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Development of participatory water management strategies for peri-urban low-income areas – A socio-hydrogeological case study in Jaipur, India

Dissertation
zur Erlangung des Grades
Doctor rerum naturalium (Dr. rer. nat.)
am Fachbereich Geowissenschaften der Freien Universität Berlin

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vorgelegt am: 29.08.2019

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Tag der Disputation:	28.05.2020

Summary

The dissertation was part of the project "Women's Action towards Climate Resilience for Urban Poor in South Asia" under the lead of the Indian NGO Mahila Housing SEWA Trust. The project took place in the frame of the Global Resilience Partnership funded by Rockefeller Foundation, USAID and SIDA for a two-year period (2016-2018). The Hydrogeology Group from Freie Universität Berlin focused on Jaipur, the capital of Rajasthan in Northwest India, and was responsible for socio-hydrogeological investigations. Two low-income communities in the peri-urban fringe of Jaipur without sufficient water supply both in quality and quantity were selected as pilot areas for socio-hydrogeological studies. They represent two different typical geological settings in Jaipur and their water problems are representative of many low-income areas throughout the country. They also differ significantly from each other in terms of social aspects being a Hindu community on the one hand (Khara Kuaa) and a Muslim community on the other hand (Nai Ki Thari).

The main research question was how to establish participatory groundwater management in these areas together with local women groups. The research was therefore structured into two parts. Next to the participatory work, which was executed with women from both communities, the hydrogeology of the two study areas was investigated to understand the groundwater-related problems occurring in peri-urban poor areas in detail and to develop scientific sound solution strategies adapted to local conditions.

The two main aquifers of the area, the overlying Quaternary alluvium (up to 100 m thick) and the deeper Proterozoic fractured hard rock aquifer show both anthropogenic and geogenic impacts which decrease groundwater quality and quantity. In general, the groundwater of both aquifers is not potable, due to high TDS values above the permissible limit of 500 mg/L given in the Indian Standard for drinking water and/or high nitrate values above the permissible limit of 45 mg/L. Declining water tables due to over abstraction put further stress on the intensively used groundwater resource.

Significant differences exist between Khara Kuaa and Nai Ki Thari in terms of water supply. In Khara Kuaa, about two thirds depend on the municipal water line (surface water mixed with groundwater) followed by >25 % ordering private tanker (groundwater), while in Nai Ki Thari the main supply source is private tanker (groundwater) followed by 30 % using wells (groundwater). In general, the water supply infrastructure is characterized by a large number of privately organized legal and illegal components which poses a challenge both for consumers and responsible authorities. The poorer the household, the higher the cost of drinking water and the more time it takes to fetch it, while wealthier households can draw water freely and "unlimited" or are connected to public water supply.

Preparatory social investigations revealed that a lack of knowledge and expertise in the communities leads to many water-related problems, such as wastage of water, illegal pipeline connections, practicing open defecation up-gradient of drinking water production wells and thinking in limited ways (temporal and spatial). A lack of capacity in terms of time, media access and confidence of the slum dwellers requires a solution, which is tailored to their needs and capabilities.

A participatory approach including three main steps – awareness raising and basic knowledge transfer, capacity development and active involvement, evaluation and upscaling – were developed and applied during a 1.5-year field stay in Jaipur. While this study showed that it is definitely possible to teach non-experts how to map their area, to take a water sample by themselves and to make a first basic assessment of the groundwater situation of their area, the concrete outcomes in terms of an improvement of the current situation were not satisfying. Reasons for this lie in miscommunications, a lack of time, a missing detailed stakeholder analysis and the fact that the branch office of the NGO in Jaipur is not yet as established within the city institutions as the head office in Ahmedabad. Furthermore, the concept of time consuming research work necessary to establish sustainable solutions is not widely known among the target group of the project.

Nevertheless, sustainable outcomes were achieved by developing a media portfolio which was handed over to the Indian NGO. It consists of various formats and is adapted to the target group of local NGOs and, in large parts, uneducated poor women. Components of the portfolio are the "water workshops", a physical groundwater model, the training manual, which is based on the experiences gained during the project, as well as the filmic documentation and the educational short film which emerged out of the transdisciplinary cooperation with a filmmaker.

The results of this study add new knowledge to the expanding field of participatory and socio-hydrogeological research in groundwater management and show that this approach can contribute to a raising awareness of groundwater among local population as well as NGOs working in the field of water management.

Zusammenfassung

Die Dissertation war Teil des Projekts „Women's Action towards Climate Resilience for Urban Poor in South Asia" unter der Leitung der indischen NGO Mahila Housing SEWA Trust. Das Projekt fand im Rahmen der von der Rockefeller Foundation, USAID und SIDA finanzierten Global Resilience Partnership für einen Zeitraum von 2 Jahren (2016-2018) statt.

Die Arbeitsgruppe Hydrogeologie der Freien Universität Berlin konzentrierte sich auf Jaipur, die Hauptstadt von Rajasthan im Nordwesten Indiens, und war für sozio-hydrogeologische Untersuchungen verantwortlich. Zwei einkommensschwache Gemeinden am Stadtrand von Jaipur ohne ausreichende Wasserversorgung in Qualität und Quantität wurden als Pilotgebiete für sozio-hydrogeologische Studien ausgewählt. Sie repräsentieren zwei verschiedene typische geologische Gegebenheiten in Jaipur und ihre Wasserprobleme sind repräsentativ für viele einkommensschwache Gebiete in ganz Indien. Weiterhin unterscheiden sie sich auch in sozialen Aspekten deutlich voneinander, die eine Gemeinde ist hinduistisch (Khara Kuaa) und die andere muslimisch (Nai Ki Thari).

Die hauptsächliche Forschungsfrage war, wie in diesen Gebieten, gemeinsam mit lokalen Frauengruppen, ein partizipatives Grundwassermanagement aufgebaut werden kann. Die Forschung war daher in zwei Teile gegliedert. Neben der partizipativen Arbeit, die mit Frauen aus beiden Gemeinden durchgeführt wurde, wurde die Hydrogeologie der beiden Untersuchungsgebiete untersucht, um die grundwasserbezogenen Probleme in den peri-urbanen Armutsgebieten im Detail zu verstehen und wissenschaftlich fundierte, an die lokalen Bedingungen angepasste Lösungsstrategien zu entwickeln.

Die beiden wichtigsten Aquifere des Gebietes, das quartäre Alluvium mit einer Mächtigkeit bis zu 100 m, und der tiefere proterozoische Festgesteins-Aquifer zeigen sowohl anthropogene als auch geogene Einflüsse, die die Qualität und Quantität der Grundwasserressource beeinträchtigen. Im Allgemeinen ist das Grundwasser beider Grundwasserleiter aufgrund hoher TDS-Werte über dem in der Indischen Norm für Trinkwasser festgelegten Grenzwert von 500 mg/L und/oder hoher Nitratwerte über dem zulässigen Grenzwert von 45 mg/L nicht trinkbar. Sinkende Grundwasserspiegel durch eine Überentnahme belasten die intensiv genutzte Grundwasserressource zusätzlich.

Zwischen Khara Kuaa und Nai Ki Thari bestehen signifikante Unterschiede in der Wasserversorgung. In Khara Kuaa hängen etwa zwei Drittel von der städtischen Wasserleitung ab (Oberflächen-

wasser gemischt mit Grundwasser), gefolgt von >25 % die auf private Wassertankwagen zurückgreifen (Grundwasser), während in Nai Ki Thari die privaten Wassertankwagen (Grundwasser) den Hauptanteil ausmachen, gefolgt von 30 % die sich durch Brunnen versorgen (Grundwasser). Im Allgemeinen ist die Wasserversorgungsinfrastruktur durch eine Vielzahl privat organisierter legaler und illegaler Komponenten gekennzeichnet, was sowohl für die Nutzer als auch für die zuständigen Behörden eine Herausforderung darstellt. Das resultiert in einer Situation in der, je ärmer der Haushalt ist, desto höher sind die Trinkwasserkosten und desto mehr Zeit braucht er für die Beschaffung, während reichere Haushalte frei und "unbegrenzt" Wasser beziehen können oder an die öffentliche Wasserversorgung angeschlossen sind.

Vorbereitende sozialwissenschaftliche Untersuchungen ergaben, dass mangelndes Wissen und Können in den Gemeinden zu vielen wasserbedingten Problemen führen, wie z.B. Wasserverschwendung, illegale Leitungsanschlüsse, öffentliche Defäkation im Anstrom von Trinkwasserbrunnen und einem Denken in räumlich und zeitlich begrenztem Raum. Mangelnde Kapazitäten in Bezug auf Zeit, Medienzugang und Vertrauen der Bewohner der Armenviertel erfordern eine Lösung, die auf ihre Bedürfnisse und Fähigkeiten zugeschnitten ist.

Ein partizipativer Ansatz wurde entwickelt, der sich aus drei Hauptteilen aufbaut: Sensibilisierung und Wissenstransfer, Kapazitätsaufbau und aktive Beteiligung, Auswertung und Verbreitung. Dieser Ansatz wurde während eines 1,5-jährigen Forschungsaufenthaltes in Jaipur angewendet. Diese Studie zeigte, dass es möglich ist, Laien beizubringen, wie ein Gebiet kartiert wird, eine Wasserprobe genommen wird und eine erste grundlegende Bewertung der Grundwassersituation des eigenen Gebietes vorgenommen werden kann. Jedoch waren die konkreten Auswirkungen, im Sinne einer Verbesserung der aktuellen Situation, nicht zufriedenstellend. Gründe dafür liegen in Missverständnissen, Zeitmangel, einer fehlenden detaillierten Stakeholder-Analyse und der Tatsache, dass die Niederlassung der NGO in Jaipur noch nicht so stark in den städtischen Institutionen verankert ist, wie die Zentrale in Ahmedabad. Darüber hinaus ist das Konzept zeitaufwendiger Forschung, die zur Etablierung nachhaltiger Lösungen notwendig ist, bei der Zielgruppe des Projekts nicht bekannt.

Dennoch wurden nachhaltige Ergebnisse durch die Entwicklung eines Medienportfolios erzielt, das zum großen Teil bereits an die indische NGO übergeben wurde. Das Portfolio besteht aus verschiedenen Formaten und ist an die Zielgruppe (lokale NGOs und, in weiten Teilen ungebildete, arme Frauen) angepasst. Bestandteile des Portfolios sind die "Wasser-Workshops", ein physikalisches Grundwassermodell, das Handbuch, das auf den Erfahrungen des Projekts basiert, sowie die filmische Dokumentation und der kurze Bildungs-Film, die aus der transdisziplinären Zusammenarbeit mit einer Filmemacherin entstanden sind.

Die Ergebnisse dieser Studie fügen dem immer wichtiger werdenden Feld der partizipativen und sozio-hydrogeologischen Forschung im Bereich des Grundwassermanagements neue und bedeutende Erkenntnisse hinzu und zeigen, dass dieser Ansatz dazu führen kann, das Bewusstsein der lokalen Bevölkerung sowie der NGOs, die im Bereich von Wassermanagement tätig sind, für das Thema Grundwasser zu schärfen.

Acknowledgements

First of all, I would like to thank Dr. Maike Gröschke and Prof. Dr. Michael Schneider for their support and supervision of my work. I thank Dr. Gröschke for her scientific advice and her true interest. I am very grateful for the always exciting, challenging and inspired discussions with her! I thank Prof. Dr. Schneider for his scientific advice and for the great freedom I had in my research enabling me to follow new ways of hydrogeological research.

My sincere thank also goes to Prof. Dr. Tilmann Rost from the Geographical Institute at Freie Universität Berlin for his evaluation of this thesis.

Big thanks and acknowledgements go to the local women assistants in Jaipur who agreed to take part in this project and without whom this study would not have been possible. I am grateful for their trust, their efforts and their friendship. Furthermore, I want to thank all women community groups in Ahmedabad, Bhopal and Jaipur, who participated at the water workshops with true enthusiasm and a lot of curiosity.

A big thank you goes to everyone who contributed to the study: Nearly all of the work in Jaipur, which often exceeded standard working hours and tasks, was conducted together with Mohsin Khan. Without his great, honest and never ending commitment, it would not have been able to conduct the field work in the way it was done. We were a perfect team, and I would like to thank him for his help and his friendship. Furthermore, I want to thank the students who conducted field work together with me: Maximillian Nölscher, Carolin Winter and Michal Mutz. All of them showed an extraordinary commitment. I enjoyed working with them and greatly appreciate their efforts that resulted in excellent theses. I also want to thank all other students who wrote or still write their thesis within this project and, therefore, contributed to the results: Christoph Brüdigam, Natja Bublitz, Nele Hastreiter, David Netscher, Nico Poschinski, Lilli Witt, Anna Wypukol and Patrick Zentel. A thank you goes also to the Indian student intern Shubhangi Jain who was a great support during field work. I also like to cordially thanks the filmmaker Katalin Ambrus for her commitment towards the project and that she opened up my mind into new directions.

I would like to thank all project partners of the GRP project, especially Dharmistha Chauhan and Srishti Singh from MHT Ahmedabad and all staff members of MHT Jaipur. Furthermore, I am grateful for the data and information sharing from RGWB Rajasthan and PHED Jaipur.

Thanks a lot to all colleagues from the Hydrogeology Group at FU Berlin who gave constructive hints. Thank you to Martin Recker of the great support regarding technical equipment, to Dietrich

Lange for constructing the flow through cells, to Benjamin Rommel for the support by constructing the physical groundwater model and to Elke Heyde for the water analyses.

Acknowledgements also go to BGR, especially Dr. Paul Königer, head of the Isotope Laboratory. His interest and extraordinary engagement made it possible to do more research about the nitrate contamination. I further want to thank for the isotopic analyses conducted at the BGR laboratory. For critical remarks and discussion about the interpretation of geoelectrical soundings my thanks go to Dr. Raphael Dlugosch from the Leibniz Institute for Applied Geophysics.

The questionnaires were developed with the help of the team of the human-centered-design online course: Evgeny Kiverin, Sarmistha Pantham, Anja Urzendowsky and Lea. The interview with Dr. Michael Gottlob from amnesty international were conducted together with Evgeny Kiverin, the interview with Srishti Singh from MHT was conducted together with Anja Urzendowsky. For the inspiring experiences in this interdisciplinary team and for their agreement to focus on my project for the course, I want to thank all of them.

I further tanks Arne and Iona for their proof-reading and my dear flat mates for delicious cooking.

Finally, I would like to say a heartfelt thank-you to Kolja Bosch for numerous hydrogeological discussions, great help at the field work and during the finalization of the manuscript.

Contents

International boundary lines shown in any of the figures are not meant as a political statement by the author. They were taken from the cited references and might differ from the currently recognized boundary lines.

Abbreviations

AFB	Aravalli Fold Belt
BGC	Banded Gneissic Complex
BW	Bore Well
CAG	Community Action Group
CBO	Community Based Organization
CGWB	Central Groundwater Board
CW	Constructed Wetland
DEM	Digital Elevation Model
D-GPS	Differential GPS
DW	Dug Well
FU	Freie Universitaet
GPS	Global Positioning System
GHG	Greenhouse Gas
GRP	Global Resilience Partnership
GWD	Groundwater Development
GWP	Global Water Partnership
HH	Household
HP	Hand pump
ICP	Inductively Coupled Plasma
INR	Indian Rupee
IWRM	Integrated Water Resource Management
JDA	Jaipur Development Authority
JMC	Jaipur Municipal Cooperation
KK	Khara Kuaa
L	Liter
Lat	Latitude
Lon	Longitude
lpcd	Liter per Capita per Cay
masl	Meter Above Sea Level
mbgl	Meter Below Ground Level
mcm	Million Cubic Meter
MHT	Mahila Housing SEWA Trust
MLD	Million Liter per Day
NDFB	Northern Delhi Fold Belt
NGO	Non-Government Organization
NHS	National Hydrograph Station
NKT	Nai Ki Thari
NN	Normal Null
OBS	Observation Well
PHED	Public Health Engineering Department
RCP	Representative Concentration Pathways
RGWB	Regional Groundwater Board
RHB	Rajasthan Housing Board
RO	Reverse Osmosis
SDFB	Southern Delhi Fold Belt
SDG	Sustainable Development Goal
SEWA	Self Employed Women Association
STP	Sewage Treatment Plant

SIDA	Swedish International Development Cooperation Agency
SW	Step Well
TAC	Technical Advisory Board
TIC	Total Inorganic Carbon
TOC	Total Organic Carbon
UN	United Nations
UNCED	United Nations Conference on Environment and Development
WHO	World Health Organization
WL	Water Line

Figures

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Glossary of Hindi Terms

Some Hindi terms are regularly used in English literature from and about India as well as in daily local usage. Therefore, these terms are also used in this work. A brief explanation of all the terms is given below. Furthermore, some relevant Hindi words, e.g. for water, are also listed:

Auto-wallah	Driver of a motorized three-wheeler, sometimes also called Tuk-tuk
Johad	Traditional recharge structures and village ponds in North India
katchi basti	Shack or non-permanent structure
khara	salty
Kuaa	Well
Mahila	Woman
Nallah	Channel, drain
Pani	Water
pucca	solid, e.g. related to the construction of houses or streets (in contrast to *katchi*)
Sari	Traditional Indian dress
Taalaab	Pond
Tehsil	administrative division within a city
Vikasini	Local feminine connotation meaning "carriers of development"

Preliminary Remarks

The terms "slum" and "low-income area" are used synonymously within this document. The word "slum" is used by the Indians involved in the project themselves, e.g. by the MHT staff (MHT - Mahila Housing SEWA Trust, 2015a) and by the local population in Jaipur to name their area. Therefore, the author decided, likewise, to use the term in this work in places where a replacement by the term low-income area was seen as inappropriate. However, the author is aware that the term "slum" has manifold historical connotations, which are mainly negative.

Gilbert (2007) discusses and heavily criticizes the use of the term "slum" because, among other reasons, it is a relative concept rather than an absolute one. That means the concept changes depending on time and place and it therefore becomes impossible to define it in a scientific way. As the term "slum" is still used within this thesis, a classification is provided below. The definition given by The American Heritage Dictionary (2019) states that a slum is "a heavily populated urban area characterized by substandard housing and squalor." This definition is not appropriate as the study areas of this project are situated in the peri-urban fringe of the city. Furthermore, it is a short and simplifying definition. The definition given by UN-Habitat is more detailed:

> "The operational definition of a slum that has recently been recommended [by a UN Expert Group Meeting] . . . defines a slum as an area that combines, to various extents, the following characteristics: inadequate access to safe water, inadequate access to sanitation and other infrastructure, poor structural quality of housing, overcrowding, and insecure residential status." (United Nations Human Settlements Programme, 2003).

Gilbert (2007) comments that in this definition the UN focusses only on the physical and legal characteristics of settlements, while excluding the more difficult social dimensions. While acknowledging this valid critique, the author has chosen to mainly use the definition given by UN-Habitat in this thesis.

PART 1 Introduction

1.1 Project Background

The dissertation was part of the project "Women's Action towards Climate Resilience for Urban Poor in South Asia" under the lead of the Indian organization Mahila Housing SEWA Trust (MHT). The project took place in the frame of the Global Resilience Partnership (GRP) funded by the Rockefeller Foundation, USAID and SIDA for a two-year period (2016-2018). The GRP addresses regional and local organization in the Sahel, the Horn of Africa and Southeast Asia working on adaptation strategies to shocks and chronic stresses in times of climate change.

1.1.1 Project: "Women's Action towards Climate Resilience for Urban Poor in South Asia"

The project "Women's Action towards Climate Resilience for Urban Poor in South Asia" aimed to empower women from low-income areas in seven South Asian cities to take action against the most pressing climate-related risks (heat waves, flooding, water scarcity and water and vector borne diseases). The project consortium was made up of an interdisciplinary team of 17 partners, 15 Indian and two international organizations, including experts in urban planning, social sciences, urban health systems, water sciences, insurance and communication. The leading organization Mahila[1] Housing SEWA Trust was founded in 1994 as an autonomous organization within the Self-Employed Women's Association (SEWA) of India. Its main vision was to realize sound housing and living environments for poor women in the informal sector. Today, six thematic areas are addressed: (1) Water, Sanitation and Hygiene, (2) Energy and Climate Change, (3) Housing and Land Rights, (4) Housing Finance, (5) Skill Development and Livelihood and (6) Urban Land Planning and Governance. MHT's way of working is to promote the development of so-called Community-Based Organizations (CBOs) and to enhance women's leadership. Since 1994, MHT has continuously increased its presence in South Asia. Today, it has branches in seven Indian states, in addition to its head office in Ahmedabad, and it also operates in Kathmandu, Nepal and Dhaka, Bangladesh (MHT - Mahila Housing SEWA Trust, 2019a). The geographical focus of the project was the seven growing cities Ahmedabad, Bhopal, Jaipur, Ranchi, Bhubaneshwar, Dhaka and Kath-

[1] *Mahila* is the Hindi word for women.

mandu (MHT - Mahila Housing SEWA Trust, 2015a). The Hydrogeology Group from Freie Universität Berlin (FU Berlin) was focused on Jaipur and was responsible for socio-hydrogeological investigations.

1.1.2 Case Study Jaipur

Jaipur was chosen among the project cities as the case study for FU Berlin due to the following hydrogeological and practical considerations:

1) Shallow groundwater levels prevail in large parts of the city (CGWB, 2007). Because the unsaturated zone is thin and the filter capacity of the soil is low, the groundwater of the shallow aquifer is highly vulnerable to contamination.

2) The sanitation situation is more disadvantageous than in the other project areas, e.g. Ahmedabad (personal communication MHT, 2015). Hence, more action is required.

3) Nitrate and fluoride contaminations occur in different areas within the city (CGWB, 2007). The fluoride contamination can be linked to geogenic fluoride contamination due to the dissolution of fluoride containing minerals in the hard rock (see point 4) as well as due to anthropogenic inputs from the dyeing and printing industries in Jaipur (CGWB, 2007). Increased nitrate and fluoride concentrations are typical water quality problems in India. Therefore, results of the case studies would be of general interest at other locations.

4) The local geology is characterized by two main layers, alluvium and quartzite. The alluvial sediments (up to 100 m thick) overlie hard rock. The hard rock partly functions as an aquifer and water-rock interactions occur (Rolta India Limited, 2013). Huge parts of northern India are covered by alluvial sediments while in southern India hard rock prevails (Wandrey & Law, 1997). Jaipur therefore offers the opportunity to investigate two aquifer types which are widespread in India.

5) Different local groundwater situations exist within the city. While in some areas groundwater levels rise or do not change much despite groundwater abstraction caused by leaking sewer systems, declining groundwater tables occur at other locations (CGWB, 2013).

6) Jaipur is not located on a major river system. This makes it more challenging to meet water demand as elements such as check dams and riverbank filtration sites, which can improve water management when incorporated into adopted water management systems, are not available. Other options therefore need to be considered.

7) Predictions of climate change in this area point to increasing drought, which is likely to increase water stress. Furthermore, the expected change in precipitation patterns will increase the occurrence of floods and droughts (Rathore et al., 2011).

8) Storm water drainage management is less developed than in the other potential focus areas, e.g. Ahmedabad. Therefore, there is a greater need for action (personal communication MHT, 2015).

After the decision to focus on Jaipur, two specific low-income areas within the city were selected. It would not have been possible to investigate more areas in detail within two years. Nevertheless, it was important to cover different hydrogeological and socio-economic situations. For the selection process, the following indicators were defined:

1) A women's network with women community leaders connected to MHT exists.

2) Groundwater plays a significant role in the water supply of the community.

3) Nitrate contamination and shallow groundwater levels prevail.

4) Elevated fluoride concentration in the groundwater occurs.

After a preliminary field visit in Jaipur in July 2015, two low-income communities in the peri-urban fringe of Jaipur without sufficient water supply both in quality and quantity were selected as pilot areas for hydrogeological studies. They represent two different typical geological settings in Jaipur and their water problems are representative of many low-income areas throughout the country. They also differ significantly from each other in terms of social aspects being a Hindu community on the one hand (Khara Kuaa) and a Muslim community on the other hand (Nai Ki Thari). Together they cover three of the four indicators mentioned above. It was not possible to include the problem of fluoride contamination, as no women community group exists in the affected areas.

1.2 Purpose of the Dissertation

1.2.1 Problem Definition

The access to clean water is a key factor in enhancing the resilience of slum dwellers against the consequences of climate change, e.g. temperature rise, water- and vector-borne diseases and droughts (Groenwall et al., 2010). However, a significant share of slum dwellers does not have access to a safe water source. For example, Iyer et al. (2014) describe a vulnerable urban ward in

Ahmedabad which consists to more than 80 % of slums and in which water supply is only established for two hours in the morning and one hour in the evening and where problems arise with low pressure and volume.

The underlying causes can be assigned to three main areas: institutional, natural and societal reasons.

Institutional Reasons

As early as 1976, de Maré stated that in most countries water problems do not mainly arise from water scarcity but from management problems (de Maré, 1976; Falkenmark, 1979). In India, water governance is a complex top-down bureaucratic system, with missing communication and linkages between the various institutions on the one hand and overlapping responsibilities on the other hand (Azhoni et al., 2017; Gessler et al., 2008). This inadequate management has manifold consequences, especially for slum dwellers. They are forced to rely on individual solutions, as their areas, especially if situated on the outskirts of cities, are often not connected to public services like water supply and sewerage systems. Even if they are connected to public water supply, this is often insufficient in terms of frequency, duration and stability (Sekhar et al., 2005). Individual solutions are based on shallow groundwater resources in areas where shallow groundwater is available. However, shallow aquifers are especially vulnerable to anthropogenic contamination. Inadequate water management can, therefore, lead to an increase in water-borne diseases from the use of contaminated water (groundwater or surface water). WHO stated that >20 % of contagious diseases in India are water-related (DeNormandie & Sunita, 2002). Furthermore, general mismanagement in the water sector has led to declining water tables on a regional level, as Shah (2007) has identified in numerous places in South Asia. Slum dwellers formerly relying on shallow groundwater resources are forced to either drill deeper wells, use stronger pumps or look for other water sources. Conversely, water management plans and frameworks for cities can be undermined at slum level as there is no control of private and often unauthorized drillings, and the quantity and quality of the pumped water. This not only influences groundwater levels but also groundwater quality. For example, inappropriate well designs can lead to the direct infiltration of flood water into aquifers, or an incorrect construction of wells can lead to a hydraulic circuit between different aquifers (CGWB - Central Groundwater Board, 2011). Iyer et al. (2014) investigated a low-income area in Ahmedabad where people mix the intermittent and insufficient municipal supply water with untreated groundwater. The main point of their conclusion is that the water quality surveillance program by the Municipal Cooperation is not sufficient with regard to microbial and chemical contamination.

To conclude, even if most cities in India have water management plans and monitoring systems and are heading towards a sustainable use of water resources, these plans do not always work at slum level.

Natural Reasons

Management problems are likely to be enhanced in the future due to the effects of climate change. The RCP2.6[2] scenario of the IPCC expects a rise in temperature of 1-1.5 °C for North India by 2081−2100, whereas the RCP8.5 models a temperature increase of 4-5 °C. This means that temperatures will definitely increase, leading to higher water demand for individual and agricultural use but also to increasing evaporation rates. As a consequence, less water will be available to infiltrate through the soil passage into the aquifer leading to less groundwater recharge. Rainfall scenarios are more complicated to model and results vary. The change in average precipitation (1986−2005 to 2081−2100) for the RCP2.6 scenario is less than one standard deviation of the natural internal variability but the RCP8.5 scenario predicts an increase of 10-20 %. At the same time, the report states that climate change will likely reduce renewable surface water and groundwater resources in most dry subtropical regions (IPCC, 2014b). This can be explained by an increase in heavy precipitation events together with a decrease in light precipitation events in South Asia (IPCC, 2014a), resulting in declining groundwater recharge because most of the water will leave the area as surface runoff. Next to changing rainfall patterns, the melting of glaciers will intensify the risk of flood events during the monsoon season (IPCC, 2014a). Without adapted and sustainable water management, extreme flooding can result in the mixing of sewage, rain water and solid waste.

The key climate change-related risks for the Asian region are heat-related human mortality, increased drought-related water and food shortage and increased flood damage to infrastructure, livelihoods and settlements. Urban areas will be increasingly exposed to risks from, among others, heat stress, storms and extreme precipitation, drought and water scarcity. In general, disadvantaged people and communities will face greater risks as their vulnerability is higher due to a lower capacity to adapt to the changes (IPCC, 2014b).

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[2] RCP2.6: stringent mitigation scenario; RCP8.5: scenario with very high GHG emissions. RCP4.5 and RCP6.0: intermediate scenarios. Scenarios without additional efforts to constrain emissions lead to pathways ranging between RCP6.0 and RCP8.5 (IPCC, 2014b).

Societal Reasons

Four primary reasons related to the social, educational and cultural situation are likely to intensify current water problems or may inhibit implementation of an adapted approach: missing knowledge, capacity and communication as well as population growth.

Groundwater is a hidden resource and the understanding of its vulnerability is low as its characteristics are unknown to most of its direct users. This leads to a problem perception only when the consequences and impacts are recognized, e.g. “groundwater is contaminated, because it is yellowish”, water levels are declining, flood events often occur and sewage is discharged into the environment in large quantities. An examination of the causes and the hydrological and hydrogeological reasons behind the numerous water problems does not occur due to a lack of knowledge of basic hydrogeological principles. The second part of the problem is the insufficient infrastructure in low-income areas to monitor groundwater resources and, for example, the success of an implemented water management system. In the case of a community-based management approach, the missing capacity of users in terms of time, access to knowledge and financial resources may constrain a sustainable outcome. Thirdly, a major barrier in establishing water management solutions in poor areas is the missing communication between users on the one hand and water supplier or governmental officials on the other hand leading to a high level of mistrust. Furthermore, there is a widespread lack of communication and knowledge transfer between “water experts”, e.g. hydrogeologists, and local communities (Limaye, 2017). Another challenge for just and sustainable management is the high population growth associated with an increasing urbanization rate which is faster than infrastructure growth (Moreno et al., 2016).

1.2.2 Research Questions

Based on the problem definition and on discussions with MHT, it was decided to use the approach of participatory groundwater management.

The main research question that evolved out of this is:

- How to establish participatory groundwater management in peri-urban low-income communities in India?

This project's main goal was to achieve a knowledge transfer so that MHT could adopt this approach in other low-income areas of Jaipur and other cities and achieve a long-term impact including an increased awareness and knowledge of water resources. With this in mind, the overarching question was divided into more specific questions:

- What minimal hydrogeological knowledge is necessary to enable local groups to independently study and assess the status of the groundwater they use and to think about solution strategies?
- How much technical knowledge can be transferred to non-experts?
- How can this knowledge be transferred sustainably (science communication)?

The project also aims to bring hydrogeology and local water projects together. This happens in two directions. There are numerous water projects which are being conducted without consideration of hydrogeological aspects or even without any knowledge of hydrogeology. It is therefore crucial to create awareness about the importance of including hydrogeology into water projects and research is necessary to understand how this can be achieved. On the other side, many hydrogeologists are working without any knowledge of the socio-economics behind water and groundwater and how local people and communities are affected by mismanagement (Barthel & Seidl, 2017). Altogether, it is widely accepted that by working in an interdisciplinary way water projects can be made more sustainable (Barthel et al., 2017).

With the goal of equipping hydrogeologists with the knowledge and tools to implement participatory management, the following questions were defined for this thesis:

- Apart from hydrogeological data, which information on a community or research area is necessary to develop strategies for better (local) groundwater management?
- Which methods are available to collect this information, when and how should they be used, and which challenges are to be expected?
- How can participatory work be prepared and carried out?

Next to the participatory work which was conducted with women from both communities, the hydrogeology of the two study areas (see Chapter 1.1.2 *Jaipur Case Study*) was investigated to understand the groundwater-related problems occurring in peri-urban poor areas in detail and finally, to develop scientifically sound solution strategies adapted to local conditions. To implement an adapted water management system, it is of utmost importance to have reliable and high-quality information on the whole water system in the area. Besides detailed information on the local hydrogeology (number and characteristics of the aquifers) and the number of wells, their depths and designs, target aquifer and abstraction rates, information about all existing water bodies e.g. talabs, rivers, channels and their use by the local people has to be known. It is also important to collect data about existing connections to municipal water services, for drinking water as well as for sewage water. In addition to the hydrogeological data, it is important to collect data about the local population. The number of people living in the study area has to be known as well as how many households are connected to the municipal water supply, including public taps and piped water and how many households depend on individual solutions such as private drillings. The same data scheme has to be applied to the sanitation sector. It is important to know the number of households equipped with their own toilets and the number of people, who use public toilets, if they are available, or who depend on open spaces for defecation. Furthermore, the quality and quantity of sewage storage capacities have to be analyzed as well as the sewage canals and other sewage infrastructures.

Therefore, the primary aims of the hydrogeological research were to:

- understand water quality problems and to differentiate between geogenic and anthropogenic causes,
- understand water quantity problems and differentiate between natural and anthropogenic causes,
- understand the current water supply infrastructure with a focus on groundwater use, and
- develop a conceptual hydrogeological model of the study areas and their surroundings.

1.3 Literature Review and State of the Art

In this section, a general overview will be given regarding the three main topics of this research. First, an introduction to the water situation in India is given, followed by an outline of peri-urban characteristics within the Indian context. The third part covers the topic of participatory water management by embedding it within similar approaches and depicting the state of the art.

1.3.1 General Water Situation in South Asia with a Focus on India

South Asia comprises the countries Afghanistan, India, Pakistan, Bangladesh, Nepal and Bhutan, as well as the island nations Sri Lanka and the Maldives. Nearly 25 % of the global population lives in South Asia but it has less than 5 % of worldwide annual renewable freshwater resources (Babel & Wahid, 2009). Its main water sources are rainfall and the Himalayan glacier snowmelt feeding the major river systems in South Asia (Ganges-Brahmaputra-Meghna Basin and Indus-Basin).

About 90 % of total water withdrawal in the region is used for agricultural irrigation purposes and livestock, which is significantly higher than the global average of 70 % (Frenken, 2012). The municipal and industrial sectors account for only 7 % and 2 % of total water use, respectively (Fig. 1). More than 340 billion m^3 of groundwater are used every year (about 34 % of total annual water withdrawal). India contributes 240 billion m^3 of groundwater abstraction. The other major freshwater source is surface water contributing 55 % to the total withdrawal quantity. Minor sources are the reuse of agricultural drainage water (11 %) and the utilization of desalination plants (<1 %) (Fig. 1).

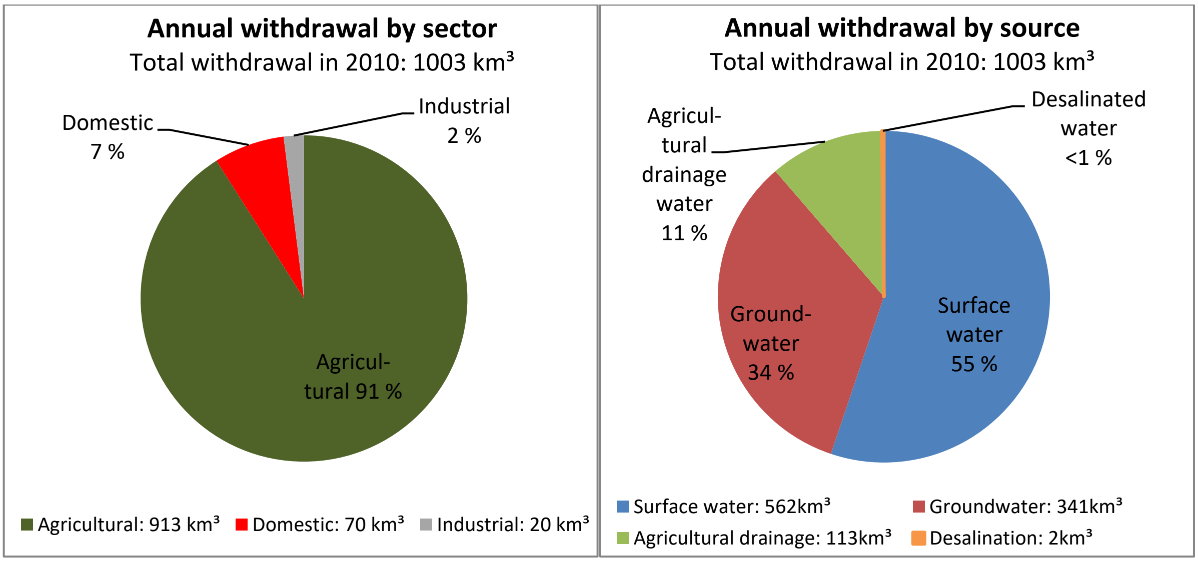

Fig. 1: Annual water withdrawal in South Asia by sector, left, and by source, right (Frenken, 2012).

