge.

9. Conclusion and recommendations

Project Bangla aimed to obtain more insight in the main pillars of the DELTAP project. The geology is studied for safe source selection, a water treatment unit is designed, build and extensively monitored. Moreover, the opportunity for smartphones as a water quality monitoring tool is examined.

The goal of the geology focussed part of the research was to find a relationship between the arsenic pollution in the tube wells and the local geology. The drillings performed in the areas with high, medium and low arsenic contamination, showed similar results as expected from literature. In absence of the XRD and XRF analysis, the SASMIT tool has been used to determine the risk on arsenic pollution in a soil sample. From the comparison between the water quality results and the results of three drillings can be concluded that the SASMIT tool forms a useful tool in finding a suitable safe drinking water source in the research area. In other words, sediment colour forms a link between geological characteristics and arsenic levels in groundwater. More particularly, tube wells that are screened in aquifers containing reddish sand are a safe source in terms of arsenic concentration. Tube wells that are screened in aquifers containing white or off-white coloured sand are a risky source of drinking water. Tube wells screened in aquifers containing dark-coloured sand are not a safe source of drinking water. Moreover, no relation between geomorphological structures and arsenic levels in groundwater could be found. No geomorphological features could be identified in the fieldwork area.

For further research, more sophisticated drilling techniques like core sampling can be used. With these methods the resolution will increase, causing less missed layers and more geological features will be visualised. This, in combination with more drillings could establish the boundary conditions for a geological and groundwater flow model. Those models could be interesting to understand the different conditions in the aquifer more thoroughly. With those results, the arsenic contamination could possibly be predicted in the future.

Besides, mobile crowd participation is a promising theory to apply in the drinking water supply field in developing countries such as Bangladesh. From this study it can be concluded that the water quality app used (AKVO Caddisfly) performs well for both studied iron tests. However, due to an update of the app the arsenic test could not be executed using smartphones which indicates that the app is still prone to failures and should be further developed. Another goal of this research was to find possible relations between arsenic and other drinking water parameters in order to apply more simple and cheaper test kits in the end-user monitoring program. However, these relations have not been found. It is recommended to perform more analyses on the relations between arsenic and other water quality parameters as the arsenic test kit is expensive and not convenient to use.

It can be concluded that for now the AKVO Caddisfly app can only be used by the operator for monitoring the iron concentrations in the water treatment unit. In the future, the mobile application might be a useful tool in water quality monitoring applying the MCP principle. It is recommended to set-up a survey in AKVO Flow with all relevant tests and sampling points of the water treatment unit. This survey could be used by the operator to monitor and maintain the built system in a convenient way. Also, the manual provided attached to this report should be incorporated in the monitoring survey. In the far future, it is aimed to set-up an extensive survey on water quality monitoring through smartphones. Besides, other smartphone applications for payment and communication might be applied in implementing Mobile Crowd Participation.

A water treatment unit has been built in Uttar Kazirpara, a village close to the city of Rajshahi in Bangladesh. The aim of water treatment unit fieldwork was to construct a system which provides safe drinking water for 5 to 10 households. The entire system has been built. However, due to time constraints the distribution of safe water has not yet been possible. Continuous monitoring of the water quality for long time is required before distributing water to the community. Currently, the water quality does not meet the drinking water standards set by the WHO. Several recommendations on how to improve the performance of the water treatment unit set-up have been provided in Section 7.3.4. Those recommendations could lead to a production of safe drinking water within the guidelines of the WHO.

Nevertheless, after analysing the results in Section 7.3.4 it has been concluded that even when the treated water is safe and within the European drinking water standards, the maintenance of the water treatment unit requires large maintenance efforts and good knowledge of the water treatment processes in the filter.

In the future it is aimed to build small scaled water supply system around the whole Bangladesh. This first pilot set-up is very promising, and it has proven that the production of arsenic free water is possible. However, more research is required to improve both the system layout and its system performance, to continuously produce safe water.

All in all, the main pillars of the DELTAP project have been analysed extensively by Project Bangla. The data collected is very relevant for the theoretical studies in the DELTAP project. Moreover, the installation and recommended improvements of the water treatment unit is a great step forward in implementing small scaled water supply systems in Bangladesh.

10. Evaluation

In this chapter the project will be evaluated from the point of view of the group members. The group process, planning and communication will be discussed.

Overall the group cooperated well. The group was updated about each part of the project. Especially when the filter set-up performance declined, brain storming sessions were conducted by all the members together to find possible solutions. However, there is always room for improvement. Upfront of the project there could be a clearer discussion about the expectations of the project for every person. This would have resolved some minor issues during the project.

Due to serious sickness of two team members in the first two weeks, the construction of the filter had an unexpected delay. This delay was created mostly due to the fact that the other students had to fully focusses on the water quality fieldwork. Moreover, the construction of the columns took more time than expected. Partly, this was caused by the fact that the PhD student organizing the columns experienced illness as well. Also the different point of view of the workshops, which sometimes did not consider our demand as a priority, resulted in a later construction than expected of the filter elements. Moreover, due the Islamic holiday Eid-al-Adha there was no progress in the construction of the filter, extra columns and the fieldwork. Most Bangladeshi celebrate this holiday with their family across Bangladesh. Therefore, during the days around that holiday students were not able to work, and the workshops were closed. This was not foreseen while establishing the lanning. Due to all the issues mentioned above among others, the last week was still full of work on the filter set-up, while the goal of that week should have been to finalize the report.

Communication during this project was a challenge for the team. Almost none of the villagers in the research area are able to speak English, and this is also the case for most of the working people involved in the project. Even some of the students which are involved in the project did not have sufficient English knowledge. Since the Bengali students helping on the project sometimes did not fully understand the demands of the project, in more than one occasion the research did not end up in the way it was expected Furthermore, the language barrier made it very difficult for the group to take initiative in making arrangements and solving problems with the stakeholders. In this way the PhD student supervising the project had to arrange a lot of things which are normally done by the project group themselves.

Besides, communication was not only problematic according to language issues. Also cultural differences created some difficulties. For example, there was some resistance for working while it was raining. Furthermore, the Dutch direct communication was sometimes unfortunately difficult or insulting for the stakeholders. Another issue related to communication that made fieldwork progress as smooth as wish was related to the lack of compromise by some stakeholders, that did not deliver their promises.

Moreover, during the fieldwork we also experienced that different position of women in the Bangladeshi society. Women have to behave differently to man and strangers in general. Due to this fact, the communication and understanding of women opinions about several parts of the project was sometimes missed or misunderstood.

Throughout this project in Bangladesh, the project members have learned to adapt upon the sudden changes of circumstances and gained patience and communication skills.

11. Bibliography

Allison, M. A. (1998). Geologic framework and environmental status of the Ganges-Brahmaputra Delta. *Journal of Coastal Research*, 827-836.

Allison, M. A., Khan, S., Goodbred Jr, S. L., & Kuehl, S. A. (2003). Stratigraphic evolution of the late Holocene Ganges–Brahmaputra lower delta plain. *Sedimentary Geology, 155*(3-4), 317-342.

APECWater. (2018). Retrieved from https://www.freedrinkingwater.com/water_quality/quality1/1-how-dissolved-oxygen-affects-water-quality.htm

BGS, & DPHE. (2001). *Arsenic contamination of groundwater in Bangladesh*. Retrieved from Keyworth:

chem.libretext.com. (2018). Retrieved from https://chem.libretexts.org/

Donselaar, M. E., Bhatt, A. G., & Ghosh, A. K. (2017). On the relation between fluvio-deltaic flood basin geomorphology and the wide-spread occurrence of arsenic pollution in shallow aquifers. *Science of the total environment, 574*, 901-913.

Dowling, C. B., Poreda, R. J., Basu, A. R., Peters, S. L., & Aggarwal, P. K. (2002). Geochemical study of arsenic release mechanisms in the Bengal Basin groundwater. *Water Resources Research, 38*(9), 12-11-12-18.

DPHE. (2018). Water Quality Parameters Bangladesh Standards & WHO Guide Lines. Retrieved from https://www.dphe.gov.bd/index.php?option=com_content&view=article&id=125&Itemid=133

Dunea. (2018). Verschillende normen. Retrieved from https://www.dunea.nl/drinkwater/waterkwaliteit-en-samenstelling/verschillende-normen

EPC/MMP. (1991). *Dhaka Region Groundwater and Subsidence*

Study, Final Report. Dhaka: Engineering and Planning Consultants,

Sir M MacDonald and Partners, UK.

Esri. (2018). How inverse distance weighted interpolation works. Retrieved from http://pro.arcgis.com/en/pro-app/help/analysis/geostatistical-analyst/how-inverse-distance-weighted-interpolation-works.htm

Fazal, M. A., Kawachi, T., & Ichion, E. (2001). Validity of the latest research findings on causes of groundwater arsenic contamination in Bangladesh. *Water International, 26*(3), 380-389.

Fendorf, S., Michael, H. A., & van Geen, A. (2010). Spatial and temporal variations of groundwater arsenic in South and Southeast Asia. *Science, 328*(5982), 1123-1127.

GSMA. (2018). *Country Overview: Bangladesh*. Retrieved from GSMA Intelligence:

Gude, J., Rietveld, L., & van Halem, D. (2018). Biological As (III) oxidation in rapid sand filters. *Journal of Water Process Engineering, 21*, 107-115.

Halem, D., Bakker, S., Amy, G., & Van Dijk, J. (2009). Arsenic in drinking water: a worldwide water quality concern for water supply companies. *Drinking Water Engineering and Science, 2*(1), 29-34.

Halem, D. v., Bakker, S., Amy, G., & Van Dijk, J. (2009). Arsenic in drinking water: a worldwide water quality concern for water supply companies. *Drinking Water Engineering and Science, 2*(1), 29-34.

Harvey, C. F., Swartz, C. H., Badruzzaman, A., Keon-Blute, N., Yu, W., Ali, M. A., . . . Brabander, D. (2002). Arsenic mobility and groundwater extraction in Bangladesh. *Science, 298*(5598), 1602-1606.

Hossain, M., Bhattacharya, P., Frape, S. K., Jacks, G., Islam, M. M., Rahman, M. M., . . . Ahmed, K. M. (2014). Sediment color tool for targeting arsenic-safe aquifers for the installation of shallow drinking water tubewells. *Science of the Total Environment, 493*, 615-625.

Hossain, M., Bhattacharya, P., Jacks, G., von Brömssen, M., Ahmed, K. M., Hasan, M. A., & Frape, S. K. (2017). Sustainable arsenic mitigation–from field trials to implementation for control of arsenic in drinking water supplies in Bangladesh. In *Best Practice Guide on the Control of Arsenic in Drinking Water* (pp. 99-116): IWA Publishing UK.

IndiaMart. (2018). Retrieved from https://www.indiamart.com/proddetail/silica-sand-30-60-mesh-10266606888.html

Islam, S. N. (2016). Deltaic floodplains development and wetland ecosystems management in the Ganges–Brahmaputra–Meghna Rivers Delta in Bangladesh. *Sustainable Water Resources Management, 2*(3), 237-256. doi:10.1007/s40899-016-0047-6

Jahan, C. S., Islam, M. A., Mazumder, Q. H., Asaduzzaman, M., Islam, M. M., Islam, M. O., & Sultana, A. (2007). Evaluation of Depositional Environment and Aquifer Condition in Barind Area, Bangladesh Using Gamma Ray Well Log Data. *JOURNAL-GEOLOGICAL SOCIETY OF INDIA, 70*(6), 1070.

Khan, A., Mojumder, S. K., Kovats, S., & Vineis, P. (2008). Saline contamination of drinking water in Bangladesh. *Lancet, 371*(9610), 385.

Khan, A. E., Ireson, A., Kovats, S., Mojumder, S. K., Khusru, A., Rahman, A., & Vineis, P. (2011). Drinking water salinity and maternal health in coastal Bangladesh: implications of climate change. *Environmental health perspectives, 119*(9), 1328.

Lytle, D. A., Chen, A. S., Sorg, T. J., Phillips, S., & French, K. (2007). Microbial As (III) oxidation in water treatment plant filters. *Journal-American Water Works Association, 99*(12), 72-86.

Mink, A., Hoque, B. A., Khanam, S., & Van Halem, D. (Submitted for publication). *Mobile Crowd Participation to Root Small-scale Piped Water Supply Systems in India and Bangladesh*.

Mustafa, S., Ahmad, T., Naeem, A., Shah, K. H., & Waseem, M. (2010). Kinetics of chromium ion removal from tannery wastes using amberlite IRA-400 Cl− and its hybrids. *Water, Air, & Soil Pollution, 210*(1-4), 43-50.

Oyem, H., Oyem, I., & Ezeweali, D. (2014). Temperature, pH, electrical conductivity, total dissolved solids and chemical oxygen demand of groundwater in Boji-Boji Agbor/Owa area and immediate suburbs. *Research Journal of Environmental Sciences, 8*(8), 444-450.

OzoneSolutionsInc. (2018). Retrieved from https://www.ozonesolutions.com

PRAN-RFLCenter. (2018). Retrieved from https://www.rflbd.com/buildings_sera_water_tank.php

Raschid-Sally, L. (2000). *Arsenic contamination of groundwater in Bangladesh*. Retrieved from Colombo, Sri Lanka:

Sincero, A. P., & Sincero, G. A. (2002). *Physical-chemical treatment of water and wastewater*: CRC press.

Smith, A. H., Lingas, E. O., & Rahman, M. (2000). Contamination of drinking-water by arsenic in Bangladesh: a public health emergency. *Bulletin of the World Health Organization, 78*, 1093-1103.

Smith, A. H., Lopipero, P. A., Bates, M. N., & Steinmaus, C. M. (2002). Arsenic epidemiology and drinking water standards. In: American Association for the Advancement of Science.

Umitsu, M. (1993). Late Quaternary sedimentary environments and landforms in the Ganges Delta. *Sedimentary Geology, 83*(3-4), 177-186.

Violante, A., Cozzolino, V., Perelomov, L., Caporale, A., & Pigna, M. (2010). Mobility and bioavailability of heavy metals and metalloids in soil environments. *Journal of soil science and plant nutrition, 10*(3), 268-292.

WHO. (2017). *Guidelines for drinking-water quality* (4th ed.). Geneva, Switzerland: World Health Organisation.

Appendices

Appendix I

Protocol for drilling fieldwork

1. Choose location of the drilling based on the data of the water quality fieldwork: first location in As contaminated area, second location in transitions are and third location in As free area.
2. Check whether that location is actually available for drilling. i.e. is there sufficient space for drilling? Who owns the land? Etc.
3. Note down GPS location, date and location description.
4. Take a soil sample every 5 feet, while the tube length is more than 5 feet this depth will have an considerable error. For each soil sample:
    - The sampling bucket is cleaned between each sampling point with water from the top layer of drilling pool (see picture)
    - The sample is collected in the bucket and the excessive water is removed from the bucket. The remaining settled sediment is taken as sample.
    - The sample is placed on a fabric sheet with the indicated depth
    - Soil description and classification based on visual and physical observation. This classification is conform NEN-EN-ISO 14688-1+A1+C11:2016 which is suitable for soil classification in the field. Furthermore use rules of thumb, see Rules of thumb for soil classification for details. See Grain size distribution for other details. The classification is directly noted down in an excel spreadsheet.
    - The colour of the sample is compared to the sediment colour tool developed by SASMIT. The corresponding colour code is noted. If possible ask local driller for interpretation.
    - An overview picture is taken of the entire soil profile
    - From every sample a detailed picture is taken with a coin for scaling.
    - Samples for XRD and/or XRF analysis are taken. In total 5 samples per drilling were taken. All samples were taken within the aquifer in which all tube wells in that area are screened.
5. Compile borehole log/soil profile

Rules of thumb for soil classification

Sand

- Put a soil sample between thumb and index finger and rub. If real shearing and non-cohesive behaviour can be felt sand is the primary material in the soil. The sample can be classified as a sandy soil.

Silt

- Dilatancy test: Put a soil sample in your hand palm and add some water. Keep hand half closed. If silt is present the sample will look shiny. When opening hand the water infiltrates in the sample and the shiny effect disappears.

Clay

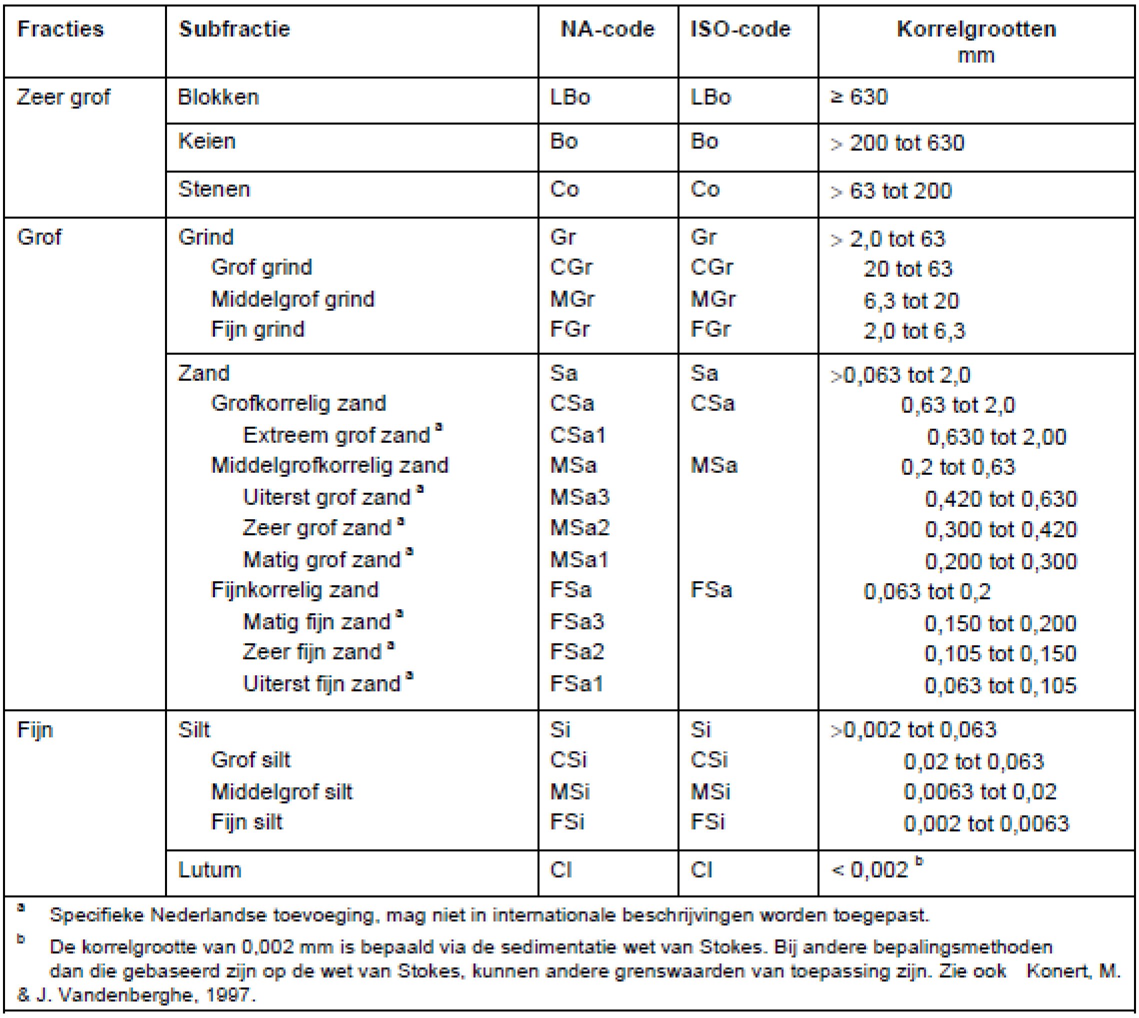
- Plasticity test: Take a soil sample in the hand. If the sample can be rolled into an approximately 3 mm thick cylinder without cracking the main fraction of the soil is clay.
- Dry strength test: Press soil sample into a briquette of approximately 1 cm^3. After drying silt material will break easily whereas clay will only break when applying force.
- Put a small soil sample on the tongue and rub it against the teeth. If grains can’t be felt no silt is present. If grains can be felt silt or sand is present is present.
- When performing dilatancy test the water will not infiltrate in the soil when opening hand.
- Clay sticks to the hands, even after drying. This is because clay is a cohesive material. Whereas sand and silt can be easily rubbed off.
- Clay is much more likely to contain organic material than sand and silt.

Peat

- Peat has often a dark colour and contain of organic matter. When wood, leaves or grass fibres are present the soil is very likely to be a peat.
- Peat falls apart easily since it is a non-cohesive material.
- Peat can often be recognized by a certain rotting odour caused by decomposition processes.

NB: all above mentioned rules of thumb are not objective. The interpretation is prone to personal interpretation and sense. It however provides a good indication.

Grain size distribution primary fraction



Fracties	**Subfractie**	**NA-code**	**ISO-code**	**Korrelgrootten** mm
Zeer grof	Blokken	LBo	LBo	≥ 630
	Keien	Bo	Bo	> 200 tot 630
	Stenen	Co	Co	> 63 tot 200
Grof	Grind	Gr	Gr	> 2,0 tot 63
	Grof grind	CGr	CGr	20 tot 63
	Middelgrof grind	MGr	MGr	6,3 tot 20
	Fijn grind	FGr	FGr	2,0 tot 6,3
	Zand	Sa	Sa	>0,063 tot 2,0
	Grofkorrelig zand	CSa	CSa	0,63 tot 2,0
	Extreem grof zand[a]	CSa1		0,630 tot 2,00
	Middelgrofkorrelig zand	MSa	MSa	0,2 tot 0,63
	Uiterst grof zand[a]	MSa3		0,420 tot 0,630
	Zeer grof zand[a]	MSa2		0,300 tot 0,420
	Matig grof zand[a]	MSa1		0,200 tot 0,300
	Fijnkorrelig zand	FSa	FSa	0,063 tot 0,2
	Matig fijn zand[a]	FSa3		0,150 tot 0,200
	Zeer fijn zand[a]	FSa2		0,105 tot 0,150
	Uiterst fijn zand[a]	FSa1		0,063 tot 0,105
Fijn	Silt	Si	Si	>0,002 tot 0,063
	Grof silt	CSi	CSi	0,02 tot 0,063
	Middelgrof silt	MSi	MSi	0,0063 tot 0,02
	Fijn silt	FSi	FSi	0,002 tot 0,0063
	Lutum	Cl	Cl	< 0,002[b]

[a] Specifieke Nederlandse toevoeging, mag niet in internationale beschrijvingen worden toegepast.

[b] De korrelgrootte van 0,002 mm is bepaald via de sedimentatie wet van Stokes. Bij andere bepalingsmethoden dan die gebaseerd zijn op de wet van Stokes, kunnen andere grenswaarden van toepassing zijn. Zie ook Konert, M. & J. Vandenberghe, 1997.

Appendix II

Water quality fieldwork protocol

1. Well-depth
   - Measure the well-depth, if possible. Otherwise inquire about the well depth.

2. Pump up water from the main drinking water source
   - Until having water from the tube well filter (screen) level: the number of pumping = depth of well in feet.

3. Take water samples
   a. Collect the ICP-MS sample:
      - Rinse the 1 liter jug two times and then collect a water sample
      - Fill the white 15ml sampling bottle (containing nitric acid and a label) with a water sample of 10ml with water from the container by using a syringe. Cap the bottle tightly.
      - If you have a duplicate sample bottle: also fill this sampling bottle (containing nitric acid and a label) with a water sample of 10ml with water from the container by using a syringe. Cap the bottle tightly.