Concerning water quantity, future scenarios show that per capita water availability will decrease due to an estimated population growth of 1.5 % per year leading to a total population of about 2 billion people in South Asia in 2050. Furthermore, the urbanization trend enhances water scarcity and will result in half of the population living in cities in 2050 (The World Bank, 2013). Due to climate change more than 65 % of the glaciers in the Himalaya are receding. This puts even more pressure on the water situation in South Asia, because snowmelt is a major source of water in the non-monsoonal season by feeding the rivers (Babel & Wahid, 2009). The fourth issue influencing the water situation in South Asia, besides population growth, urbanization and climate change, is economic development. India's economy is growing by 7 % per year (Briscoe & Malik, 2006) and goes hand in hand with rising demand for water and also energy. Hydropower is one of the largest potential energy resources in the region. Total generating potential for South Asia is around 436 GW (India: 300 GW), of which only 9 % has been developed (The World Bank, 2013). With regard to water quality, even with increased access (about 90 %) to improved drinking water infrastructure, more than 100 million people still live with poor water quality (Jena, 2015). Additionally, even an improved source does not guarantee that the obtained drinking water is safe. Only 39 % of the South Asian population has access to improved sanitation facilities (Babel & Wahid, 2009), with significant differences between rural (28 %) and urban (60 %) areas. More than 900 million people do not have access to basic sanitation infrastructure (GWP - Global Water Partnership, 2012), including 196 million urban dwellers. 610 million people have no toilet at all and practice open defecation (Unicef, 2015).

Focus on India

India's main water sources are monsoonal rainfall (3000 km^3/a), rivers (more than 20 major rivers), which are in the North mainly fed by the glacier and snow melt in the Himalayas, and groundwater. A general problem is the spatial and temporal variability of the monsoon and India's important dependency on it (Price et al., 2014). The water consumption pattern in India is similar to the average for South Asia with >90 % being used in the agricultural sector. The main water source is surface water with over 50 %, followed by groundwater (33 %) and direct use of agricultural drainage water (15 %). In rural areas of India, 60 % of agricultural irrigation and 85 % of drinking water depend on groundwater. In 2004, 30 % of all aquifers in India were in a critical condition (Pahuja et al., 2010); it is assumed that this number will increase to 60 percent in 2025. India has 26 million groundwater constructions, which leads to uncontrolled water withdrawal and as a result, 54 % of the area of India showed high to very high water stress in 2015 (Jena, 2015). According to the FAO (2016), more than 90 % of India's population has access to improved drinking water sources (e.g. household connection, borehole), with slight differences in rural and urban areas (Fig. 2). The numbers show a positive picture, but in reality, they may be much lower as informal settlements are often not included into statistics produced at the national level.

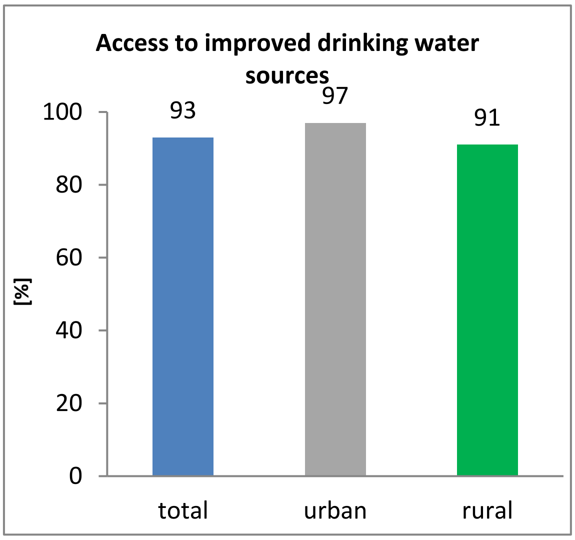

Fig. 2: Access of Indian population to improved drinking water sources in 2012 (FAO, 2016).

The produced municipal wastewater increased from 10 billion m³/a in 2002 to 15.4 billion m³/a in 2011. Wastewater treatment rose from 16 % to about 28 % ,still leaving the major part untreated (Fig. 3) (FAO, 2016).

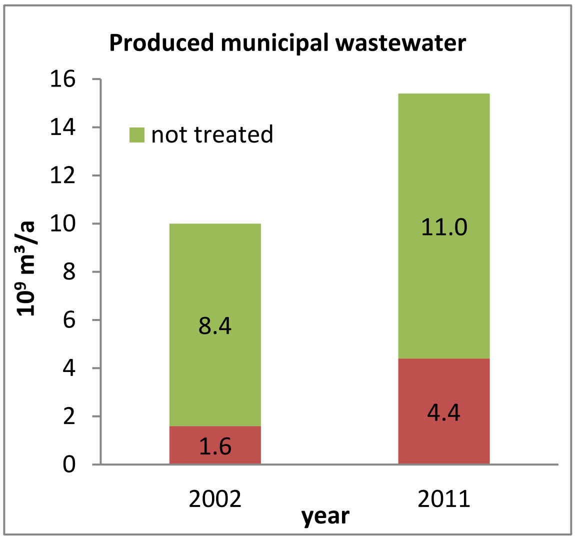

Fig. 3.: Produced municipal wastewater in 2002 and 2011 with portion being treated in red (FAO, 2016).

Similar to the whole South Asia region, several factors will increase the water problems in India. The population of India is estimated to reach 1.3 billion people in 2025 (Kumar et al., 2005), which will probably result in a decrease of the annual per capita water availability to less than 1,000m³ (Babel & Wahid, 2009). The largest increase in urban population in the world over the next four decades – involving almost 500 million people – will take place in India (Price et al., 2014). Increasing evaporation rates (due to climate change) are a significant factor, especially in the state of Gujarat where the water supply is partly based on open channel systems, which are subject to high evaporation rates (Patel et al., 2016).

1.3.2 Peri-Urban Indian Setting

Urbanization and the Peri-Urban Space

In the last two decades, urbanization has been one of the most important factors shaping the world. In 2015, 54 % of the total global population lived in urban areas, with Asia having the largest urban population with more than 2.1 billion people living in cities (Moreno et al., 2016). The shift from rural to urban areas is more dominant in developing countries than in developed countries and the causes of urbanization are also different. In the Global South, natural catastrophes, famine and war often force people to leave their rural homes and move to the cities (supply push), whereas in developed countries it is the prospect of better job opportunities (demand pull) in the cities (UN-Habitat, 2013). Especially in developing nations, urbanization is a highly complex process with a lot of possibilities but also significant challenges. The area most affected by the growing population of cities is the zone at its borders (Howard, 2014). The so-called peri-urban area can be defined as a transitional zone of mixed rural and urban uses in terms of economic, social, cultural and natural resources at the periphery of cities (Phillips et al., 1999). Important is the term transitional as it refers to the fact that the peri-urban is not a spatially fixed area but rather a dynamic temporal-spatial phenomenon (Karpouzoglou et al., 2018; McGregor et al., 2006; Shrestha et al., 2018). Vishal et al. (2014) further understand the peri-urban as an analytical construct characterized by an exchange of goods and services, e.g. natural resources or labor, between the rural and the urban. As a consequence, the recognition and understanding of these interactions is essential for formulating meaningful policy recommendations for the peri-urban zone (Phillips et al., 1999).

The challenge of current and future urbanization is also covered by the Sustainable Development Goals with Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable (United Nations General Assembly, 2015). Two sub-points highlight, on the one hand, how urbanization should happen in the best case and on the other hand, in which areas support is needed to achieve this by mentioning explicitly the connection of cities with their surroundings including the peri-urban area:

> “11.3: By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.”

> “11.a: Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning.”

Even if these goals are phrased in a general way, they show two things: besides the fact that urbanization is placed prominently within the SDGs, it is additionally seen as a holistic challenge including economic, social as well as environmental aspects.

Terms used in the literature in a synonymous way to peri-urban are “urban-rural fringe”, “urban transition zone” and “semi-urbanized area”. This wide range of expressions indicate a problem that Phillips et al. (1999) has also highlighted, namely the inconsistent use of the term peri-urban. Within this thesis, the above mentioned definition will serve as a basis to describe the current status and to identify past and future processes.

The Situation in India and Related Consequences for Groundwater Resources

The growth rate of the urban population in India between 2000 and 2010 was 2.6 %. The projection for India for 2050 is that another 404 million people will live in cities at that time (UN-Habitat & ESCAP, 2015). In the census decade from 2001 to 2011, about 44 % of urban growth resulted from natural population growth, only 25 % from rural-urban migration and nearly 30 % from reclassification (Bhagat, 2011; Pradhan, 2013). Reclassification is a process in which former rural areas are reclassified as urban areas due to political or administrative decisions. This often happens in already densely populated peri-urban areas showing many urban characteristics. Another important reason for a reclassification is the administrative conversion from, for example, agricultural land into real estate or industrial land to facilitate future economic development (UN-Habitat & ESCAP, 2015).

Many issues affecting peri-urban areas worldwide are also true for the situation found in Indian cities. As already mentioned 20 years ago by Phillips et al. (1999), these areas are often characterized by huge deficiencies regarding public services, leading to a situation, where NGOs or community groups are trying to fill this gap. Howard (2014) concluded in his study that in developing countries many suburban and peri-urban settlements like slums are ignored during urban planning and construction of water infrastructure. This results in well-serviced city centers surrounded by informal settlements without access to key infrastructure systems. Furthermore, poor health is strongly correlated to a poor physical environment including, among others, the water and sanitation sector, air pollution and an inadequate solid waste collection system. This significantly affects the condition of natural resources in the peri-urban area and, therefore, natural processes in those spaces, e.g. water quality degradation, cannot be separated from socio-economic and political developments (Phillips et al., 1999). Also with planned peri-urban development, the impact on natural resources is significant. Narain (2009) reports the impacts of the growing city of Gurgaon near the capital

Delhi where land acquisition for industrial and residential buildings diminishes the number of *Johads*[3] traditionally used by farmers and potters. Some of the *Johads* are filled to acquire land, while others are no longer usable due to pollution from industrial waste. Karpouzoglou et al. (2018), who conducted research in peri-urban Ghaziabad, stated that in such a context, water quality decline is politically induced.

In the present day, water tables are decreasing in many urban areas in India (MacDonald et al., 2016). This trend can also be observed in semi-arid rural areas, for example in Rajasthan (Yadav et al., 2016). Construction on former recharge areas may result in decreasing groundwater quantity. However, urbanization can also lead to an increase in recharge rates, e.g. through leaking sewerage system and, hence, to rising groundwater tables (Foster, 2001). As Nölscher (2017) has shown for the peri-urban area of Jaipur, the conversion from groundwater-irrigated agricultural land under semi-arid climatic conditions into a built-up area can lead to an increase in water demand of 23 % but can also lead to a decrease of 80 %, mainly depending on the original type and intensity of agriculture, the daily per capita water demand and the population density. Another factor related to the transformation of arable land is the reduction of areas previously used for food production. The process behind it can be compared to the water sector, as with growing income, the demand on land per capita also increases (UN-Habitat & ESCAP, 2015). The close links between land, water and food is the topic of many publications (Ibarrola-Rivas et al., 2017). It is not the focus of this work but it is mentioned here to emphasize the importance of seeing the peri-urban system as one closely related to water problems, but also to food issues. In their paper, Ibarrola-Rivas et al. (2017) present possible global scenarios related to food and/or water scarcity depending on population growth, diet habits and the rate of deforestation. Furthermore, they discuss competition with non-food crops which also has a significant influence on the availability of water resources.

In addition to direct anthropogenic impacts, meteorological patterns also play a significant role with regard to groundwater resources. Asoka et al. (2017) have shown that in northwestern India, groundwater storage variability is mainly due to groundwater abstraction, whereas in north-central and southern parts of India, changing precipitation patterns control the fluctuations of groundwater tables. This shows that a prognosis regarding the development of groundwater resources, especially in peri-urban areas, is complicated, as it is influenced by a number of different factors.

Peri-urban areas often serve as a source of water for the ever increasing demand of cities (Butterworth et al., 2007). Besides the water provided by the public water supplier, which often uses a significant share of groundwater in its supply scheme, a large part of the cities' demand is

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[3] Johad: Traditional recharge structures and village ponds typically to be found in North Indian states.

being served by an informal water market, in which groundwater is transported, for example via private tanker, from the outskirts to the city centers (Prakash & Singh, 2014). This informal market makes it nearly impossible to manage groundwater abstraction in a sustainable way. At the same time, peri-urban areas often function as disposal sites for wastewater from the cities. A failure to view the peri-urban space as a resource worth protecting and insufficient wastewater treatment capacities lead to the accumulation of wastewater in lakes, ponds and lowlands with the expected negative impacts on groundwater quality (Karpouzoglou et al., 2018). In addition, the lack of sanitation and sewerage infrastructure in many unplanned peri-urban areas increases the effect of anthropogenic pollution of groundwater resources (Prakash & Singh, 2014; Sekhar et al., 2005), which is typically characterized by elevated nitrate and fecal pathogen concentrations (MacDonald et al., 2016; Yadav et al., 2016). Chauhan et al. (2010) demonstrated in their study a direct link between an outbreak of jaundice in 2008 in a low-income area of Ahmedabad and the simultaneous contamination with sewage of the drinking water supply.

Apart from anthropogenic contamination, geogenic contaminants lead to a regional deterioration of groundwater quality. They are not restricted to peri-urban zones but may in cases complicate the use of groundwater in these areas. The lack of monitoring may lead to late detection of geogenic contamination. Besides high fluoride and arsenic concentrations (the latter mainly in West Bengal), elevated groundwater salinity is a frequent cause of concern in many parts of India, posing difficulties for both irrigation and drinking purposes (Bhardwaj, 2005; MacDonald et al., 2016). Causes are saline intrusion in coastal areas, but also historic marine influences, dissolution of evaporates and the evaporation of surface water and shallow groundwater. In many areas, e.g. in the Indo-Gangetic plain, the natural salinity is increased by intensive agricultural irrigation practices (MacDonald et al., 2016).

In summary, it is evident that processes within the peri-urban zone of Indian cities significantly influence groundwater availability and quality and should therefore be studied in detail. As socio-economic and political dynamics also play a key role in the development of peri-urban areas, hydrogeological studies should always be conducted in an interdisciplinary manner, including at least urban planners, social scientists, governmental and public stakeholders as well as relevant local organizations.

1.3.3 Participatory Water Management in the Frame of Socio-Hydrogeology

Changing Frameworks for Water Management

In 1977, at the United Nations Water Conference in Argentina, the Mar del Plata Action Plan was adopted, aiming on all components of water management including assessment of water resources; water use and efficiency; environment, health and pollution control; policy, planning and management; natural hazards public information, education, training and research; and regional and international cooperation (Biswas, 2004; United Nations, 1977). It was the first point where at a global level the prevailing premise of engineered solutions which were omnipresent for decades were questioned and criticized (Smith & Jønch Clausen, 2015). Fifteen years later at the International Conference on Water and the Environment in Dublin in 1992, the Dublin Statement on Water and Sustainable Development better known as the Dublin Principles were defined which serve later as the base for the concept of Integrated Water Resource Management (IWRM) (GWP, 2000).

The four Dublin Principles (Smith & Jønch Clausen, 2015) are:

- Principle 1 – Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment.
- Principle 2 – Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.
- Principle 3 – Women play a central part in the provision, management and safeguarding of water.
- Principle 4 – Water has an economic value in all its competing uses and should be recognized as an economic good.

Later in 1992, the four principles get global support at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro. Following up the conference, the international network called Global Water Partnership (GWP) was established to foster the development of IWRM. From 1996 to 1999, the Technical Advisory Committee (TAC) of the GWP worked on a clarification and formulation of the principles underlying IWRM. Despite that IWRM practices may vary between regional and national institutions, the TAC formulated a definition to provide a common framework:

> "IWRM is a process which promotes coordinated development and management of water, land and related resources in order to maximize the resultant economic and

social welfare in an equitable manner without compromising the sustainability of vital ecosystems." (GWP, 2000)

Imbedded in the global frameworks described above, in the following decades various approaches tackling the human-water system evolved (Tab. 1). Some of them, which are regarded as milestones or from which experience is gained in the work, are explained below.

Tab. 1: Concepts evolved in the context of society and water (or natural resources in general), sorted alphabetically.

Term	Theme/Definition	Included disciplines
Hydrosocial Cycle	"…a socio-natural process by which water and society make and remake each other over space and time, and […] an analytical tool for investigating hydrosocial relations." (Linton & Budds, 2014)	Political Ecology, Hydrology
Hydrosociology	"improved analysis of social consequences of water projects" (Falkenmark, 1979)	Hydrology, Geography, Sociology
IWRM	"IWRM is a process which promotes coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP, 2000)	Hydrology
Social-ecological systems (SES)	"…multiple sets of actors consume diverse resource units extracted from multiple interacting resource systems in the context of overlapping governance systems." (McGinnis & Ostrom, 2014)	Ecology, Sociology, Political Theory, Economy
Socio-economics of groundwater	"..understanding the social, economic, institutional and political dimensions of sustainable management of the world's groundwater resources…"(Burke et al., 1999)	Hydrogeology, Social Sciences
Socio-hydrology	"explores the co-evolution and self-organization of *people* in the landscape, also with respect to water availability" (Sivapalan et al., 2012)	Hydrology, Social Sciences
Socio-hydrogeology	"…a way of incorporating the social dimension into hydrogeological investigations." (Re, 2015)	Hydrogeology, Social Sciences

Falkenmark (1979) analyzed the interrelations between society and water and introduced the term "hydrosociology". She is arguing that more social sciences have to be included in water planning to investigate the social consequences of water related measures. In regard to development cooperation, she points out that problems arise with the transfer of knowledge and methods to other regions due to cultural, religious and social reasons. Therefore, she emphasizes the importance of having a two-way knowledge exchange. Experiences and knowledge of people living and dealing with certain cultural and climatic conditions different to the western world should be recognized by the international scientific community. In this early publication many important points were already mentioned, which should be discussed in the following years in the scientific community (Tab. 2).

Tab. 2: Selected publications in the broad field of the interaction between society and (ground)water, with a focus on socio-hydrogeology, sorted by date.

Author (Year)	Title	Journal/Book	Country	Keywords
Falkenmark (1979)	Main problems of water use and transfer of technology	GeoJournal	-	Hydrosociology
Burke et al. (1999)	Groundwater management and socio-economic responses	Natural Resources Forum	-	Socio-economic aspects
Budds (2008)	Whose scarcity? The hydrosocial cycle and the changing waterscape of La Ligua river basin, Chile.	Contentious Geographies: Environment, Meaning, Scale	Chile	Hydrosocial Cycle
Baldwin et al. (2012)	How scientific knowledge informs community understanding of groundwater	Journal of Hydrology	Australia	Science Communication, Participatory Approach
Mitchell et al. (2012)	Directions for social research to underpin improved groundwater management	Journal of Hydrology	-	Social Research (Literature Review)
Sivapalan et al. (2012)	Socio-hydrology: A new science of people and water	Hydrological Processes	(Australia)	Socio-hydrology
Sivapalan et al. (2014)	Socio-hydrology: Use-inspired water sustainability science for the Anthropocene	Earth's Future	-	Socio-hydrology
Re (2015)	Incorporating the social dimension into hydrogeochemical investigations for rural development: the Bir Al-Nas approach for socio-hydrogeology	Hydrogeology Journal	Tunisia	Socio-hydrogeology
Krueger et al. (2016)	A transdisciplinary account of water research	Wiley Interdisciplinary Reviews: Water	United Kingdom	Socio-hydrology, Hydrosocial Cycle, Transdisciplinarity
McMillan et al. (2016)	Panta Rhei 2013–2015: global perspectives on hydrology, society and change	Hydrological Sciences Journal	-	Hydrological Decade, Socio-hydrology
Limaye (2017)	Socio-hydrogeology and low-income countries: taking science to rural society	Hydrogeology Journal	India	Socio-hydrogeology, Science Communication
Re et al. (2017)	Integrated socio-hydrogeological approach to tackle nitrate contamination in groundwater resources. The case of Grombalia Basin (Tunisia)	Science of The Total Environment	Tunisia	Socio-hydrogeology
Hynds et al. (2018)	Muddy Waters: Refining the Way forward for the "Sustainability Science" of Socio-Hydrogeology	Water	-	Socio-hydrogeology

Coming from a political ecology perspective, Budds (2008) introduces in her paper the term "hydrosocial cycle" and defines it as a concept which simultaneously takes into account the physical water cycle and the way in which water is influenced by social power relations and institutions. While Falkenmark focuses on the effects of water-related measures on people, Budds goes one step further by analyzing the social and political causes leading to these measures. In 2012, Sivapalan et al. (2012) introduced the term "socio-hydrology", which is focusing on the co-evolution of water and people by using methods and concepts of the discipline of "eco-hydrology" which is focusing on the co-evolution of water and vegetation. The authors set their research in connection to the concept of IWRM by stating that it could be understand as "the fundamental science underpinning the practice of IWRM". However, the authors do not consider in their publication the ideas of hydrosociology nor the concept of the hydrosocial cycle but saying they established a "new science". Therefore, their understanding of socio-hydrology is limited in a sense that it looks on humans and water as two coupled but singular systems rather than investigating the ever changing dependencies between them.

Krueger et al. (2016) developed a helpful framework by analyzing the different applications of socio-hydrology from which they could derive four different approaches (Fig. 4). The first approach is the one Sivapalan et al. (2012) is applying by studying the hydrological *and* social systems as coupled but separated system. The second approach lays the focus on useful outcomes *for* the society (Falkenmark, 1979), whereas the third approach works together *with* the society (Baldwin et al., 2012). The last approach finally can be placed on a meta-level as it investigates how and why water knowledge is produced within different societies and how this is reflected in research and practice (Budds, 2008; Krueger et al., 2016; Linton & Budds, 2014; McMillan et al., 2016).

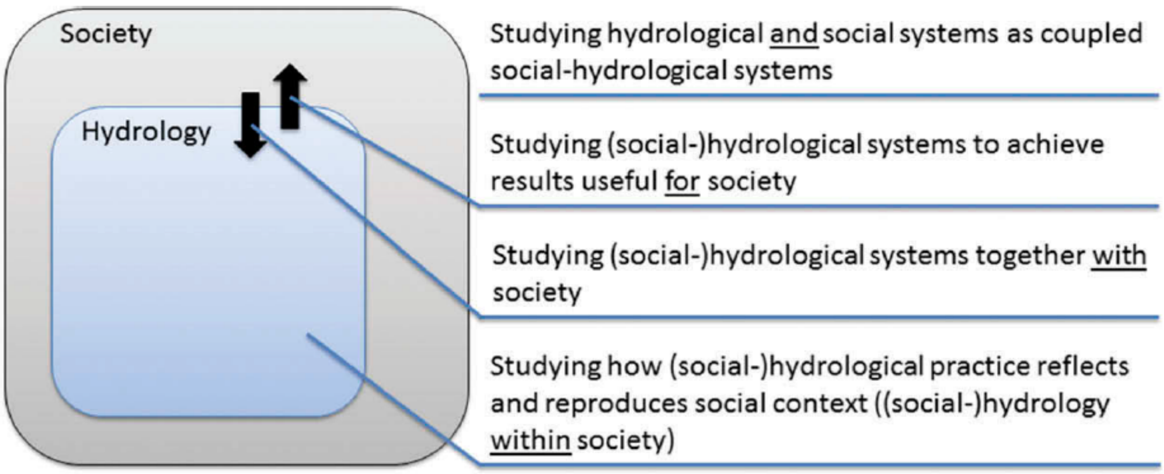

Fig. 4: Four different ways in which socio-hydrology is understood (McMillan et al., 2016).

Integrating Groundwater into Socio-Hydrology

Despite mentioning groundwater at some places together with surface water, Falkenmark (1979) does not differentiate significantly between the two sources. In the Mar del Plata Action Plan groundwater occurs regularly but only by recommending to improve its management, use it more efficiently and prohibit its pollution (United Nations, 1977). Groundwater is even less discussed in the TAC Background Paper No.4 dealing with IWRM (GWP, 2000). Therefore, Burke et al. (1999) criticize in their paper that groundwater is often neglected in IWRM projects or that no distinction is made between surface water and groundwater. However, there are crucial differences that are important for management, e.g. mostly individual small-scale groundwater users as opposed to large surface water infrastructures. The authors further argue that community participation for establishing sustainable groundwater management strategies is necessary in light of the highly distributed uses. More than ten years later the scientific literature concerning the combination of social research and groundwater management grew to about 300 peer-reviewed publications (Mitchell et al., 2012) reflecting the increasing need for inter-and transdisciplinary approaches also within in groundwater science. Based on their detailed literature review Mitchell et al. (2012) critically conclude that much of the literature lack a sound social theory and show a deficiency in the methods applied.

Finally, in 2015, the approach of socio-hydrogeology was defined by Re (2015) "as a discipline that embeds the social dimension into hydrogeological and hydrogeochemical investigations." Her understanding of this new discipline includes six major points:

- Impact of human activities on groundwater;
- Impact of groundwater resources and its changes both in quality and quantity on humans;
- Stakeholders and their relations, e.g., power, knowledge flux, financial transfer, and possible conflicts;
- Better use of the outcomes of hydrogeological investigations;
- Bridge the gap between science and practice; and
- Demystifying science and scientists.

So far, there are only a few publications that explicitly refer to the term socio-hydrogeology. (Tab. 2). Limaye (2017) focusses on the rural society in low-income countries and promotes for a science communication adapted to their needs and educational background. In general, he demands that funding of research projects should be oriented at the usefulness of the projects for the civil society. In her work in Northern Tunisia, Re et al. (2017) used an integrated approach by using both hydrochemical data and information obtained through public participation with local stakeholders to identify the contaminant sources of the area. Recently, Hynds et al. (2018) discussed the current trends in socio-hydrogeological research and stated that due to the manifold tasks within a socio-hydrogeological approach a "circular socio(hydro)economy" should be in place. Within such a model, tasks will be fulfilled by different stakeholders but connected to each other in a close way.

Participatory Groundwater Management as a Tool within Socio-Hydrogeology

Principle 2 of the Dublin Principles clearly states that water management should apply participatory approaches. In the detailed explanations it says that "water is a subject in which everyone is a stakeholder. Real participation only takes place when stakeholders are part of the decision-making process" (GWP, 2000). At that time, participatory approaches were rather new for water sciences but already applied widely within other areas.

Participatory research and action have a long tradition, mainly rooted in the politically changes in the late 1960s where marginalized groups demand more power in various processes. It was applied and discussed in planning research (Arnstein, 1969; Burke, 1968) before it become popular in water sciences, especially in water management. Arnstein (1969), who was director of the non-profit research institute of "Community Development Studies for The Commons" at that time, published a paper where she lay out her understanding of citizen participation:

> "It is the redistribution of power that enables the have-not citizens, presently excluded from the political and economic processes, to be deliberately included in the future. […] In short, it is the means by which they can induce significant social reform which enables them to share in the benefits of the affluent society."

For Arnstein, participatory approaches are highly politically and aim at changing the social exclusion of certain groups from planning decisions. Burke (1968) even says that this is an intrinsic part of the democratic tradition of them [USA] and, therefore, a necessary process. However, in her paper Arnstein (1969) analyzes governmental social projects and criticizes that most of them are using participatory approaches as "empty rituals". She defined a typology of participation including eight steps to indicate where, how and why most projects failed to achieve citizen participation in the sense defined above (Fig. 5).

Even if Arnstein's ladder is based on examples of and experiences with urban renewal programs in the USA and some steps might not be widely applicable, e.g. the second rung "therapy" which Arnstein describes as an arrogant "clinical group therapy" of the powerless masked as public participation in planning, it is a useful tool for classification and clarification of participatory approaches.

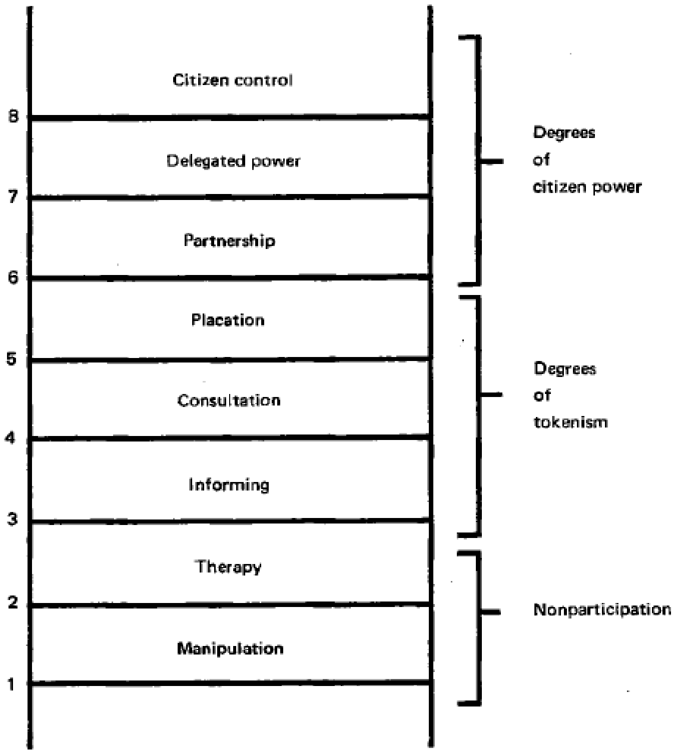

Fig. 5: The ladder of city participation by Arnstein (1969). The classification is based on experiences during urban development programs in the 1960 in US cities.

In regard to groundwater management, the early publication of Hofmann and Mitchell (1995) already argues for a participatory approach in governmental water management projects to make decision process more open and transparent including perspectives of all stakeholders. From 2010 on, more publications are available dealing with participatory approaches. In Saurastra, Gujarat, India, participatory groundwater management was successful implemented. Widespread groundwater depletion in the 1980s causes, among others impacts, fluorosis and severe problems in the agricultural sector. Many small recharge measures like sink pits and small check dams were promoted and successfully implemented. In this frame a training kit called "Participatory Groundwater Management" which includes many samples of practical experiences was developed (van Steenbergen, 2011). Several other participatory projects took place in different countries and with slightly different approaches (Tab.3).

Tab. 3: Selected publications regarding participatory approaches in water management with a focus on India.

Author (Year)	Title	Journal	Country	Keywords
Hofmann and Mitchell (1995)	Evolving Toward Participatory Water Management: The Permit to Take Water Program and Commercial Water Bottling in Ontario	Canadian Water Resources Journal	Canada	Transparent Decision Making, Credible Participatory Approach
van Steenbergen (2011)	Participatory Groundwater Management – Training Kit	Online available	India, Yemen, Mexico	Participatory Water Management

Author (Year)	Title	Journal	Country	Keywords
Von Korff et al. (2012)	Implementing participatory water management: recent advances in theory, practice, and evaluation.	Ecology and Society	-	Participatory Approaches (Literature Review)
Verma (2012)	Andhra Pradesh Farmer Managed Groundwater Systems (APFAMGS) - A Reality Check.	Water Policy Research Highlight (IWMI)	India	Groundwater Management by Communities
Maheshwari et al. (2014)	The Role of Transdisciplinary Approach and Community Participation in Village Scale Groundwater Management: Insights from Gujarat and Rajasthan, India	Water	India	Participatory Water Management, Transdisciplinarity
Walker et al. (2016)	Filling the observational void: Scientific value and quantitative validation of hydrometeorological data from a community-based monitoring program	Journal of Hydrology	Ethiopia	Community-based Approach
Tringali et al. (2017)	Insights and participatory actions driven by a socio-hydrogeological approach for groundwater management: the Grombalia Basin case study (Tunisia)	Hydrogeology Journal	Tunisia	Public Engagement and Communication

However, even if it is a widespread consensus that participatory approaches improve water management projects, there are several critical aspects. Pretty (1995) already criticized very early the use of the term participation without any sound consideration by the development aid sector. As a result, the term is often used in contrary ways, e.g. to justify the expansion of state control as well as to build local capacity and autonomy. Furthermore, "people are asked or dragged into partaking in operations of no interest to them, in the very name of participation" (Rahnema, 1992).

Prokopy (2005) summarizes the most common critiques on participatory approaches which are that the participating people have to carry an unfair and extra burden through the participation, that individuals are forced to participate regardless of their will and that participation can be shameful and disappointing if the local population has no real power to influence the course of a project. Therefore, people should be included on higher level of decision making.

1.4 Arrangements of Topics and Contributions by Students

The thesis is divided into four parts with a number of sub-chapters, respectively. The first part is the introduction giving the background of the project, the aim of this thesis and a literature review. The next two parts are forming the main element of the thesis. Similar to the field work, in which the hydrogeological research was divided from the participatory research, Part 2 covers the hydrogeology and water management of the study areas while in Part 3 the participatory work is being described and discussed. In Part 4 the results and conclusion from all former parts are used to develop solution strategies and to give a summarizing conclusion.

Several parts of the dissertation are already published or planned for publishing. Chapter 2.3 'Hydrogeological Conceptual Model' is in preparation for submission[4] to the *Hydrogeology Journal*. It is structured in way that it can be read as a stand-alone text. Therefore, some general facts about the study area which are already mentioned in Chapter 2.2, are repeated within Chapter 2.3. As the first author, I have written the entire manuscript. I am grateful for the intense discussions with and the proofreading by my co-authors, especially Dr. Gröschke.

Chapter 3.3 'Awareness Raising and Basic Knowledge Transfer' include parts of the Training Manual (Appendix A18) which was the project deliverable, comparable to a project report, and is published on the website of the project lead Mahila Housing SEWA Trust[5]. I am responsible for the content of the Training Manual and have written the entire deliverable. However, the manual has profited from the advice from the co-authors and the layout by Maximilian Nölscher.

Parts of Chapter 3.5 'Evaluation and Upscaling' are published on the website of the *Andrea von Braun Foundation* under the title 'Pani Check & Pani Doctors' as a so-called learning paper[6]. This learning paper constitutes the final report about the transdisciplinary cooperation with the filmmaker Katalin Ambrus, which was mainly funded by the above mentioned Andrea von Braun Foundation. I have written, as the first author, the main part of the text. The contribution of my co-author Katalin Ambrus was, next to advices and proof-reading, the visual design with pictures (Appendix A20).

The complete Chapter 3.6 'Water and Conflicts' was published 2018 in the peer-reviewed journal *perspektive mediation*[7]. I have written the entire paper. However, I am grateful for the helpful advices and proof-reading by Dr. Maike Gröschke (Appendix A19).

Thirteen bachelor and master students were involved in the project (Tab. 4). In case their work contributed to this dissertation, the respective chapter is given in Table 4. If it was a concrete contribution to a particular part of this study, it is mentioned directly in the chapters themselves.

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[4] Frommen, T., Groeschke, M., Noelscher, M., Königer, P. & Schneider, M. (2019) Anthropogenic and geogenic impacts on peri-urban aquifers in India – Insights from a Case Study in the Northeast of Jaipur (in prep.)

[5] Frommen et al. (2018)

[6] Frommen and Ambrus (2019)

[7] Frommen (2018)

Tab. 4: Theses and term papers written in frame of the Jaipur Case Study.

Name	Topic	Type	Contribution	Remarks
Anna Wypukol	Hydrogeology of Jaipur Urban Area, India - Evaluation of Regional Hydrochemical Data and Literature Review	B.Sc.	-	
Maximilian Nölscher	Water Resources and Infrastructure in Low Income Communities in Peri-Urban Jaipur, India	M.Sc.	Part 2	
Nele Hastreiter	Participatory Water Management Projects considering Hydrogeological Investigations - A Literature Review with Focus on India	B.Sc.	Chapter 1.3.3	
Carry Forest	Development of a Participatory Water Management in Slum Areas of Jaipur, India – Stakeholder and Decision Chain Analysis and Recommendations for Policy Adaptations	M.Sc.	-	unfinished
Nico Poschinski	Evaluation of Residential Reverse Osmosis Systems used in Slums in Jaipur, India	B.Sc.	Chapter 4.1.1	
Lilli Witt	Typical Groundwater Contaminations in Urban Areas of India and suitable Treatment Systems on a Community Level	B.Sc.	Chapter 4.1	
Natja Bublitz	Water Resources of the Ranchi Urban Area, India: Water Supply and Options for a Participatory Community-based Water Management in Slum Areas	M.Sc.	-	
Michael Mutz	Modeling Water Supply and Demand in two peri–urban slum areas in Jaipur, India	M.Sc.	Chapter 2.4	
Carolin Winter	Exchange Resin Method for $\delta^{15}N$ under Different Storage Conditions to identify Main Sources of Nitrate in Groundwater of two Peri-Urban Areas of Jaipur, India	Term paper	Chapter 2.3	
David Netscher	Gegenwärtige und zukünftige Migrations- und Urbanisierungsbewegungen in Rajasthan, Indien – Ursachen dessen und Folgen für das Wassermanagement in Städten und peri-urbanen Räumen	Term paper	-	
Christoph Brüdigam	Grundwasserressourcen und deren Bewirtschaftung – Erstellung von Lehrmaterialien	B.Sc.	Chapter 3.3.2	
Cherine Jasmine	Sediment Analysis of Drilling Samples from Jaipur, India	B.Sc.	-	not finished yet
Patrick Zentel	Laboratory Tests of Hard Rock Quartzites to examine possible Leaching Processes of Nitrogen into Water	B.Sc.	Chapter 2.3	not finished yet

PART 2 Hydrogeology, Water Infrastructure and Socio-Economic Characteristics of the Study Areas

This part gives an overview of the environmental characteristics and water-related infrastructure of the two study areas and the corresponding catchment area (Chapter 2.2). In the next chapter (2.3), a hydrogeological conceptual model of the area is presented based on the hydrochemical and hydrogeological investigations conducted between 2016 and 2018. Chapter 2.4 focuses on water management aspects including the current status of the water supply.

But first, a rather unconventional chapter opens this part because the dissertation took place in the frame of an inter- and transdisciplinary project. This means that more non-hydrogeologists than hydrogeologist were part of it. Therefore, a short introduction into the science of hydrogeology is given in Chapter 2.1.1, followed by Chapter 2.1.2 in which certain adaptions to established methods are explained. This is necessary as working conditions in India differ significantly from working conditions in Germany.