4. Execute the App Analysis
   - Open AKVO Flow and open the survey "*Researcher App Analysis*". Press "+" to enter a new data point
   - For "Observation ID" fill in the label on the sample bottle you just filled
   - Follow the survey and by doing so execute the following tests:

     By multi-meter:
     - electrical conductivity
     - water temperature
     - hardness
     - turbidity
     - pH

     By strip test:
     - pH (visually and with Caddisfly)
     - Total iron HACH (visually and with Caddisfly)
     - Total iron Quantofix (visually)
     - Arsenic (visually and with Caddisfly)
     - Manganese (visually)
     - Ammonium (visually)

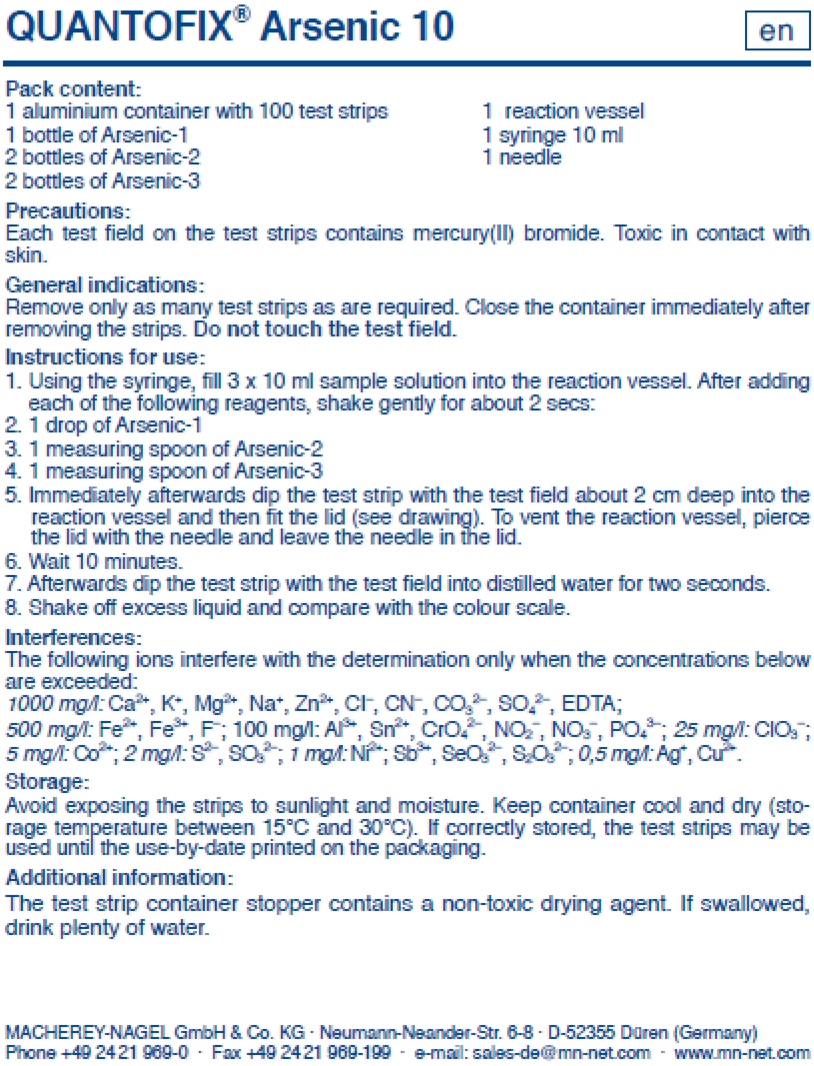
     By PhotoFlex cell-test:
     - Ammonium

       Measure the ammonium content of the PhotoFlex sample:
       - Put the fold-out cell shaft in an upright position until it locks into place.
       - Pull up the height adapter. The cell shaft is extended.
       - Switch the machine on.
       - Measuring mode by –M- (long pressure): Photometry
       - Measured parameter within measuring mode by –M- (short pressure): Concentration
       - If zero adjustment is required, execute a calibration process by inserting a 16mm cell containing distilled water. Insert the 16mm cell and push it to the bottom of the cell shaft (you feel some resistance and you hear a click).
       - Close the light cover before measurement.
       - Blank value measurement by CAL/ZERO: with an unused 16mm cell containing blank solution. Insert the 16mm cell and push it to the bottom of the cell shaft

    (you feel some resistance and you hear a click). Close the light cover before measurement.
    - Select program by PROG: 48
    - Select the right citation form by FORM: NH_4^+(range: 0.26 - 10.30 mg/l), and NOT for NH4+-N (range: 0.20 - 8.00 mg/l)!!!
    - Switch measurement unit by UNIT, if required
    - Insert the 16mm cell and push it to the bottom of the cell shaft (you feel some resistance and you hear a click). Close the light cover before measurement.
- Submit the survey when all questions have been answered.

Appendix III

Manual and information of Quantofix Arsenic 10



QUANTOFIX® Arsenic 10

en

Pack content:

1 aluminium container with 100 test strips
1 bottle of Arsenic-1
2 bottles of Arsenic-2
2 bottles of Arsenic-3
1 reaction vessel
1 syringe 10 ml
1 needle

Precautions:

Each test field on the test strips contains mercury(II) bromide. Toxic in contact with skin.

General indications:

Remove only as many test strips as are required. Close the container immediately after removing the strips. **Do not touch the test field.**

Instructions for use:

1. Using the syringe, fill 3 x 10 ml sample solution into the reaction vessel. After adding each of the following reagents, shake gently for about 2 secs:
2. 1 drop of Arsenic-1
3. 1 measuring spoon of Arsenic-2
4. 1 measuring spoon of Arsenic-3
5. Immediately afterwards dip the test strip with the test field about 2 cm deep into the reaction vessel and then fit the lid (see drawing). To vent the reaction vessel, pierce the lid with the needle and leave the needle in the lid.
6. Wait 10 minutes.
7. Afterwards dip the test strip with the test field into distilled water for two seconds.
8. Shake off excess liquid and compare with the colour scale.

Interferences:

The following ions interfere with the determination only when the concentrations below are exceeded:
1000 mg/l: Ca^{2+}, K^+, Mg^{2+}, Na^+, Zn^{2+}, Cl^-, CN^-, CO_3^{2-}, SO_4^{2-}, EDTA;
500 mg/l: Fe^{2+}, Fe^{3+}, F^-; 100 mg/l: Al^{3+}, Sn^{2+}, CrO_4^{2-}, NO_2^-, NO_3^-, PO_4^{3-}; *25 mg/l:* ClO_3^-;
5 mg/l: Co^{2+}; *2 mg/l:* S^{2-}, SO_3^{2-}; *1 mg/l:* Ni^{2+}; Sb^{3+}, SeO_3^{2-}, $S_2O_3^{2-}$; *0,5 mg/l:* Ag^+, Cu^{2+}.

Storage:

Avoid exposing the strips to sunlight and moisture. Keep container cool and dry (storage temperature between 15°C and 30°C). If correctly stored, the test strips may be used until the use-by-date printed on the packaging.

Additional information:

The test strip container stopper contains a non-toxic drying agent. If swallowed, drink plenty of water.

MACHEREY-NAGEL GmbH & Co. KG · Neumann-Neander-Str. 6-8 · D-52355 Düren (Germany)
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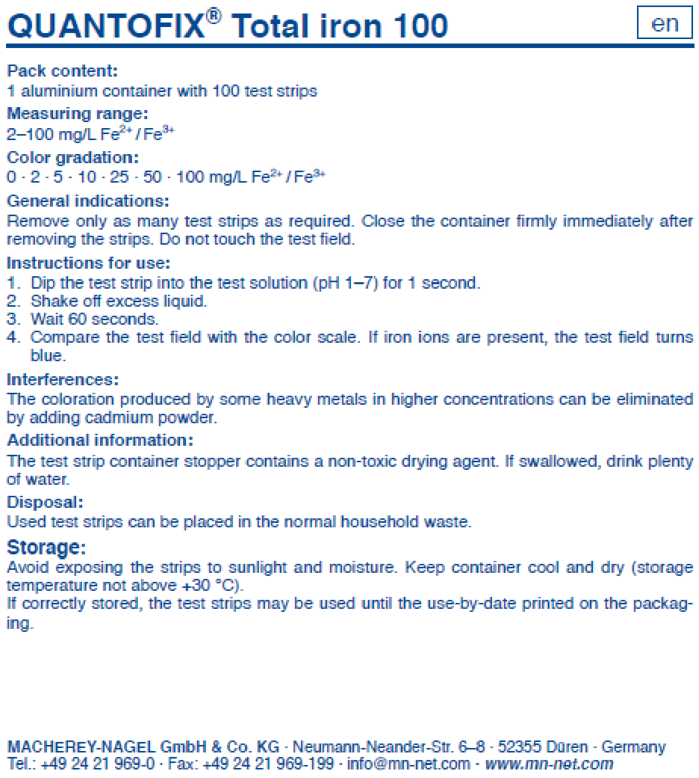
Appendix IV

Manual and information of Quantofix Total Iron 100



QUANTOFIX® Total iron 100

en

Pack content:
1 aluminium container with 100 test strips

Measuring range:
2–100 mg/L Fe^{2+} / Fe^{3+}

Color gradation:
0 · 2 · 5 · 10 · 25 · 50 · 100 mg/L Fe^{2+} / Fe^{3+}

General indications:
Remove only as many test strips as required. Close the container firmly immediately after removing the strips. Do not touch the test field.

Instructions for use:

1. Dip the test strip into the test solution (pH 1–7) for 1 second.
2. Shake off excess liquid.
3. Wait 60 seconds.
4. Compare the test field with the color scale. If iron ions are present, the test field turns blue.

Interferences:
The coloration produced by some heavy metals in higher concentrations can be eliminated by adding cadmium powder.

Additional information:
The test strip container stopper contains a non-toxic drying agent. If swallowed, drink plenty of water.

Disposal:
Used test strips can be placed in the normal household waste.

Storage:
Avoid exposing the strips to sunlight and moisture. Keep container cool and dry (storage temperature not above +30 °C).
If correctly stored, the test strips may be used until the use-by-date printed on the packaging.

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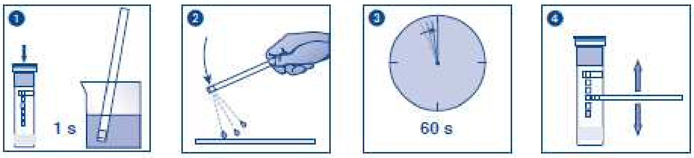
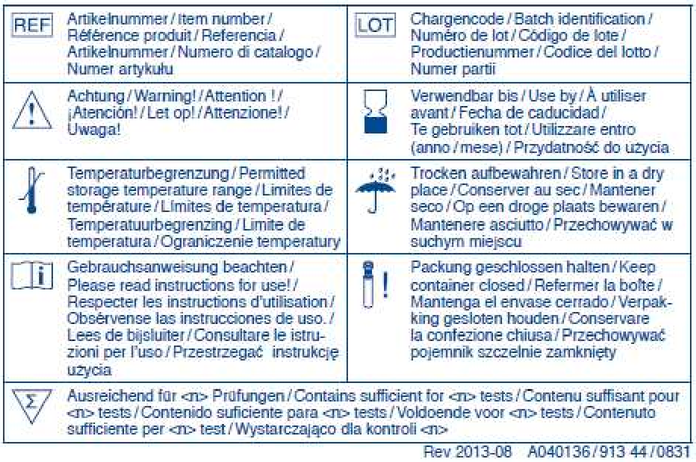