2.1 Theoretical Background

2.1.1 Hydrogeological Basics and Important Definitions

Hydrogeology is a science branch within geological sciences focusing on groundwater by investigating its occurrence, distribution, movement and geological interaction in the Earth's crust as well as its interaction with surface water.

Important Terms and Principles of Hydrogeology

Groundwater is defined as underground water that fills the soil pores and fractures of rock formations of the lithosphere in a continuous manner and whose movement is determined only by gravity. The layers of porous soil or fissured rock underneath the land surface in which groundwater can be stored are called *aquifer*. If an aquifer is *unconfined* the groundwater surface can rise and fall freely within the ground without being hindered by a low-permeable upper layer. The water table is at the same time the pressure level (Fig. 6b). In contrast to that, within a confined aquifer the groundwater is tapped by a low-permeable layer, so that the groundwater surface is under pressure. The pressure level lies above the water table (Fig. 6a). These low-permeable layers are called *aquitards*. They consist of soil or rock which is too dense to store a significant amount of water and to transmit water in a significant amount and on a time scale appropriate for groundwater abstraction (for example clay).

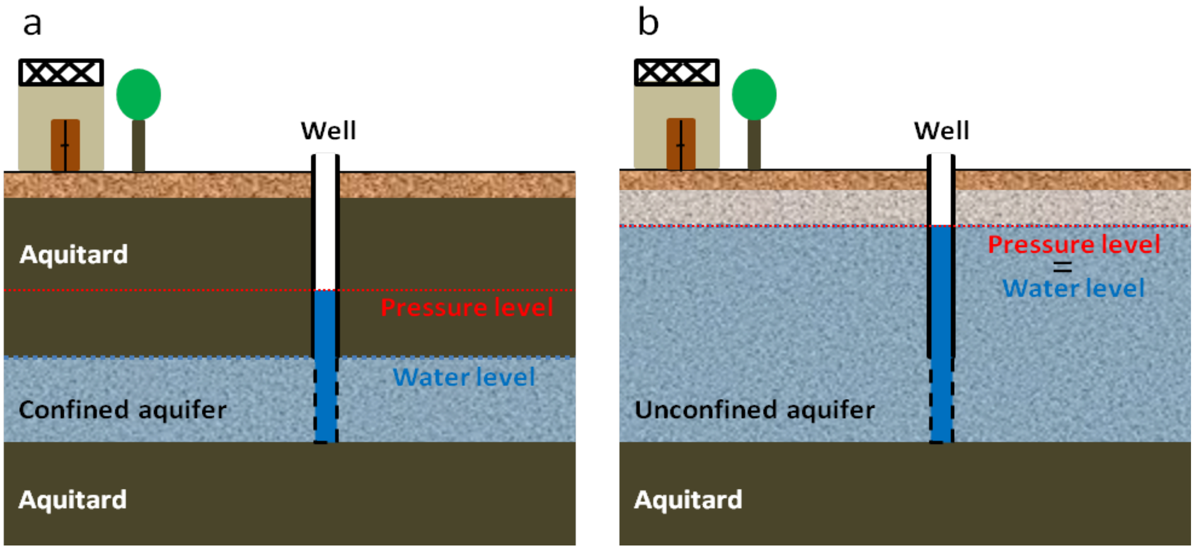

Fig. 6: Simplified schematic of a confined (a) and an unconfined aquifer (b) with related water level in the well.

On a regional scale, *recharge* and *discharge areas* are important hydrogeological areas (Fig. 7). Recharge areas are typically areas of higher elevation and, usually, little urban development, where the hydrogeological condition for groundwater recharge is excellent. Discharge areas are mostly found in low lying areas where water from the underground is released to the surface, e.g. groundwater discharging into a river. The intermediate area between recharge area and discharge area is called transit area. Here the groundwater flow is almost parallel to the topographic gradient.

The *catchment area* defines a basin where water gets collected when it rains and which is often bounded by hills. The highest points of the hills define the border (*water divide*) to the neighboring catchment area. The collected rainfall flows from the elevated hills to the lower parts of the basin where it often cumulates in rivers or lakes. Rivers transport the collected water following the topographic gradient. The same process applies to groundwater when rainwater infiltrates and flows along the gradient from highest areas of the basin (with the highest pressure levels) to the lowest areas of the basin (with the lowest pressure levels). Catchment areas can be defined on different scales: local, regional and supraregional. For example, a supraregional catchment can be subdivided in numerous regional and local sub-basins. Under most conditions, the surface water catchment area can be used to define the groundwater catchment area as a first approximation. In limestone areas, where karstic aquifers occur and in areas with complex geological and tectonic conditions surface water and groundwater catchments might differ.

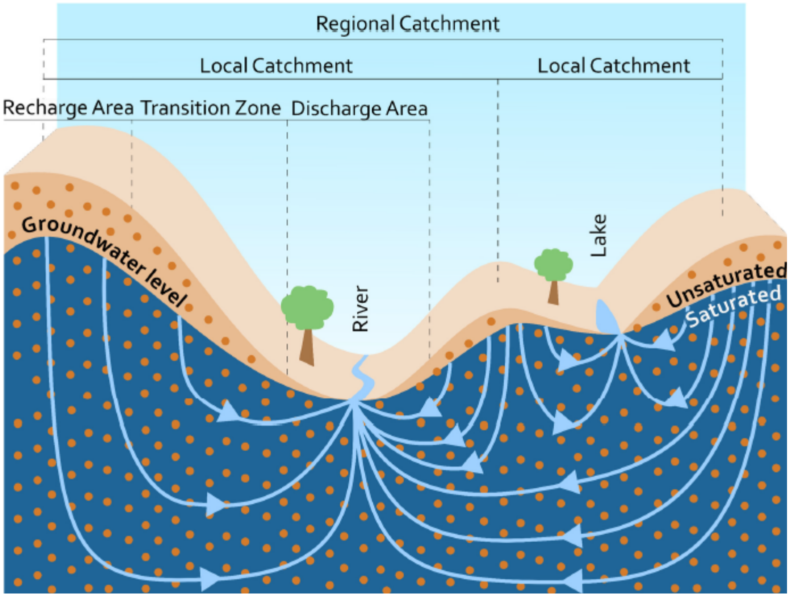

Fig. 7: Key components within a catchment and schematic of regional and local groundwater flow systems (Frommen et al., 2018). Figure designed by Maximillian Nölscher.

Artificial groundwater recharge is the practice of increasing the amount of water that enters a groundwater reservoir by artificial means (Todd, 1959). This includes, for example, injection of water into the subsurface through wells or ponds.

Hydrogeological Methods

The main tasks within the field of hydrogeology are the investigation of the formation, distribution, condition and possible future evolution of groundwater, both in term of quality and quantity, its reaction with the surrounding rocks, its flow and interaction with surface water as well as anthropogenic impacts on it, e.g. by wells extracting water or by pollution through infiltrating wastewater. This is achieved by the application of a wide range of methods. Among the most important ones are hydrochemical investigations, depth-to-groundwater measurements and hydraulic tests. For that, special wells are needed, called observation wells. An observation well (sometimes also called monitoring well or piezometer) is only used for investigation purposes. Generally, it is constructed with a short filter screen tapping one aquifer and a smaller diameter compared to production wells. For hydrochemical investigations a groundwater sample is taken, normally from an observation well, and analyzed for its chemical characteristics. Depth-to-groundwater measurements and hydraulic tests are conducted to get information about the size and extent of aquifers and their physical characteristics, e.g. storage capacity and permeability.

2.1.2 Hydrogeological Methods adapted to Indian Conditions

A diverse set of methods was used to characterize the hydrogeological situation in the study areas as well as to understand the water and sanitation infrastructure. Both, the choice of the methods and the methods themselves may differ from the conventional approaches as the Indian context requires sometimes an adaption to local conditions, for example regarding the availability and reliability of data.

Mapping and Data Acquisition

A detailed water infrastructure mapping of the area was conducted before the start of the hydrogeological field work, because only little information was available. The main part of the mapping took place from September to November 2016 in the study area Nai Ki Thari (NKT) and the surrounding of the study area Khara Kuaa (KK). Within Khara Kuaa itself the mapping was conducted together with the local women assistants from November to December 2016 in the frame of the participatory activities (Chapter 3.4.1). Main goals of the mapping were to understand the role of groundwater in the area, including how and where it is used by whom, its connection to surface water bodies, possible contamination pathways and, based on this, to identify suitable wells for hydrogeological investigations.

The mapping covered dug wells (Fig. 8), bore wells[8], hand pumps[9], taps, *nallahs*, waste disposal sites, industrial workshops, private water sellers and other water supply systems. It was conducted by transect walks with help of a GPS device and informal conversations with well owners and users regarding their wells (e.g. age, depth, reliability, pump, well screen depth). They were also inter-

Fig. 8: Measuring the depth of a traditional dug well near to Khara Kuaa during the mapping in November 2016.

viewed about the water supply in general and the permanent observation of water-related activities, e.g. maintenance of a well, complaints about the pump times or the tanker distribution system. These informal interviews were crucial for getting relevant information about the wells. In addition to the mapping, structured interviews were conducted previous to the field work with four women living in the study areas in order to get information about their water sources and typical water consumption behavior (Chapter 3.2.2).

Adapted Sampling Procedures

In contrast to Germany, the annual monitoring of groundwater resources is not related to the hydrogeological year starting on 1 September but is orientated by the monsoon and seasons. The CGWB carries out the following sampling: The annual monitoring is divided into pre –monsoon groundwater level measurements taking place from 20th-30th of May and post-monsoon measure-

[8] Bore well: The term bore well include all bore wells where an electric pump is attached to the well.

[9] Hand pump: The term hand pump includes all bore wells where an Indian handpump is attached to the well.

ments taking place from 1st-10th of November. Water samples for hydrochemical analysis are collected once a year during the pre-monsoon measurement campaign (Yadav et al., 2016). Therefore, the sampling for this work was adapted to the Indian sampling procedures.

Furthermore, as no official observation well (only one abandoned bore well used for this study as observation well) was located within the study area, hand pumps and bore wells were selected as sampling points. Bore wells are equipped with electric pumps and hand pumps with manual pumps connected to metal pipes. Therefore, a pumping with the own pumping equipment was not possible.

2.2 Study Area Overview

2.2.1 Geography, Topography and Land Use

Jaipur is the capital of the Indian state Rajasthan in northwestern India situated between latitude 26.82° to 27.00° and longitude 75.73° to 75.85° (WGS 84). About 250 km southwest of New Delhi, the city lies on the eastern border of the Thar Desert within the Aravalli Mountain Range (Fig. 9). Jaipur covers an area of 485 km² within the Jaipur district (11,143 km²) (Census of India, 2011). The district is divided into 13 blocks, also called *Tehsil*, of which three blocks, Sanganer, Jhotwara and Amer, are falling partly under Jaipur city area (CGWB, 2007). Most of the city, including the old part within the walls as well as the newer areas, shows a relatively flat topography with an average altitude of about 430 m NN. From NE to W Jaipur is surrounded by steeply rising hills (up to 650 m NN) which are belonging to the Aravalli Mountains (Fig. 9). Three old forts from the time of the Rajputs (11th-18th century) are situated on top of the hills with Amer Fort being historical and, nowadays touristic, the most important one (Rajora, 2013). The other two forts, Jaigarh and Nahargarh, are situated on the main peaks (648 masl and 599 masl, respectively) around the city area (CGWB, 2007).

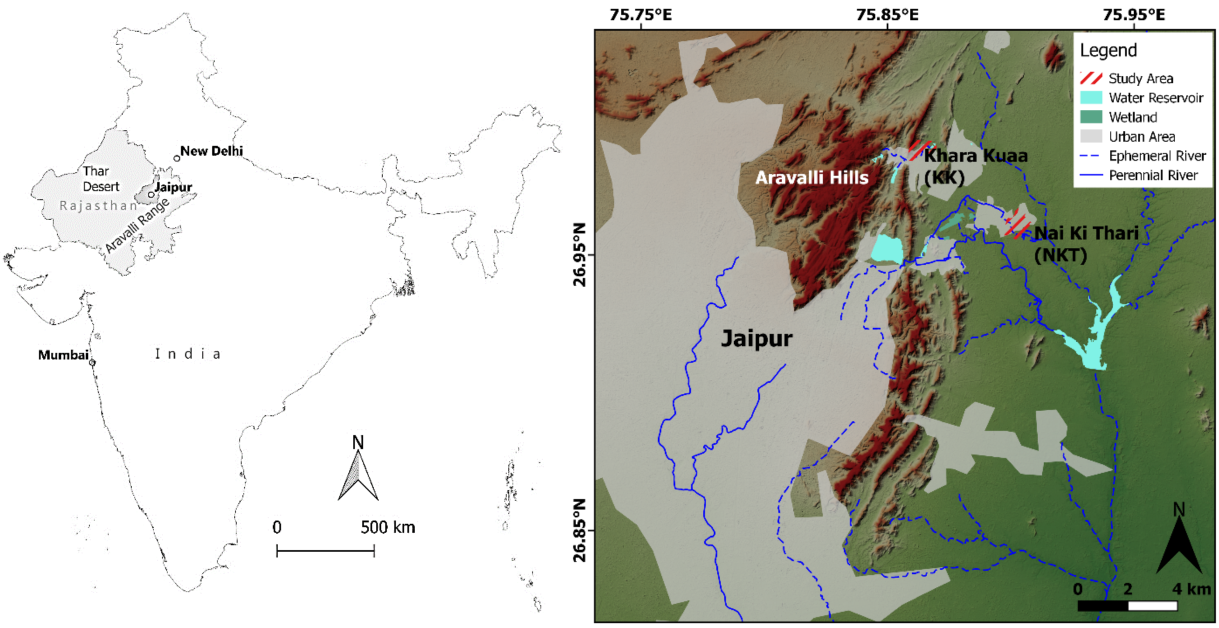

Fig. 9: Left: Map of India with Rajasthan and its capital Jaipur, which is located at the eastern border of the Thar Desert. The Aravalli Hill Range stretches from North Gujarat up to Delhi. Right: DEM of Jaipur with Aravalli Hills and the two study areas Khara Kuaa and Nai Ki Thari on the Northeast of Jaipur city.

With 3,046 Ma inhabitants Jaipur is the most populated city of Rajasthan. Jaipur district shows a decadal population growth between 2001 and 2011 of 26.19 % which is significantly higher than the population growth of the state 21.31 % (Census of India, 2011) showing the urbanization trend, which can be seen in most parts of India although the urban growth rate in per cent is decreasing again since the 1980s (Kundu, 2011). However, the total numbers of people living in urban areas are still increasing and in 2030, Jaipur will have a population of more than 4,884 Ma inhabitants as projected by UN-Habitat and ESCAP (2015). In 2006, about 58 % of the district area was under cultivation with nearly half of it (45 %) being irrigated by groundwater (except during the monsoon season). The remaining 40 %, consist of barren land, built-up area, forest area, pasture land and hills (CGWB, 2007; NRCS - National Remote Sensing Center, 2016). However, as Nölscher (2017) has shown, the land use in the north-eastern peri-urban fringe of Jaipur is subject to huge changes. He found that from 2004/2005 to 2015/2016 the crop pattern changed significantly from double/triple crops to *Kharif* (cropping season: monsoon). A second major trend was the change from agricultural area into barren land and built-up area.

Khara Kuaa is a low-income area at the northeastern fringe of Jaipur still falling within the city boundaries. The established Hindu community is situated directly at the foot of the hill ridge in the north of Amer Fort (Fig. 10). It has mostly *pucca* (solid) roads and houses. Open drains for grey water lead the wastewater into a *nallah* transporting it to the *taalaab* in the east of the area. Most households have individual toilets with soak pits. Open defecation takes place, too. The water supply is based on municipal water line connections, hand pumps and several private solutions, e.g. water tanker.

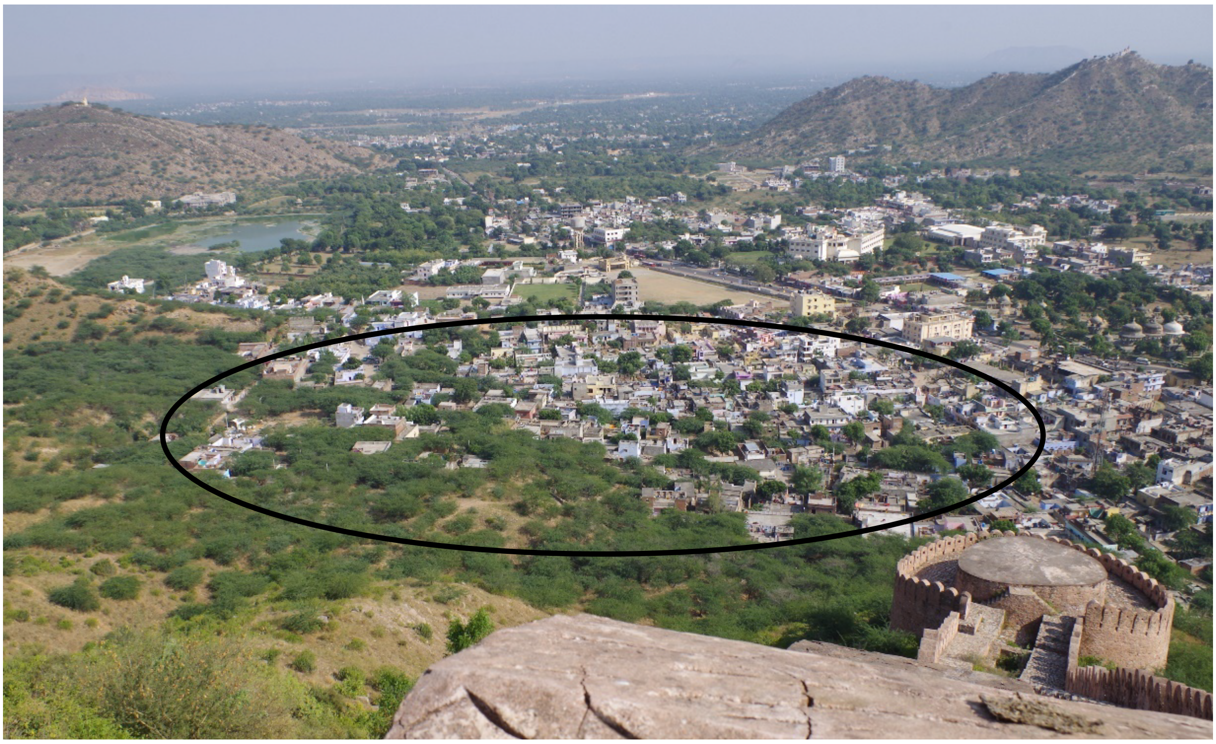

Fig. 10: Overview of the study area Khara Kuaa, November 2016, view direction: NE. Khara Kuaa (black circle) lays on the foot of a hill ridge. The *taalaab* (left upper corner) forms the main discharge structure for grey waters drained from the surrounding settlements.

Nai Ki Thari is a low-income community which developed in the last two decades on a formerly agricultural used area 5 km to the northeast of Jaipur. The mainly Muslim community is situated on a flat plain and has no *pucca* roads but mainly dirt roads. Also here, households have individual toilets with soak pits, however, open defecation is practiced, too. Nai Ki Thari neither has a drainage system nor is it connected to the municipal water line system (Fig. 11). Water supply relies mainly on bore wells from religious institutions, on hand pumps and bore wells from PHED and on private solutions. A huge landfill covering about 12 hectares is located 2 km southeast of Nai Ki Thari.

Fig. 11: Typical, unpaved street of Nai Ki Thari, July 2015, with septic tank (left), grey water outflow, solid waste disposal and drinking water production well (background and right side).

2.2.2 Climate

Jaipur is classified as a semi-arid area with an average annual rainfall in Jaipur district of 565 mm (based on data from 1977 to 2006). 90 % of the annual rainfall take place during the south-west monsoon from June to September (CGWB, 2007). Next to the monsoon season, two other main seasons are structuring the year, the summer or hot-weather season from March until end of June and the winter or cold-weather-season from October until February (Fig. 12, 13). High variability of the monsoonal precipitation amount is common. In 2006, only 387 mm rainfall was measured for Jaipur district, whereas in 2010 it nearly doubled up to 792 mm (Yadav et al., 2016).

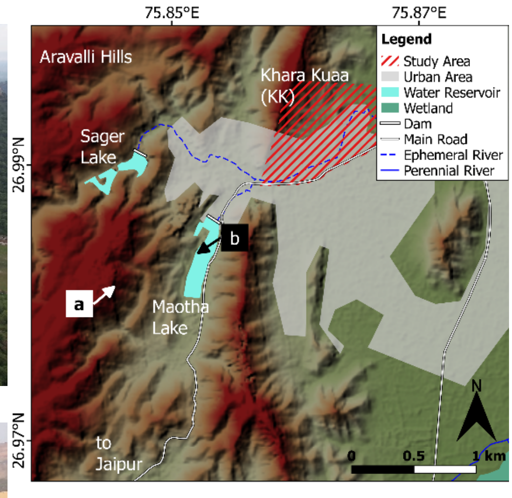

Fig. 12: a) Monsoon season in Jaipur, July 2017. View from Jaigarh Fort to NE direction with Amer Fort and Maotha Lake in the front and Amer village in the back. b) Winter season in Jaipur, November 2017. View from Maotha Lake at Amer Fort in SW direction with Jaigarh Fort in the background.

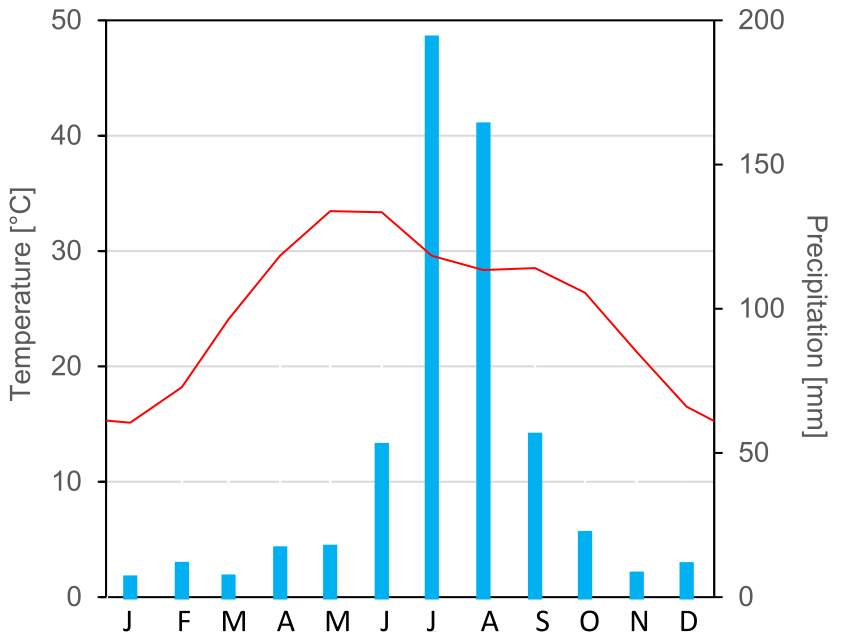

Fig. 13: Climate diagram for Jaipur, Sanganer weather station. Data retrieved from tutiempo.net.

2.2.3 Hydrology

Jaipur is situated within the Ganges river basin. The area is drained via the rivers Dhund (Fig. 14), Morel, Banas, Chambal, Yamuna and finally to the Ganges. The hydrology is significantly influenced by anthropogenic structures and activities like check dams, diverting streams or construction on river basins. Together with the semi-arid monsoon climate this results in many ephemeral rivers. The only perennial river in Jaipur is the Amanisha Nallah flowing from North to the South and then to the East joining the Dhund. However, the Amanisha Nallah is mainly fed by wastewater (JDA - Jaipur Development Authority, 1998).

The study area Khara Kuaa is drained by one *nallah* which originates at the two historic water reservoirs (Maotha Lake and Sagar Lake) and transports mainly grey water of the area outside the settlements to a *taalaab* (lake) in the east. Two *nallahs* exist in and near the study area Nai Ki Thari both starting from Man Sagar as one *nallah*, before splitting up shortly thereafter. Upstream of Man Sagar the *nallah* drains the northeastern part of Jaipur. According to PHED officials the *nallah* transports often untreated sewage as the sewage treatment plant (STP) situated southwest to Man Sagar often fails (personal communication, 2017). Down gradient of Man Sagar, the more southern *nallah* is the main tributary of the Dhund upstream of the Kanota dam (Fig. 14). It drains the wastewater of the rural areas east of the city. About 4 km east of Man Sagar, the effluent from a wastewater treatment STP is also discharged into this *nallah*. Its natural origin can be derived from the meandering form. The more northern *nallah* flows through Nai Ki Thari. Both *nallahs* are intensively used for irrigation purposes in historic as well as modern times (green shaded area in Fig. 14)

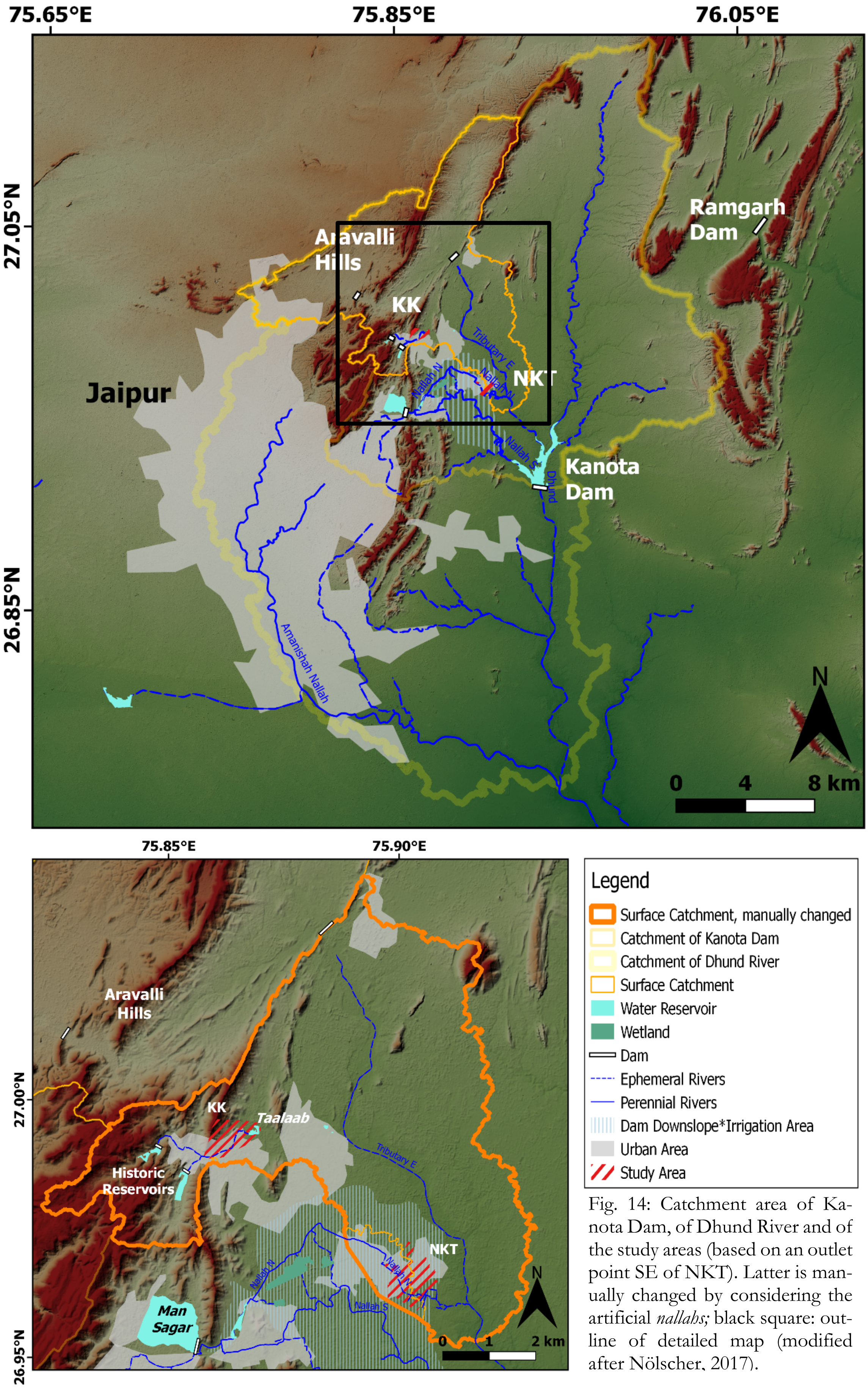

Fig. 14: Catchment area of Kanota Dam, of Dhund River and of the study areas (based on an outlet point SE of NKT). Latter is manually changed by considering the artificial *nallahs;* black square: outline of detailed map (modified after Nölscher, 2017).

2.2.4 Geology and Geomorphology

Jaipur is situated within the Proterozoic Aravalli Mountain Range which extends over 700 km from North Gujarat in the SW up to Delhi in the NE. The mountain range, made up of supracrustal rocks, is divided into the Paleoproterozoic Aravalli Fold Belt (AFB) and the Mesoproterozoic Delhi Fold Belt (DFB), both deposited on the Archean crystalline Banded Gneissic Complex (BGC). The DFB shows isoclinal folding with NE-striking axial planes. It comprises the Delhi Supergroup which consists of two distinct fold belts, the Northern Delhi Fold Belt (NDFB) with intrusions by granites aged 1750 Ma or somewhat younger and the Southern Delhi Fold Belt (SDFB) characterized by intrusive granites with an age of 850±50 Ma (Sharma, 2009). The NDFB covers the Jaipur district (GSI, 2011) (Tab. 5) with Jaipur city being surrounded by steeply rising outcrops of the Alwar series consisting of quartzite, conglomerate and schists. The Alwar series reaches a thickness of 3000-4000 meter (Antea International, 1999). The valleys between the hill ridges are covered by Quaternary alluvium, which can be divided into a Younger and an Older Alluvium whereby the Younger is found in northern part of the district and the Older in the southern part of the district. Beneath the Quaternary cover probably the more easily erodible Ajabgarh and Pre-Aravalli series appears more frequently than the hard Alwar series. The alluvium consists of fluvial and aeolian sediments as well as denudational material close to the hills, leading to a wide range of sediments from silt and fine sand to coarse sand and gravel near the hills and in buried river channels. Furthermore, *kankar* ($CaCO_3$ nodules) layers occur at various depth and at different development states from white $CaCO_3$-rich stains in the original sand/silt-texture up to hard, stony layers with $CaCO_3$ concretions in boulder size. The alluvium can reach a thickness of 120 m (Antea International, 1999). The geomorphology of the district reflects the Precambrian and Quaternary geology and shows a variety of landforms, including hills, pediments, undulating fluvial plains, aeolian dune fields, ravines and paleo-channels. Furthermore, anthropogenic processes like mining and leveling of natural slopes and fluvial erosion structures shapes the modern landscape.

The study area Khara Kuaa is situated directly on the quartzite of the Alwar series whereas in the study area Nai Ki Thari, the Quaternary alluvium overlies the Precambrian rocks (Fig. 15).

Tab. 5: Stratigraphic overview of the Aravalli Mountain Range.

Era	Supergroup	Group*	Series	Lithologies
Paleoproterozoic	Aravalli	Lower shelf facies/Aravalli Group		shale-sand-carbonate assemblage
		Upper deep-water facies/Aravalli Group		carbonate-free shale-arenite association with ultramafic rocks (serpentinites)
Mesoproterozoic	**Delhi**	**NDFB**	**Alwar**	**Quartzite, Conglomerate, Schists**
			Ajabgarh	Schists, Phyllites, Marble, Quartzite
		SDFB		

** Classification of the stratigraphy of the Aravalli Supergroup after Sharma (2009).*

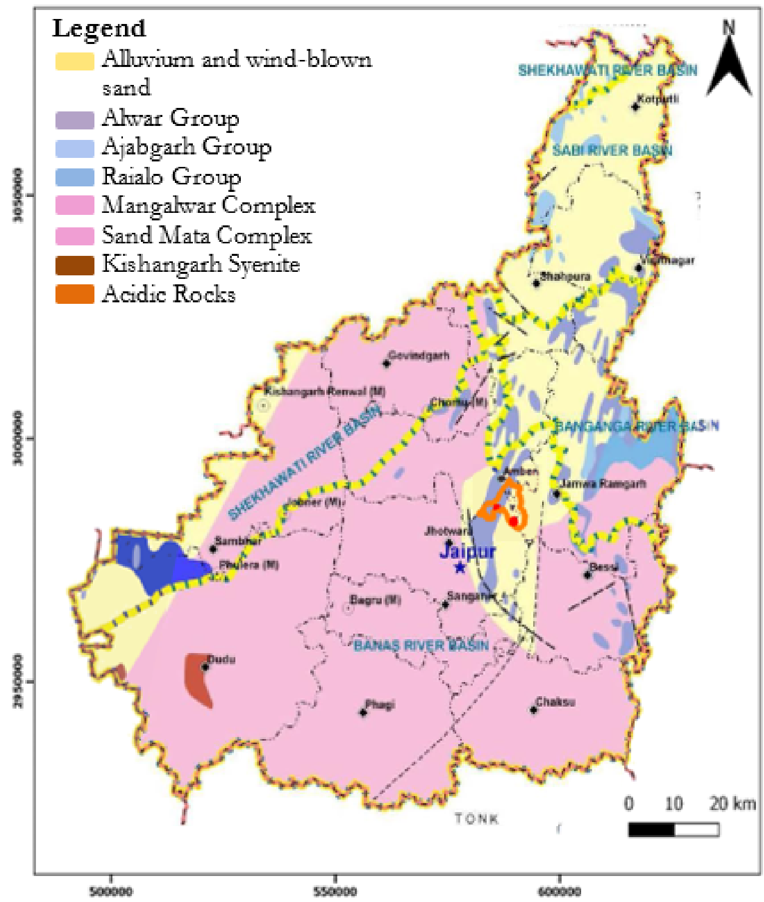

Fig. 15: Geology of Jaipur District. The surface catchment of the study areas is shown in orange with the two study areas as red marks (modified after Rolta India Limited, 2013).

2.2.5 Hydrogeology

Important aquifers in the wider region are the Quaternary alluvium, the Proterozoic quartzite, the recent aeolian dune sand aquifer in the western part of the district as well as the altered and closely jointed granitic gneiss aquifer belonging to the Archean Bhilwara Supergroup in the south of Jaipur district. Data on aquifer characteristics are rare. Based on data from 25 exploratory wells in and around Jaipur a transmissivity of 10-1000 m^2/d is given with medium to high values in the East of the city in the Dhund river basin (see Fig. 14). Storativity values range from $5x10^{-5}$ to $1x10^{-1}$. Medium to high values $>5x10^{-4}$ are found South, East and at some locations North of Jaipur. However, the data show a wide range and are not specifically assigned to a single aquifer. At most places groundwater occurs under unconfined conditions in the quartzite and alluvial aquifer but a lens-like structure of the alluvial deposits with 16 % of clay content causes locally confined conditions. Furthermore, *kankar* can form confining layers on a local scale.

As on March 2015, the GWB had 51 national hydrograph stations (NHS) in operation to monitor the groundwater level within the whole district. Out of these 51 wells, 15 are dug wells and 36 are observation wells (Antea International, 1999; Yadav et al., 2016). With this districtwide monitoring network of the Regional Groundwater Board Jaipur the general development of the water tables can be shown (Tab. 6, Fig. 16). The long-term groundwater development in the Jaipur District shows decreasing water tables both in the alluvial and the hard rock aquifers (quartzite and schist). Reasons are the overexploitation by agriculture, industry and the increasing population. Major groundwater quality problems in the district are elevated EC values and increased nitrate and fluoride concentrations exceeding the Indian drinking water standard. Latter occurs mostly in the south of the district (Rolta India Limited, 2013).

In the two study areas, the Quaternary alluvium and the Proterozoic quartzite are forming the main aquifers.

Tab. 6: Key data of representative wells in Jaipur District. Criteria for the selection were the most complete available data sets, the coverage of all aquifers of the district and the inclusion of observation wells closest to the study areas, e.g. Amer. Numbers in brackets refer to numbers in Figure 16. Data from Ground Water Board Jaipur, Rajasthan.