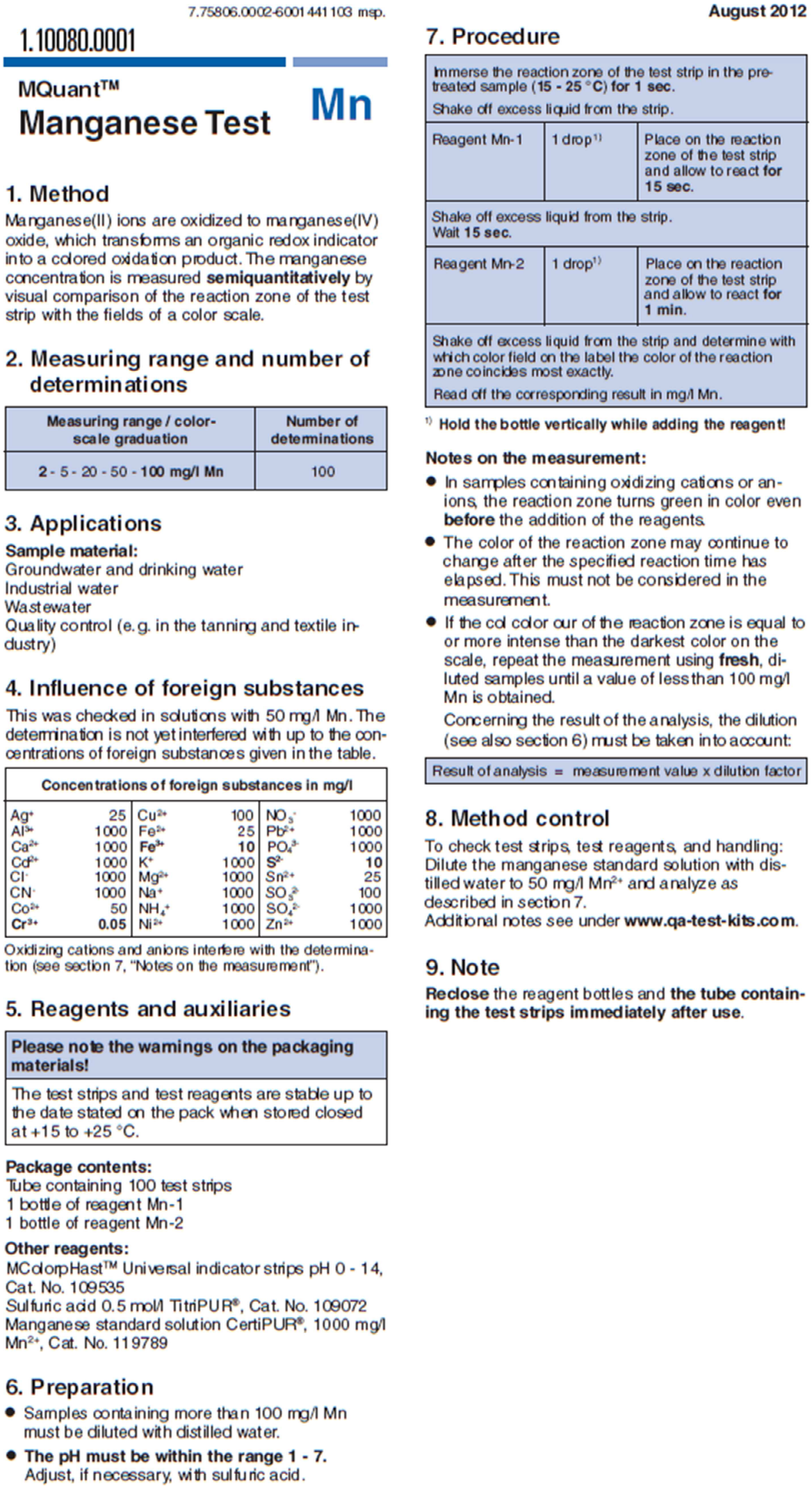


REF	Artikelnummer / Item number / Référence produit / Referencia / Artikelnummer / Numero di catalogo / Numer artykułu	LOT	Chargencode / Batch identification / Numéro de lot / Código de lote / Productienummer / Codice del lotto / Numer partii
⚠	Achtung / Warning! / Attention ! / ¡Atención! / Let op! / Attenzione! / Uwaga!	⌛	Verwendbar bis / Use by / À utiliser avant / Fecha de caducidad / Te gebruiken tot / Utilizzare entro (anno / mese) / Przydatność do użycia
🌡	Temperaturbegrenzung / Permitted storage temperature range / Limites de température / Límites de temperatura / Temperatuurbegrenzing / Limite de temperatura / Ograniczenie temperatury	☂	Trocken aufbewahren / Store in a dry place / Conserver au sec / Mantener seco / Op een droge plaats bewaren / Mantenere asciutto / Przechowywać w suchym miejscu
i	Gebrauchsanweisung beachten / Please read instructions for use! / Respecter les instructions d'utilisation / Obsérvense las instrucciones de uso. / Lees de bijsluiter / Consultare le istruzioni per l'uso / Przestrzegać instrukcję użycia	!	Packung geschlossen halten / Keep container closed / Refermer la boîte / Mantenga el envase cerrado / Verpakking gesloten houden / Conservare la confezione chiusa / Przechowywać pojemnik szczelnie zamknięty
Σ	Ausreichend für <n> Prüfungen / Contains sufficient for <n> tests / Contenu suffisant pour <n> tests / Contenido suficiente para <n> tests / Voldoende voor <n> tests / Contenuto sufficiente per <n> test / Wystarczająco dla kontroli <n>		

Rev 2013-08 A040136 / 913 44 / 0831

Appendix V

Manual and instructions of MQuant Manganese test



7.75806.0002-6001 441 103 msp.

August 2012

1.10080.0001

MQuant™

Manganese Test

Mn

1. Method

Manganese(II) ions are oxidized to manganese(IV) oxide, which transforms an organic redox indicator into a colored oxidation product. The manganese concentration is measured **semiquantitatively** by visual comparison of the reaction zone of the test strip with the fields of a color scale.

2. Measuring range and number of determinations

Measuring range / color-scale graduation	Number of determinations
2 - 5 - 20 - 50 - **100 mg/l Mn**	100

3. Applications

Sample material:
Groundwater and drinking water
Industrial water
Wastewater
Quality control (e.g. in the tanning and textile industry)

4. Influence of foreign substances

This was checked in solutions with 50 mg/l Mn. The determination is not yet interfered with up to the concentrations of foreign substances given in the table.

Concentrations of foreign substances in mg/l					
Ag^+	25	Cu^{2+}	100	NO_3^-	1000
Al^{3+}	1000	Fe^{2+}	25	Pb^{2+}	1000
Ca^{2+}	1000	**Fe^{3+}**	**10**	PO_4^{3-}	1000
Cd^{2+}	1000	K^+	1000	**S^{2-}**	**10**
Cl^-	1000	Mg^{2+}	1000	Sn^{2+}	25
CN^-	1000	Na^+	1000	SO_3^{2-}	100
Co^{2+}	50	NH_4^+	1000	SO_4^{2-}	1000
Cr^{3+}	**0.05**	Ni^{2+}	1000	Zn^{2+}	1000

Oxidizing cations and anions interfere with the determination (see section 7, "Notes on the measurement").

5. Reagents and auxiliaries

Please note the warnings on the packaging materials!

The test strips and test reagents are stable up to the date stated on the pack when stored closed at +15 to +25 °C.

Package contents:
Tube containing 100 test strips
1 bottle of reagent Mn-1
1 bottle of reagent Mn-2

Other reagents:
MColorpHast™ Universal indicator strips pH 0 - 14, Cat. No. 109535
Sulfuric acid 0.5 mol/l TitriPUR®, Cat. No. 109072
Manganese standard solution CertiPUR®, 1000 mg/l Mn^{2+}, Cat. No. 119789

6. Preparation

- Samples containing more than 100 mg/l Mn must be diluted with distilled water.
- **The pH must be within the range 1 - 7.** Adjust, if necessary, with sulfuric acid.

7. Procedure

Immerse the reaction zone of the test strip in the pretreated sample (**15 - 25 °C**) **for 1 sec.** Shake off excess liquid from the strip.		
Reagent Mn-1	1 drop[1]	Place on the reaction zone of the test strip and allow to react **for 15 sec.**
Shake off excess liquid from the strip. Wait **15 sec.**		
Reagent Mn-2	1 drop[1]	Place on the reaction zone of the test strip and allow to react **for 1 min.**
Shake off excess liquid from the strip and determine with which color field on the label the color of the reaction zone coincides most exactly. Read off the corresponding result in mg/l Mn.		

[1] **Hold the bottle vertically while adding the reagent!**

Notes on the measurement:

- In samples containing oxidizing cations or anions, the reaction zone turns green in color even **before** the addition of the reagents.
- The color of the reaction zone may continue to change after the specified reaction time has elapsed. This must not be considered in the measurement.
- If the color of the reaction zone is equal to or more intense than the darkest color on the scale, repeat the measurement using **fresh**, diluted samples until a value of less than 100 mg/l Mn is obtained.

  Concerning the result of the analysis, the dilution (see also section 6) must be taken into account:

Result of analysis = measurement value x dilution factor

8. Method control

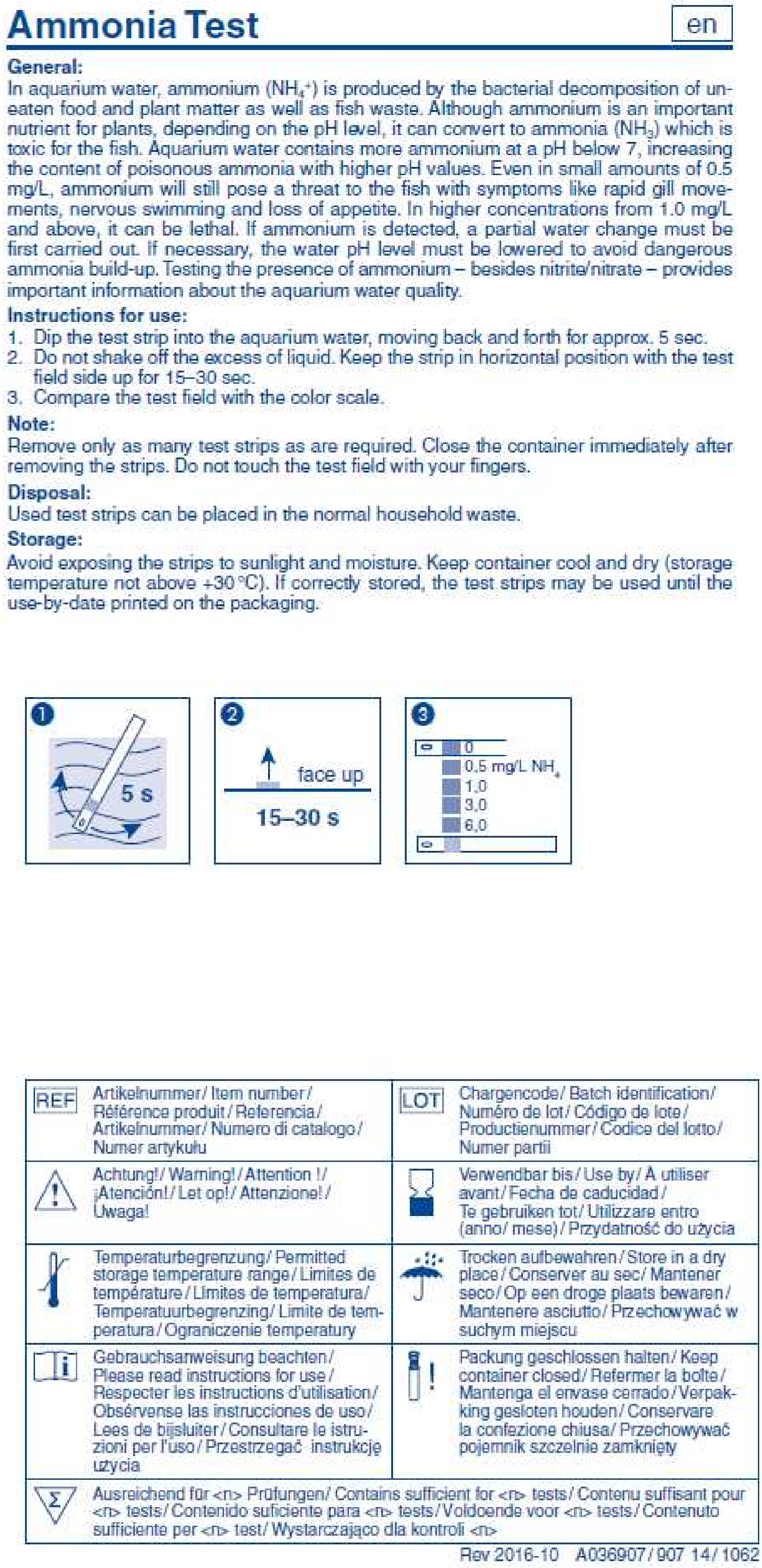
To check test strips, test reagents, and handling:
Dilute the manganese standard solution with distilled water to 50 mg/l Mn^{2+} and analyze as described in section 7.
Additional notes see under **www.qa-test-kits.com**.

9. Note

Reclose the reagent bottles and **the tube containing the test strips immediately after use.**

Appendix VI

Manual and instructions of Ammonia test



Ammonia Test

en

General:

In aquarium water, ammonium (NH_4^+) is produced by the bacterial decomposition of uneaten food and plant matter as well as fish waste. Although ammonium is an important nutrient for plants, depending on the pH level, it can convert to ammonia (NH_3) which is toxic for the fish. Aquarium water contains more ammonium at a pH below 7, increasing the content of poisonous ammonia with higher pH values. Even in small amounts of 0.5 mg/L, ammonium will still pose a threat to the fish with symptoms like rapid gill movements, nervous swimming and loss of appetite. In higher concentrations from 1.0 mg/L and above, it can be lethal. If ammonium is detected, a partial water change must be first carried out. If necessary, the water pH level must be lowered to avoid dangerous ammonia build-up. Testing the presence of ammonium – besides nitrite/nitrate – provides important information about the aquarium water quality.

Instructions for use:

1. Dip the test strip into the aquarium water, moving back and forth for approx. 5 sec.
2. Do not shake off the excess of liquid. Keep the strip in horizontal position with the test field side up for 15–30 sec.
3. Compare the test field with the color scale.

Note:

Remove only as many test strips as are required. Close the container immediately after removing the strips. Do not touch the test field with your fingers.

Disposal:

Used test strips can be placed in the normal household waste.