Village name	Well depth	Longitude	Latitude	Aquifer type
Nangal Pur (6)	80.5	75°46’50”	27°04’43”	Younger Alluvium
Tala (5)	23.5	76°02’20”	27°12’15”	Younger Alluvium
Malawala (10)	65	75°55’09”	26°59’25”	Younger Alluvium
Bagwara (9)	32.7	75°50’45”	27°05’15”	Younger Alluvium
Muhana (7)	56	75°48’00”	26°48’00”	Older Alluvium
Nevta (8)	63	75°40’45”	26°47’45”	Older Alluvium
Raisar (3)	26	76°12’16”	27°10’12”	Quartzite
Amer (4)	99	75°53’00”	26°59’00”	Quartzite
Kukas (2)	72.5	75°52’39”	27°04’07”	Quartzite
Thali (1)	23.5	76°13’00”	27°04’00”	Schist

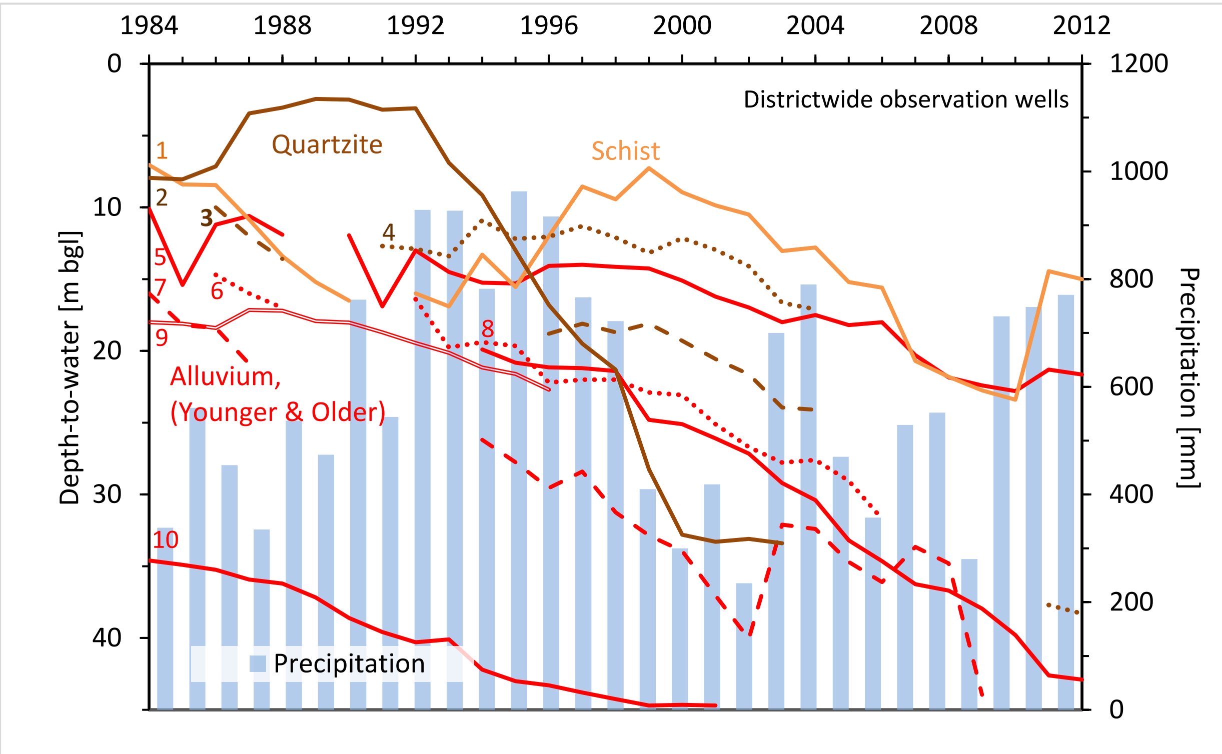

Fig. 16: Mean annual precipitation compared to the evolution of water tables of representative wells (Tab. 6) in Jaipur District (from 1984 to 2012). Data from Ground Water Board Jaipur, Rajasthan.

2.3 Hydrogeological Conceptual Model

Title[10]:

Anthropogenic and Geogenic Impacts on Peri-Urban Aquifers in India – Insights from a Case Study in the Northeast of Jaipur

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Abstract:

The increasing demand for water due to population growth and industrialization results in a high pressure on groundwater resources in the city of Jaipur in northwestern India. The main part of the city's water supply is ensured by the Bisalpur dam (Banas-River) situated approximately 100 km southwest of Jaipur, but often the supply infrastructure does not reach the fast and often unplanned growing urban fringe of Jaipur. Therefore, water supply in these low-income areas is mainly informal and based on groundwater which implies that people have to rely on water without any quality examination and quantity regulation though severe problems prevail with both issues. Jaipur is located on the eastern border of the Thar Desert within the Aravalli Mountains and has a semiarid climate with monsoonal rainfall from June to September. The Proterozoic quartzites of the Aravallis constitute a hard-rock aquifer which, in the valleys, is covered by alluvial sediments with a thickness of up to 100 m. The various impacts on groundwater quantity and quality in both aquifers have not yet been fully understood making it difficult to develop sustainable groundwater protection and management plans. Hydrochemical samplings, stable water and nitrate isotopes analysis, depth-to-water level measurements and geoelectrical investigations were conducted to get information about the local, extensively used aquifers. The two-year monitoring program in two study areas in the northeastern part of the city revealed that, despite the anthropogenic influences, the complex geological setting has a strong effect on the groundwater flow regime, leading to substantial local differences in the water composition. Although it is of great importance, the existing monitoring network cannot depict these small-scale changes, because it is not dense enough and

[10] Frommen, T., Groeschke, M., Noelscher, M., Königer, P. & Schneider, M. (2019) Anthropogenic and geogenic impacts on peri-urban aquifers in India – Insights from a Case Study in the Northeast of Jaipur (in prep.)

the observation points are allocated chiefly according to administrative units. This study is a first step towards sustainable management of a water resource many people rely on by improving the understanding of the local hydrogeology. This knowledge is essential for the development of an adapted catchment wide monitoring network.

2.3.1 Introduction

In the last two decades, urbanization was one of the most important factors shaping the current world. In 2015, 54 % of the world total population lived in urban areas with Asia being at the top with more than 2.1 billion people living in cities (Moreno et al., 2016; Turekian & Kulp, 1956). In India, the growth rate of the urban population between 2000 and 2010 was 2.6 % and until 2050 another 404 million Indian people are expected to live in cities (UN-Habitat & ESCAP, 2015). The area most affected by the rapid growth of cities is the zone at its borders (Howard, 2014). This so-called peri-urban area can be defined as a transitional zone of mixed rural and urban uses in terms of economic, social, cultural and natural resources at the periphery of cities (Phillips et al., 1999). The shift from rural to urban has and will have huge influences on the natural resources, including groundwater. To date, in many urban areas in India water tables are decreasing (MacDonald et al., 2016). This trend can also be observed in semi-arid rural areas, for example in Rajasthan (Yadav et al., 2016). However, urbanization can also lead to an increase in recharge rates, e.g. through a leaking sewerage and, hence, to rising groundwater tables (Foster, 2001). In addition to direct anthropogenic impacts, meteorological patterns also play a significant role regarding groundwater resources. Asoka et al. (2017) have shown that in northwestern India groundwater storage variability is mainly due to groundwater abstraction, whereas in north-central and southern parts of India changing precipitation patterns control the fluctuations of groundwater tables. This shows that a prognosis regarding the development of the groundwater resources, especially in peri-urban areas, is complicated as various factors influence it.

Peri-urban areas often serve as a source of water for the ever increasing demand of the cities (Butterworth et al., 2007). Besides the water provided by the public water suppliers, which often use a significant share of groundwater in their supply schemes, a large part of the cities demand is being served by an informal water market, in which groundwater is transported, for example via private tankers, from the outskirts to the city centers (Prakash & Singh, 2014). This informal market makes it nearly impossible to manage the groundwater abstraction in a sustainable way. At the same time, peri-urban areas often function as disposal sites for wastewater from the cities. A failure to view the peri-urban space as a resource worth protecting and insufficient wastewater treatment capacities lead to the accumulation of wastewater in lakes, ponds and lowlands with the expected negative impacts on groundwater quality (Karpouzoglou et al., 2018). In addition, the lack of a sanitation and sewerage infrastructure in many unplanned peri-urban areas increase the effect of anthropogenic pollution of groundwater resources (Prakash & Singh, 2014; Sekhar et al., 2005), which is typically characterized by elevated nitrate concentrations and occurrence of fecal pathogens (MacDonald et al., 2016; Yadav et al., 2016).

Apart from anthropogenic contamination, geogenic contaminants regionally lead to a deterioration of groundwater quality. They are not restricted to peri-urban zones but may in cases complicate the use of groundwater in these areas. Besides high Fluoride (mostly in northwestern and southern India, (Podgorski et al., 2018)) and Arsenic (e.g. in large parts of the Indo-Gangetic plain and the Brahmaputra floodplain (Ghosh & Singh, 2010)) concentrations, elevated groundwater salinity is a frequent cause of concern in many parts of India, posing difficulties for both irrigation and drinking purposes (Bhardwaj, 2005; MacDonald et al., 2016). Reasons are saline intrusion in coastal areas, but also historic marine influences, dissolution of evaporates and the evaporation of surface water and shallow groundwater. In many areas, for example in the Indo-Gangetic plain, the natural salinity is increased by intensive irrigation practices in agriculture (MacDonald et al., 2016).

Because the processes within the peri-urban zone of Indian cities influence groundwater availability and quality significantly, they have to be studied in detail to find the best options to achieve sustainable water management, for both, the peri-urban areas itself and the city. This was done in two peri-urban areas in the northeast of Jaipur, the capital of Rajasthan, where, as in many peri-urban areas in India, data on groundwater is sparse. The goal of the study was to develop a conceptual model of the local hydrogeological condition, including groundwater flow and hydrochemical evolution. This includes the identification of areas of special concern with a high risk of geogenic or anthropogenic contamination of groundwater, leading to the identification of possible solution approaches.

2.3.2 Study Area

Jaipur, the capital of the state Rajasthan in northwestern India is situated between latitude 26.82° to 27.00° and longitude 75.73° to 75.85° (WGS 84) on the eastern border of the Thar Desert (Fig. 17). It is classified as a semi-arid area with a long-term average annual rainfall of 565 mm in Jaipur district, based on data from 1977 to 2006 (CGWB, 2013). 90 % of the annual rainfall take place during the south-west monsoon from June to September (CGWB, 2007). A high variability of the annual monsoonal precipitation amount can be observed. In 2006, only 387 mm rainfall was measured for Jaipur district, whereas in 2010 it nearly doubled to 792 mm (Yadav et al., 2016).

The city is situated within the Proterozoic Aravalli Mountain Range which extends over 700 km from North Gujarat in the SW up to Delhi in the NE (Sharma, 2009). The steeply rising hills (up to 650 m NN) surrounding Jaipur from NE to W belong to the Alwar Series of the Mesoproterozoic Northern Delhi Fold Belt and mainly consist of fractured and partly weathered Quartzite. The Geological Survey of India (GSI, 2011) reports for the Alwar Series a feldspathic Quartzite. In the occasionally wide valleys in-between the NNE-SSW striking hills (GSI, 2011) the bedrock is covered by Quaternary alluvial sediments, which can reach a thickness of up to 100 m (CGWB, 2007). The alluvium does not only consist of fluvial sediments, but also aeolian sediments and denudational material close to the hills, leading to a wide range of sediments from silt and fine sand to coarse sand and gravel near the hills. Three fluvial phases during the Quaternary reworked the sediments and formed the landscape so that today buried river channels as well as undulating fluvial plains can be found (Antea International, 1999; CGWB, 2013; GSI, 2011). Kankar layers, consisting of secondary calcite rich nodules occur at various depth within the Quaternary alluvium (Antea International, 1999).

The main soil types in Jaipur district following the USDA Soil Taxonomy are entisols and, to a lesser amount, aridisols, with a loamy sand to sandy loam, sandy clay loam or sandy clay texture (CGWB - Central Groundwater Board, 1997; Yadav et al., 2011). Furthermore, river and wind-blown sand can be found at the land surface, whereas latter mainly occurs in the westernmost part of the district (CGWB, 2007).

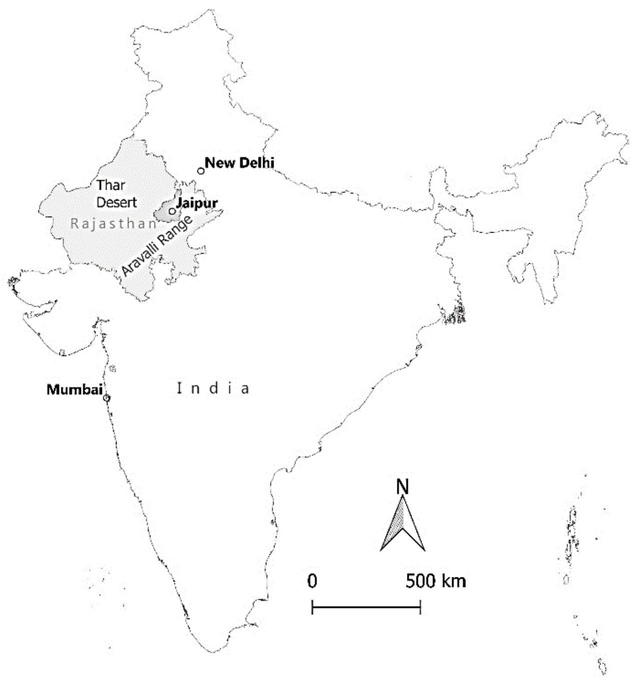


Fig. 17: Map of India with Rajasthan and its capital Jaipur which is located at the eastern border of the Thar Desert. The Proterozoic Aravalli Range stretches from North Gujarat up to Delhi.

Two peri-urban communities situated in the NE of Jaipur in the sub-district Amer were chosen exemplary as study areas due to their socio-economic, topographic and geologic heterogeneity (Fig. 18). Khara Kuaa (KK) is a well-established Hindu community lying at the foothills of the Aravallis behind the Amer Fort, relying mainly on groundwater from the weathered parts of the Proterozoic quartzite (fractured hard rock aquifer). The second study area, Nai Ki Thari (NKT), is a Muslim community located in the flat plain 5 km outside of the current city boundary, which was developed within the last 20 years only. The main aquifer in this study area is the Quaternary alluvium.

2.3.3 Material and Methods

Data Collection, Mapping and Well Selection

In preparation of the water sampling campaigns, a detailed mapping of the water infrastructure was conducted in both study areas to understand the role of groundwater in the target zones and identify wells suitable for hydrogeological investigations. Mapping activities included interviews about how and where groundwater is used by whom and about possible sources of contamination (e.g. location, construction and maintenance of septic tanks). An emphasis was laid on surface water bodies and their possible connection to the aquifer. Data regarding the design of the wells was mainly collected by interviews with well owners and well users as no bore logs were available. Within the wider surroundings of the study areas the mapping was done with the focus on representative well locations rather than a complete mapping of all wells.

Wells for regular hydrochemical sampling were chosen according to the following criteria:

Functioning: The well is in a good condition and the pump is working.

Permission: The well owner (private or public) agreed to a regular sampling.

Accessibility: The well is accessible by auto rickshaw or foot during all seasons.

Importance: The well has a high importance for the formal or informal water supply, e.g. many people depend on it.

Distribution: Both communities and their surroundings are covered in a meaningful way by considering geology, surface water bodies and possible contamination sources.

Depth: A large range of total depth of the wells is covered to be able to detect depth-dependent differences in water quality.

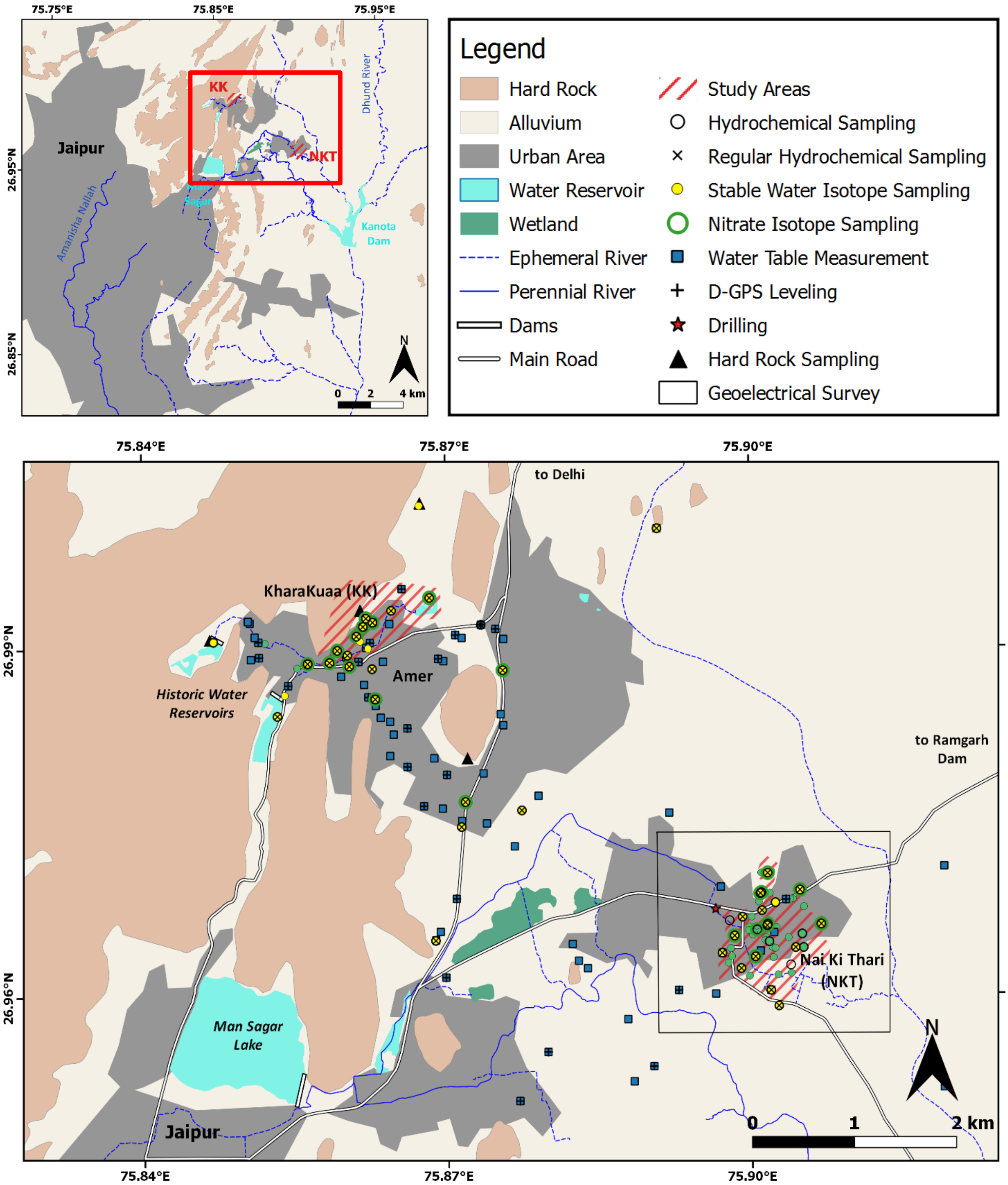


Fig. 18: Overview study areas with all sampling points.

Water Sampling Strategy

With the aim of characterizing the groundwater chemistry of the study area, detecting seasonal changes and possible influences through surface water bodies, water samples were taken for analyses of major ions and stable isotopes of water and nitrate. For hydrochemical analyses, 121 water samples were collected from a total of 34 wells and two surface water bodies from November to

December 17 (Tab. 7). Thirty of these wells were chosen for regular sampling at a three-to-five months' interval, the number varying slightly at each campaign due to some wells falling dry or pumps braking (Fig. 18). Additionally, one rain sample was collected for a full hydrochemical analyses in January 2017.

Tab. 7: Number and type of wells for the sampling campaigns.

Type of well	Nov/Dec '16 *winter*	Apr '17 *pre-monsoon*	Oct '17 *post-monsoon*	Dec '17 *winter*
Bore well	16	13	14	11
Hand pump	11	12	14	14
Bore well (from water supplier)	2	2	2	1
Dug well	2	1	0	0
Observation well	1	1	0	0
Lakes	1	0	2	0
Rain	1	0	0	0
Total	34	29	32	26

At the observation well, samples were taken using a submersible pump (a GEO-DUPLO-PLUS 12V connected with three inline booster pumps GEO-INLINE-PLUS 12V) once on-site parameters (T, EC, pH, ORP, O_2 measured in a flow through-cell) were stabilized. At all other types of wells, the installed pumps (manual or electric) were used for sampling. Because of frequent power cuts, reluctance of well owners, wastage of water at private wells, environmental conditions (manual pumping at >40 °C), pre-pumping was difficult at some sampling points. In such cases, sampling was conducted at the usual pumping times of the wells – in the morning or evening. In this way, it was guaranteed that the well was already running for more than 30 minutes, sometimes up to 2 hours. The physicochemical parameters (T, EC, pH, ORP, O_2) were measured on-site by customary probes (Intellical Probes, Hach) with a digital portable multimeter (Hach HQ40D). After a complete screening in the first sampling campaign, colorimetric tests to determine redox-sensitive species (NH_4^+, NO_2^-, NO_3^-, S_2^-) were applied in the field wherever necessary. Details of the applied field tests can be found in Appendix A1. Bicarbonate was always determined using a titrimetric test (accuracy 0.2 mmol/L). Color, odor and turbidity were assessed in the field by observation. All samples were filtered (0.2 µm Polyethersulfone membrane filter) and samples for cation analysis were acidified with ultra-pure 60 % nitric acid to pH < 2, before being filled in polyethylene bottles and stored under cold conditions. The storage period lasted from a few days up to one month.

Cations were analyzed by ICP-OES (Optima 2100 PerkinElmer) and anions by ion chromatography (Dionex ICS 1100) at the hydrogeochemical laboratory at the Institute of Geological Science of the Freie Universitaet Berlin, Germany.

A total of 152 stable water isotope samples were taken between November 16 and October 2018. Out of the 152 samples, 112 are groundwater samples, 28 surface water samples and twelve rain samples (Fig. 18). Groundwater samples were taken from all hydrochemical sampling points and from two additional hand pumps, KK_HP26 next to an historic water reservoir and KK_HP08 to the North of Khara Kuaa. Surface water samples were taken regularly from three lakes (one reservoir and one *taalaab* which also have been sampled for hydrochemistry and one additional historic reservoir) and once from two canals (*nallahs*), which have not been part of the hydrochemistry sampling. The sampling at the lakes was mainly carried out with a 2 L plastic bucket connected to a 1.5 m long stab. Rain samples were taken on top of a small building in the East of Jaipur City (Lon: 75.841136°, Lat: 26.903073°) with a self-made rain isotope collector using the design by Gröning et al. (2012). The samples were collected during seven rainfall events during the monsoon season 2017 and at single rainfall events in January and March 2017. The samples were filled in tightly sealed glass vials without pretreatment and stored in a dark and cool place until analysis (Picarro L2120-i cavity ringdown analyzer) at the BGR laboratory in Hannover, Germany. All samples were analyzed as replicates, drift-corrected and calculated against international standards (VSMOW/VSLAB). The values are given as δ-value in ‰. Analytical error for quality check sample measured with the values is better than 0.2 ‰ and 0.8 ‰ for $\delta^{18}O$ and $\delta^{2}H$ respectively.

Stable nitrogen isotopes of nitrate were analyzed in 31 samples (23 groundwater samples, three surface water samples - two from the *taalaab* and one from the historic reservoir -, two wastewater samples and one sample of cow dung, fertilizer and from a public water supply line, respectively) collected between November 2016 and October 2017 (Fig. 18). Oxygen isotopes were analyzed in nine of the 31 nitrate samples (Appendix 6). The samples were taken by applying the anion exchange resin approach developed by Silva et al. (2000), improved by Xing and Liu (2011) and adapted to the field by using a 50 ml syringe to create a vacuum and force the sample water through the anion exchange resin instead of a peristaltic pump. All samples were analyzed as triplicates. ^{15}N was measured with an elemental analyzer (EA Flash 2000) and ^{18}O by high temperature pyrolysis TC-EA coupled with an IRMS Delta V Advantage (Thermo Fisher Scientific) via ConFlo IV system with a precision better than 0.5 ‰ for $\delta^{15}N(NO_3)$ (AIR) and 1.0 ‰ for $\delta^{18}O(NO_3)$ (VSMOW) and reported as delta values calibrated relative to international standards (USGS40, USGS41).

Depth-to-Water Measurements and Leveling Survey

Regular depth-to-water measurements were conducted to identify seasonal water table changes. For the regular water table measurements every two months, 30-50 wells were chosen within both communities and their surroundings (~30 km², altitude difference of about 45 m) including hand pumps, bore wells, dug wells, step wells and observation wells (Fig. 18). The number of wells varied slightly from campaign to campaign mainly due to dry wells but also due to completely closed or overgrown wells. A water level data logger (Solinst) was installed in an unused hand pump tapping the fractured quartzite aquifer. In May 2017, a leveling survey was conducted to determine the absolute elevation of the 31 most important wells. The applied D-GPS Leica Viva GS14 system can give, under favorable conditions, a horizontal accuracy of 8 mm + 1 ppm and a vertical of 15 mm + 1 ppm when applying the RTK mode (real time kinematic) with a single baseline (Leica, 2016).

Geophysical Survey and Rock Samplings

To get more information about the thickness of the Quaternary alluvial sediments/aquifer and the distribution of thickness of possible clay layers, 30 geoelectrical resistivity soundings were conducted in Nai Ki Thari, in September 2017 (Fig. 18, Appendix 7). The work was carried out by the company Hydro-Geosurvey Consultants Pvt. Ltd. which recorded the soundings with a computerized resistivity meter CRM-500 and adopted Schlumberger's configuration.

Seven hard rock samples were collected from four outcrop locations around Khara Kuaa for batch experiments (Fig. 18). The batch experiments were carried out at the Freie Universität Berlin according to the procedure described in DIN 19529.

Statistical Methods for Hydrochemical Facies Interpretation

To get a more objective classification of the hydrochemical facies, multivariate statistical analysis (MSA) were applied and compared to graphical methods (Durov plots, binary plots). For that, the original data base was edited. As a first step, only the groundwater samples from one sampling campaign (October 2017) were used to avoid duplicates which could lead to an overestimation for certain wells. The October 2017 sampling campaign was chosen because all samples of this campaign show a CBE within ± 3 %. Regarding the input parameters, the variables were reduced to 17 variables (main ions, EC, pH, O_2, Br, Sr, Zn, F, Ba, B) including only variables with results for all samples (Güler et al., 2002). Values below the detection limit were replaced by multiplying the respective lower detection limit with 0.55 to avoid non-numerical values. This simple substitution method is possible if the data set shows only a small portion (<10 %) of censored values (Sanford et al., 1993) and if the choice of the substitution method does not have an effect on the final geochemical interpretation (Miesch & Barnett, 1976). In a next step, descriptive statistics (mean, median, standard deviation, 25th and 75th percentile, minimum, maximum and skewness) were calculated and histograms were generated using the statistical software statistiXL 2.0, which can be used as an add-in with Microsoft Excel. Based on this, the data were checked for normal distribution as multivariate statistical methods assume a normal distributed data set. As a result, all variables, except EC, pH and Ba, were log-transformed to achieve a more normal distribution. Both, the transformed and the untransformed values were then standardized by calculating their standard scores to guarantee that all variables are equally weighted in the following multivariate statistical calculations regardless of their magnitude (Güler et al., 2002).

Hierarchical Cluster Analysis (HCA) was chosen as it provides the possibility to generate homogenous groups which helps to define hydrochemical facies (Newman et al., 2016). Distance/Similarity Measure was calculated with the Squared Euclidean Distance method. In order to avoid a tendency in the subsequent analysis, the HCA was first performed with the nearest neighbor clustering method with which outliers can be identified (Daughney & Reeves, 2005; King et al., 2014). In a second step, the clustering was performed following Wards method. Güler et al. (2002) had shown that the combination of these methods gives best results for hydrochemical data. Next to the distance matrix and the clustering strategy, results of the HCA are displayed as a dendrogram giving a visual summary of the grouping.

2.3.4 Results

Out of the 121 water samples taken in total for hydrochemical analysis (Tab. 7, Appendix A2), 93 samples are used for further interpretation based on their belonging to the regular sampling campaigns and on their analytical accuracy (CBE < 10 %) (King et al., 2014; Montcoudiol et al., 2015). Due to the fact that nearly all wells in the study area are in use and are not built for monitoring purposes compromises had to be made in terms of suitability for research.

Hydrochemical and Hydrogeological Characterization

Identification of Hydrochemical Units

Based on the HCA, which was conducted with groundwater samples from 34 locations, two groups were distinguished (Fig. 19). To avoid an unpractical large number of groups and sub-groups in the HCA, four locations were classified as outliers in the HCA (KK_OBS02, KK_BW08, NKT_DW02, Amer Inflow) due to their greatly differing chemical properties. Additionally, a third group consisting of three surface water samples from two locations was defined (Tab. 8). Plotting the HCA groups on a map, reveals that the HCA groupings indeed represent different geographic locations (Fig. 20). However, there are some interesting deviations. Surprisingly, the easternmost part of Nai Ki Thari belongs to group 1, which consists otherwise of all wells located in and around Khara Kuaa. Group 2 consists mainly of wells in Nai Ki Thari and the plain between the two study areas but one hand pump (KK_HP20) close to Khara Kuaa falls also into this group.

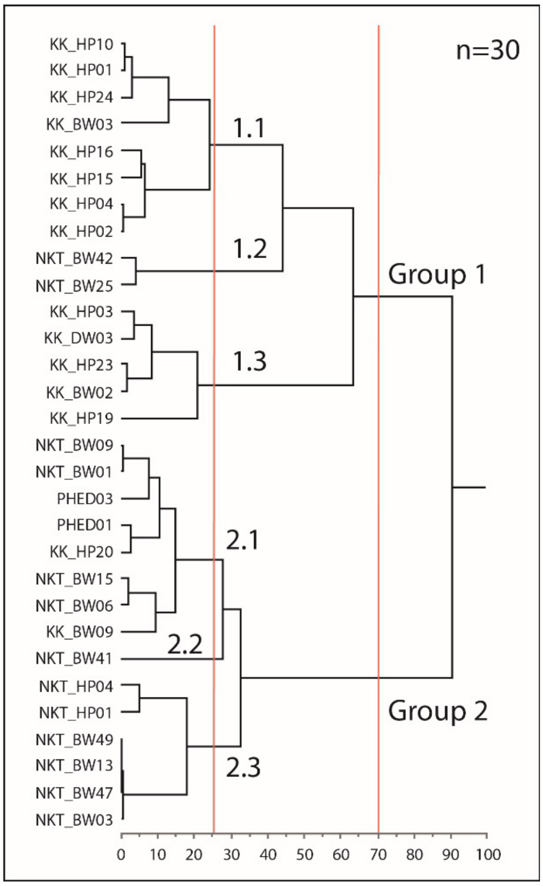


Fig. 19: Dendrogram of the HCA

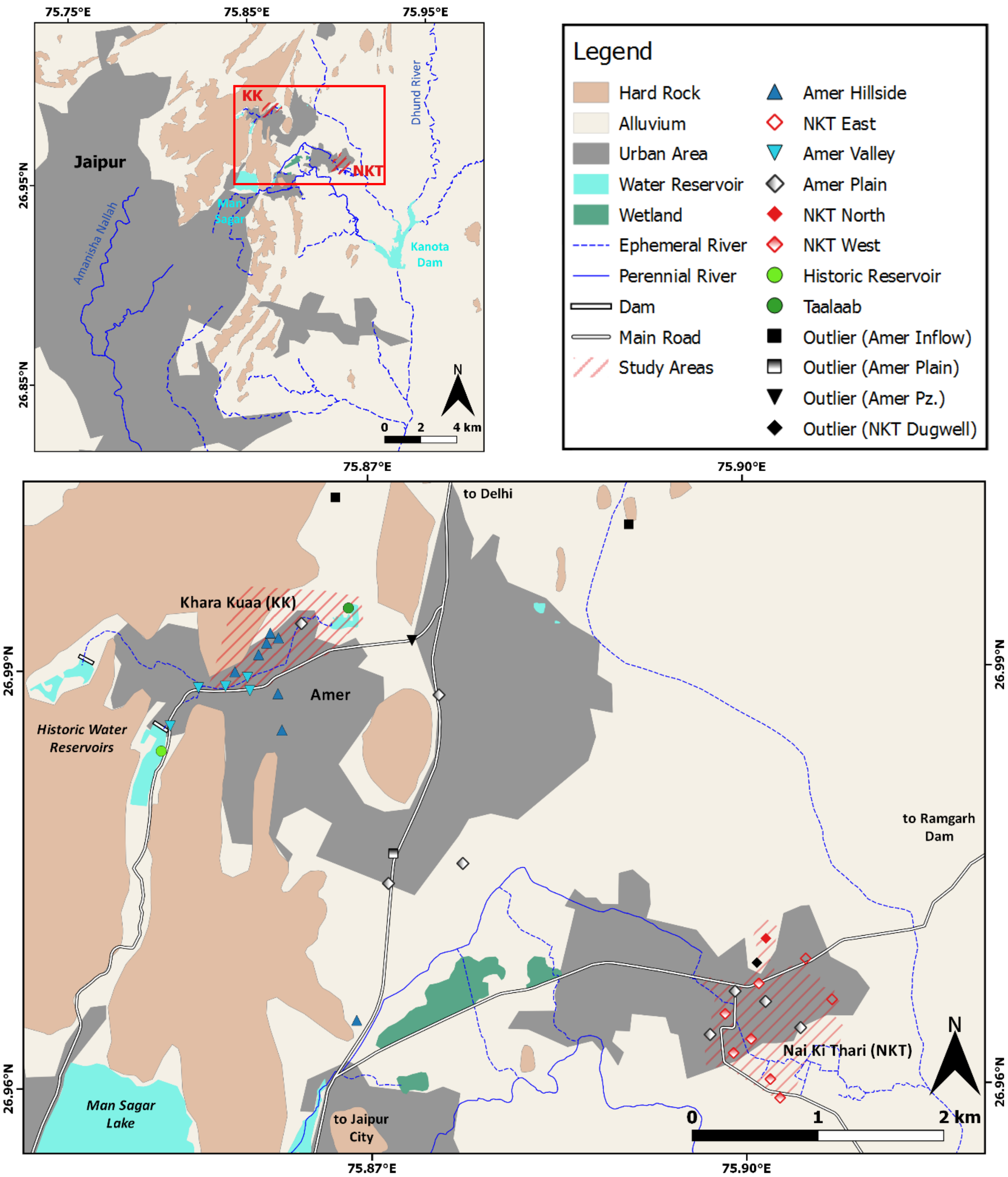


Fig. 20: Map showing the spatial distribution of the hydrochemical groups determined by HCA.

The graphical evaluation using a Durov plot of the samples grouped according to the HCA, including the outliers and the surface water samples shows that the main difference between group 1 (*Amer Hillside, NKT East, Amer Valley*) and group 2 (*Amer Plain, NKT North, NKT West*) is the mineralization, here shown as TDS in mg/kg, with the latter being higher mineralized than the first (Fig. 21). Group 3 (surface water samples) is made up of two samples from the *taalaab*, where greywater from the surrounding area get accumulated and of one sample from the historic water reservoir at Amer Fort. The *taalaab* samples have alkaline ph values (9.54 and 11.04) and TDS concentrations below 1000 mg/kg. The sample from the historic water reservoir has a lower pH value but still slightly alkaline (7.74) and a TDS concentration in the range of the samples from the sub-group *Amer Valley*.

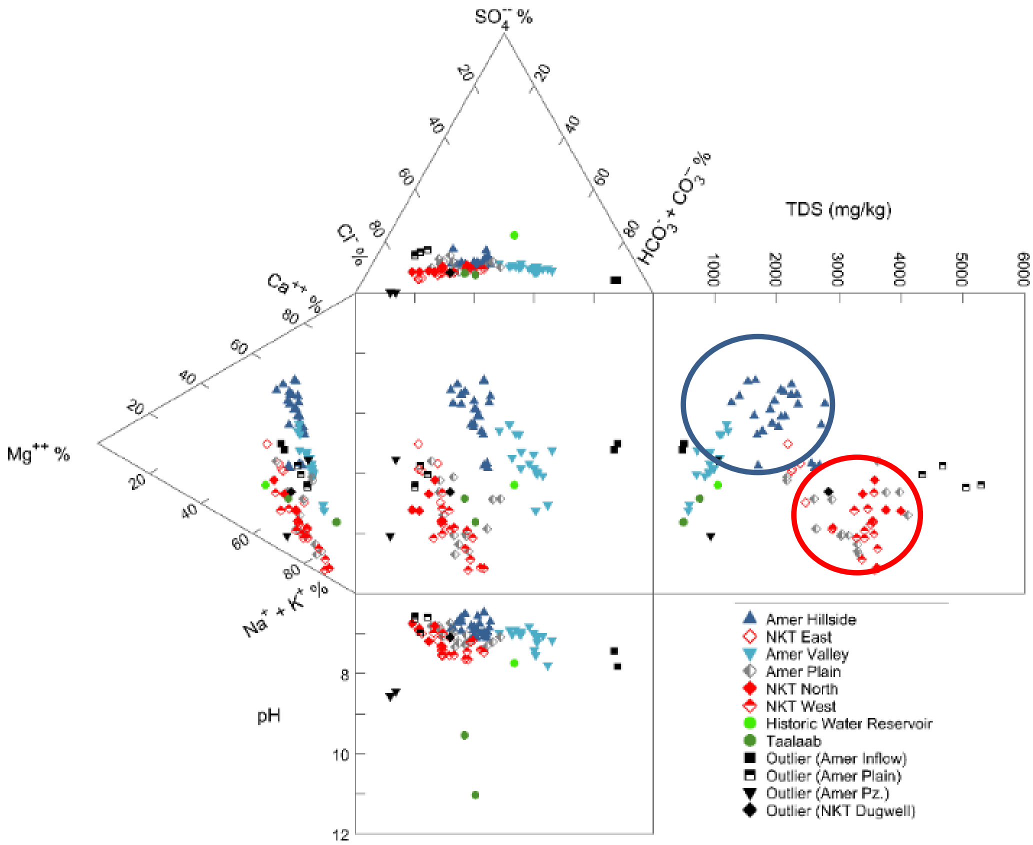


Fig. 21: The differences between the two HCA groups (blue circle: group 1, red circle: group 2,) can be also seen in the Durov plot.