Storage:

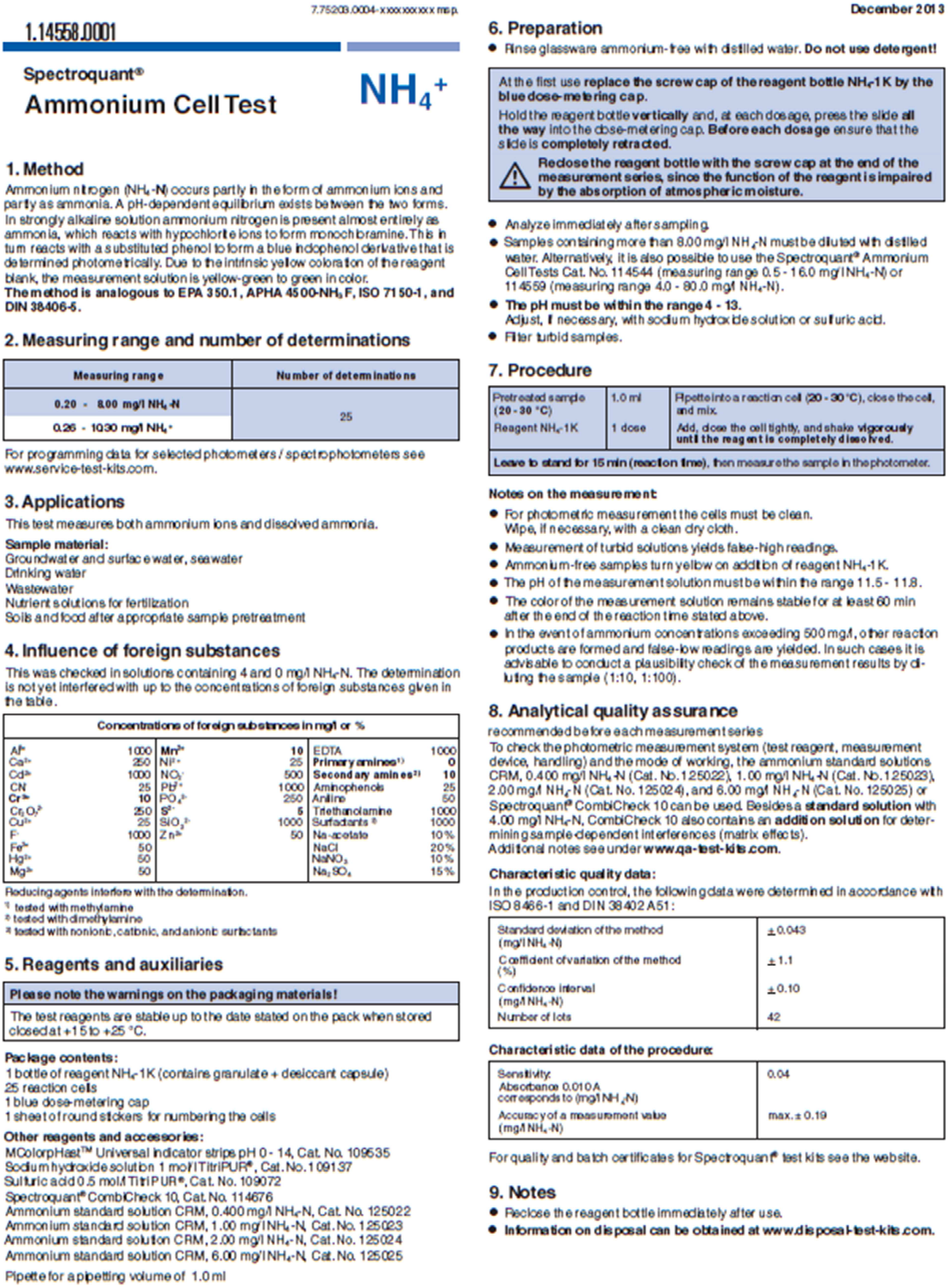
Avoid exposing the strips to sunlight and moisture. Keep container cool and dry (storage temperature not above +30 °C). If correctly stored, the test strips may be used until the use-by-date printed on the packaging.

REF	Artikelnummer/ Item number/ Référence produit/ Referencia/ Artikelnummer/ Numero di catalogo/ Numer artykułu	LOT	Chargencode/ Batch identification/ Numéro de lot/ Código de lote/ Productienummer/ Codice del lotto/ Numer partii
⚠	Achtung!/ Warning!/ Attention !/ ¡Atención!/ Let op!/ Attenzione!/ Uwaga!	⌛	Verwendbar bis/ Use by/ À utiliser avant/ Fecha de caducidad/ Te gebruiken tot/ Utilizzare entro (anno/ mese)/ Przydatność do użycia
🌡	Temperaturbegrenzung/ Permitted storage temperature range/ Limites de température/ Límites de temperatura/ Temperatuurbegrenzing/ Limite de temperatura/ Ograniczenie temperatury	☂	Trocken aufbewahren/ Store in a dry place/ Conserver au sec/ Mantener seco/ Op een droge plaats bewaren/ Mantenere asciutto/ Przechowywać w suchym miejscu
i	Gebrauchsanweisung beachten/ Please read instructions for use/ Respecter les instructions d'utilisation/ Obsérvense las instrucciones de uso/ Lees de bijsluiter/ Consultare le istruzioni per l'uso/ Przestrzegać instrukcję użycia	!	Packung geschlossen halten/ Keep container closed/ Refermer la boîte/ Mantenga el envase cerrado/ Verpakking gesloten houden/ Conservare la confezione chiusa/ Przechowywać pojemnik szczelnie zamknięty
Σ	Ausreichend für <n> Prüfungen/ Contains sufficient for <n> tests/ Contenu suffisant pour <n> tests/ Contenido suficiente para <n> tests/ Voldoende voor <n> tests/ Contenuto sufficiente per <n> test/ Wystarczająco dla kontroli <n>		

Rev 2016-10 A036907/ 907 14/ 1062

Appendix VII

Manual and instructions of Ammonium Cell Test



7.75203.0004-xxxxxxxxxx msp.

December 2013

1.14558.0001

Spectroquant®

Ammonium Cell Test

NH_4^+

1. Method

Ammonium nitrogen (NH_4-N) occurs partly in the form of ammonium ions and partly as ammonia. A pH-dependent equilibrium exists between the two forms. In strongly alkaline solution ammonium nitrogen is present almost entirely as ammonia, which reacts with hypochlorite ions to form monochloramine. This in turn reacts with a substituted phenol to form a blue indophenol derivative that is determined photometrically. Due to the intrinsic yellow coloration of the reagent blank, the measurement solution is yellow-green to green in color.
The method is analogous to EPA 350.1, APHA 4500-NH_3 F, ISO 7150-1, and DIN 38406-5.

2. Measuring range and number of determinations

Measuring range	Number of determinations
0.20 - 8.00 mg/l NH_4-N	25
0.26 - 10.30 mg/l NH_4^+	

For programming data for selected photometers / spectrophotometers see www.service-test-kits.com.

3. Applications

This test measures both ammonium ions and dissolved ammonia.

Sample material:
Groundwater and surface water, seawater
Drinking water
Wastewater
Nutrient solutions for fertilization
Soils and food after appropriate sample pretreatment

4. Influence of foreign substances

This was checked in solutions containing 4 and 0 mg/l NH_4-N. The determination is not yet interfered with up to the concentrations of foreign substances given in the table.

Concentrations of foreign substances in mg/l or %					
Al^{3+}	1000	**Mn^{2+}**	**10**	EDTA	1000
Ca^{2+}	250	Ni^{2+}	25	**Primary amines[1]**	**0**
Cd^{2+}	1000	NO_2^-	500	**Secondary amines[2]**	**10**
CN^-	25	Pb^{2+}	1000	Aminophenols	25
Cr^{3+}	**10**	PO_4^{3-}	250	Aniline	50
$Cr_2O_7^{2-}$	250	**S^{2-}**	**5**	Triethanolamine	1000
Cu^{2+}	25	SiO_3^{2-}	1000	Surfactants[3]	1000
F^-	1000	Zn^{2+}	50	Na-acetate	10%
Fe^{3+}	50			NaCl	20%
Hg^{2+}	50			$NaNO_3$	10%
Mg^{2+}	50			Na_2SO_4	15%

Reducing agents interfere with the determination.

[1] tested with methylamine
[2] tested with dimethylamine
[3] tested with nonionic, cationic, and anionic surfactants

5. Reagents and auxiliaries

Please note the warnings on the packaging materials!
The test reagents are stable up to the date stated on the pack when stored closed at +15 to +25 °C.

Package contents:
1 bottle of reagent NH_4-1K (contains granulate + desiccant capsule)
25 reaction cells
1 blue dose-metering cap
1 sheet of round stickers for numbering the cells

Other reagents and accessories:
MColorpHast™ Universal indicator strips pH 0 - 14, Cat. No. 109535
Sodium hydroxide solution 1 mol/l Titripur®, Cat. No. 109137
Sulfuric acid 0.5 mol/l Titripur®, Cat. No. 109072
Spectroquant® CombiCheck 10, Cat. No. 114676
Ammonium standard solution CRM, 0.400 mg/l NH_4-N, Cat. No. 125022
Ammonium standard solution CRM, 1.00 mg/l NH_4-N, Cat. No. 125023
Ammonium standard solution CRM, 2.00 mg/l NH_4-N, Cat. No. 125024
Ammonium standard solution CRM, 6.00 mg/l NH_4-N, Cat. No. 125025

Pipette for a pipetting volume of 1.0 ml

6. Preparation

- Rinse glassware ammonium-free with distilled water. **Do not use detergent!**

> At the first use **replace the screw cap of the reagent bottle NH_4-1K by the blue dose-metering cap.**
>
> Hold the reagent bottle **vertically** and, at each dosage, press the slide **all the way** into the dose-metering cap. **Before each dosage** ensure that the slide is **completely retracted.**
>
> ⚠ **Reclose the reagent bottle with the screw cap at the end of the measurement series, since the function of the reagent is impaired by the absorption of atmospheric moisture.**

- Analyze immediately after sampling.
- Samples containing more than 8.00 mg/l NH_4-N must be diluted with distilled water. Alternatively, it is also possible to use the Spectroquant® Ammonium Cell Tests Cat. No. 114544 (measuring range 0.5 - 16.0 mg/l NH_4-N) or 114559 (measuring range 4.0 - 80.0 mg/l NH_4-N).
- **The pH must be within the range 4 - 13.**
  Adjust, if necessary, with sodium hydroxide solution or sulfuric acid.
- Filter turbid samples.

7. Procedure

Pretreated sample (20 - 30 °C)	1.0 ml	Pipette into a reaction cell (20 - 30 °C), close the cell, and mix.
Reagent NH_4-1K	1 dose	Add, close the cell tightly, and shake **vigorously until the reagent is completely dissolved.**
Leave to stand for 15 min (reaction time), then measure the sample in the photometer.		

Notes on the measurement:

- For photometric measurement the cells must be clean.
  Wipe, if necessary, with a clean dry cloth.
- Measurement of turbid solutions yields false-high readings.
- Ammonium-free samples turn yellow on addition of reagent NH_4-1K.
- The pH of the measurement solution must be within the range 11.5 - 11.8.
- The color of the measurement solution remains stable for at least 60 min after the end of the reaction time stated above.
- In the event of ammonium concentrations exceeding 500 mg/l, other reaction products are formed and false-low readings are yielded. In such cases it is advisable to conduct a plausibility check of the measurement results by diluting the sample (1:10, 1:100).

8. Analytical quality assurance

recommended before each measurement series

To check the photometric measurement system (test reagent, measurement device, handling) and the mode of working, the ammonium standard solutions CRM, 0.400 mg/l NH_4-N (Cat. No. 125022), 1.00 mg/l NH_4-N (Cat. No. 125023), 2.00 mg/l NH_4-N (Cat. No. 125024), and 6.00 mg/l NH_4-N (Cat. No. 125025) or Spectroquant® CombiCheck 10 can be used. Besides a **standard solution** with 4.00 mg/l NH_4-N, CombiCheck 10 also contains an **addition solution** for determining sample-dependent interferences (matrix effects).
Additional notes see under **www.qa-test-kits.com.**

Characteristic quality data:

In the production control, the following data were determined in accordance with ISO 8466-1 and DIN 38402 A51:

Standard deviation of the method (mg/l NH_4-N)	± 0.043
Coefficient of variation of the method (%)	± 1.1
Confidence interval (mg/l NH_4-N)	± 0.10
Number of lots	42

Characteristic data of the procedure:

Sensitivity: Absorbance 0.010 A corresponds to (mg/l NH_4-N)	0.04
Accuracy of a measurement value (mg/l NH_4-N)	max. ± 0.19

For quality and batch certificates for Spectroquant® test kits see the website.

9. Notes

- Reclose the reagent bottle immediately after use.
- **Information on disposal can be obtained at www.disposal-test-kits.com.**

Appendix VIII

ICP-MS results

Observation ID	As ICP-MS (µg/L	DUPLICATE (µg/L)	Final As (µg/L)	Fe ICP-MS (mg/L)	DUPLICATE (mg/L)	Final Fe (mg/L)	Mn ICP-MS (mg/L)	DUPLICATE (mg/L)2	Final Mn (mg/L)
1-RA-AM	34.953			1.330			0.341		
2-RA-AM	233.944			0.927			0.249		
3-RA-AM	223.633			2.308			0.553		
4-RA-AM	119.488			6.073			0.173		
5-RA-AM	589.008	584.882	586.945	0.713	0.903	0.808	0.538	0.5361	0.5372925
7-RA-AM	3.056			0.431			0.573		
8-RA-AM	238.367			5.525			0.400		
9-RA-AM	407.853			7.802			0.291		
10-RA-AM	608.702	602.313	605.508	0.394	0.361	0.378	0.677	0.646772	0.661979
12-RA-AM	1041.364			0.361			0.410		
13-RA-AM	221.598			6.008			0.125		
14-RA-AM	1123.662			0.238			0.693		
15-RA-AM	751.718	758.048	754.883	1.952	1.967	1.960	0.526	0.524981	0.5255145
17-RA-AM	217.899			4.771			0.156		
18-RA-AM	588.393			0.356			0.817		
19-RA-AM	188.221			0.597			0.591		
20-RA-AM	102.078	105.032	103.555	1.949	1.953	1.951	0.511	0.513051	0.5118125
22-RA-AM	178.060			10.690			0.151		
23-RA-AM	4.493			0.247			0.408		
24-RA-AM	387.411			0.742			0.531		
25-RA-AM	375.088	350.612	362.850	0.517	0.474	0.495	0.658	0.657613	0.6576745
27-RA-AM	80.069			0.549			0.629		
28-RA-AM	13.729			0.375			1.459		
29-RA-AM	547.952			1.288			0.595		
30-RA-AM	363.171	394.782	378.977	0.778	0.858	0.818	0.964	0.979755	0.9720525
32-RA-AM	324.780			5.631			0.420		
33-RA-AM	109.667			8.487			0.167		
34-RA-AM	28.377			0.590			0.421		
35-RA-AM	108.065	109.221	108.643	0.586	0.288	0.437	0.416	0.426235	0.421047
37-RA-AM	66.674			0.288			0.373		
38-RA-AM	10.263			0.186			0.401		
39-RA-AM	180.216			1.031			0.333		
40-RA-AM	49.550	49.128	49.339	0.297	0.257	0.277	0.300	0.295885	0.2979845
42-RA-AM	1.381			0.341			0.239		
43-RA-AM	1.010			0.101			0.217		
44-RA-AM	31.791			0.252			0.345		
45-RA-AM	1.269	1.256	1.263	0.190	0.195	0.193	0.482	0.506324	0.4940985
47-RA-AM	73.259			0.422			0.347		
48-RA-AM	24.042			0.194			0.383		
49-RA-AM	51.902			0.155			0.496		
50-RA-AM	1.215	1.361	1.288	0.387	0.369	0.378	0.357	0.357416	0.3570365

52-RA-AM	1.384			0.279			0.327		
53-RA-AM (without filter)	239.332			0.188			0.302		
54-RA-AM	109.904			2.980			0.376		
55-RA-AM-DRINKWATERWE	6.607	246.196	126.402	0.142	0.181	0.162	0.481	0.284942	0.3831685
57-RA-AM	110.960			6.633			0.221		
58-RA-AM	173.374			7.088			0.185		
59-RA-AM	363.971			1.582			0.685		
60-RA-AM	22.175	16.944	19.560	0.735	0.548	0.642	0.405	0.39897	0.401869
62-RA-AM	33.393			0.356			0.409		
63-RA-AM	204.136			0.889			0.779		
64-RA-AM	78.250			8.862			0.209		
65-RA-AM	380.977	349.741	365.359	1.598	1.411	1.504	0.512	0.50014	0.5058705
67-RA-AM	301.847			0.263			0.694		
68-RA-AM	131.888			6.221			0.325		
69-RA-AM	0.704			0.270			0.292		
70-RA-AM	76.486	76.013	76.250	6.170	6.041	6.105	0.159	0.161961	0.1606785
72-RA-AM	121.567			4.587			0.097		
73-RA-AM	271.367			6.061			0.127		
74-RA-AM	202.979			0.391			0.573		
75-RA-AM	242.762	238.904	240.833	4.757	4.596	4.677	0.686	0.659482	0.672672
77-RA-AM	183.710			5.480			0.432		
78-RA-AM	56.653			3.494			1.077		
79-RA-AM	55.795			5.616			0.334		
80-RA-AM	39.583	39.736	39.660	3.499	3.422	3.460	0.828	0.834377	0.8312155
82-RA-AM	21.433			0.081			1.029		
83-RA-AM	60.973			5.523			1.008		
84-RA-AM	0.395			0.257			2.031		
85-RA-AM	415.826	420.962	418.394	2.880	2.918	2.899	0.288	0.290451	0.289167
87-RA-AM	62.730			7.329			0.167		
88-RA-AM	112.294			5.549			0.249		
89-RA-AM	8.231			0.264			0.503		
90-RA-AM	2.597	2.759	2.678	0.698	0.673	0.686	0.117	0.11694	0.117048
92-RA-AM	30.762			1.646			0.269		
93-RA-AM	21.263			1.509			1.419		
94-RA-AM	0.340			0.953			1.830		
95-RA-AM	100.240	101.081	100.661	9.977	10.212	10.095	0.174	0.175839	0.1747335
97-RA-AM	116.731			9.647			0.150		
98-RA-AM-DRINKINGWATER	157.108			2.038			0.461		
99-RA-AM	49.238			0.240			0.344		
100-RA-AM	63.599	60.597	62.098	2.337	2.216	2.277	0.580	0.56253	0.5713705

102-RA-AM	101.514			0.057			0.604		
103-RA-AM	5.386			0.097			0.456		
104-RA-AM	43.514			4.712			0.271		
105-RA-AM	57.306	58.945	58.126	5.532	5.567	5.550	0.608	0.623619	0.6157345
107-RA-AM	19.977			4.687			0.316		
108-RA-AM	58.111			10.529			1.042		
109-RA-AM	54.601			4.610			0.575		
110-RA-AM	29.449	34.983	32.216	7.769	8.870	8.319	0.643	0.592538	0.6177525
112-RA-AM	0.156			0.044			1.759		
113-RA-AM	0.205			0.071			1.526		
114-RA-AM	166.287			3.849			0.558		
115-RA-AM	23.451	22.645	23.048	2.580	2.462	2.521	0.219	0.222822	0.2210365
117-RA-AM	85.305			7.370			0.465		
118-RA-AM	74.103			6.347			0.400		
119-RA-AM	70.488			0.296			0.502		
120-RA-AM	24.179	40.359	32.269	2.691	3.044	2.867	1.211	1.216656	1.213896
122-RA-AM	132.681			0.334			0.935		
123-RA-AM	0.275			0.150			1.868		
124-RA-AM	0.299			0.194			1.829		
125-RA-AM	0.204	0.158	0.181	0.078	0.055	0.066	1.948	1.936858	1.9425165
127-RA-AM	1.106			0.335			1.757		
128-RA-AM	0.962			0.640			1.627		
129-RA-AM	1.095			0.764			1.467		
130-RA-AM	0.817	0.882	0.850	0.246	0.250	0.248	1.443	1.538416	1.49078
132-RA-AM	1.070			0.069			1.206		
133-RA-AM	43.249			1.627			0.634		
134-RA-AM	1.277			0.104			1.898		
135-RA-AM	101.521	117.923	109.722	0.400	0.471	0.436	0.582	0.595299	0.588767
137-RA-AM	0.929			0.555			1.012		
138-RA-AM	3.409			1.835			0.938		
139-RA-AM	0.816			0.175			1.380		
140-RA-AM	0.962	0.934	0.948	0.047	0.051	0.049	1.280	1.238072	1.2590815
142-RA-AM	1.096			0.099			1.274		
143-RA-AM	3.830			0.102			0.659		
144-RA-AM	1.063			0.085			1.313		
145-RA-AM	0.863			0.103			1.513		
146-RA-AM	1.269			0.096			1.498		
147-RA-AM	1.287			0.146			0.757		
148-RA-AM	1.196			0.422			0.859		
149-RA-AM	0.956			0.107			1.052		
150-RA-AM	1.135	0.923	1.029	0.215	0.225	0.220	1.344	1.303979	1.324004

152-RA-AM	4.118			0.132			1.414		
153-RA-AM	1.156			0.478			1.089		
154-RA-AM	1.147			0.114			1.352		
155-RA-AM									
156-RA-AM	64.019			7.880			0.709		
157-RA-AM	1.256			0.179			1.574		
158-RA-AM	1.080			0.445			1.274		
159-RA-AM	1.346			0.150			1.335		
160-RA-AM	1.065			0.260			1.175		
161-RA-AM	46.454			9.106			0.598		
162-RA-AM	1.104			0.090			1.610		
163-RA-AM	0.893			0.315			1.351		
164-RA-AM	1.230			0.639			1.586		
165-RA-AM	94.454			9.837			0.788		
166-RA-AM	2.395			0.122			0.691		
167-RA-AM	64.314			7.120			0.601		
168-RA-AM	260.224			0.250			1.208		
169-RA-AM	2.129			0.235			0.566		
170-RA-AM	5.862			0.211			0.861		
171-RA-AM	135.514			2.306			0.828		
172-RA-AM	2.311			0.355			1.356		
173-RA-AM	0.919			0.077			0.803		
174-RA-AM	80.833			1.762			0.869		
175-RA-AM	75.051			2.239			0.686		
176-RA-AM	2.443			1.206			0.376		
177-RA-AM	0.991			0.044			1.093		

Appendix IX

Soil profiles

Date	18-aug																	
Location	latitude	N24°22'51.38"																
(high As contami	longitude	E88°42'10.35"																
Drilling method	percussion drilling																	
Sample type	disturbed																	
Drilling ID	Drilling-1																	
								SASMIT										
	Depth								dry observation				Sand					
	feet	metres	principal fraction	secondary fraction	remarks	soil type	colour code (fiel	As risk	BART	TIEMEN	Clay	Silt	very fine	fine	medium	coarse	very coarse	gravel
	0	0.0																
	5	1.5	silt		low quality sample, yellowish colour	silt					▨	▨						
	10	3.1	clay	sand	yellowish colour, contains shell remnants	sandy soft clay					🟫							
	15	4.6	clay		grey	soft clay					🟫							
	20	6.1	clay	organic matter	very dark grey/black	medium soft clay					🟫							
	25	7.6	clay	silt	light grey	silty medium soft clay					🟫							
	30	9.2	silt	clay	grey	clayey silt					▨	▨						
	35	10.7	clay	silt	grey	silty clay					🟫							
	40	12.2	silt	clay	grey	clayey silt					▨	▨						
	45	13.7	sand		dark colour, small minerals visible <1mm	fine to medium coarse sand	B1	B1			🟨	🟨	🟨	🟨	🟨			
	50	15.3	sand		dark colour, small minerals visible <1mm	fine to medium coarse sand	B1	B1			🟨	🟨	🟨	🟨	🟨			
	55	16.8	sand		small minerals visible <1mm	fine sand	B1	B1			🟨	🟨	🟨	🟨				
	60	18.3	sand		small minerals visible <1mm	fine sand	B1	B1			🟨	🟨	🟨	🟨				
	65	19.8	sand		small minerals visible <1mm	medium coarse sand	B1	B1			🟨	🟨	🟨	🟨	🟨			
	70	21.4	sand		small minerals visible <1mm	medium coarse sand	B1	B1			🟨	🟨	🟨	🟨	🟨			
	75	22.9	sand		small minerals visible 1mm	medium coarse sand	B1	B1			🟨	🟨	🟨	🟨	🟨			
	80	24.4	sand		less abundant minerals 1mm	medium coarse sand	B1	B1			🟨	🟨	🟨	🟨	🟨			
	85	25.9	sand		extremely shiny apearance of minerals 1 mm, bit darker than 80	medium coarse sand	B3	B3			🟨	🟨	🟨	🟨	🟨			
	90	27.5	sand		minerals visable 1mm	coarse sand	W3	W3			🟨	🟨	🟨	🟨	🟨	🟨		
	95	29.0	sand		minerals visable 1mm	very coarse sand	W3	W3			🟨	🟨	🟨	🟨	🟨	🟨	🟨	
	100	30.5	clay		between 100 and 105, 3cm stone found	hard clay					🟫							
	105	32.0	sand		minerals visable 1mm, few 2mm minerals	medium coarse sand	B1	B1	B2	W1	🟨	🟨	🟨	🟨	🟨			
	110	33.6	sand		lighter/more yellow than 105, goldish shine, minerals visible 1mm	medium coarse sand	OW3	OW3	B1	OW1	🟨	🟨	🟨	🟨	🟨			
	115	35.1	sand		same color as 110, minerals visible 2-3 mm	coarse sand	R1	R1	W1	OW1	🟨	🟨	🟨	🟨	🟨	🟨		
	120	36.6	sand	gravel	darker than 115, after 120 very had clay or petrified clay	gravely coarse sand	B1	B1	W1	B1	🟨	🟨	🟨	🟨	🟨	🟨		
	125	38.1	sand		minerals visible 1 mm	medium coarse sand	B1	B1	W1	B1	🟨	🟨	🟨	🟨	🟨	🟨		
	130	39.7	sand		small pebbles, angular grains 3-5 mm.	coarse-very coarse sand	B1	B1	W1	B2	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
	135	41.2	sand	gravel	angular grains, minerals visable	gravely very coarse sand	W3	W3	W2	B1	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
	140	42.7	sand	gravel	bit more yellowish than 135, angular grains, minerals visible	gravely coarse sand	OW3	OW3	OW1	OW1	🟨	🟨	🟨	🟨	🟨	🟨		
	145	44.2	sand		bit more dark, many minerals visible	coarse sand	B1	B1	W2	W1	🟨	🟨	🟨	🟨	🟨	🟨		
	150	45.8	sand		few more bigger minerals visible	coarse sand	B1	B1	W2	W1	🟨	🟨	🟨	🟨	🟨	🟨		
	155	47.3	clay	sand or hard clay gr	sand possibly caused by contamination through flushing	sandy medium soft clay					🟫							
	160	48.8	sand	clay	Clay posibly cause by contamination through flushing, minerals visible	clayey medium coarse sand			W3	W1	🟨	🟨	🟨	🟨	🟨			
	165	50.3	clay	coarse sand/gravel	light gray clay, sand possibly caused by contamination through flushing	mix clay coarse sand and gravel					🟫							
	170	51.9	clay	sand	hard particles of probably clay, contains small red spots in the clay	sandy medium soft clay					🟫							