<u>Hydrochemical Characterization of Sub-Groups</u>

According to the HCA, a total of six groundwater sub-groups were identified. Group 1 and 2 were divided into three sub-groups each, while the surface water group (group 3) was divided into two sub-groups (Tab. 8).

Tab. 8: All samples considered for interpretation divided into three groups and eight sub-groups with respective characteristics and mean values for important parameters.[a]

Group	**Group 1**			**Group 2**			**Group 3 Surface Water**	
Sub-group	**Amer [b] Hillside 1-1**	**NKT East 1-2**	**Amer Valley 1-3**	**Amer Plain [c] 2-1**	**NKT North 2-2**	**NKT West 2-3**	**Historic Reservoir 3-1**	**Taalaab 3-2**
Location	study area KK and wells at hillsides	easternmost part of study area NKT	valley near Amer Fort, down-gradient of historic reservoirs	plain area between KK and NKT	northernmost part of study area NKT	west part of study area NKT	up-gradient of Amer Valley	down-gradient of Khara Kuaa

Housing	dense	dense	dense	sparsely	sparsely	dense	sparsely	sparsely
Land use	built-up	built-up, agriculture, industry	built-up	agriculture, built-up	agriculture	built-up, agriculture, industry	forest	fallow
No. of wells	8	2	5	8	1	6	1 (lake)	1 (lake)
Dominant water type	Ca-Cl (Na-Cl)	Na-Cl	Na-HCO_3	Na-Cl	Na-Cl	Na-Cl		
EC [µS/cm]	2822 (± 582)	3586 (± 322)	1325 (± 375)	4230 (± 1038)	5470 (± 353)	5056 (± 653)	1457 -	1082 -
pH	6.47 - 7.11	6.91 - 7.18	6.84 - 7.8	6.74 - 7.34	6.75 - 7.2	6.99 - 7.65	7.74	10.29
SiO_2 [mg/L]	44.0 (± 7.4)	28.7 (± 0.9)	31.6 (± 3.0)	35.5 [31.5] [d] (±12.1) [6.6]	29.1 -	25.6 (± 2.1)	-	-
NO_3 [mg/L]	318 (± 110)	89 (± 3)	71 (± 25)	161 (± 61)	210 (± 6)	164 (± 35)	bdl	1.65 -

[a] Rain sample not shown here [b] *Amer* is the name for a sub-district as well as for the city around *Amer Fort* and, therefore, serves a name-giver for four of the seven sub-groups with *Amer Inflow, Plain* and *Valley* containing sample locations in the surrounding of both study areas *KK* and *NKT* (Fig. 18). [c] 1 sample has a CBE of -11.2 %. [d] Concentrations given in squared brackets without KK_HP20.

Sub-group 1-1 (Amer Hillside): The sub-group *Amer Hillside* consists of all four hand pumps located in the study area Khara Kuaa (KK_HP01, KK_HP02, KK_HP15, KK_HP16), one bore well located close to the study area Khara Kuaa (KK_BW03) and three more hand pumps in the wider surroundings which are also located close to hills (KK_HP10, KK_HP24 and KK_HP04) (Fig. 20). EC values in all 26 samples from the eight locations vary between 1521 and 4060 µS/cm (average 2822 ± 582 µS/cm). This corresponds to TDS between 1272 and 2722 mg/L, exceeding the acceptable limit of 500 mg/l given by the Bureau of Indian Standards (2012) by far with 14 samples even exceeding the permissible limit (in absence of alternate source) of 2000 mg/L. At one well (KK_BW03) the owners reported a "salt crust" in their water storage tank (personal communication, 2017). However, it is still the second lowest mineralized sub-group in the investigated area after sub-group 1-3 *Amer Valley* (Tab. 8). The pH value of the groundwater is between 6.47 and 7.11. The groundwater chemistry is dominated by Ca-Cl except for two samples, KK_HP10 and KK_HP24, which show a Na-Cl water type. SiO_2 concentration is with 44.0 ± 7.4 mg/L the highest of the area (Tab. 8). All samples show high nitrate concentrations between 125 and 555 mg/L. The groundwater of KK_BW03 always shows concentrations > 20 % meq NO_3 and the samples from KK_HP01, KK_HP02 and KK_HP16 always have concentrations > 15 % meq NO_3 related to the total anion concentration.

Sub-group 1-2 (NKT East): Two wells, situated at the eastern end of the study area Nai Ki Thari, fall into this sub-group (NKT_BW25 and NKT_BW42). They have a higher EC – between 3280 and 3950 µS/cm, average 3586 µS/cm – than the samples of sub-group 1-1, but still considerably lower than the average EC of group 2. The groundwater shows a Na-Cl water type and one of the highest SiO_2 concentrations (up to 29.3 mg/L) compared to the other wells located within the study area Nai Ki Thari. The nitrate concentrations of 80-100 mg/L are comparatively low but still exceed the Indian drinking water threshold value of 45 mg/L by twofold (Bureau of Indian Standards, 2012). The similarity of *NKT East* to samples from Khara Kuaa (*Amer Hillside*) is mainly coming from a comparable TDS and main cation concentrations, namely Ca and Mg (Fig. 21).

Sub-group 1-3 (Amer Valley): The groundwater in *Amer Valley* (KK_HP03, KK_HP19, KK_HP23, KK_BW02, KK_DW03), situated next to the study area Khara Kuaa and down-gradient of the historic water reservoirs shows comparatively low EC values between 760 and 1951 µS/cm with an average of 1325 ± 375 µS/cm. The pH varies between 6.8 and 7.8. Unlike the groundwater in *Amer Hillside* (sub-group 1-1), the dominating anion is HCO_3 followed by Cl. On the cation side, Na is the main ion followed by Ca. Nitrate concentrations do not exceed 108 mg/L with an average of 71 mg/L. The SiO_2 concentration (31.6 ± 3.0 mg/L) is lower than in the neighboring sub-group 1-1 (*Amer Hillside*) but in consideration of the relatively low overall mineralization still high.

Sub-group 2-1 (Amer Plain): Going further away from the valley and historic water reservoirs into easterly direction a plain area between hill ridges opens (Fig. 20). The wells from this area (KK_BW09, PHED_01, PHED_03) fall together with the wells located in the middle of the study area Nai Ki Thari (NKT_BW01, NKT_BW06, NKT_BW09, NKT_BW15) into the sub-group *Amer Plain*. In addition, one hand pump located close to Khara Kuaa (KK_HP20) belongs to this sub-group. *Amer Plain* shows again high EC values (between 2840 and 6060 µS/cm) and mainly a Na-Cl water type. pH values between 6.7 and 7.3 indicate a nearly neutral system. Including the well KK_HP20, which has the highest SiO_2-concentrations (59.3 mg/L) of all samples, into the average concentration would give a result of 35.5 mg/L. However, the other samples within the sub-group show concentrations between 24 and 40 mg/L SiO_2 resulting in an average concentration of 31.5 mg/L. Nitrate concentrations vary between 68 and 250 mg/L. The average nitrate concentration of 161 mg/L exceed the Indian drinking water threshold value nearly fourfold. One sample from KK_HP20 was excluded for the calculation as it shows an extreme outlier with 567 mg/L NO_3. In general, *Amer Plain* is the sub-group with the highest variance in all physico-chemical parameters in the associated wells.

Sub-group 2-2 (NKT North): The sub-group *NKT North* consist of only one well (NKT_BW41) located in the northeast part of the study area Nai Ki Thari. It is the sub-group with the highest mineralization (between 5100 and 5850 µS/cm). The groundwater is of Na-Cl type. In difference to the neighboring wells of Nai Ki Thari grouped into *Amer Plain* and *NKT West*, the proportion of HCO_3 in the total anion content is lower (14.3-21.6 meq%) which also result in a lower average pH value of 6.91. The SiO_2 concentrations are with 29.1 mg/L comparable to subgroup 1-2 (*NKT East*). Nitrate concentrations are second highest of all sub-groups with values between 201 and 214 mg/L.

Sub-group 2-3 (NKT West): The wells situated mainly in the western part of Nai Ki Thari form the sub-group *NKT West* (NKT_HP01, NKT_HP04, NKT_BW03, NKT_BW13, NKT_BW47, NKT_BW49). They have the second highest average EC of 5056 µS/cm (values range between 4560 and 6200 µS/cm) and the highest average pH value which is slightly alkaline (7.39). SiO_2 concentration is the lowest of all groups with an average concentration of 25.6 mg/L. Nitrate concentrations vary between 100 and 216 mg/L (average 164 mg/L).

Outliers: Four outliers were not grouped in the HCA analysis, of which three were discarded for the further interpretation altogether. The observation well KK_OBS02, located in the area *Amer Valley* (sub-group 1-3), shows similar EC values as the other samples of this area. However, the pH is more alkaline (pH 8.5) than that of the samples of sub-group 1-3 and the water is of Na-Cl type. KK_BW08, a bore well located in the area of *Amer Plain* (sub-group 2-1), shows unusually high sulfate concentrations, probably resulting from anthropogenic activities. In the dug well NKT_DW02, located in the area of Nai Ki Thari, the large open surface of the well leads to DO concentrations close to oxygen saturation with all related influences on the redox chemistry. However, one of the outliers, Amer Inflow, a hand pump located in the North of both study areas, is probably not influenced by anthropogenic activities and therefore serves as a reference for the original/pristine groundwater. It shows a significantly lower mineralization then all other samples with an EC of 576 µS/cm.

Isotope Analyses

Stable Water Isotopes

Stable isotopes values of twelve rain water samples collected in January and March 2017 and during the monsoon season (July-September) of the same year range from 2.4 to -14.2 ‰, and 34.1 to -102.2 ‰, for $\delta^{18}O$ and $\delta^{2}H$, respectively (Fig. 22). The twelve samples result in a local meteoric water line for Jaipur of $y = 7.8x + 9.1$. The isotopic composition of the surface waters varies with the type of surface water bodies. The historic reservoirs show a very wide range of $\delta^{18}O$ and $\delta^{2}H$ values (from 7.8 to 0.0 ‰ and 24.5 to -12.3 ‰, respectively), while the *taalaab* shows only slight variations between 1.2 and 0.2 ‰ and -8.9 to -16.5 ‰, $\delta^{18}O$ and $\delta^{2}H$ respectively (Appendix A3). The *nallah* samples are more negative than the surface water samples from the historic reservoirs and the *taalaab*, and plot close to the groundwater samples. The regression line through the water samples of the historic reservoir (y = 4.6x + 9.9) has a slope of 4.6 which is typical for evaporation lines for arid to semi-arid regions (Sharp, 2007).

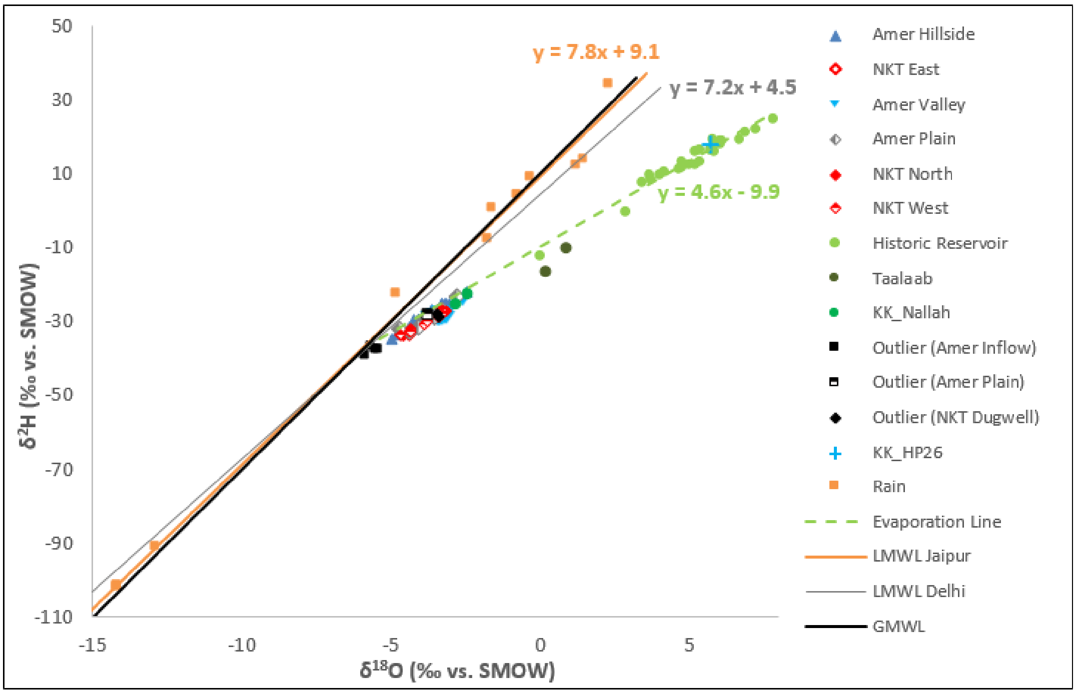


Fig. 22: Overview stable water isotopes. The LMWL based on samples taken in Jaipur (orange square) is similar to the GMWL. Surface water samples (circles) show a clear impact from evaporation. Hand pump KK_HP26 (blue cross) ca. 100 m down-gradient of historic reservoir show also strong evaporation impact. Isotopic values of hand pumps grouped into *Amer Inflow* is close to rain signature indicating a recharge area. All other groundwater samples plot roughly on a line between the two end members. For outlier (*Amer Pz.*) no isotope samples were taken.

All groundwater samples, with exception of KK_HP26, have isotopic compositions between -2.5 and -5.8 ‰ $\delta^{18}O$ and -21.9 and -38.8 ‰ $\delta^{2}H$ (Fig. 23). The most negative δ-values belong to the hand pumps situated up-gradient of the study areas and grouped into *Amer Inflow* (KK_HP08, NKT_HP12). These samples plot very close to the LMWL indicating that they are not much influenced by evaporation. The samples of the groundwater sub-groups *Amer Hillside*, *NKT East*, *Amer Plain*, *NKT North* and *West* (1-1, 1-2, 2-1, 2-2, 2-3) seem to be located on an evaporation or mixing line, while the samples of the sub-group *Amer Valley* (1-3) plot on a cluster around -3.4 and -28.9 ‰ $\delta^{18}O$ and $\delta^{2}H$, respectively. The sample from hand pump KK_HP26 has much higher $\delta^{18}O$ and $\delta^{2}H$ values (5.7 and 17.3 ‰) than all other groundwater samples, and plots in the region of the historic reservoir samples (Fig. 23).

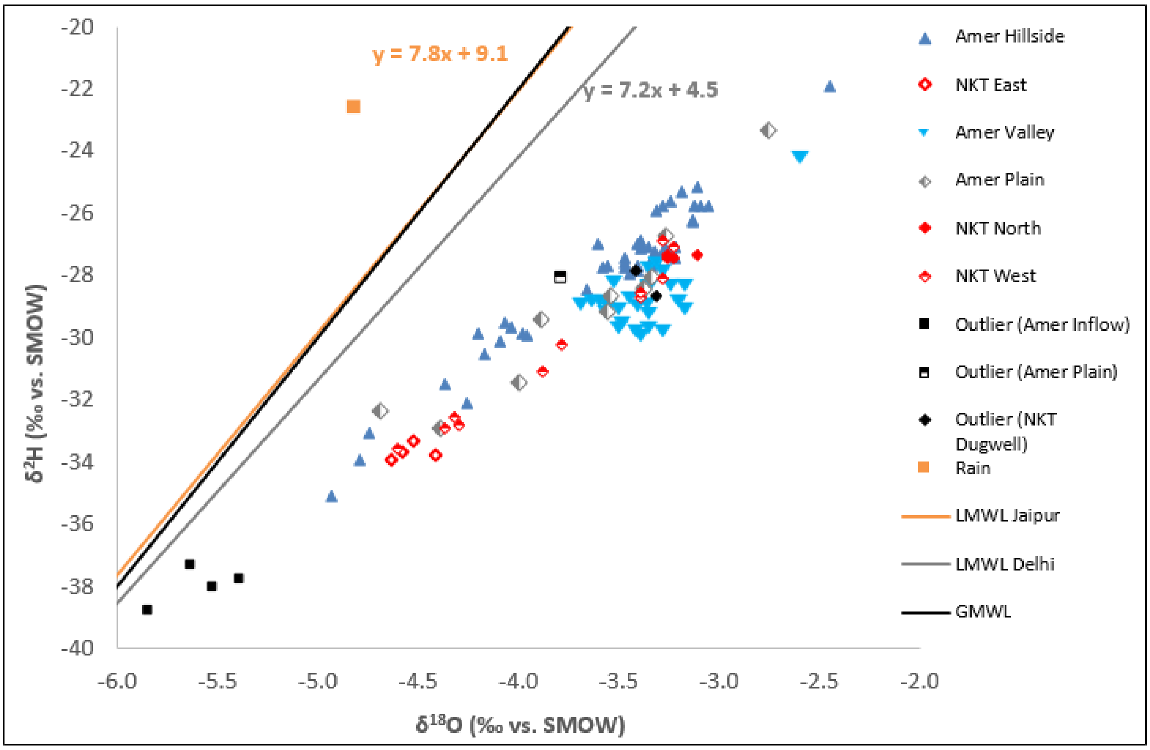


Fig. 23: Details of the stable groundwater isotopes plotted together with the LMWL and GMWL.

<u>Nitrogen Isotopes</u>

Out of 31 samples collected in the field, 28 samples contained sufficient nitrate concentrations for a successful analysis of $\delta^{15}N$ (Appendix A4). Nine of them were additionally analyzed for $\delta^{18}O(NO_3)$. Both wastewater samples and one sample from a historic reservoir did not provide results. In the groundwater samples, the $\delta^{15}N(NO_3)$ values in the range between 12.8 - 17.7 ‰, while the sample from the historic reservoir shows with 6.5 ‰ a significantly lower $\delta^{15}N(NO_3)$ value than the groundwater. Urea, according to local farmers the most important inorganic fertilizer in the area, shows a low $\delta^{15}N(NO_3)$ value of -0.21 ‰. The other important agricultural fertilizer in the region is the manure from cows and water buffalos which has a $\delta^{15}N(NO_3)$ value of 12.3 ‰. This is still slightly below the values for $\delta^{15}N$ - NO_3 in groundwater. Average $\delta^{18}O(NO_3)$ value for groundwater in Khara Kuaa is -11.0 ‰ and -6.7 ‰ in Nai Ki Thari. The *taalaab* sample shows a positive value of 8.4 ‰ while the public water supply line sample shows a negative value of -14.2 ‰ $\delta^{18}O(NO_3)$.

Groundwater Flow and Aquifer Characteristics

According to the interpretation of the geoelectrical resistivity soundings, two main layers could be distinguished in Nai Ki Thari: alluvium and quartzite, whereby the quartzite is divided into a smaller weathered and a hard layer. The weathered layer is situated at the transition between the alluvium and the hard rock (Appendix A5). The alluvium has its maximum thickness in the central part of the Nai Ki Thari with quartzite at depth of 50 to 60 m. However, it is probably, that the hard rock was not detected with the given configuration so the thickness of the alluvium may be even greater. The shallowest occurrence of quartzite is encountered in the northeast and southwest of the investigated area (Appendix A5) with quartzite at a depth range of 30 to 40 mbgl. The deeper part of the alluvium and the quartzite appear to be water saturated. The general groundwater flow direction is roughly from West to East, towards the Tributary E and Dhund River (Fig. 24, overview map). Superficial N-S striking outcrops of the quartzite in the East of Khara Kuaa probably lead to local changes of the groundwater flow direction towards the southeast.

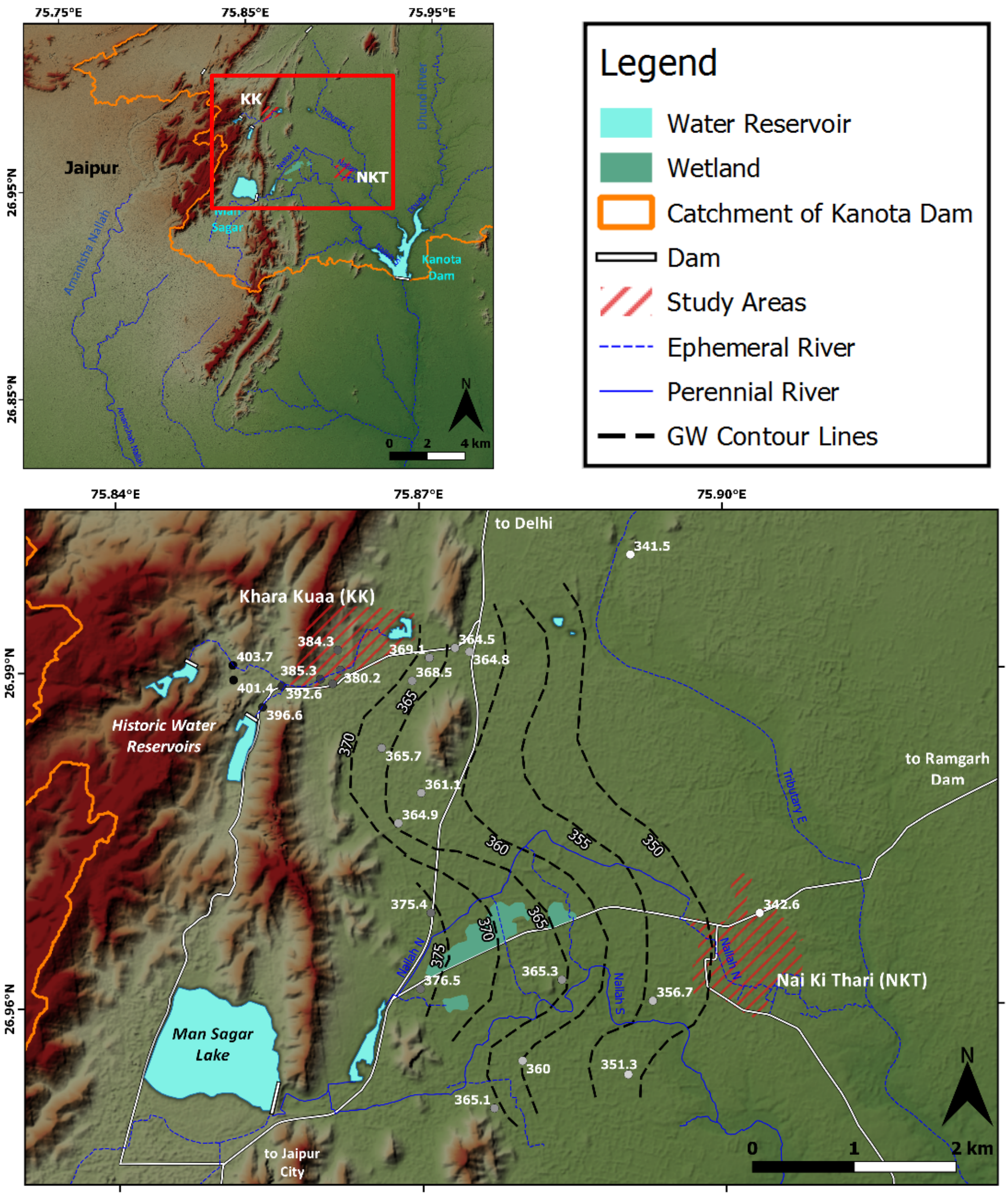


Fig. 24: Groundwater contour lines based on pre-monsoon depth-to-water measurements at 24 wells, April 2017 (Appendix A6).

The data of the water level logger shows the development of the water table at the quartzite aquifer from pre-monsoon season (end of April 2017) until post-monsoon season (end of September 2017) (Fig. 25). The data gap is caused by a rapid water table decline below the depth of the installed logger, which was then installed at a deeper level on 15 July 2017. Based on the data it can be concluded that the water table of the quartzite aquifer dropped by about 20 m within two months in the pre-monsoon season from May to beginning of July (red dotted line). During monsoon, the aquifer reacts within several days to rainfall events. However, all interpretation is only a rough assumption as both the data from the levelogger as well as from the weather station are incomplete and no corrections for changes in air pressure were done.

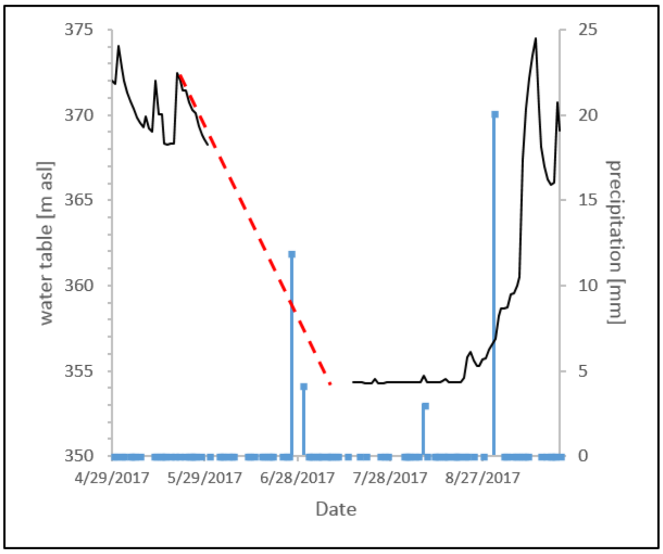


Fig. 25: Levelogger data of hand pump tapping the quartzite aquifer in Khara Kuaa (KK_HP18). Red dotted line shows probable date of the well running dry. Rainfall data are incomplete. Days with missing data are indicated by gaps within the blue bars. Rainfall data are retrieved for Jaipur, Sanganer weather station, from tutiempo.net.

2.3.5 Discussion

Two aquifers exist in the northeastern part of Jaipur, a fractured and partly weathered hard rock aquifer and an alluvial aquifer. The geology is heterogeneous. Large variations in depth-to-hard rock exist. It is very likely that mixing and interactions between both aquifers occur locally and regionally. A statistical analysis (HCA) of the physico-chemical parameters made it possible to group the samples obtained mostly from sampling points of which key information (total depth, well design, bore log) do not exist. In combination with data from water level measurements revealing a general groundwater flow direction from West to East (and locally towards the southeast) and isotope analysis, main processes occurring in the groundwater system can be identified.

Groundwater Recharge

The findings show that groundwater recharge takes place in the hills and from the historic reservoirs. At sampling points at the hillsides, one situated North (up-gradient) of Khara Kuaa, isotope data points towards the presence of probably uninfluenced "pristine" groundwater (Amer Inflow), because the stable water isotope values plot closest to the LMWL of all samples indicating that no or only little evaporation took place. Furthermore, little anthropogenic influences were observed around the sampling points and the groundwater shows a much lower mineralization than in the rest of the study area. In the Cl/Br diagram the sample from Amer Inflow plots in the range of recharge waters (Fig. 28).

In contrast, the hand pump closest to the historic reservoir (KK_HP26) shows isotope compositions much heavier than all other groundwater samples. Because the isotopic composition lies within the range of the historic reservoir samples, it is assumed that the hand pump draws a large part of infiltrated water from the historic reservoir. The samples of sub-group 1-3 (*Amer Valley*) also show a number of characteristics which point towards a strong influence of groundwater recharge from the historic reservoirs. It is assumed that main processes influencing the chemistry of this sub-group are rock-water interactions but that a dilution process through the infiltration of lake water decreases the EC. The sub-group is the only sub-group plotting as a cluster, indicating that there is little seasonal or local variation in isotopic composition caused by evaporation effects or different proportions of mixing. Next to the hydrochemistry, the depth-to-water measurements and the groundwater contour map (Fig. 24) point towards a strong influence of the historic water reservoirs. Wells tapping the hard rock aquifer close to the historic water reservoirs (blue lines) show stable water tables while wells in and around Khara Kuaa show high seasonal variations in groundwater levels (green lines). Wells of the blue lines were not part of the HCA analysis, however, they are located in the area of the sub-group *Amer Valley*. In March 2017, the dug wells located far away from the lake ran dry with only two recovered again after the monsoon (Fig. 26). For comparison, wells situated near Nai Ki Thari tapping the alluvial aquifer show much less pronounced seasonal variations (red lines).

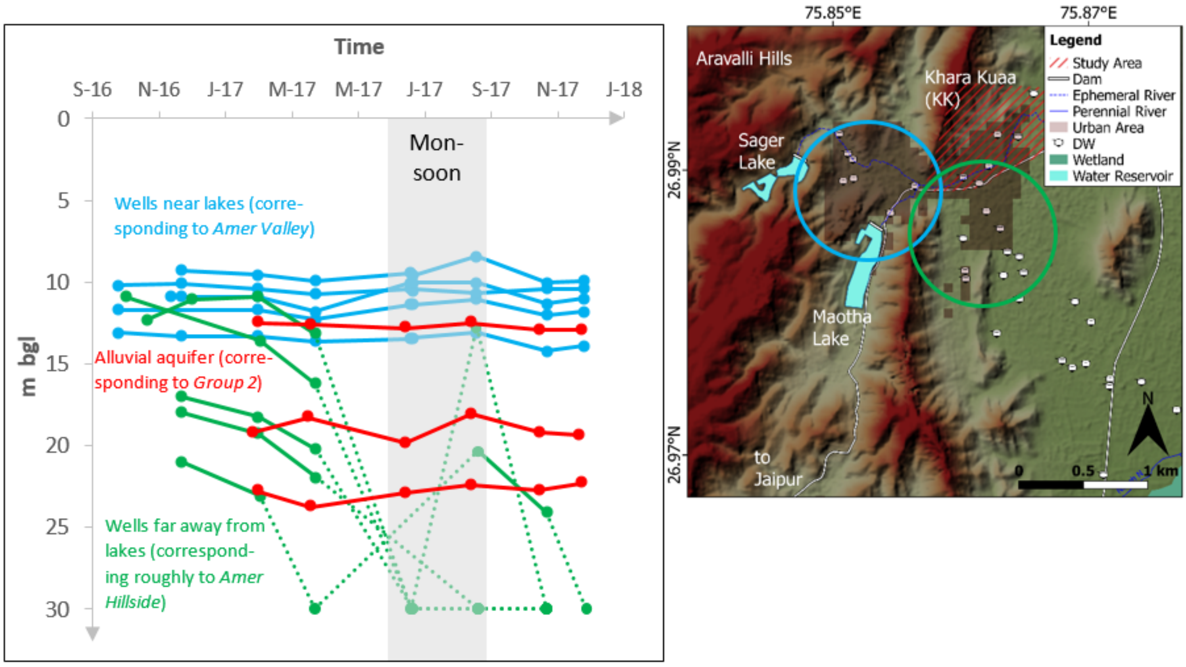


Fig. 26: Local water level change in the surrounding of the study area Khara Kuaa. Light blue lines belong to wells directly down-gradient of the historic water reservoirs (light blue circle) and green lines to wells in the plain east of Amer Valley (green circle). Dashed lines symbolize that the wells ran dry. Red lines represent results from wells tapping the alluvial aquifer (not shown on the map).

Hard Rock Aquifer

Three sub-groups, 1-1 (*Amer Hillside*), 1-2 (*NKT East*) and 1-3 (*Amer Valley*) represent groundwater samples from the hard rock aquifer. However, *Amer Valley* is significantly influenced by recharge and is, therefore, discussed in the previous paragraph. Samples from sub-group 1-1 are taken in an area, where the hard rock crops out at the ground surface or is discovered at a depth of up to 10 mbgl. The SiO_2 average concentrations of 44 mg/L are in the range of literature values for the quartzite rocks. Datta and Tyagi (1996) mentioned for the groundwater of the Delhi quartzite similar concentrations of 10-40 ppm dissolved silica. High bicarbonate values could be explained by the weathering of silicate minerals converting dissolved CO_2 to bicarbonate (Weaver et al., 1999). The Ca-Sr system shows that the samples of *Amer Hillside* and *Amer Valley* plot around the silicate weathering line (Fig. 27).

High evaporation rates and low precipitation can lead to an accumulation of the soluble salts from the weathering process in the small soil cover and in the fractured parts of the quartzite which are leached to the saturated zone during the rainy season (Garduño et al., 2011). The source for the ions, despite the rain itself, are feldspar, glimmer and iron-oxide minerals partly grown within the quartzite and partly filling the fractures. Microprobe analysis (results not shown here) show for nearby hard-rock samples (Fig. 20) quartz and albite spotted grown. As Na is well transportable in water it is assumed that the albite developed during hydrothermal activities at green-facies conditions.

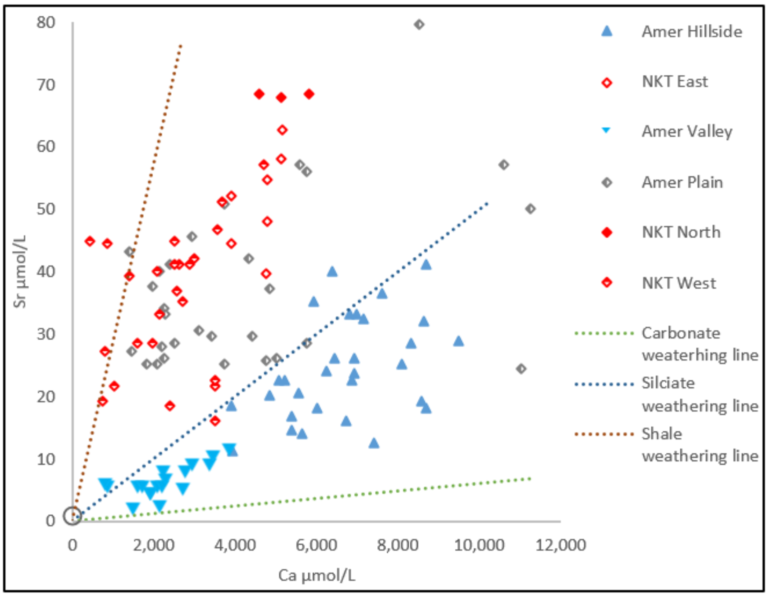


Fig. 27: Sr- Ca plot of all groundwater sub-groups. The dashed lines correspond to the weathering of carbonate, silicate and shales, respectively (Huh et al., 1998; Meybeck, 1986; Turekian & Kulp, 1956)

All samples of sub-group 1-2 (*NKT East*) are taken in an area covered by Quaternary alluvial sediments. However, it is assumed that the wells tap the hard rock underlying the alluvial sediments. Geoelectrical resistivity soundings point towards a comparable shallow depth of the hard rock layer in the northeast of Nai Ki Thari (30-40 mbgl). Interviews with the well owners revealed well depths of 110-140 m. Relatively high SiO_2 concentration compared to the other wells in Nai Ki Thari further support the hypothesis. Comparably light isotopic composition indicates that there might be only little evaporation taking place (in contrast to sub-group 1-1) or that there is mixing with unevaporated water. According to the groundwater contour map the groundwater comes from the West where the Aravalli hill ridge is located. It is assumed that the recharge takes place there. In the hard rock, the infiltration process is faster than in the alluvium and, therefore, less evaporation out of the soil zone can take place.

Alluvial Aquifer

Groundwater samples from the alluvial aquifer locally show different characteristics, presented by the three sub-groups of group 2 (*Amer Plain*, *NKT North* and *West*). The common characteristic of all group 2 samples are high EC values, ranging from 2840 to 6200 µS/cm.

In general, several conditions can lead to an increase in salinity of groundwaters (Etcheverry & Vennemann, 2009; Gat, 1975). In coastal areas the infiltration of mineralized water (e.g. sea water) can take place, while in semi-arid and arid areas evaporation processes play a major role. Depending on the geology, the dissolution of minerals from rock-water interactions during infiltration of water may increase groundwater salinity. Next to these natural reasons at locations of anthropogenic activities the infiltration of surface water of poor quality (e.g. irrigation water, grey water) can decrease groundwater quality and lead to an increase in EC values.

In this study area, evaporation processes are likely to occur due to the semi-arid climate of Rajasthan. Also, the infiltration of surface water with poor quality is possible as at most places a sanitation and wastewater infrastructure is missing and irrigation occurs widely. One method to detect the origin and evolution of salinity in groundwater is the application of the Cl/Br ratio (Fig. 28). Regarding anthropogenic influences, Davis et al. (1998) report in their paper ratios for urban sewage in England and the United States from 670-1350 (corresponding to mass ratio of 300-600) which is similar to the ratios detected by Vengosh and Pankratov (1998) for domestic wastewater in Israel (920-1970). The wide ranges in Cl/Br ratios of sewage can be, among others, due to variations in source water or salt intake (Katz et al., 2011).

With a Cl/Br ratio between 550-1100 and a Cl concentration between 920-1700 mg/L most samples from *NKT West* (sub-group 2-3) plot in the range of "anthropogenic and urban effects", more precisely in the range of "leaching of garbage and solid waste". Sub-group *NKT North* (Cl/Br Ratio:700-1100; Cl: 1350-2000 mg/L) also falls under "anthropogenic and urban effects" as well as sub-group *Amer Plain* (Cl/Br Ratio: 600-1560; Cl: 550-1700 mg/L) which shows more variation. Hence, it could conceivably be hypothesized that infiltration of grey water, next to the evaporation impacts as seen in the isotope data, contributes to the high EC values of the groundwater in the alluvial aquifer. Furthermore, an influence from agriculture is probable. The high EC concentrations and the clear evaporation impact seen in the isotopic composition of the sub-group 2-2 (*NKT North*) may point towards a strong influence from agricultural practices. The well falling in this subgroup (NKT_BW41) is located at a farm where irrigation takes places by regular flooding of the fields.