Date	17-aug																
Location	latitude	N24°22'48.95"															
(medium As con	longtitude	E88°42'15.58"															
Drilling method	percussion drilling																
Sample type	disturbed																
Drilling ID	Drilling-2																
							SASMIT										
Depth								dry observation				Sand					
feet	metres	principal fraction	secondary fractior	remarks	soil type	colour code (fiel	As risk	Bart	tiemen	Clay	Silt	very fine	fine	medium	coarse	very coarse	gravel
5	1.5	clay		angular pebbles, top layer is yellow	clay					🟫							
10	3.1	clay		pebbles	clay					🟫							
15	4.6	sand		yellow	medium coarse sand					🟨	🟨	🟨	🟨	🟨			
20	6.1	clay		Dark grey colour	soft clay					🟫							
25	7.6	clay	silt	harder than 20 feet	silty clay					🟫							
30	9.2	sand		Dark grey colour	medium coarse sand	B3	B3			🟨	🟨	🟨	🟨	🟨			
35	10.7	sand		Dark grey colour	medium coarse sand	B3	B3			🟨	🟨	🟨	🟨	🟨			
40	12.2	sand		light mixed color	fine sand	B3	B3			🟨	🟨	🟨					
45	13.7	sand	silt	grey colour	silty sand	B3	B3			🟨	🟨	🟨	🟨				
50	15.3	sand		grey colour	medium coarse sand	B3	B3			🟨	🟨	🟨	🟨	🟨			
55	16.8	sand		grey colour	medium coarse sand	B1	B1			🟨	🟨	🟨	🟨	🟨			
60	18.3	sand		grey colour	coarse sand	B2	B2			🟨	🟨	🟨	🟨	🟨	🟨		
65	19.8	sand		big minerals up to 2 mm, probably quartz, grey colour	coarse sand	B2	B2			🟨	🟨	🟨	🟨	🟨	🟨		
70	21.4	sand	clay	big minerals up to 2 mm, probably quartz, grey colour	mix of coarse sand and clay	B2	B2			🟨	🟨	🟨	🟨	🟨	🟨		
75	22.9	sand		small minerals visible, Slightly lighter colour than 70	medium coarse	W1	W1			🟨	🟨	🟨	🟨	🟨			
80	24.4	clay		grey colour	soft clay					🟫							
85	25.9	sand		more big multiple types of minerals up to 2 mm,(quarts, muscovite)	coarse sand	W2	W2			🟨	🟨	🟨	🟨	🟨	🟨		
90	27.5	sand		more green than layer before	fine sand	B3	B3			🟨	🟨	🟨	🟨				
95	29.0	sand		minerals present, bit lighter than 90ft	very coarse sand	B1	B1			🟨	🟨	🟨	🟨	🟨	🟨	🟨	
100	30.5	sand		grey colour	very coarse sand	B2	B2	W1	B1	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
105	32.0	sand		Bit more yellow and lighter than 100	Very coarse sand	OW3	OW3	W1	W1	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
110	33.6	sand		More yellow than 105, orange particles inside	Very coarse sand	OW3	OW3	W1	W1	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
115	35.1	sand		More yellow than 110, orange particles inside	Very coarse sand	OW2	OW2	OW1	OW1	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
120	36.6	sand		reddish colour	Very coarse sand	R1	R1	OW1	OW2	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
125	38.1	sand		Contains pebbles , reddish colour	Very coarse sand	R1	R1	OW2	OW3	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
130	39.7	sand		Contains pebbles, bit darker than 125	Very coarse sand	R1	R1	OW1	OW1	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
135	41.2	sand		Contains pebbles, darker than 130	Very coarse sand	B1	B1	B1	W1	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
140	42.7	sand		Dark grey colour	Very coarse sand	B1	B1	W2	W1	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
145	44.2	sand		Dark grey colour	Very coarse sand	B1	B1	W3	W2	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
150	45.8	sand		Dark grey colour	Coarse sand	B2	B2	W2	W1	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
155	47.3	Gravel	loam	Mixture of coarse sand gravel 1cm clay nodules 2cm (possibly mixed with earlier samples during drilling)	Loamy gravel					▨	▨	▨	▨	▨	▨	▨	▨
160	48.8	clay	coarse sand	5cm big clay pebbles (possibly mixed with earlier samples during drilling)	sandy medium hard clay					🟫							
165	50.3	clay	coarse sand	(possibly mixed with earlier samples during drilling)	sandy hard clay					🟫							

Date	27-aug	
Location	latitude	N24°22'33.67"
(low As contami	longitude	O88°42'35.63"
Drilling method	percussion drilling	
Sample type	disturbed	
Drilling ID	Drilling-3	

Depth						SASMIT						Sand					
								dry observation									
feet	metres	principal fraction	secondary	remarks	soil type	colour coc	As risk	BART	TIEMEN	Clay	Silt	very fine	fine	medium	coarse	very coarse	gravel
5	1.5	clay		plant remnants, yellow brownish, small angular pebbles	soft clay					🟫							
10	3.1	clay		shell remnants, yellow brownish	medium soft clay					🟫							
15	4.6	clay		small angular grains pebbles, yellow brownish	medium soft clay					🟫							
20	6.1	sand		round pebbles 5mm darker color(grayish)	fine sand					🟨	🟨	🟨	🟨				
25	7.6	silt		shiney appearance, plant remnants, browner color maybe because of flushing	silt					⬜	⬜						
30	9.2	clay		grey	medium clay					🟫							
35	10.7	clay	silt	grey	silty medium hard clay					🟫							
40	12.2	clay		grey	medium hard clay					🟫							
45	13.7	clay		grey	medium hard clay					🟫							
50	15.3	clay	sand	grey	sandy hard clay					🟫							
55	16.8	clay	sand	grey, realy hard clay	sandy hard clay					🟫							
60	18.3	clay	sand	grey	sandy hard clay					🟫							
65	19.8	clay	sand	more yellowish grey, large sand fraction	sandy medium clay					🟫							
70	21.4	sand	silt	goldish shiney appearance, <1mm minerals visable	silty medium sand	W1	W1			🟨	🟨	🟨	🟨	🟨			
75	22.9	sand		goldish shiney appearance, more <1mm minerals visible	medium sand	OW1	OW1			🟨	🟨	🟨	🟨	🟨			
80	24.4	sand		<2mm minerals many minerals visible	coarse sand	OW3	OW3	OW1	OW2	🟨	🟨	🟨	🟨	🟨	🟨		
85	25.9	sand		minerals visible <2mm	very coarse sand	R1	R1			🟨	🟨	🟨	🟨	🟨	🟨	🟨	
90	27.5	sand		minerals visible <2mm	coarse sand	R1	R1	OW1	OW1	🟨	🟨	🟨	🟨	🟨	🟨		
95	29.0	sand		minerals visible <3mm, some angular pebbles	coarse sand	R1	R1			🟨	🟨	🟨	🟨	🟨	🟨		
100	30.5	sand		minerals visible <1mm,	coarse sand	R1	R1	OW2	OW1	🟨	🟨	🟨	🟨	🟨	🟨		
105	32.0	sand	gravel	small pebbles, minerals visible <1mm	gravely very coars	R2	R2	OW2	OW3	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
110	33.6	sand		Large pebbles 1 cm, minerals visible <2mm, plant remnants	very coarse sand	R3	R3	R1	R1	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
115	35.1	sand		minerals visible <1mm	very coarse sand	OW3	OW3	OW1	OW1	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
120	36.6	sand		more greyish colour, minerals visible <1mm	coarse sand	W1	W1	W2	W1	🟨	🟨	🟨	🟨	🟨	🟨		
125	38.1	sand		same colour as 120ft., minerals visible <1mm	very coarse sand	W1	W1	W2	W1	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
130	39.7	sand		more greyish colour, minerals visible <2mm	coarse sand	B1	B1	W2	W2	🟨	🟨	🟨	🟨	🟨	🟨		
135	41.2	sand		more yellow colour, sub-rounded pebbles present, minerals visible <2mm	coarse sand	B1	B1	OW1	OW1	🟨	🟨	🟨	🟨	🟨	🟨		
140	42.7	sand		more greyish colour, some sub-rounded pebbles present, minerals visible <2mm	coarse sand	B2	B2			🟨	🟨	🟨	🟨	🟨	🟨		
145	44.2	sand	gravel	again more greyish, minerals visible <1mm	gravely coarse san	W1	W1			🟨	🟨	🟨	🟨	🟨	🟨	🟨	
150	45.8	sand		dark grey colour, minerals visible <2mm	coarse sand	B1	B1	W1	W1	🟨	🟨	🟨	🟨	🟨	🟨		
155	47.3	sand		round pebbles present, minerals visible <2mm	very coarse sand	B2	B2			🟨	🟨	🟨	🟨	🟨	🟨	🟨	
160	48.8	sand		minerals visible <2mm	coarse sand	B2	B2	W2	W1	🟨	🟨	🟨	🟨	🟨	🟨		
165	50.3	clay	sand	hard clay with clay clumps and coarse sand grains	sandy clay					🟫							
170	51.9	sand		minerals visible <1mm	medium sand	W1	W1			🟨	🟨	🟨	🟨	🟨			
175	53.4	sand		grey colour, many minerals visible <3mm	coarse sand	B1	B1	W2	W3	🟨	🟨	🟨	🟨	🟨	🟨		

Appendix X

Water treatment unit results

GW									
Date	**Day**	**SAMPLE**	**pH [-]**	**DO [mg/L]**	**EC [microS/cm]**	**ORP [mV]**	**T [ºC]**	**As [microg/L]**	**Fe [mg/L]**
9-8-2018	1	1-PT-F1-GW-X	6.94	0.07	675	-84.2	26.7		
		2-PT-F1-GW-F						300	1.9
		3-PT-F1-GW-FR						200	
	2	4-PT-F1-GW-X							
		5-PT-F1-GW-F							
		6-PT-F1-GW-FR							
17-8-2018	3	7-PT-F1-GW-X	7.15	1.86	676	-88.4	27		
		8-PT-F1-GW-F						450	1
		9-PT-F1-GW-FR						400	
27-8-2018	4	X							1.5
		F						450	1
		FR						350	
		10-PT-F1-GW-X							
		11-PT-F1-GW-F							
		12-PT-F1-GW-FR							

BC									
Date	**Day**	**SAMPLE**	**pH [-]**	**DO [mg/L]**	**EC [microS/cm]**	**ORP [mV]**	**T [ºC]**	**As [microg/L]**	**Fe [mg/L]**
9-8-2018	1	1-PT-F1-BC-X	7.01	1.49	671	-117	29		
		2-PT-F1-BC-F						300	0.84
		3-PT-F1-BC-FR						150	
10-8-2018	2	4-PT-F1-BC-X							
		5-PT-F1-BC-F							
		6-PT-F1-BC-FR							
13-8-2018	3	7-PT-F1-BC-X	7.05	1.04	error	-67.8	27.3		
		8-PT-F1-BC-F						400	1
		9-PT-F1-BC-FR						200	
14-8-2018	4	10-PT-F1-BC-X	7.03	0.423	662	-150	28.6		
		11-PT-F1-BC-F							
		12-PT-F1-BC-FR							
15-8-2018	5	13-PT-F1-BC-X	7.04	0.73	662	-29.6	28.8		
		14-PT-F1-BC-F							
		15-PT-F1-BC-FR							
16-8-2018	6	16-PT-F1-BC-X	7.08	1.38	662	181.8	30.4		
		17-PT-F1-BC-F							
		18-PT-F1-BC-FR							
17-8-2018	7	19-PT-F1-BC-X	7.1	1.87	663	144	31.4		
		20-PT-F1-BC-F						400	0
		21-PT-F1-BC-FR						0	
25-8-2018	8	22-PT-F1-BC-X	7.02	0.56	661	204	28.6		
		23-PT-F1-BC-F							
		24-PT-F1-BC-FR							
27-8-2018	9	X							0.15
		F						250	0
		FR						0	
28-8-2018	10	25-PT-F1-BC-X	7.05	0.37	662	90.7	28.6		1
		26-PT-F1-BC-F						250	0
		27-PT-F1-BC-FR						0.05	
29-8-2018	11	X							1.5
		F						250	0.21
		FR						30	