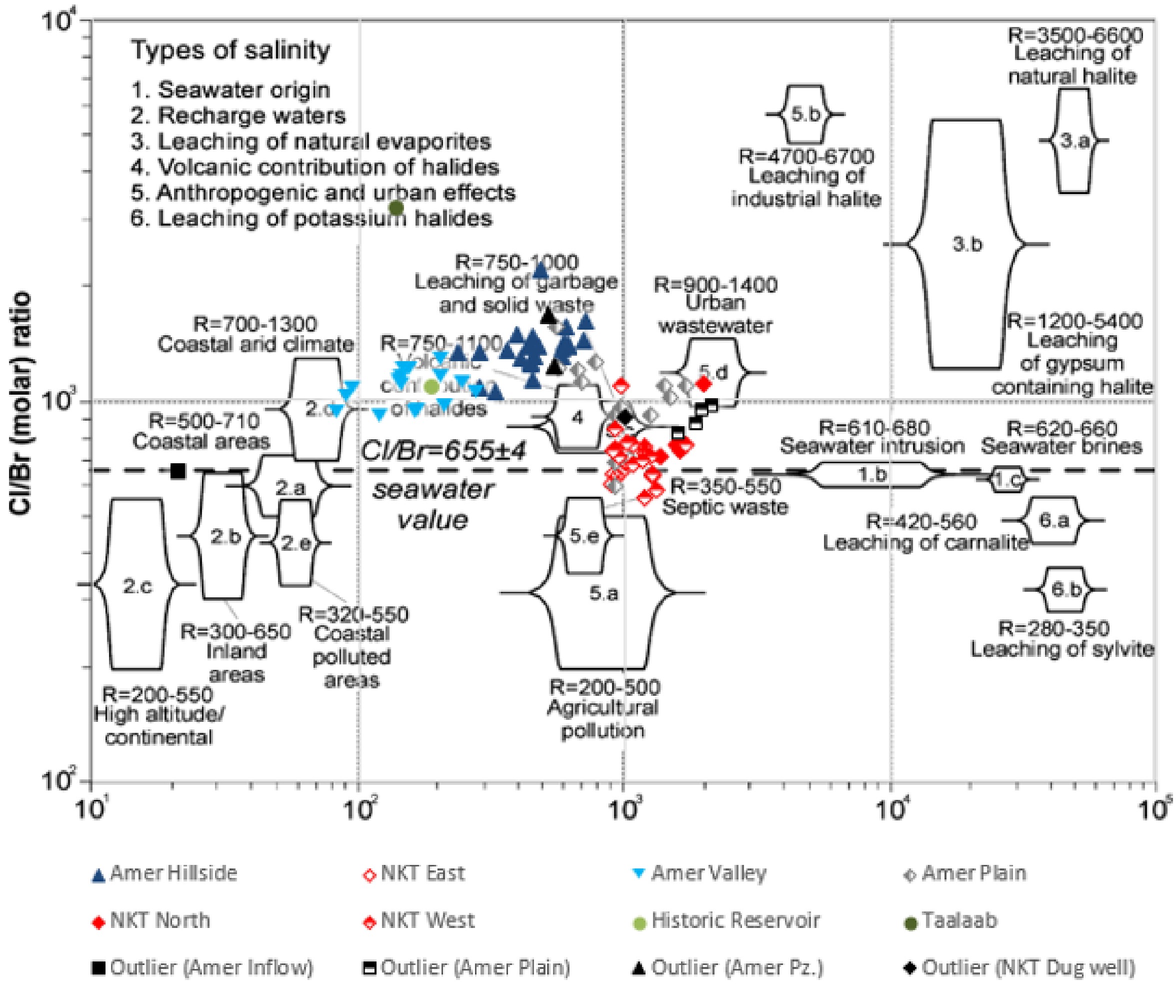


Fig. 28: Typical Cl/Br ratios for different types of salinity with field data plotted on it (modified after Alcalá & Custodio, 2008).

The binary plot of Ca vs. Na shows for *NKT West* and *Amer Plain* a negative relationship, increasing Na concentrations are correlated with decreasing Ca concentrations (Fig. 29). This can be hint of cation exchange where Ca is replaced by Na in the agricultural used regions.

The hand pump KK_HP20 has high Si Concentrations similar to the wells from *Amer Hillside* and is situated close to Khara Kuaa but falls into *Amer Plain* group suggesting that it is tapping both the alluvial aquifer as well as the hard-rock aquifer. One sample from this hand pump has a nitrate concentration of 567 mg/L and an ammonium concentration of 20 mg/L NH_4. It is supposed that a case of direct infiltration by sewage took place as the other three samples show NO_3 concentrations around 200 mg/L. The hand pump is not protected and is situated near to houses and on a street frequently used by animal herds.

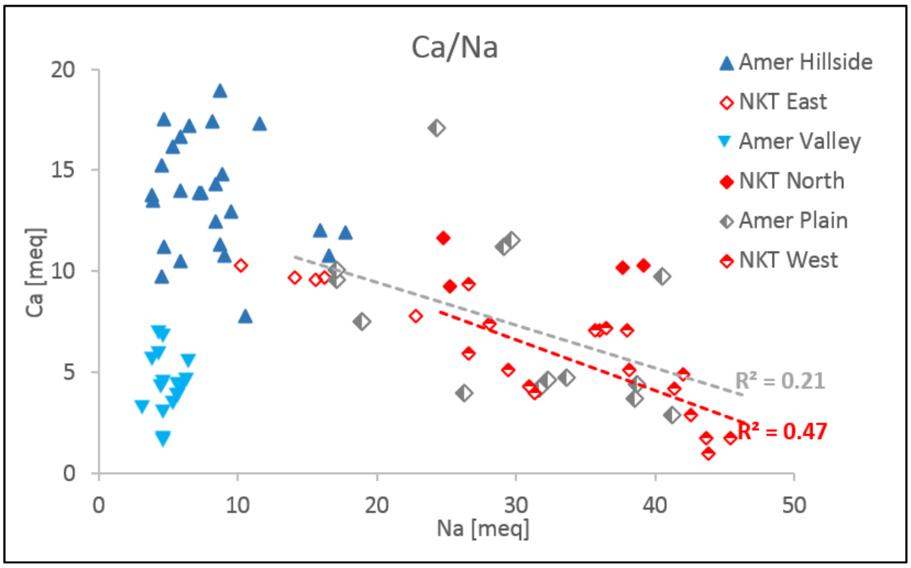


Fig. 29: Ca-Na binary plot.

Nitrogen Contamination

The high nitrogen concentration is most likely not only caused by anthropogenic impacts but also by geogenic reactions since some of the hand pumps affected are located at the edge of the settlements directly on the mountain slope (KK_HP16, KK_HP02). Above them, there are only bushes, stones, some wild boars and from time to time a herd of goats. The results of isotopic studies indicate that the sampled potential nitrate sources urea, manure and contaminated surface water plot within the value range given in literature (Fig. 30).

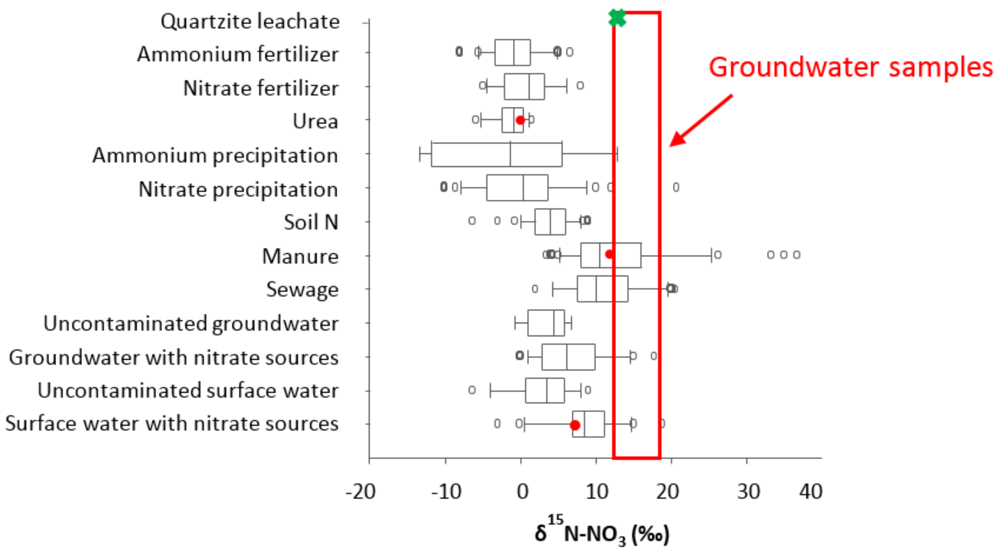


Fig. 30: $\delta^{15}N$ - NO_3 values compared to literature values (Modified afterXue et al., 2009).The green cross shows the value for the quartzite leachate (Gupta et al., 2015). Red dots and rectangle present the results from $\delta^{15}N$ - NO_3 analysis within this study.

The results from the 16 groundwater samples (distributed over all sub-groups) suggest that manure and sewage might be the origin of the high nitrate concentrations. However, in addition to nitrate input from untreated sewage, water rock interactions could be a source of the contamination. Gupta et al. (2015) report a $\delta^{15}N$ - NO_3 value of +13.3 ‰ for rock leachate of quartzite with a nitrate concentration of 131 mg/L. First result from the batch experiments conducted with hard rock samples taken above Khara Kuaa show that it was possible to leach > 100 mg/kg NO_3 from the pulverized quartzite.

Conceptual Model

Together with the results of the hydrochemical sampling, the stable water and nitrate isotopes analysis, depth-to-water level measurements and geoelectrical investigations, a conceptual model of the study areas could be developed (Fig. 31).

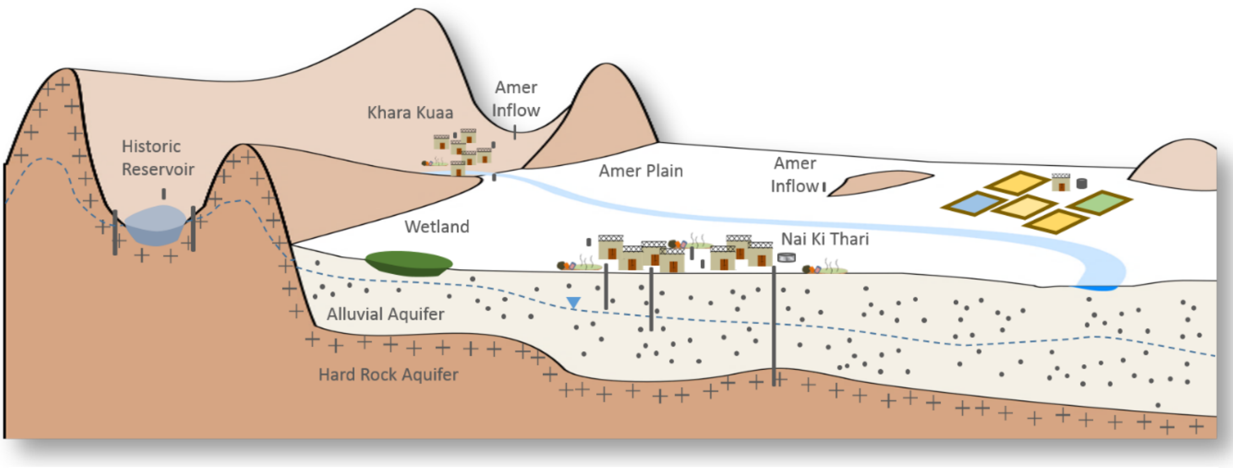


Fig. 31: Conceptual model of the study area. The Quaternary alluvium is overlying the Proterozoic fractured hard rock. Various anthropogenic and geogenic influences characterize groundwater quality and quantity (Nölscher, 2017)

Based on the model, zones of special concern were identified. In Nai Ki Thari, the widespread infiltration of waste water into the alluvial aquifer increases the EC values of the groundwater. In its surrounding (*Amer Plain*) irrigation practices, e.g. flooding of fields, strengthen the evaporation effect as well as leading to high abstraction rates. To conclude, the groundwater of the alluvial aquifer is not potable and further degradation is probable. The hard rock aquifer in and around Khara Kuaa has a low storage capacity as fast and strong changes in water table indicate. It is, thus, an unreliable source for the local users. Furthermore, the results point towards a contribution to the reported high nitrate contamination through water rock interaction. However, with artificial reservoirs both problems could be solved as can be seen in the groundwater of *Amer Valley*, where the infiltration of surface water lead to stable water tables and a dilution of the groundwater. On a local scale, unprotected and broken hand pumps can lead to severe groundwater quality degradation.

2.3.6 Conclusion

The goal of this study was to develop a conceptual model of the local hydrogeology in the north-eastern peri-urban area of Jaipur and to identify the main problems to be able to develop possible groundwater management strategies for the future. The results show that Quaternary alluvium aquifer is overlying Proterozoic fractured hard rock aquifer, with a thickness up to 100 m.

In general, the groundwater of both aquifers is not potable, due to high TDS values above the permissible limit of 500 mg/L given in the Indian Standard for drinking water and/or high nitrate values above the permissible limit of 45 mg/L. For the present, it could be used by mixing with surface water, what is already done to some part at the municipal pump house in Amer. However, many people in the low-income areas depend on the local groundwater to satisfy their daily water demands. In future, artificial recharge structures could be enhanced since it works already good in the hill area of Amer where infiltrating rainwater dilutes the salty groundwater. Further research in this direction would be necessary.

The $\delta^{15}N(NO_3)$ values of the groundwater samples suggest that manure and sewage might be the origin of the high nitrate concentrations. However, in addition to nitrate input from untreated sewage, water rock interactions could be a source of the contamination in the hard rock aquifer at Khara Kuaa which shows very high nitrate concentrations (up to 550 mg/L) and an average $\delta^{15}N(NO_3)$ value of 16 ‰ what is heavier than possible end-members of sampled anthropogenic/agricultural origin (sewage contaminated surface water, fertilizer, manure). Batch experiments showed that the hard rock leach nitrate in significant quantities. However, further isotope investigations are necessary to understand in detail the process of geogenic nitrate contamination.

In frame of the urbanization process going on in Jaipur which is especially affecting the peri-urban space, it would be advisable to act now to protect the parts with the pristine groundwater. Two hand pumps in areas with still few anthropogenic activities (sub-group *Amer Inflow*) show significant better water quality than all other samples. In addition, at least one of the hand pumps is located in a recharge area. It would be a future-oriented strategy to implement groundwater protection zones there as long as it is still possible. Regarding the urbanization process further research is needed how this affects groundwater resources. For example, the conversion from groundwater-irrigated agricultural land under semi-arid climate conditions into built-up area can lead to an increase in water demand by >20 % but can also lead to a decrease by 80 %, mainly depending on the original type and intensity of agriculture, the daily per capita water demand and the population density. To conclude, societal as well as hydrogeological conditions vary locally and strongly influence each other especially in a fast changing peri-urban space. Further studies, which take both these variables into account, will need to be undertaken.

Overall, this study has shown that it is important to have a denser network of observation wells as currently present. Small-scale changes, which are significant for both an understanding of the local hydrogeology as well as for the users, cannot be detected otherwise.

2.4 Water Management, Supply and Demand

This chapter gives an overview of the historical water system of Amer and Jaipur to show how urban planners in the past dealt with the challenging climatic conditions. Furthermore, it aims to make a qualitative assessment of the current water supply and demand situation in the two peri-urban study areas of Jaipur by setting it in context to the current water supply status of Jaipur city. Information and data regarding the different water sources, supply systems, use patterns and population development are crucial to develop future water management strategies.

2.4.1 Historic Water Supply System of Amer and Jaipur

In historic times (11th to 17th century) when Jaipur did not exist yet, the capital of the Rajput empire Amer, located about ten kilometers north of present Jaipur city in the hills, had an impressive water management system inspired by knowledge from ancient Hindu texts *Shilpa Shastras* as well as from the Mughals and adapted perfectly to the semi-arid climate conditions of the area (Rajora, 2013).

Fig. 32: Historic views of Amer Fort with the Maotha Lake in the front. Left: drawing from William Simpson, (1823-1899), dated to 1860 (William Simpson, 1860). Right: Photograph from Lala Deen Dayal, dated 1885 (Lala Deen Dayal, 1885)

The most obvious are the two lakes, Maotha in front of Amer fort (Fig. 32) and Sagar in the valley to the north-western direction. In addition, *kunds* (tanks) to store water and *baoris* (step wells) to reach groundwater were important parts of the water management system (Salam, 2011). Nine of these step wells are distributed all over Amer town and the surrounding. They were built between the 12th and 16th century (Rajora, 2013).

The two forts above Amer Fort, Nahargarh and Jaigarh, had elaborate water supply system. The latter was self-sufficient in terms of water and had water tanks which could store water for thousands of men for several years. The network of channels constructed along the hills supplied the rain water to the tanks of the fort. These channels had silt traps to let the sediments settle down and only clear water was allowed to flow further by overflowing these traps. Furthermore, the rain coming from the first rain events were collected in open tanks and used for the animals in order to avoid contamination of the drinking water reservoirs by accumulated residuals in the channel system during dry season. By closing the channels leading to the open tanks the cleaner water of the following rains was collected in closed tanks within the fort. The tanks were covered to prohibit evaporation and contamination. To sum up, it can be stated that this water system was designed in a way that hardly any water was allowed to get wasted. From Sagar lake, where the surface run-off of the surrounding hills gets collected, the water was transported to Jaigarh Fort by various systems including elephants, manual uplift with buckets and Persian wheels (Khangarot, 2016). Canals originating from both artificial lakes, Maotha and Sagar, lead the excess water to a third reservoir, Van Sagar Talab, outside the town of Amer. In this way, a flooding of the town beneath the forts is prevented (Rajora, 2013).

In the 18th century, when the Rajput King Sawai Jai Singh started to plan the new capital Jaipur on the flat plain, he put huge empathize on water system planning. Lying in a semi-arid area with rainfall only during monsoon months and not situating near a huge river, measures for storage, distribution and infiltration has to be implemented. As a first step, canals from nearby rivers were planned, for example, in 1726, a project proposal was submitted to construct a canal from the Jhotwara river in the north west to support the water supply of the new city. In the northeast of the city a narrow valley between two hill ridges was dammed to create a huge water reservoir, the Man Sagar Lake (Salam, 2011). The catchment area of this surface water reservoir is 16.09 km² (Irrigation Department, 1978). Two canals consist on the down-stream side of the dam flowing in easterly direction. Within the city many smaller water reservoirs were constructed not only for water supply but also for the gardens and temples. These water bodies were connected through canals and aqueducts. Today, a part of them are filled up and do not exist anymore. This is also true for the *kunds*, which originally existed at central places, Choti and Badi Chaupar, within the young city of Jaipur (Fig. 33). Underground tunnels from the Aravalli hills probably supplied fresh water to them (Nandgaonkar, 2016) and they were connected through conduits to other water bodies within the city. Between 1870-1880 they lost their importance due to a newly established

Fig. 33: Historical water system of Jaipur. Left: Badi Chaupar, a central place in the city in 1905 showing the already abandoned *kund* in the middle of the place. Photo taken by Gobindram and Oodeyram, (Gobindram & Oodeyram, 1905). Right: Barah Mori, one of twelve spouts in the city wall to channel the water to the city (Horstmann, 2016). Photograph by Monika Horstmann.

water supply by pipes (Salam, 2011). They only recently get recovered through construction work going on for the new metro lines (Nandgaonkar, 2016). Another attribute of the water supply system were the *baoris* (step wells). These made it possible to access water even during times when low groundwater levels prevail in pre-monsoon time. Furthermore, they served as social places, where, especially during hot summer days, people gather to take rest and exchange news (Salam, 2011).

In the beginning of the 20th century, the Ramgarh dam was finished which dammed the Banganga river and supplied water to Jaipur and to adjacent irrigated areas (Fig. 34). The reservoir had a capacity of 75 M m^3 and a catchment area of 770 km^2. Due to heavily encroachments in its catchment area, diversion of the contributing rivers for irrigation purposes and decreasing amount of rainfall the reservoir dried up in the early 2000s. The water supply to Jaipur from Ramgarh was therefore discontinued at some point between 2000 and 2006 (Dass Amit et al., 2013; Development Alternatives Inc., 2013; PHED, --b). Next to surface water the water demand of Jaipur is also met by deep tube wells in and around the city.

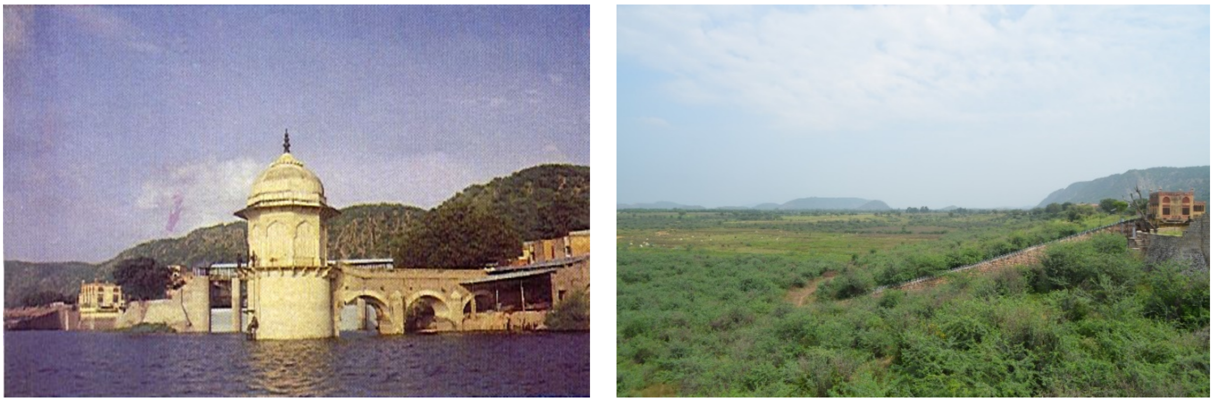


Fig. 34: Left side: Filled Ramgarh Lake east of Jaipur during the 1980s (Jaipur Beat, 2017). Right side: Dried up Ramgarh Lake, 2017.

2.4.2 Current Water Supply, Sanitation and Sewage Treatment Status of Jaipur

The growing city of Jaipur poses numerous challenges to water management. A range of different institutions on local, city and state level are responsible for water supply and sewage management. This chapter aims to give a picture of the current status of water management with a focus on the poor peri-urban area. Due to the fact that absolute numbers differ between sources but also within the same source, only rough numbers will be given in this chapter.

Water Supply

According to Government of India (2016) in 2012, 78 % of the rural and 85 % of the urban population in Rajasthan got sufficient water throughout the year. In Jaipur, the official institutions responsible for the current water supply system are the Public Health and Engineering Department (PHED), who is actually in charge for securing the water supply and constructing the infrastructure, the Municipal Cooperation of Jaipur (JMC) and the Jaipur Development Authority (JDA), who is responsible for planning of long-term city infrastructure development. JDA was commissioned by the Department of Urban Development and Housing, Government of Rajasthan in 1982. Since then it created three master plans concerning the development and expansion of the city. The current plan envisages the year 2025 (Development Alternatives Inc., 2013). These plans are important as they give the institutional frame for all future development, e.g. defining which new areas fall under city classification. Furthermore, concrete measures are proposed, like rooftop rainwater harvesting to meet future water demands or the mandatory construction of two supply lines for new houses, one for drinking water and the other for treated grey water for non-drinking purposes. The monitoring of the groundwater resources and their scientific and sustainable management are the task of the Central Ground Water Board (CGWB) and the Regional Ground Water Board (RGWB).

Today, the formal water supply of Jaipur is based on surface water and groundwater. Since 2010, the surface water is coming from the Bisalpur reservoir which is situated about 110 km to the southwest of Jaipur. Here, the Banas river is dammed up at geological favorable conditions (Fig. 35, left side). The dam has a capacity of 1096 Million m^3 and supplies water to Jaipur, villages en route and for irrigation purposes. Before the water is further distributed it is treated at the water treatment plant (WTP) Surajpura 8 km to the north of the dam. The WTP has a capacity of 600 MLD and the main treatment steps are sand-filtration and chlorination (Fig. 35, right). From here, the clear water is transported through a 2300 mm diameter pipeline to the intermediate pumping station Balawala south of Jaipur. The further distribution within Jaipur is guaranteed by six pumping stations throughout the city partly equipped with in-situ chlorination systems. In 2017, the average supply was 450-460 MLD for Jaipur satisfying about two third of Jaipur's water demand (PHED, 2017a, 2017b; Rathore et al., 2011). The other third is supplied by groundwater through more than 1800 tube wells (Development Alternatives Inc., 2013). For areas connected to the water supply system, groundwater is distributed via private or public taps. Otherwise, water tankers transport

Fig. 35: Bisalpur reservoir 110 km south of Jaipur. water supply system. Left: Dam. Right: Sand filtration unit at Surajpura Water Treatment Plant., 2017.

the water to the users or hand pumps are installed. A second pipeline is currently being built from Bisalpur to Jaipur to meet the growing demand from population growth on the one hand and to reduce the pressure on groundwater resources on the other. For 2021, PHED projected a population for Jaipur of 5.3 Million inhabitants. With an estimated consumption of 153 lpcd (including non-domestic demand), the total water demand would be 960 MLD, leakage losses already included (PHED, 2017b). However, a study conducted by Rathore et al. (2011) showed that the reliability of this supply is low. Erratic rainfalls and abstractions in the catchment area of the Banas River regularly result in low water levels in the reservoir.

Next to the formal water sector, a huge informal water sector has developed as the official water supply does not satisfy the needs. Only 90 % of the population is served by PHED in some way, leaving 10 % completely unserved. Additionally, the served users are often not satisfied with the quantity and quality of the water supplied. The informal water sector consists of private tankers, private bore wells (partly illegal) and so-called private camper (10-20 L) which can be bought or ordered from local water shops. In general, prices are much higher in the informal sector than in the formal. However, concerning groundwater it may be cheaper as it is often abstracted without any costs (Rathore et al., 2011). Especially in peri-urban areas, many houses are not yet connected to an official water supply scheme and, therefore, depending on own solutions. The Census of India (2011) reports for the sub-district Amer, where both study areas are situated, that 45 % of the population rely on water from tube wells, 24 % get tap water from treated sources, 12 % use hand pumps, 9 % tap water from untreated sources, 4 % get water from ponds, tanks or lakes, 3 % from dug wells and 3 % from other undefined sources. These numbers show that only 30-35 % in the pre-dominantly peri-urban area of Amer are connected to piped water supply.

The water management of the last two decades led to severe groundwater depletion throughout the city. From about 2000 to 2010, most of the water demand was covered by groundwater causing unsustainable withdrawal rates. Nowadays, the numerous private and partly illegal wells which are common in all sectors, domestic, agricultural and industrial, further strengthen the declining trend of the groundwater table. Gessler et al. (2008) estimated that the number of private wells in the city exceeds 20,000.

Sanitation and Drainage System

In Rajasthan, 87 % of the urban population has access to an improved kind of latrine such as “flush/pour-flush to piped sewer system/septic tank/pit latrine”, “ventilated improved pit latrine”, “pit latrine with slab” and “composting toilet”. Numbers for rural population are with 26 % much lower. About 10 % of the urban population in Rajasthan goes for open defecation. According to

Census of India (2011), in Amer 63 % of the households are practicing open defecation as they do not have a latrine within their premises (Tab. 9). 26 % have a septic tank and only less than 2 % have a latrine connected to piped sewer system. The percentage of HHs in Rajasthan with no drainage arrangement is 60 % for rural and 14 % for urban areas, respectively. In Amer, only 35 % of HHs have a connection to a drainage with most of them, 29 %, having open drains and only 6 % closed ones. A further problem for a proper drainage system is the high percentage of households with no garbage disposal arrangement with 72 % in rural and 39 % in urban settlements of Rajasthan (Census of India, 2011; Government of India, 2016).

Tab. 9: Percentage of households by type of latrine facility for the sub-district Amer, 2011 (Census of India, 2011).

		Sub-District Amer		
		Rural	**Urban**	**Total**
Total number of households		48,559	9,838	58,397
Type of latrine [%]				
Flush/Pour latrine	Piped sewer system	0.9	5.9	1.8
	Septic tank	18.8	62.6	26.1
	Other system	3.02	1.4	2.8
Pit latrine	With slab/ventilated improved pit	5.2	5.7	5.3
	Without slab/open pit	0.3	0.1	0.3
Night soil disposed into open drain		0.1	0	0.1
Service latrine	Night soil removed by human	0	0	0
	Night soil serviced by animals	0	0.2	0.1
No latrine within premises	Public latrine	0.4	0.4	0.4
	Open	71.2	23.6	63.2

Sewage Treatment

In Jaipur the laying of sewer lines is done by JMC, JDA and Rajasthan Housing Board (RHB). Maintenance of sewer line is done by JMC. In 2009, the sewage treatment capacity of Jaipur was 11 % with a capacity of 54 MLD out of 452 MLD sewage generation. Two years later, a capacity of 90 MLD is reported and in 2013 a capacity of 202 MLD. There are three existing major STPs constructed by JMC. Brahmpuri in the North with 27 MLD capacity, Jaisinghpura in the Northeast with 50 MLD and Delawas in the South with 125 MLD capacity. Two more plants are under construction, as of 2013. The sewage treatment at these plants is with conventional treatment technology. However, the actual sewage treatment percentage may be even lower due to inadequacy of the sewage collection system and due to operation and maintenance problem (Development Alternatives Inc., 2013; JDA - Jaipur Development Authority, 2011b).

This is a huge thread to surface and groundwater resources as the untreated sewage is disposed into rivers and canals or directly on the land from where it can infiltrate into the underground. Groundwater quality problems, e.g. nitrate concentrations exceeding the Indian Standard by far, are common in many parts of Jaipur (CGWB, 2007; CPCB - Central Pollution Control Board, 2009).

Irrigation

When looking on the current water supply and demand situation one has to consider the agricultural sector as irrigation is by far the biggest groundwater user in the district. Irrigation by canal and tanks makes only 1.2 % of the total irrigation amount. The CGWB and the Rajasthan Ground Water Department have estimated the groundwater resources and drafts block-wise for the Jaipur district (Tab. 10). The annual groundwater draft in Amer as well as at the whole district doubles the annual groundwater availability. The draft for irrigation purposes is with 87 % and 82 %, respectively, the main reason for the over exploitation of the aquifers (CGWB, 2013).

Tab. 10: Groundwater resources and draft by different sectors as in March 2009 for Jaipur district and Amer block (CGWB, 2013).

Block (km^2)	**Total Annual GW Recharge (mcm)**	**Annual GW Availability (mcm)**	**GW Draft Irrigation (mcm)**	**GW Draft Dom. & Ind. (mcm)**	**GW Draft all uses (mcm)**	**Stage of GW Development[11] (%)**	**Category**
Amer (846)	83 (= 98 mm)	75	137 (87 %)	21 (13 %)	158	212	Over-exploited
Total (11,061)	742 (= 67 mm)	677	1146 (82 %)	253 (18 %)	1400	207	Over-exploited

To conclude, the situation of the water supply, sanitation and sewage system in Jaipur is not satisfying in terms of coverage, quality and resulting impacts on public and environmental health.

[11] The sum of all groundwater withdrawals in a year versus all inflows to groundwater in a year in respect to a catchment.

2.4.3 Material and Methods

Secondary Data

Socio-economic data were derived from a slum-profiling done by MHT in preparation for the Global Resilience Partnership in Jaipur in 2015 and 2016 and from an app-based survey conducted by MHT staff in autumn 2016. Twenty-five women of Khara Kuaa and 26 of Nai Ki Thari within an age range from 15 to 60 years were included in the survey, whereby in Nai Ki Thari only women from the Shanti Nagar colony were part of the survey.

Survey of Water Demand and Sources in the Study Areas

No secondary data were available regarding the domestic, industrial and agricultural water demand and supply in the two study areas. Accordingly, by taken into consideration the results of the former mapping (Chapter 2.3.3), a survey was planned and conducted to get more detailed information about the supply infrastructure and to quantify water demands in the study areas.

To depict the domestic demand, 216 interviews were conducted in Nai Ki Thari and 83 interviews in Khara Kuaa. The focus of the survey lay on the following questions:

– number of people living in the household,
– water consumption with respect to various sources,
– amount of money that is being paid for water,
– share of reused water,
– RO (reverse osmosis) system for water purification present, and
– animals present and if so, amount of water consumed by them.

To get data about the industrial water demand, interviews at the ten mapped factories in Nai Ki were conducted. In Khara Kuaa, only household size manufacturing units exists but no bigger factories. It was more difficult to obtain data about the agricultural demand in the study areas. The focus lay hereby at the

– spatio–temporal cropping patterns,
– frequency and quantity of irrigation, and
– the exact size of the farmland.

However, these numbers were often unknown by the farmers themselves as they do not play any role for their day-to-day work (Mutz, 2018). Furthermore, interviews conducted with various PHED officials (chief engineer of the Amer district, junior engineer at the Brahmpuri pump house, staff at Amer pump house) aimed at getting more information about the total amount of supplied water to the study area, the share of groundwater and surface water, the treatment methods and possible challenges. The influence of the current system on groundwater resources was modeled with WEAP by Mutz (2018) for a baseline scenario. In addition, a best- and a worst-case scenario was set up considering different numbers for demand, transmission loss and share of surface water.

Sampling of Water Supply System

To get information about the quality of the supplied water, samplings were taken at several points of the supply system in addition to the groundwater sampling (see Chapter 2.3). The sampling procedure were the same as described in the Chapter 2.3.3. In summary, five RO systems, three water tanker and two water lines were sampled. The five domestic RO systems were tested by taking samples from the source water (bore well, tanker water or water line) and from the RO tap (Fig. 36). Four of the RO systems are installed in Nai Ki Thari and the fifth is installed at a flat in Jaipur city. The water of two tanker distributing water in November 2016 and one tanker distributing water in August 2017 in Nai Ki Thari were sampled. One tap connected to a pipe line passing through Nai Ki Thari and one municipal household water line connection in Khara Kuaa were tested whereby the testing in Khara Kuaa was done in the frame of the participatory water sampling (Chapter 3.4.2).

Fig. 36: Sampling of domestic RO systems in Nai Ki Thari, November 2016. Left side: Sample taken at the RO tap. Right side: Typical RO system with a pre-filter unit (left) and the main RO unit (right).

2.4.4 Results

Socio-Economic Characteristics

Nai Ki Thari is a non-notified slum, which means it is a settlement that is not recognized by the government. Nölscher (2017) has shown that there are ~ 1400 HHs in the study area with about 9500 inhabitants. Based on the survey data, the average household size is 8.18 persons. The average monthly family income is 5000-10000 INR which is about 60-120 € but there are also families with less income (<5000 INR) and with higher income (10000-20000) indicating essential discrepancies in economic status (Tab.11).

Khara Kuaa is a legal slum with about 500 HHs and 3000-4000 inhabitants based on data from MHT (Appendix 7). The survey has shown that the average household size is 8.05 persons. Even if the area has a legal status, not all HHs have a *patta*, which is a legal document telling about the ownership of a particular property. Especially, many of the houses situated in the upper area on the hillside are illegally constructed. This fact is part of a bigger pattern of significant differences within this small community in terms of economic status and, consequently, access to water. This is also reflected in the monthly family income. Over one-third of those surveyed reported that their monthly family income is below 5000 INR whereas one out of the 25 participants reported an income of two to four times the amount of it (Tab. 11). However, the majority said that their income is between 5000-10000 INR which is similar to the results of Nai Ki Thari.

Tab. 11: Monthly family income in the two study areas based on data from the MHT app-based survey.

	Sample Size	**>5000 INR**	**5000-10000 INR**	**10000-20000 INR**
Khara Kuaa	25	9	15	1
Nai Ki Thari	26	6	18	2

Water Demand

Based on the survey, the mean daily per capita consumption in the *domestic sector* amounts to 47 L in Khara Kuaa and to 60 L in Nai Ki Thari. The higher consumption in Nai Ki Thari could be explained by the higher number of animals, mainly goats, and perhaps also by the difference in access to water. In the *industrial sector* the water demand was approximated by dividing the total daily water demand of each factory [L] with its area [m²], which was determined by using satellite images. The average monthly demand for the industries therefore adds up to 20 L/m² (Mutz, 2018). For the *agricultural sector* it was not possible the derive the water demand out of the survey results. However, taken into consideration that about 99 % of the irrigation demand in Jaipur district is satisfied by groundwater during the non-monsoon seasons the agricultural groundwater draft numbers can be used for estimating the demand which is 137 × 10^6 m^3 per year for Amer block (CGWB, 2013).

Water Supply System on the Household and Community Scale

The results from the survey show significant differences in the water sources between Khara Kuaa and Nai Ki Thari (Tab. 12). In Khara Kuaa, about two thirds depend on the municipal water line while in Nai Ki Thari the main supply source is private tanker.

Tab. 12: Percentage of water source in Khara Kuaa and Nai Ki Thari and related average costs based on the domestic survey data from April 2017.