SB

Date	Day	SAMPLE	pH [-]	DO [mg/L]	EC [microS/cm]	ORP [mV]	T [ºC]	As [microg/L]	Fe [mg/L]
		1-PT-F1-SB-X							
		2-PT-F1-SB-F							
		3-PT-F1-SB-FR							
14-8-2018	2	4-PT-F1-SB-X	7.22	2.91	11370*	189.4	29.3		
		5-PT-F1-SB-F						350	0.03
		6-PT-F1-SB-FR						25	
15-8-2018	3	7-PT-F1-SB-X	not taken	not taken	not taken	not taken	not taken		
		8-PT-F1-SB-F							
		9-PT-F1-SB-FR							
16-8-2018	4	10-PT-F1-SB-X	7.32	3.64	662	191.8	31.5		
		11-PT-F1-SB-F							
		12-PT-F1-SB-FR							
17-8-2018	5	13-PT-F1-SB-X	7.28	2.55	662	179	32.6		
		14-PT-F1-SB-F						350	0
		15-PT-F1-SB-FR						0	
25-8-2018	6	16-PT-F1-SB-X	7.27	3.36	662	201.2	31.2		
		17-PT-F1-SB-F							
		18-PT-F1-SB-FR							
28-8-2018	7	19-PT-F1-SB-X	7.27	3.41	661	193.8	30.3		2
		20-PT-F1-SB-F						200	0
		21-PT-F1-SB-FR						30	

FB

Date	Day	SAMPLE	pH [-]	DO [mg/L]	EC [microS/cm]	ORP [mV]	T [ºC]	As [microg/L]	Fe [mg/L]
9-8-2018	1	1-PT-F1-FB-X	7.26	3.25	667	36	29.9		
		2-PT-F1-FB-F						200	0.1
		3-PT-F1-FB-FR						40	
10-8-2018	2	4-PT-F1-FB-X	7.23	1.41	658	21.7	30.6		
		5-PT-F1-FB-F							
		6-PT-F1-FB-FR							
13-8-2018	3	7-PT-F1-FB-X	7.2	2.01	error	10.5	29.8		
		8-PT-F1-FB-F						200	0.01
		9-PT-F1-FB-FR						60	
14-8-2018	4	10-PT-F1-FB-X	7.22	2.43	660	76	29		
		11-PT-F1-FB-F							
		12-PT-F1-FB-FR							
15-8-2018	5	13-PT-F1-FB-X	7.28	2.73	660	104.5	29.7		
		14-PT-F1-FB-F							
		15-PT-F1-FB-FR							
16-8-2018	6	16-PT-F1-FB-X	7.3	3.15	660	177	30.9		
		17-PT-F1-FB-F							
		18-PT-F1-FB-FR							
17-8-2018	7	19-PT-F1-FB-X	7.25	2.56	661	144	31.5		
		20-PT-F1-FB-F						200	0
		21-PT-F1-FB-FR						0	
18-8-2018	8	X							0.1
		F						130	0
		FR						0	
25-8-2018	9	22-PT-F1-FB-X	7.21	1.65	657	138.8	30.2		
		23-PT-F1-FB-F							
		24-PT-F1-FB-FR							
27-8-2018	10	X							0.2
		F						200	0
		FR						0	
28-8-2018	11	25-PT-F1-FB-X	7.3	2.12	658	120.8	295		0.3
		26-PT-F1-FB-F						200-250	0
		27-PT-F1-FB-FR						0	
29-8-2018	12	X							0.36
		F						100	0
		FR						0	

SS

Date	Day	Sample	pH [-]	DO [mg/L]	EC [microS/cm]	ORP [mV]	T [ºC]	As [microg/L]	Fe [mg/L]
10-8-2018	1	1-PT-F1-SS-X	7.34	2.66	660	140.5	30.5		
		2-PT-F1-SS-F							
		3-PT-F1-SS-FR							
13-8-2018	2	4-PT-F1-SS-X	7.47	5.41	error	121.1	30		
		5-PT-F1-SS-F						200	0
		6-PT-F1-SS-FR						35	
14-8-2018	3	7-PT-F1-SS-X	7.37	3.85	660	129.1	29.8		
		8-PT-F1-SS-F							
		9-PT-F1-SS-FR							
15-8-2018	4	10-PT-F1-SS-X	7.46	4.41	658	not taken	29.7		
		11-PT-F1-SS-F							
		12-PT-F1-SS-FR							
16-8-2018	5	13-PT-F1-SS-X	7.41	4.32	659	183	30.6		
		14-PT-F1-SS-F							
		15-PT-F1-SS-FR							
17-8-2018	6	16-PT-F1-SS-X	7.37	3.97	660	106	31.4		
		17-PT-F1-SS-F						200	0
		18-PT-F1-SS-FR						0	
25-8-2018	7	19-PT-F1-SS-X	7.35	3.16	656	194.5	30.2		
		20-PT-F1-SS-F							
		21-PT-F1-SS-FR							
28-8-2018	8	22-PT-F1-SS-X	7.35	3.14	657	154.3	29.5		0.27
		23-PT-F1-SS-F						200	0
		24-PT-F1-SS-FR						0.01	

AA

Date	Day	SAMPLE	pH [-]	DO [mg/L]	EC [microS/cm]	ORP [mV]	T [ºC]	As [microg/L]	Fe [mg/L]
	1	1-PT-F1-AA-X							
		2-PT-F1-AA-F							
		3-PT-F1-AA-FR							
13-8-2018	2	4-PT-F1-AA-X	7.39	4.08	error	146	30.1		
		5-PT-F1-AA-F						100	0
		6-PT-F1-AA-FR						25	
14-8-2018	3	7-PT-F1-AA-X	7.35	4.2	659	139	29.9		
		8-PT-F1-AA-F							
		9-PT-F1-AA-FR							
15-8-2018	4	10-PT-F1-AA-X	7.42	3.04	656	95	29		
		11-PT-F1-AA-F						150	0.03
		12-PT-F1-AA-FR						13	
16-8-2018	5	13-PT-F1-AA-X	7.34	3.25	656	92	29.9		
		14-PT-F1-AA-F						150	0
		15-PT-F1-AA-FR						3	
17-8-2018	6	16-PT-F1-AA-X	7.28	1.56	658	40	30.7		
		17-PT-F1-AA-F						200	0.05
		18-PT-F1-AA-FR							
25-8-2018	7	19-PT-F1-AA-X	7.34	3.96	655	177.8	29.7		
		20-PT-F1-AA-F						100	
		21-PT-F1-AA-FR						8	
27-8-2018	8	X							0.1
		F						200	0
		FR						0	
28-8-2018	9	22-PT-F1-AA-X	7.44	2.93	655	108	29.2		0.17
		23-PT-F1-AA-F						90	0
		24-PT-F1-AA-FR						0	

FS									
Date	Day	SAMPLE	pH [-]	DO [mg/L]	EC [microS/cm]	ORP [mV]	T [ºC]	As [microg/L]	Fe [mg/L]
9-8-2018	1	1-PT-F1-FS-X	7.2	5.13	691	72.8	30.1		
		2-PT-F1-FS-F						5/10*	0.05
		3-PT-F1-FS-FR						9	
10-8-2018	2	4-PT-F1-FS-X	7.38	5.97	667	116.2	30.1		
		5-PT-F1-FS-F							
		6-PT-F1-FS-FR							
13-8-2018	3	7-PT-F1-FS-X	7.59	6.26	652	174.5	28.9		
		8-PT-F1-FS-F						70	0
		9-PT-F1-FS-FR						1	
14-8-2018	4	10-PT-F1-FS-X	7.29	1.28	654	170	30.1		
		11-PT-F1-FS-F							
		12-PT-F1-FS-FR							
15-8-2018	5	13-PT-F1-FS-X	7.36	1.77	655	183.3	28.8		
		14-PT-F1-FS-F						38	0
		15-PT-F1-FS-FR						5	
16-8-2018	6	16-PT-F1-FS-X	7.43	4.76	656	245.3	28.9		
		17-PT-F1-FS-F						110	0
		18-PT-F1-FS-FR						5	
17-8-2018	7	19-PT-F1-FS-X	7.2	0.11	656	20.5	30.5		
		20-PT-F1-FS-F						100	0
		21-PT-F1-FS-FR						8	
18-8-2018	8	X							0.15
		F						80	0.02
		FR						3	
25-8-2018	9	22-PT-F1-FS-X	7.38	2.02	656	183.4	29		0.1
		23-PT-F1-FS-F						100	0
		24-PT-F1-FS-FR						6	
26-8-2018	10	X							0.3
		F						200	0
		FR						0	
28-8-2018	11	25-PT-F1-FS-X	7.5	4.1	652	132.1	28.7		1.5
		26-PT-F1-FS-F						75	0
		27-PT-F1-FS-FR						0	
29-8-2018	12	X							0.64
		F						82	0
		FR						3	

AR

Date	Day	SAMPLE	pH [-]	DO [mg/L]	EC [microS/cm]	ORP [mV]	T [ºC]	As [microg/L]	Fe [mg/L]
9-8-2018	1	1-PT-F1-AR-X	6.87	4.44	791	118	30.4		
		2-PT-F1-AR-F						3	0
		3-PT-F1-AR-FR						3	
10-8-2018	2	4-PT-F1-AR-X	7.39	5.48	688	94.4	29.8		
		5-PT-F1-AR-F							
		6-PT-F1-AR-FR							
13-8-2018	3	7-PT-F1-AR-X	7.53	3.28	631	192	28.8		
		8-PT-F1-AR-F						0	0
		9-PT-F1-AR-FR						0	
14-8-2018	4	10-PT-F1-AR-X	7.27	0.95	654	202.9	29.8		
		11-PT-F1-AR-F							
		12-PT-F1-AR-FR							
15-8-2018	5	13-PT-F1-AR-X	7.36	1.27	667	190	28.8		
		14-PT-F1-AR-F							
		15-PT-F1-AR-FR							
16-8-2018	6	16-PT-F1-AR-X	7.44	4.99	659	251	28.9		
		17-PT-F1-AR-F						53	0
		18-PT-F1-AR-FR						0	
17-8-2018	7	19-PT-F1-AR-X	7.12	0.04	661	36.6	30.3		
		20-PT-F1-AR-F						93/63*	0
		21-PT-F1-AR-FR						3	
18-8-2018	8	X							0
		F						70	0
		FR						16	
19-8-2018	9								
								4	
25-8-2018	10	22-PT-F1-AR-X	7.38	1.46	653	118	28.7		0
		23-PT-F1-AR-F						84	0
		24-PT-F1-AR-FR						13	
27-8-2018	11	X	LEFT RESIN COLUMN						0
		F						92	
		FR						0	
27-8-2018	11	X	RIGHT RESIN COLUMN						0
		F						76	
		FR						0	
28-8-2018	12	25-PT-F1-AR-X	LEFT RESIN COLUMN						0
		26-PT-F1-AR-F						84	0
		27-PT-F1-AR-FR						0	
28-8-2018	12	25-PT-F1-AR-X	RIGHT RESIN COLUMN						0.15
		26-PT-F1-AR-F						80	0
		27-PT-F1-AR-FR						0	
29-8-2018	13	X	FINAL. AFTER THE TWO RESINS IN PARALLEL						0.36
		F						50	0
		FR						1	

BWB-O

Date	Day	SAMPLE	pH [-]	DO [mg/L]	EC [microS/c	ORP [mV]	T [ºC]	As [microg/L	Fe [microg/L]
13-8-2018	1	1-PT-F1-BWB-O-X	7.06	33	error	-51	29		
		2-PT-F1-BWB-O-F						300	0.15
		3-PT-F1-BWB-O-FR						30	
17-8-2018	2	4-PT-F1-BWB-O-X	7.11	18	662	172.6	29.6		
		5-PT-F1-BWB-O-F						200	0
		6-PT-F1-BWB-O-FR							

BWS-O

Date	Day	SAMPLE	pH [-]	DO [mg/L]	EC [microS/c	ORP [mV]	T [ºC]	As [microg/L]	Fe [microg/L]
13-8-2018	1	1-PT-F1-BWS-O-X	7.08	4.86	error	155.2	29.2		
		2-PT-F1-BWS-O-F						30	0
		3-PT-F1-BWS-O-FR						NO FOR BW	
17-8-2018	2	4-PT-F1-BWS-O-X	7.14	0.74	667	170	29.7		
		5-PT-F1-BWS-O-F						100	0
		6-PT-F1-BWS-O-FR							

Appendix XI

This Appendix contains the supportive pictures of the drillings. The pictures are merged in the zip file with name *Supportive Documents Project Bangla.rar*. The pictures contain all the retrieved samples and the three different soil profiles.


BRASIL
BRASIL
BRASIL
CBF
FIFA
adidas