Water source	Khara Kuaa [%]	Nai Ki Thari [%]	Average costs
Water line	68.5	-	110 INR/month
Private tanker	25.7	66.5	250-300 INR/4000 L
Municipal tanker	3.5	-	free
Groundwater	2.0	30.6	free*
Private camper	0.2	0.1	1 INR/L (NKT)
Tap	-	2.8	free

** Mosques usually provide free water for direct collection but charge 300 INR/month for a pipe connection to neighboring houses.*

The distribution, condition and use of the water line connections within Khara Kuaa differ. There are taps on the street which are shared by neighbors (Fig. 37, left), pipes going directly into a house (Fig. 37, middle) and connections which are (illegally) connected to a pump to increase the amount of water (Fig. 37, right). In total, 173 water line connections were mapped in Khara Kuaa out of which 138 were operational. Only twelve public taps exist in the community. Two main supply times can be distinguished, one half gets water early in the morning between 5 and 6 o'clock and the other half between 8.30 and 9.30 o'clock.

Fig. 37: Diversity of water line connections within Khara Kuaa. Left: Tap shared by several HHs. Middle: Pipe going, above the open drain, into a house. Right: Some HHs attached (illegally) a pump to their water connection to get more water out of it. Here, it is a small stone factory.

In addition to the water line, municipal water tankers ensure the water supply of Khara Kuaa as some households do not have a (functional) connection (Fig. 38). However, water demand still cannot be met by public sources, which means that ¼ of the total amount is provided by private sources, that is mainly private tanker. Users also stated that the complicated application procedure as well as the unreliable service by municipal tankers let them chose private tankers. Direct groundwater withdrawal plays with 2 % only a minor role in the water supply. Two old dug wells, who are not used anymore, one broken bore well and nine hand pumps, of which only four are operational, exist within Khara Kuaa. 25 % of those who were interviewed indicated that they reuse water. e.g. the water from laundry washing is reused for cleaning floors or flushing toilets.

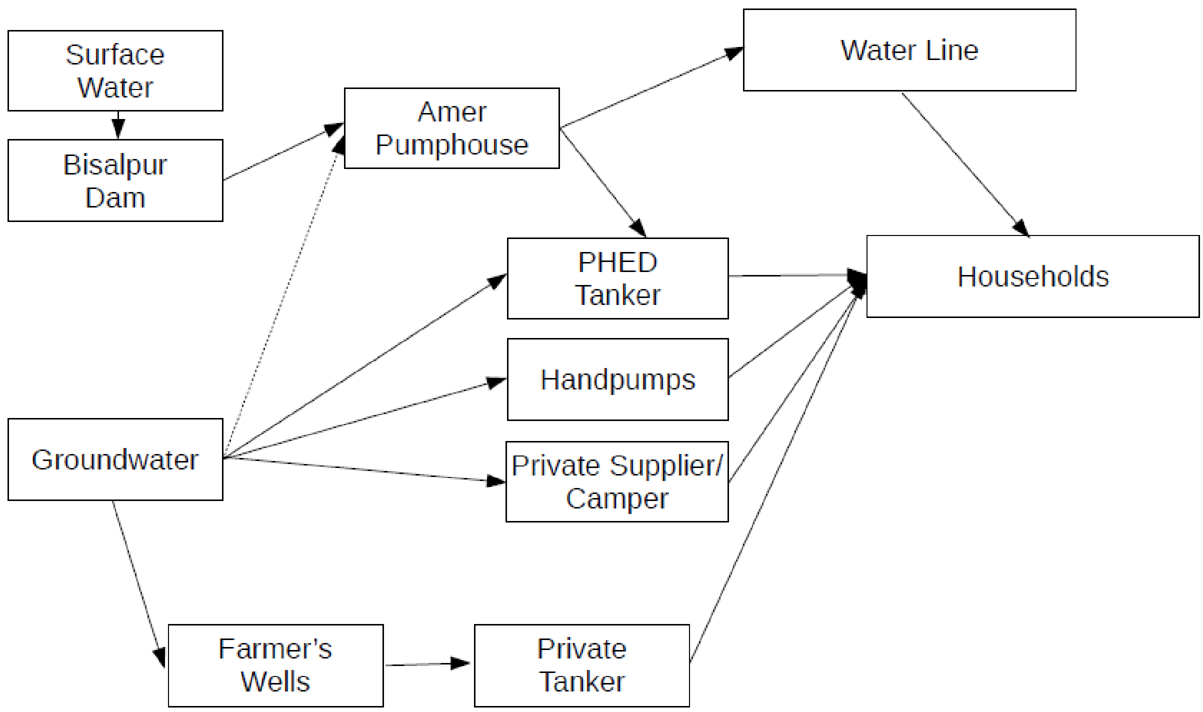


Fig. 38: Water supply infrastructure of Khara Kuaa.

The groundwater in Nai Ki Thari is accessed through bore wells, dug wells and hand pumps, with the dug wells playing a minor role as most of them are dry (Fig. 39).

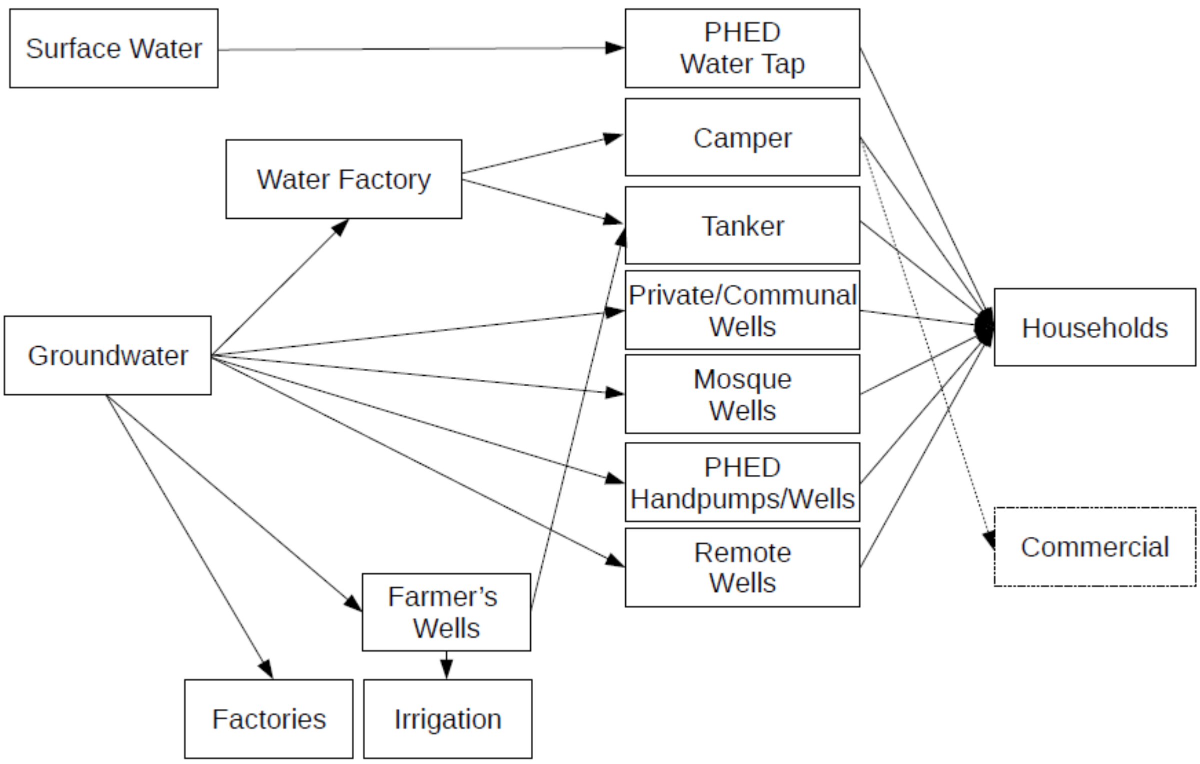


Fig. 39: Water supply infrastructure of Nai Ki Thari.

There are more than 70 bore wells, most of which are in operation, and nine hand pumps, of which only four are functional (Fig. 40a). About 20 % of the bore wells are public, the rest are private wells. The bore well depth ranges from 30 to 150 m according to the statements of the well owners. The public bore wells are either installed by PHED or public institutions, e.g. schools, mosques or temples. A typical bore well, which belongs to a temple, is seen in Figure 40b. It is connected to a tank with a capacity of 1500 L which is filled every morning and evening. Then, the women from the surrounding houses (up to a distance of about 100 m) queue up to fetch the water (Fig. 41a). Figure 40c shows a private tanker waiting to be filled at a private "water company" at the main road of Nai Ki Thari. This "water company" also uses groundwater. It has a bore well connected to a large RO system. After the treatment, the water is distributed via tanker, which has to be ordered and paid (Fig. 41b). No water quality control takes place. An exception within the water supply of Nai Ki Thari is the tap located at the main road in Nai Ki Thari which is connected to the old pipe line coming from Ramgarh Lake (Fig. 40d). Due to its comparable low mineralization (~660 µS/cm) it is very popular and women come from greater distance to fetch this water. However, its reliability is not given as the water supply stopped suddenly in summer 2017.

Fig. 40: Major types of water sources in Nai Ki Thari. a) A boy gets water at a hand pump. b) Tank connected to a bore well c) Private tanker. d) Women and children fetching water at the tap connected to the pipe line from Ramgarh Lake.

Next to public bore wells, numerous private bore wells exist within Nai Ki Thari. Households with better financial resources can afford their own bore well within their houses or backyards. Furthermore, some larger plots, which usually have a lawn, are used exclusively as weekend houses by richer people from the city. These plots usually have private drilled wells that provide a reliable supply with groundwater, if the well is sufficiently deep and equipped with an adequately dimensioned submersible pump. In this way, the entire irrigation requirement for the garden can be met next to the household and drinking purposes (Fig. 41c). A minority of participants (11 %) reported that they reuse water.

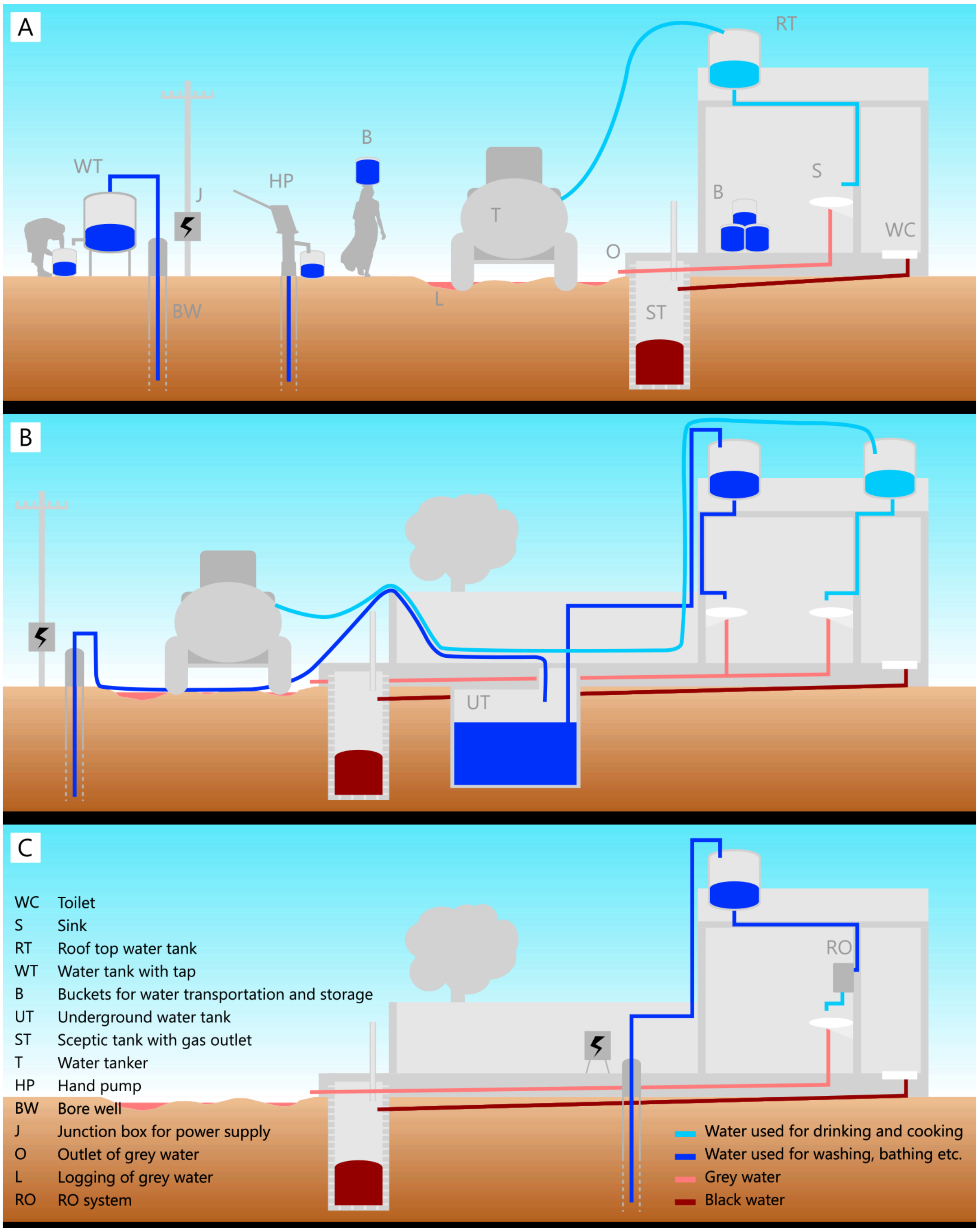


Fig. 41: Difference's in access to water sources in Nai Ki Thari depending on the economic status of the user. A) Bad, B) middle and C) good economic status (Nölscher, 2017).

Most industries in Nai Ki Thari have their own bore well to satisfy their water demand. In addition, water for drinking purposes is ordered from private suppliers via camper or tanker. All farms around Nai Ki Thari own one or more bore wells which are usually deeper and which larger diameter than the domestic bore wells. They are used for irrigation as well as for household needs. Farms located next to the *nallahs* use also *nallah* water for irrigation. Dug wells are still commonly used. Since groundwater is free of charge, except for electricity, which is partly freely available through illegal connections, the farmers pump more water than they need and sell it to neighboring settlements.

Water Supply System on Catchment Scale

The diverse water supply system of the study areas can be seen in the WEAP model set-up (Fig. 42). The two main sources of water for the study areas are surface water from Bisalpur dam and local groundwater. The Bisalpur water is distributed from the pump house (KK pump house) via water lines and tanker to Khara Kuaa and other communities inside and outside the catchment. The pump house also receives water from several PHED bore wells according to some PHED officials. However, the statements regarding this mixing and the respective shares of surface and groundwater vary. The private tanker supplying water to Khara Kuaa get their water from nearby farmers who have a bore well. These farmers also supply water to other communities in Amer. Nai Ki Thari does not get any water from Bisalpur but completely depends on groundwater which is distributed via different ways, e.g. directly by bore wells or indirectly via a tanker.

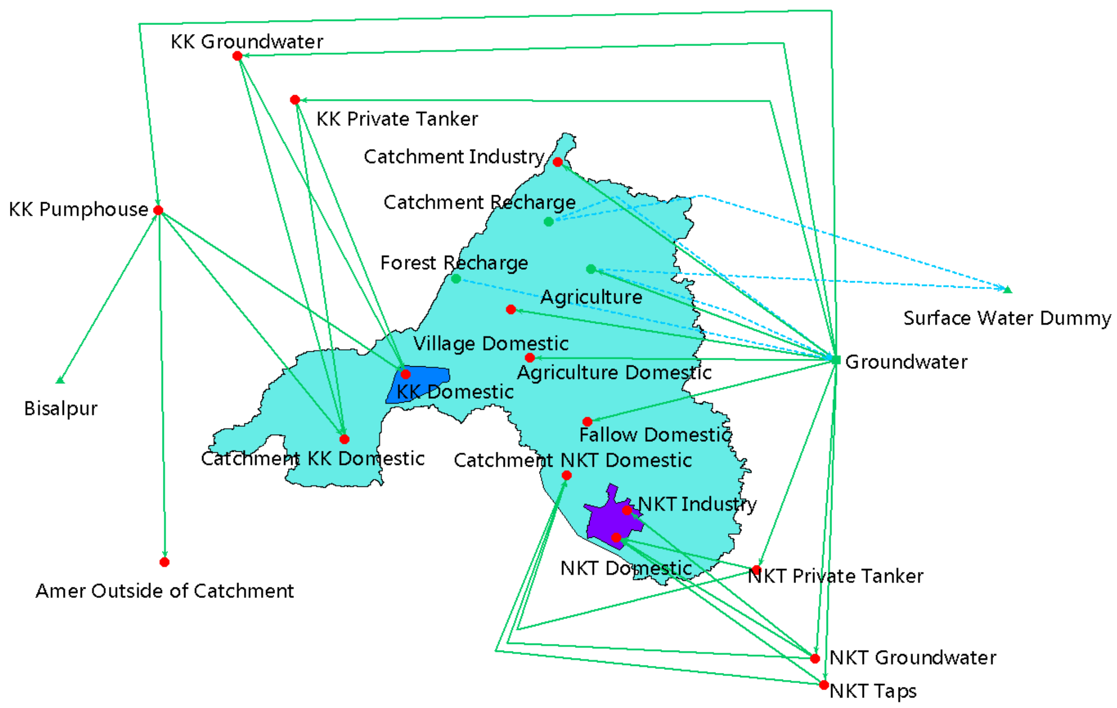


Fig. 42: WEAP model set-up for the surface catchment area, which was calculated based on an outlet point SE of NKT. The two study areas are shown in blue (KK) and purple (NKT). Red dots symbolize demand sites and green dots supply sites. The green lines indicate water transmission (Mutz, 2018).

The modeled baseline scenario indicates that the main user of groundwater by far is the agricultural sector with a demand of about 4 x 10^6 m^3/a followed by the urbanized area around Nai Ki Thari that strongly depends on private tankers (Mutz, 2018) (Fig. 43). The baseline scenario uses the field data, assumes no groundwater contribution at the pump house and no transmission losses. Also, in the modeled worst- and best-case scenarios, the agricultural sector remains the most important groundwater user. The worst-case scenario assumes 50 % transmission loss, a demand of 70 lpcd, a HH size of nine persons and a 50 % share of surface water, representing the maximum groundwater withdrawal scenario. The best-case scenario assumes no transmission loss, a demand of 40 lpcd, a HH size of 6.34 persons (the reported census mean for villages in Jaipur District) and a 100 % share of surface water. For all modeled scenarios, the stage of groundwater development (GWD) is unsustainable with 214 %, 196 % and 322 % for the baseline, best- and worst-case scenarios, respectively.

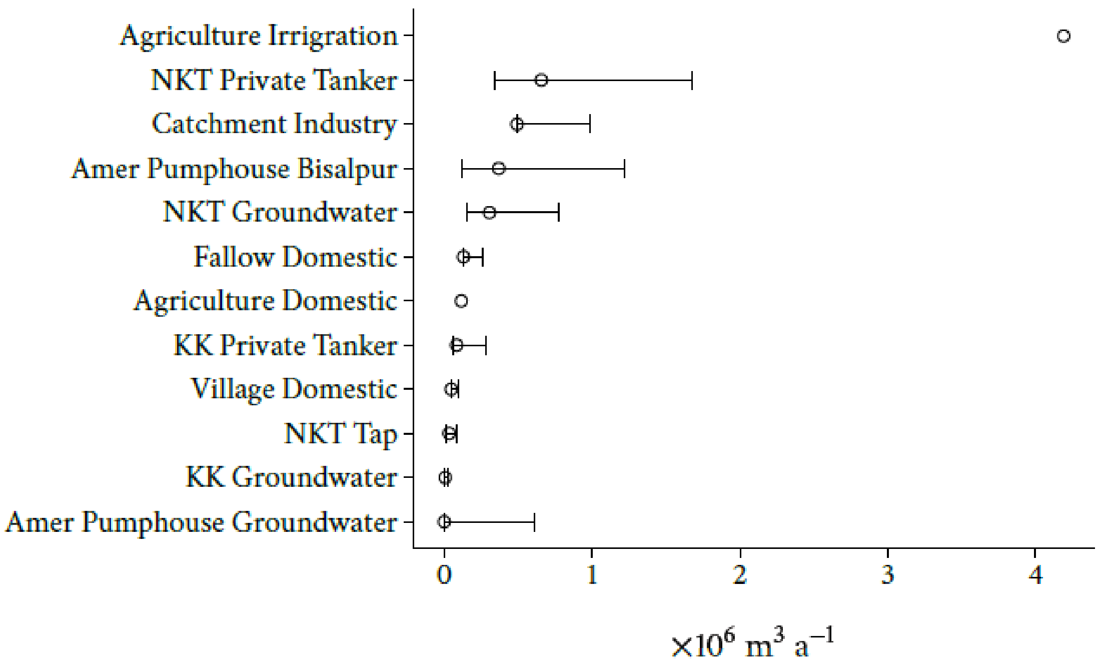


Fig. 43: Demands from local groundwater and the Bisalpur dam under the baseline scenario (hollow circles) and the best- and worst-case scenario (error bars) (Mutz, 2018).

Water Quality

The water quality differs significantly between the supply sources (Tab. 13). The municipal water supply in Khara Kuaa has elevated EC values (~2000 µS/cm) and NO_3 concentrations exceeding the Indian Drinking Water Standard (Bureau of Indian Standards, 2012). One of the three sampled private tanker in Nai Ki Thari shows an EC value of 3260 µS/cm, a nitrate concentration of 146 mg/L and also a slightly elevated fluoride concentration. The best water quality belongs to the tap in Nai Ki Thari, which is connected to the pipe line from Ramgarh. Even if the Ramgarh dried up years ago there are many bore wells located in the former lake area. This water is (sometimes) transported via the old pipe line to Jaipur. The most striking result to emerge from the data is that of the sampled RO systems. During the mapping it turned out that few inhabitants of NKT (<5 %)

are using domestic RO systems to filter their bore well or tanker water, latter being provided by a private company. In doing so the users trust the RO system totally, without understanding the principle behind it and without checking the water quality on a regular basis in order to know when to change the filters. However, this is a problem as the results show. On the one hand, RO systems may not treat the water sufficiently anymore after a while (see RO 4 in Table 13), or, on the other hand, the filtration works efficiently but there is no system installed within the RO which ensures the re-mineralization of the purified water. The lack of re-mineralization results in very low mineralized drinking water (see RO 3 in Table 13), representing hazard for consumers' health.

Tab. 13: Key physicochemical parameter of sampled water sources compared to the Requirement (Acceptable Limit) of the Indian Drinking Water Standard (Bureau of Indian Standards, 2012). Results for Reverse Osmosis systems (RO) are shown for pre- and post-treatment. RO 2 and 3 are supplied by tanker, RO 4 and 5 by bore wells.

Water source		n	EC [µS/cm]	pH	NO_3 [mg/L]	F [mg/L]
Requirement (Acceptable Limit)		-	500 (TDS in mg/L)	6.5-8.5	45	1.0
Water line (KK)*		6	717 (TDS in mg/L)	7.3	45-100	<0.6
Private tanker (NKT)		1	1985	8.22	16	bdl
Private tanker (NKT)		1	1151	8.32	70	1.0
Private tanker (NKT)		1	3260	7.48	146	1.06
Tap (NKT)		2	661	7.92	16.1	0.4
RO 2 (NKT)	Pre	1	1985	8.22	16	bdl
	Post	1	103.8	7.23	2.5	bdl
RO 3 (NKT)	Pre	1	1151	8.32	70	1.0
	Post	1	60.4	7.01	13	bdl
RO 4 (NKT)	Pre	1	4770	7.45	200	7.0
	Post	1	2340	7.61	155	3.0
RO 5 (NKT)	Pre	1	5650	7.14	73	0.2
	Post	1	472	6.32	26	bdl

** Participatory Water Testing with water testing kit (see Chapter 3.4.2)*

Sanitation and Sewage System

At most places in Khara Kuaa open *pucca* drains for grey water exist (Fig. 44, left) which lead the wastewater into the *nallah* at the entrance to the community. Some streets do not have *pucca* drains (Fig. 44, right). The *nallah* transports the wastewater to the *taalaab* some kilometers to the east of the area. Most households have individual toilets with soak pits. However, open defecation, especially by children, takes place, too.


Fig. 44: Left: Ventilation pipe of latrine and open *pucca* drain for grey water. Right: Grey water flowing on the street without a *pucca* drain, Khara Kuaa 2017.

In Nai Ki Thari, the sewage system is similar for most households and more or less independent of wealth. The black water is collected in septic tanks made of a stone wall or concrete with a gas outlet pipe. Septic tanks are emptied about once a year. The grey water is directed via pipes to the road from where it evaporates and infiltrates.

2.4.5 Discussion and Conclusion

The present study was designed to indicate and assess the past and current water management of Jaipur with a focus on the study areas in a primarily qualitative way. Based on the results from field research and secondary data the diverse picture of the water supply situation in the two study areas and their connection to the catchment as well as to the city could be shown. On a city level, the situation of the water supply, sanitation and sewage system is not satisfying in terms of coverage, quality and resulting impacts on public and environmental health. These effects are intensified on the study area scale in the peri-urban fringe of Jaipur, where a huge informal water sector exists as the formal supply does not meet the demand, which is, however, a typically situation in Indian cities as discussed in the literature review (Chapter 1.3.2). The informal water sector has huge impacts on the local groundwater resources and makes centralized water management challenging.

Unjust Situation on Household Scale

The results of this study show that the water supply system of the two study areas differs significantly from each other but they have one thing in common: that the current system is highly unjust. Following factors causing an unequal access to water were identified: the location of the house within the community and whether there is some kind of storage infrastructure for tanker water, the economic situation of the user, but also if there are any arrangements or, on the contrary, conflicts with neighbors. In Nai Ki Thari, the situation is worse than in Khara Kuaa as the amount of public supply is less which on consequence forces people to rely on individual and costlier solutions. For example, on a monthly average, customers purchase two private tankers per month in Khara Kuaa and three in Nai Ki Thari (corresponding to 750 - 900 INR), placing a huge financial burden on families with low income (< 5000 INR/month). They have to spend about one fifth of their monthly income only on water supply. In summary, the poorer the household, the higher the cost of drinking water and the more time it takes to fetch it, while wealthier households can draw water freely and "unlimited" or a connected to public water supply. The situation that weekend houses exist within low-income peri-urban area is not limited to Jaipur. Vishal et al. (2014) report on an increase in the purchase of land for weekend houses by an urban elite for a village 15 km from the city of Gurgaon, which leads, among other things, to the appropriation of rural water supply by wealthy urban citizens.

Impacts on Groundwater

The results support previous research into this field which links urbanization with the degradation of water resources (Chapter 1.3.2). The impacts on groundwater by the current water supply system are manifold. As was shown in Chapter 2.3, water tables in the study area are decreasing due to over abstraction. The main user of groundwater by far is the agricultural sector as modeled with WEAP by Mutz (2018). For all modeled scenarios, the stage of groundwater development is unsustainable. A change of irrigation practices and cropping patterns and the extend of the surface water supply scheme, what is currently under planning with the second pipe line from Bisalpur reservoir, would decrease the demand on groundwater resources. On a quality perspective, insufficient or missing sanitation facilities and sewerage networks result in the infiltration of wastewater into the underground affecting groundwater quality, e.g. causing high EC values and high nitrate concentrations. Furthermore, local irrigation practices lead to an increase in the mineralization of the upper soil and infiltrating water by the effects of evaporation.

Management Issues/Policy Level

Gessler et al. (2008) argue that the overlapping responsibilities between the various authorities are one reason for the ineffective and poor performance of water management. Furthermore, water management strategies are challenging to develop because the official institutions publish differing data about water demand and supply (Rathore et al., 2011).

Next to these overall problems concrete actions to improve water management could be to improve the efficiency of the water supply system, to install an effective pricing system, to put in practice the already existing ban on new bore wells, to install enough wastewater treatment capacities in order to avoid the pollution of water resources, to protect the ecosystems where recharge takes place and to implement aquifer-wise groundwater management similar to surface water management which works on catchment or river-basin scale (Rathore et al., 2011).

To sum up, the large number of privately organized legal and illegal components of the water supply infrastructure poses a challenge both for consumers and decision-makers. The monitoring, maintenance and control of these ever growing structures and the connected resources is fundamental to ensure sustainable management of water resources in peri-urban areas and demands therefore for more action and awareness on the decision-maker level but also on community and users level.

PART 3 Participatory Approach & Interdisciplinary Work

This part gives an overview of the cooperation with the local organization Mahila Housing SEWA Trust (MHT), of the participatory approach applied and activities conducted as well as of the sometimes unexpected results from the transdisciplinary cooperation with the filmmaker. Basically, the participatory work was diverted into four parts: preliminary investigations to identify main problems and get first information about the communities to be able to develop an adapted approach (Chapter 3.2), water workshops to raise awareness about and transfer basic knowledge of groundwater to a huge group of women (Chapter 3.3), recruitment of local women assistants to teach a small group of women in-depth knowledge about groundwater management (Chapter 3.4) and, lastly, producing films to be able to scale up the impact of the project by transferring the results to other places and people (Chapter 3.5). Chapter 3.6 contains the publication 'Water and Conflict'. The last chapter (3.7) discusses challenges of the applied approach.

3.1 Theoretical Background

In addition to the general literature review in the introduction (Chapter 1.3), a background on inter- and transdisciplinarity is given here as it is relevant for the following chapters.

Since there are many different definitions of inter- and transdisciplinarity, the following definitions are used within this work. Interdisciplinarity is understood as the cooperation of different disciplines on a problem as well as the integration of strategies and approaches of other disciplines into one's own work (Barthel & Seidl, 2017; Repko et al., 2011). Transdisciplinarity is seen as the application of non-scientific methods in a scientific project and the cooperation of scientists with non-scientists in order to ensure the relation to practical suitability and social reality (Maheshwari et al., 2014; Scholz et al., 2000). Another part of transdisciplinary work is the critical reflection of science, which is sometimes only made possible by it. Finally, new knowledge can be produced when working in a transdisciplinary way, that would not have been created within a scientific discipline (Marshall et al., 2018).

3.2 Preparatory Work and Preliminary Investigations

3.2.1 Cooperation with Local Organization MHT

MHT's grassroots approach is organized in three steps. The first step involves the building of a Community Based Organization (CBO) with the women from all households (HHs) of one community (150-250 HHs). Together with MHT they identify the specific needs of their community. In a second step then, the CBO members decide on women leaders among themselves who form the so-called Community Action Group (CAG) comprising of 10-12 women. The CAG is trained by MHT in technical issues, e.g. regarding hygiene, but also in interacting with government agencies. In cities where MHT is working already for many years, e.g. Ahmedabad, out of the CAGs a city-wide group of the most engaged and capable women is formed, called Vikasinis[12]. This women group works independently with officials from government or service providers, fights actively for their citizen rights and is involved in city-level planning and implementation strategies, e.g. City Sanitation Plan, Waste Management Plan (MHT - Mahila Housing SEWA Trust, 2015b, 2019b).

Two communities were chosen as pilot areas for this project (Chapter 1.1.2). Most of the cooperation took place with the CAG of each community and especially with the leader of both CAGs, who will be called in the following women community leader. To a minor extent, CAGs from other communities of Jaipur were also involved, e.g. during the water workshops (Chapter 3.3.1). Because the women federation Vikasini does not exist in Jaipur yet, no cooperation on that level could take place.

Working with the MHT women's network had several advantages for the field work:

1) By coming into the communities together with a local and respected organization, the hydrogeological field work was strongly supported by the women right from the beginning;

2) The local women have a good and detailed knowledge of their area and are very aware of related problems;

3) Collaborating with the women leader of the CAGs gave the opportunity to work with some of the most engaged and understanding women of the area;

[12] The term Vikasini has a local feminine connotation meaning "carriers of development" (MHT - Mahila Housing SEWA Trust, 2019b).

4) The local women leaders are respected members of the community and their support of the project enhanced the acceptance of it among the local population. This is crucial for a successful and long-term field work.

During the normal hydrogeological field work (see Part 2), the women community leaders were always informed if the work took place in their community. They could then decide, if they would like to accompany the team. However, this does not happen often (~ 5-10 %).

In practice, the cooperation with MHT developed as follows. After being introduced to the CAGs of Jaipur and especially to the CBOs of the two chosen communities by MHT, accompanied field visits were conducted to get to know MHTs work better as well as to get familiar with the area and the people living there. Subsequently, field work was carried out independently in consultation with MHT. This consultation was divided into two parts. A general information about the work plan, timeframe and long-term aims were given to the project lead in Ahmedabad, whereas the day-today issues were discussed with the field worker in Jaipur.

3.2.2 Preliminary Investigations

The aim of the preliminary investigations was to identify study areas, but also to gain an initial insight into the lives of the women with whom the participatory project was to take place. Two field visits in summer and autumn 2015 allowed first social scientific investigations. But before, it was necessary to get information about how to approach local communities and about available methods to understand how non-scientists think about groundwater. Within current classical hydrogeological education, students do not learn about the people using groundwater, some being affected by its inadequate quality or quantity every day, about the interrelationship between humans and groundwater (despite from a technical view, e.g. anthropogenic contaminations or abstraction rates), how this relationship can be analyzed and how it may affect the work of a hydrogeologist. Human-centered design thinking courses, e.g. given by IDEO.org[13] and +Acumen[14], filled this knowledge gap. IDEO.org is a global company and platform focusing on creative design approaches to tackle poverty among people and vulnerable communities. +Acumen is a platform offering online courses to a global community in all categories of social change.

Human-centered design thinking has its roots in classical design thinking, where products are developed thinking them from a user perspective. This can be also applied to services and, in the case

[13] https://www.ideo.org/
[14] https://www.plusacumen.org/about

of human-centered, this means to think solutions from the perspective of those affected by the problem (IDEO.org & +Acumen, -). To do this, it is necessary to understand the people and their needs with whom and for whom the interventions are planned.

The first field visit in summer 2015 last for two days and allowed only short spontaneous conversation with the locals. However, this first impression helped to prepare the investigations for the next visit. In social research, a wide range of methods both qualitative and quantitative are applied for data sampling and analysis. Often, a mixed methods approach is used. In this work, the focus lay on qualitative methods because a vivid and deep picture of the people were needed which can be best achieved by qualitative methods. Limitation of qualitative methods are the low number of views and perspectives covered which does not give a statistically sound result. However, this was balanced to some point by secondary data gathering, e.g. information extracted from literature (Charnley et al., 2017).

Structured Interviews

One of the most common qualitative methods are interviews, which can be conducted in many different ways, e.g. open or structured interviews, group or single interviews. Structured interviews are characterized by a prepared questionnaire which is organized in a certain way, e.g. going from broad questions to more specific ones. Structured interviews were chosen as an interview method as they are easier to conduct and to analyze compared to other interviews types, e.g. open interviews. This was important because the hydrogeologist never conducted interviews before. It was also suspected that if open interviews were conducted, much information would be lost as a result of the translation during the interviews. One section of the interview is concerned with the daily schedule of the interviewees. This schedule represents a detailed day-to-day routine of an average day from getting up in the morning until going to bed in the evening. In addition to the questions, part of the interview is a creative task where the interviewees are asked to "draw something that would make them happier".

During the second field visit in September 2015, structured interviews were conducted with five women from three different low-income areas of Jaipur. Four of them are living in the two study areas and two of them are the women community leader of these areas. All interviews were conducted in the persons' space for two reasons. First, to get more information about the person by seeing where and how she is living and secondly, to create a familiar atmosphere for the interviewee (Fig. 45). The questionnaires (Appendix A8) were designed in a way that they started with general and easy to answer questions regarding for example the family and the community. In that way, the interviewee had time to get comfortable with the interviewer. At a next steep, the questions were getting deeper and more related to water, e.g. the existing knowledge of water or the water problems of the area. In addition, the questions changed from yes/no questions to open-ended questions which allowed for a more detailed answer and, therefore, more and sometimes unexpected insights. The last block of questions was not related to water but a very different kind of questions, e.g. "Imagine you can live in any place on earth. Where and why?" The aim of this block was to get to know more about the fears, hopes and ambitions of the interviewee.

Fig. 45: Conducting an interview with the CAG member in Khara Kuaa. The women community leader (below left) accompanied the hydrogeologist (middle) and the staff member of MHT (2nd from left), who translated. September 2015, Jaipur.

Before the interviews took place, all questions were discussed with the MHT staff member, who were later also doing the translation, for two reasons: first, to check if no cultural or religious inadequate questions are included and secondly, to prepare the staff person, so that she understands all questions and why they are part of the questionnaire. The interviews took about 1-2 hours and were conducted on two consecutive days.

In general, all women were open to take part in the interviews and to answer all questions. However, there were great significances between the three community leaders on the one side and the two CAG members on the other side in terms of knowledge, understanding and self-confidence. The following example clearly illustrate the differences. As answer to the question "Do you feel you can change some part of this [the water situation in the community] by yourself?" the CAG member of KK was saying "alone I cannot do anything, I am not able to think in this line, but together with the community leader I can do it". And the reply to the question what prevents her from doing something, was that "her mind is not working in this direction". In contrast, the community leader of KK answered directly, "yes, she can do something by herself and the only thing what prevents her, are people who are jealous of her, because she already achieved so much."

Several questions were understood by all interviewees in a completely different way from what the interviewer meant. Some of these questions are listed here:

- Can you tell me something about the social groups in your community?
- How are your friendships in your community?
- Tell me about the last time you learned something new.
- How do you spend your free time?

The problem with all of these questions does not lay at the interviewees side but with the hydrogeologist. As an untrained interviewer in general and especially in other cultures, she transferred concepts of social structures, of differences which are made between working time and free time, of a society where learning is an incremental part, to a place which is fundamentally different. The answers to the last question were particularly striking, as the women did not understand the concept of free time as it is understood in a western context. Their answers were for example "sari work" or "if there are any issues in the community, she goes there". For them the free time was a time where they did not have to do household work but could do other work to earn some extra money for the family. Because the last two women replied that they "do not have any free time, they are always engaged in work, e.g. sari making", it is supposed that at that time the translator changed the way how she framed the questions slightly by telling the women that if they are doing work, that has nothing to do with free time.

Turning now to the actual content of the answers the most relevant conclusions will be discussed here. The complete answers can be found in the Appendix A8. The information from the interviews were analyzed according to the qualitative content analyses with a focus on the differences and similarities of the women and on water-related issues.

Three of the four women who are living in the study areas indicated water, among others, as biggest problem they face on a daily basis. In all cases, the informants reported that they are checking the water quality mainly by visual observation, odor or taste. In regard to water quantity, the women from KK, who are mostly connected to a municipal water line, felt that the water quantity in general decreases due to less rainfall, while the women from NKT, which is not connected to any water line, argued that the problem lays within the missing public water supply line. On average, the participants spend 2-5 hours for water issues per day with a supply system which is highly divers, from wells, to municipal and private tankers, to a public water supply line, to 20 L buckets sold by private vendors. In times of water scarcity all of them are trying to spend less water for bathing, cleaning and washing purposes. Only one woman, the community leader of KK, stated that "she also tries to reuse water by using the washing water for the toilet". All women have an awareness of water-borne diseases, which is, however, sometimes wrong, when they relate, for example, a cold to the water quality. Here again a difference between the leaders and the normal CAG members can be seen, with two leaders relating diseases also to the seasons, e.g. that in the rainy season more people fall ill. All of the women have also a basic understanding of the water cycle: "if it is raining: water comes from the mountains and percolates into the soil/underground, ground sucks it". However, the concept of groundwater stays very abstract. Concerns regarding the government were widespread with four of the five interviewees not expecting anything from it. They all expressed their mistrust into governmental services.

For the *creative part* during the interview, the women were asked in between to "draw something that would make them happier". Some of the women were first too shy to draw something or did not know what was expected from them. But after a while, some explanations and at one place by the help of the daughter, all women sketched something. Even if it is probable that the drawings are influenced by the explanations given by the translator, they are still interesting. Next to one temple, two houses and some flowers, four of the five women decided to draw things related to their work, e.g. sari stitching, the machine which makes holes in pearls or jewelry (Fig. 46). These results suggest that they like their work and are proud to contribute to the income of their families. Another interesting result is that the community leader of NKT, which is not connected to the public water line like KK, included a water supply system for the community in their sketches.

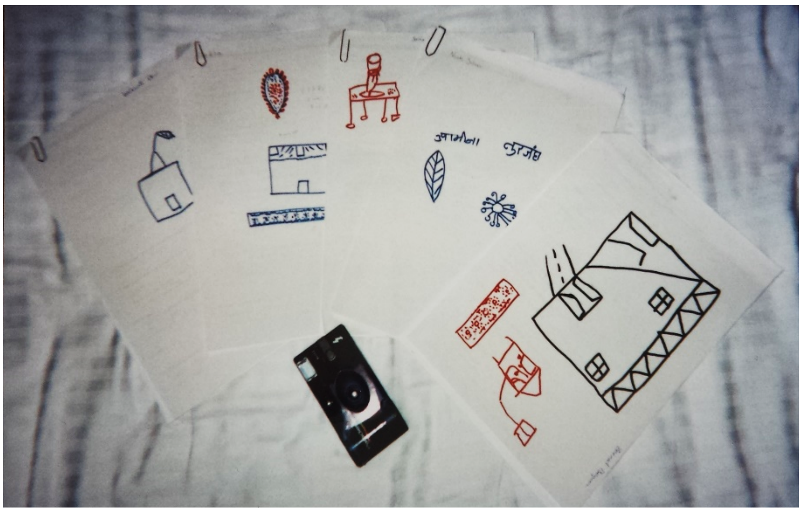


Fig. 46: Drawings of the five women resulting from the interviews, September 2015, Jaipur.

The main aim of the *daily schedule* exercise was to get an insight into the work load the women have to be able to develop realistic participatory scenarios.

Tab. 14: Daily schedule of the women who were interviewed in September 2015 in frame of the preliminary investigations. All of them are living in low-income areas of Jaipur.

Time	Community Leader KK (45 years old)	CAG Member KK* (60 years old)	Community Leader NKT (55 years old)	CAG Member NKT (36 years old)	Community Leader Bhanda Basti (>50 years old)
4 am	- Washroom - Fills up water	- Washroom - Sweep rooms			
5 am	- Making tea	- Worship at temple - Making tea	- Cooks & packs for children	- Worship - Prepare food for family	- Fills up water - HH activities
6 am	- Cooking - HH work		- Tea + breakfast - Cooks for lunch		- Children to school - Husband goes to work
7 am	- Packs food for family	- Goes to school			
8 am	- Cleaning house	- Sweeps at school - Takes care of small children (e.g. goes with them to the washroom)	- HH activities - Sari work		
9 am				- HH activities	
10 am				- Own work (making holes in pearls with special machine)	
11 am	- MHT work, e.g. collect loans				- MHT work: • Meeting with women
12 am	- Sari work				• Gives loans
1 pm			- Children back from school - Eat together		• Talks about problems - Goes to bank/ Nagar Nigam
2 pm			- Husband comes for lunch - Serves food	- Lunch with children	- Takes people to hospital - Goes to diff. govern. offices
3 pm		- Sleeps	- Watches TV - Talks - Sari work	- Own work	- If free time: Sari work, make patches
4 pm	- goes to market - buys vegetables	- goes to market - buys vegetables			- Buying vegetables etc.
5 pm				- Cooking - HH activities	
6 pm	- HH work - cooking etc.	- rests - takes dinner	- HH activities - Husband comes back from work	- Goes to bed	- HH activities - Cooking
7 pm	- goes to bed	- goes to bed			- Goes to bed
8 pm			- Serves food - Goes to bed		
9 pm					
10 pm					
11 pm					
12 pm					

* *Daughter-in-law is doing most of the cooking and other HH activities.*

Even though the daily routine differs in some parts, several general conclusions can be drawn. All the women get up between 4 and 5 am and go to bed between 10 and 12 pm. Issues related to water were not particularly prominent in the interview data with only two women reporting that they fill up the water storage every morning. However, it is assumed that most of the women include water-related issues into general HH activities. Comparing the schedule of the young women from NKT with the schedules of the older women, it can be seen that she does not have time to take rest during the day and goes to bed last.

The same as for the interviews applies here that probably some information got lost by translation which often included a shortening by the translator. Furthermore, as the translator were familiar with the procedure after the first daily schedule exercise, from time to time she was giving the next four women suggestions what to say. However, the information from this exercise is still valuable. It shows the tight daily routine most of the women have, especially the young one. These results indicate on the one hand that it might make more sense to consider the older women as local assistants and, on the other hand, that the work time might change every day always depending on the availability of the women.

Expert Interviews

Next to the interviews with the women, four expert interviews were conducted to get more in-depth knowledge of relevant fields. Expert interviews are conducted with people who can provide key insights into specific topics and in the best case, also a system-level view of the area of interest. These interviews were conducted in a semi-structured way with an interview guide prepared in advance. That means the topics to be explored are defined preliminary and also some basic questions to each topic, but parts of the interview stay open allowing to divert into the most interesting directions evolved during the interview (IDEO.org, 2015). For that, extra questionnaires were prepared, respectively (Appendix 9, 10).

One of the experts is a staff member of MHT, Srishti Singh, who were interviewed regarding the following themes:

- MHTs experience with educating women and youth in the informal settlements,
- structure of the women community groups
- educational level of women and youth,
- experience with governmental/city institutions,
- challenges within the GRP project,
- perception of slum dwellers towards their water,

- local/traditional solutions,
- access to information and communication technology in the informal settlements,
- cultural/religious/political characteristics, which should be kept in mind and
- general field experiences, e.g. during FGDs, interviews.

The complete questions and answers can be found in Appendix A9. Two interesting excerpts of the interview will be given here. The first is related to the theme of MHT's experience with educating women and youth in the informal settlements: "What resources (e.g. projector and a screen, meeting room) could we get for education and/or what would be effective?" Srishti Singh's response to this question included: "Audio/visual shows, role plays and folk media are the best ways to transfer relevant information to the wider audience in the community. […] However, once the community starts recognizing, one to one interviews and FGDs/trainings would be really helpful." This statement reflects exactly what is planned by developing a visual documentation of the project (Chapter 3.5). In a first step, the films are intended to attract the attention of people which, in a next step, can then by followed by water workshops.

The second excerpt is a rather surprising answer to the question "Are there any cultural barriers we should be aware of?". Srishti Singh from MHT said "No, not exactly." It is likely that she understood the question differently than the interviewer meant, thinking in great detail about certain cultural barriers at work in Jaipur, while the interviewer had general cultural differences in mind. Another possible explanation for this remarkable answer would be that Srishti Singh was not aware of the significant cultural differences between India and Germany and what this means for a participatory approach that focuses on low-income communities and is carried out by a German scientist. However, a detailed answer would have been helpful for the preparations. This result indicates that other experts have to be interviewed. The next paragraph, therefore, moves on to discuss the outcomes of an interview with Dr. Michael Gottlob and Bianca Negri, who are part of the German Section of Amnesty International where they are active at the India Co-group. The conversation with them revolved around the following questions:

- What are your learnings from your projects from other areas/cities in India?
- What are your experiences working in Indian low-income areas and what were the biggest barriers?
- How can we make our design project sustainable?
- Do you think it make sense to educate slum dwellers about their water? Why?
- What is your impression of the role of women in Indian communities?
- How are your experiences with educating communities? How have you done this?

The summary of the talk is given in Appendix A10. As already recommended by MHT employee Srishti Singh, Dr. Gottlob and Bianca Negri also emphasized the importance of working with interactive and visual methods, e.g. movie on the road. But regarding possible challenges they became much more concrete giving valuable advices, e.g. to be aware of conflicts within the communities and the caste- and religious-based hierarchical structures. Their recommendation concerning the cooperation with officials was to "Be concrete!", "Make clear, who is supposed to do what!", and "Ask every time what can be done together." These suggestions were tried to apply in the last expert interviews which were conducted in frame of the preliminary investigations.

During the field visit in September 2015, a local water expert from the water supplier (PHED) were interviewed about the current water supply and wastewater treatment situation of the study areas. The last expert interview took place at the RGWB. Questions were asked about the official groundwater monitoring network and the current status of the groundwater resources. In addition, data regarding the qualitative and quantitative development of the groundwater within Jaipur district were obtained.

Shadowing (Participating Observation)

One of the biggest challenges of the interdisciplinary work was the *shadowing*, also called participating observation. Shadowing is a tool from the social sciences, especially applied in anthropological and ethnographical sciences, where scientists spend time with the people they want to know more about at their house or area (IDEO.org, 2015). It can be one day, but can also extend up to weeks or even months. This method is not about interaction with the people but observing how they are living and what they are doing in their normal daily routine. In the best way, it is as if the observer is not present. However, this is nearly impossible as the presence of a stranger and in this case even a foreigner, has an influence on the behavior of the people being observed. Due to time and organizational limitations, only one participating observation was possible in frame of the preliminary investigations. The observation started early in the morning and lasted the entire day until the evening. It took place at the house of the community leader in NKT and was carried out without translator or personnel from MHT.

The day-long observation allowed a change of perspective from a scientific view to a user perspective. The personal experience of problems with which the local population is confronted every day, e.g. heat stress, dust, an uncertain water supply in both quality and quantity, led to a better understanding of the user's needs and expectations for an improved water supply. Therefore, this method is recommended for every (natural) scientists who wants to understand how a certain problematic situation, in this case the insufficient water supply, affects the people in their daily life.

Camera-User-Study

Another method applied was the *Camera-User-Study*. The idea of it is to give the people you are going to work with a single-use camera and ask them to take pictures to a certain theme from their very own perspective (Fig. 47). In this way, they are becoming partners in your research, moving from pure objects to actively participating subjects (IDEO.org, 2015). This can be set into context with the term of non-certified experts in contrast to certified disciplinary experts, as applied by Krueger to highlight the fact that water knowledge is produced by various stakeholders within the society (McMillan et al., 2016).

Fig. 47: First attempts to use the single-use camera by the women community leader from Khara Kuaa after an explanation was given to her about the function camera. September 2015, Jaipur.

Cameras were given to the four women from the study areas who also participated in the interviews. The task given to two women was to take pictures about positive aspects regarding the water situation in their area whereas the other two women were asked to take pictures of negative water related issues in their area. The fifth women, who are living in another low-income area (Bhanda Basti) was not concluded in this exercise as the main focus lay on water issues within the two study areas.

The results were surprising. While the women community leader in both communities, who had the task to take negative pictures, fulfilled the mission very good (Fig. 48, Fig. 49), the other two women took not one single picture related to water (Fig. 50, Fig. 51). Furthermore, it can be assumed that they did not take the pictures by themselves or did not decide alone where to go to take the pictures. In Khara Kuaa, it is likely, that the women community leader accompanied the other women for taking the pictures, as she is seen on one of the photos (Fig. 50).

Fig. 48: Pictures taken by the women community leader of Khara Kuaa to the topic of negative water issues in her area. The left side shows open canals which transport the grey water to a nearby *nallah* (not seen here). The picture on the right side shows a solid waste disposal within the community where cows are looking for something to eat. In the middle of the picture a non-functioning bore well can be seen. September 2015, Jaipur.

In Nai Ki Thari, it seems that the camera was given to a male member of the community as many pictures with male persons exists as well as pictures during the prayer of male Muslims (Fig. 51). The most probable explanation for this unexpected result is that the task to take photos of positive water related issues were misunderstood or wrongly translated and instead general positive things were photographed, as for example a temple (Fig. 50, left) or family members (Fig. 51, right). Another conclusion from this exercise is that the normal CAG members were not self-confident

Fig. 49: Two examples of the photos taken by the women community leader from NKT: typical unpaved street in NKT with missing canalization for grey water (left side) and resulting water-logging (right side). September 2015, Jaipur.

Fig. 50: Pictures taken by the CAG member of Khara Kuaa. Instead of water issues, religious aspects (Hindu temple at the left picture) and foreign Muslim people on the street (right side) were photographed. September 2015, Jaipur.

enough to realize the task by themselves but asked the women leader or a male member of the community for help, respectively. An overview of all photos can be found at Appendix A11.

Fig. 51: Pictures taken by the CAG member (or very likely by a male member of the community) in NKT. Instead of positive water issues, religious aspects (Muslim prayer at the left picture) as well as family members (right) were photographed. September 2015, Jaipur.

User Experience Map

Based on the results from the preliminary investigations, a user experience map, sometimes also called journey map, was developed (Fig. 52). With the map, the way how a potential user of the

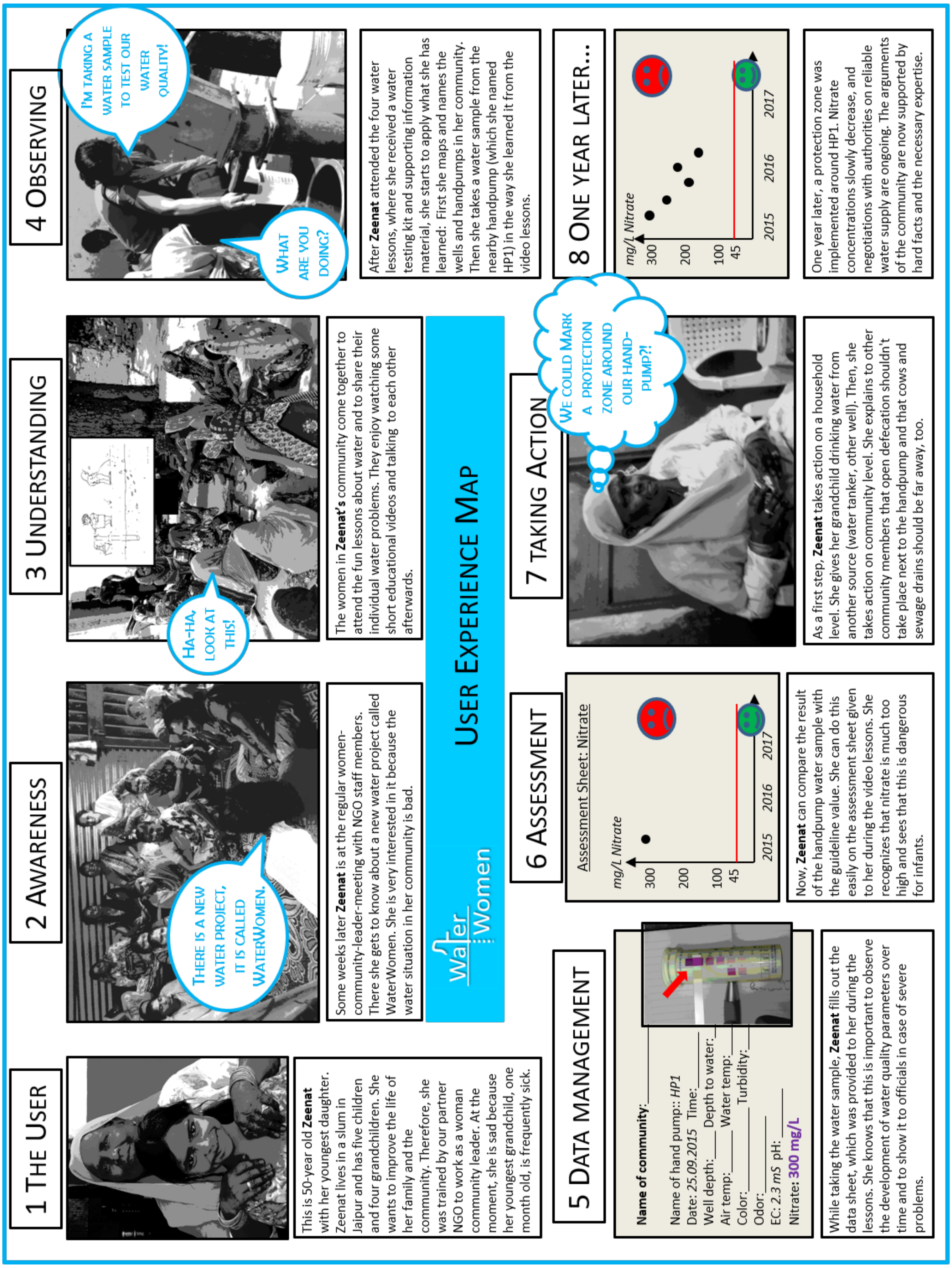


Fig. 52: User experience map developed based on the results from the preliminary investigations.

product or service, experiences this product or service, can be visualize from the beginning to the end. If you think through the entire project from the users' point of view, you are forced to think through every single step (IDEO.org, 2015) what can be useful for putting up the project's work plan. The women community leader from NKT served as an example to create the map. This tool helped to imagine how and where the target group gets to know about the project, how it is then implemented and what a possible end could look like. Especially the first step and the end are rather neglected in project planning. Additionally, it can be used to explain the project idea in a demonstrative way to the target group or other stakeholders involved.

3.2.3 Conclusion

The preliminary investigations were undertaken to get more knowledge about the women and their lives. With the applied human-centered design methods this goal could be accomplished. Every method made sense and contributed knew knowledge. However, it would have been advisable to repeat the application of all of the methods more often in order to be able to not only draw qualitative conclusions but also more quantitative ones. The main conclusions for the next step, the establishment of a participatory groundwater monitoring in Jaipur, are:

1) Most women have mobile phones but no smartphones. Therefore, solutions requiring mobile applications or mobile data connections are not suitable for the target group. When designing for the younger generation, an educational mobile application might be appropriate because some young people use smartphones;

2) Time is very precious, and the women have little free time. The educational modules will have to be relatively short and entertaining, so they will enjoy them;

3) The target group is not willing to pay for groundwater;

4) There is a strong need for communication between official water supplier and community.

In summary, the preparatory field visits in summer 2015 revealed that a lack of knowledge and expertise in the communities leads to many water-related problems, such as wastage of water, illegal pipeline connections, practicing open defecation up-gradient of drinking water production wells and thinking in limited ways (temporal and spatial). A lack of capacity in terms of time, media access and confidence of the slum dwellers requires a solution, which is tailored to their needs and capabilities.

3.3 Awareness Raising and Basic Knowledge Transfer

3.3.1 Water Workshops

Intention

After the preliminary investigations, which took place before the main project started, the water workshops were the first activity within the participatory part of the project. They serve as a tool to create a basic awareness and knowledge about groundwater among a broad group of people with many of them dealing with groundwater every day without understanding basic hydrogeological processes. However, this is important at a later stage, if measures will be implemented which include the necessity of behavior change of people and communities.

Organization

The workshops were conducted in close cooperation with MHT in three of the project cities, namely Ahmedabad, Jaipur and Bhopal. They consist of different modules. An exemplary schedule of one of the workshops is given in Table 15. The duration of all workshops were two days and they were designed to be hold with a large group (~30 participants per workshop). At every workshop, a staff member of MHT translated from English to Hindi and sometimes also used Indian-adapted metaphors to explain certain terms or concepts. In order to illustrate, for example, that the underground and thus the groundwater differ from place to place, the MHT employee compared it with traditional saris, which are all saris but have certain local characteristics, e.g. colors or print patterns that are different for each region.

Tab. 15: Agenda of the water workshop in Jaipur, 24-25 November 2016.

Session	Topic	Method	Objective	Person in charge
Day 1				
11.30 – 12.00	Overview of water situation in India	PPT with interactive part	Create awareness on why we should get involved in this issue	Theresa
12.00-1.30	Groundwater & Water Cycle	PPT with group exercises	Create basic understanding of water cycle	Theresa
1.30-2.30	Lunch			
2.30 – 4.30	Overview of water situation in Jaipur	PPT with interactive questions	That women understand how their local water situation is connected to the city's situation	Theresa

Day 2				
11.30 – 12.45	Typical contamination paths and impacts on slum dwellers	PPT with interactive questions	Create awareness about human impact on groundwater source	Theresa
12.45 – 1.30	Why to monitor groundwater	PPT	Motivate women to take part in participatory water management	Theresa
1.30-2.30	Lunch			
2.30 - 4	How to test your water (samples by the community)	Testing kits	Introduction to participatory water testing	Srishti & Theresa
4—4.30	Water Quiz	Quiz	Test, what women have learnt and repeat important messages	Theresa

Based on the findings of the preliminary studies, the workshops were developed in such a way that they are informative, interactive, diverse and illustrative. The hydrogeologist decided to include three thematic blocks, the water situation in India, the water cycle and groundwater. Vivid power point presentations alternated with small experiments, e.g. dissolving salt in a glass of water, group work, quiz rounds and questions sessions. In the afternoon of the second day, the women could test water they brought from their place by their own with a local water testing kit (TARA - Technology and Action for Rural Advancement, -). Detailed explanations of each method can be found in the first section - Understanding - of the Training Manual in Appendix A18 (Frommen et al., 2018).

Results and Discussion

In the following, selected results will be discussed which are representing in the best way the overall outcome of the workshops in regard to its aims. Furthermore, surprising and unexpected results will be discussed too, as valuable insights can be drawn from them.

One of the goals was to raise awareness about groundwater among the women. For that, the hydrogeologist first wanted to get an impression of the current understanding the women have of the

Fig. 53: Left side: Exercise sheet: Draw your imagination of the underground. Right side: First water workshop in Ahmedabad, September 2016. The participants presenting the results of the exercise "Draw your imagination of the underground" to the rest of the group.

underground and groundwater. Therefore, she developed an exercise called "Underground Drawing Sheet" where the women were asked to draw their imagination of the subsurface beneath their houses (Fig. 53). Next to the information the hydrogeologist hoped to get from it, this tool added to the interactivity of the workshop.

The results were interesting (Fig. 54). During the first workshop in Ahmedabad most of the women draw a top view of their area including the water supply and wastewater lines (Fig. 31, left side). It is possible that the translator did not understand the sheet by herself and, therefore, explained the

Fig. 54: Three examples of the completed underground drawing sheets. Left side: Ahmedabad workshop; middle sheet: Jaipur workshop; right side: Bhopal workshop.

task in another way. However, for the hydrogeologist it was interesting to see that the pictures the women have in mind when someone is talking about groundwater are mainly of water and gutter lines laid beneath the surface. The example chosen here (see Fig. 54) is one of the few which also included a "water layer" beneath the underground. For the next two workshops in Jaipur and Bhopal the task was explained more carefully resulting eventual in profiles of the underground as was planned. But still the concept of the worksheet was not fully understood as most of the women did not use the given surface but drawing an own again (Fig. 54, middle and right side). However, the completed sheets revealed nicely the common imagination of the underground in general and groundwater in specific. The drawing in the middle is a representative example from the Jaipur workshop showing a water layer (पानी - pani) which is followed by a sand/soil layer (मिट्टी - mittee) and a stone layer (पत्थर - patthar). In Bhopal the women added numerous other things, like dead bodies (कंकाल - kankaal), gold (सोना - Sona), petrol (पेट्रोल - petrol), diamonds (हीरे - heere) and microorganism (Fig. 54, left). This clearly shows that they are aware of various functions of the underground but what is common for nearly all drawings is that water appears in layers, symbolizing underground lakes or rivers. The explanations given by the women also point to the widespread idea of a huge underground water reservoir. A group at the Jaipur workshop who explained their completed sheet to the other women, argued that if a hand pump is situated within a water layer it gives water and if it is not giving any water it is situated in a layer without water.

Concerning the topic of the hydrological cycle the exercise called "Water Cycle Sheet" was developed (Fig. 55). All participants completed this exercise having a lot of fun and discussed each step in detail within the group. Furthermore, they also enjoyed showing and explaining it to family members and friends at home after the workshop, what can be clearly seen in the documentary (Chapter 3.5) (Ambrus, 2019). The water cycle sheet was supported by a second exercise called

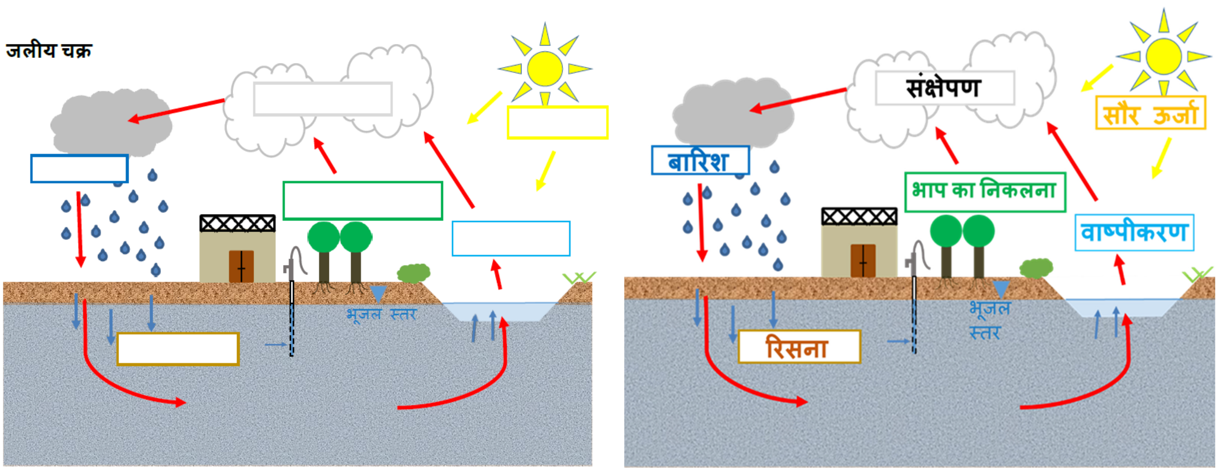


Fig. 55: Water cycle exercise. The women had to put the all terms of the water cycle into the correct spaces (see sketch at the right). In the end, they could take the completed water cycle sheet with them.

"Water Cycle Wristband". A long yellow string was used to represent solar energy as the motor of the whole cycle and beads of the colors light blue (representing evaporation), green (transpiration), white (condensation), dark blue (precipitation) and brown (infiltration) were used to represent the respective processes. The participants were asked to tie a wristband for their neighbor in the order of the hydrological cycle: light blue – green – white – dark blue – brown (Frommen et al., 2018). Like the water cycle sheet, this exercise was very much appreciated by the women who liked the idea of the wristband.

During the session about water quality and typical anthropogenic contaminations paths an unexpected problem arose at day two of the Jaipur workshop. The women were not able to understand that the presentation only showed how contamination could happen in general and, therefore, they were afraid that all their water is contaminated. The hydrogeologist realized that the women were incapable to grasp the concept of an example and, therefore, adapted the presentation for the next workshop in Bhopal where the problem did not recur.

3.3.2 Physical Groundwater Model

A physical groundwater model, also called sand tank in the literature, is usually a long and narrow box made of Plexiglas, which is filled with one or more types of sediments, e.g. sand, clay and which can be filled by water. Numerous additions, like wells, surface water bodies, observation well, can be added adapted to the requirements. Physical groundwater models are used to illustrate and often also to investigate groundwater-related process in the subsurface on a laboratory scale (Gleeson et al., 2012; Rodhe, 2012; Trop et al., 2000).

Confronted with the problem to visualize groundwater, a simplified groundwater model was developed for the workshop in Ahmedabad. It was made of the bottom of a plastic bottle, filled with sand and a syringe symbolizing a well (Fig. 56). However, this was not sufficient.

Fig. 56: Simplified groundwater model constructed by the master student Maximilian Nölscher under guidance of Theresa Frommen for the water workshop in Ahmedabad, September 2016.

Based on the experiences during the water workshops (see above) the necessity to develop something more visual become clear. Therefore, a concept for an adapted physical groundwater model was developed. Former sand tanks developed at the FU Berlin were not suitable because they were too complicated, too heavy and too expensive. The aim of the new sand tank was to create one which shows only the basic hydrogeological principles, e.g. that, normally, groundwater does not build underground lakes or rivers but is found in between sand grains. Therefore, following content requirements had to be fulfilled:

– showing an aquifer and aquitard to be able to explain the difference between them,
– including a surface water body in order to show surface water - groundwater interactions,
– containing one or two wells, preferable a shallow one and a deep one,
– including, if possible, typical characteristics of low-income areas, e.g. soak pits, hand pumps,
– it should be able to illustrate typical anthropogenic contaminations paths, e.g. polluted surface water body infiltrating in an aquifer.

Furthermore, the technical requirements include that the model is transportable, cost-effective, reproducible in India with local material and simple.

The result is a model with a length of 45 cm, a width of 4 cm and a height of 30 cm (Fig. 57). It has two feet to stand stable. The water level within the model can be regulated with a water chamber at each side of the model and one outlet at the right side at the bottom. The front cover is made of Plexiglas so that all process can be observed while the back cover is made of PVC which reduces the costs. Furthermore, to make the cleaning of the model easier, the front cover can be easily detached. The bottom layer consists of clay representing an aquitard and the upper layer consists of well-sorted sand representing an aquifer. Two wells are included in the model. One deep fixed well which is, after being halved, attached directly to the front cover and one shallow well, which

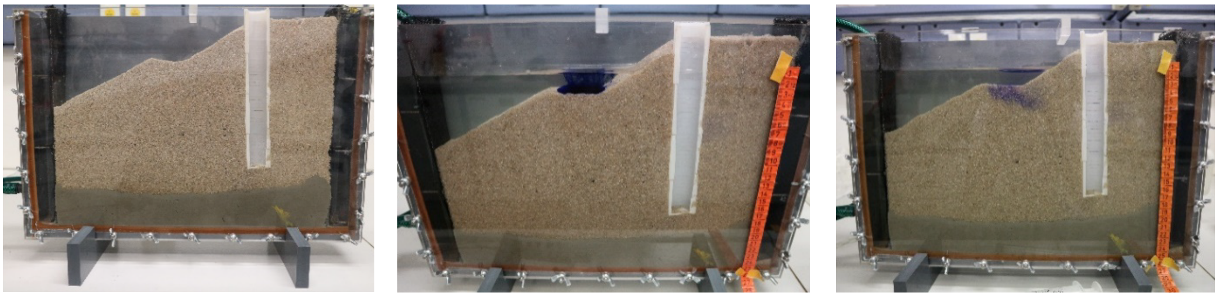


Fig. 57: Physical Groundwater Model developed in frame of the project. The picture on the left shows the model in normal condition. In the middle, s surface water contamination is represented by adding ink to the surface water body. Due to pumping in the deep well, a contamination plume can be seen on the right picture. Photos taken by Christoph Brüdigam.

can be added in a flexible way. With this setting it is possible to demonstrate all aspects and processes mentioned above.

As a support for potential users a groundwater model manual was composed (Appendix A17). In the first part of the manual, a step by step guidance how to build the model can be found together with a comprehensive list of the required material. The second part of the manual gives examples of experiments which can be executed with this model.

The model was designed for educational purposes to support the learning content in the water workshops with the aim to give a visual insight into the structure of the subsurface (e.g. permeable and impermeable layers) and to elucidate important processes in it (e.g. typical contamination paths into groundwater). First conclusions about the effect of the model can be drawn based on a workshop with and about the groundwater model given to MHT staff members in Ahmedabad. It revealed that the visualization of processes otherwise hidden in the underground improved the understanding of the participants significantly. A further advantage of the model is the possibility for the participants to be actively engaged with the model by filling in the ink or pumping water out of the well with the help of the syringe. Additionally, it is possible to develop own experiments adapted to individual requirements. Baldwin et al. (2012) made similar experiences in Australia where the workshop participants judged afterwards that "the 3D groundwater model [was] the 'best' tool for engaging participants to share information about groundwater issues, its uses and values." Due to the three points mentioned above, the workshop received absolutely positive feedback from the MHT employees.

3.3.3 Conclusion

In general, the water workshops were successful. At the end of the two days, an evaluation round took place where the women told what they have learnt. One participant commented, that "she knows now that groundwater is limited", while another stated that "groundwater is flowing and rain percolates to the underground filling up the groundwater". Furthermore, the women asked for more workshops and information about water after the two days. It was also interesting that the women told in the workshops that they do less washing and cleaning or cannot go to work, when there is a shortage of water. These statements are similar to the ones given in the interviews (Chapter 3.2.2). In summary, this means that water scarcity, in addition to direct negative health effects, always has major hygienic and thus secondary health effects and also immense economic effects on the affected people.

Using interactive tools were central when giving the workshops. They help to transfer the knowledge and, at the same time, keep the motivation and concentration of the participants at a high level. This is important as most of the participants are not used to concentrate for a long time. A similar experience is reported by Maheshwari et al. (2014) who have introduced participatory groundwater management at rural level in India, stressing the importance of including practical exercises to demystify groundwater.

3.4 Capacity Development and Active Involvement

With the previous chapter a basic awareness was built, constituting the first level of participation. The present chapter aims at an active involvement, which forms the next level of participation. The main aim was to develop and implement a groundwater monitoring plan together with the local women assistants and to train them how to do it. This work would be time-intensive and requiring a certain level of understanding, therefore, it was done with a smaller number of women. It was decided to work with two women per community, of whom at least one was able to read and write. Furthermore, one of the women was a younger woman in order to include the future generation. Next to the women, a local *auto-wallah* (Tuk-tuk driver) was integrated into the team in order to assure transport and translation during field work.

The chapter is structured into four parts, starting with the preparatory mapping of the water infrastructure of the area. The following two parts cover the participatory water sampling and groundwater level measurement. The participatory data management and interpretation of the data is discussed in Chapter 3.4.4. The actual hydrogeological results of the mapping and sampling, e.g. number of wells or water quality status, will not be presented in this chapter. Mapping results are incorporated in Part 2.

3.4.1 Participatory Water Infrastructure Mapping

Before starting with the water testing, the water infrastructure of the area had to be mapped for a number of reasons:

1) to get an overview of the water supply system of the community;
2) to quantify the different water sources (e.g. groundwater, tanker water, waterline);
3) to be able to make a reasonable decision where to take samples.

All wells (bore wells, hand pumps, dug wells, step wells), surface water bodies (*nallahs*, *taalaab*s, lakes and rivers), and waterline connections (public/private, legal/illegal) have been mapped. To use a single term covering all mapped water sources, the term "local water points" is hereby defined and will be used in the following.

Implementation

The participatory mapping was planned and implemented according to the professional mapping described in Part 2. Due to time constraints, it was only possible to do the participatory mapping in Khara Kuaa. It was conducted with a simple handheld GPS device, prepared mapping sheets and a camera. The mapping sheets were designed by the hydrogeologist according to the local conditions including one for water line connections (Appendix A12) and one for wells (Appendix A13). Before starting the participatory mapping, a preparatory meeting with the two local women assistants in Khara Kuaa was done. During this meeting the mapping sheets as well as the function of the GPS and the camera were explained in detail. The older local women assistant, who is the community leader of Khara Kuaa, decided where to go and showed the way. The young local assistant was taking the GPS points and interviewing people at the hand pumps or owners of water line connections, about the characteristics, use and condition of the respective local water point (Fig. 58). The translator took photos and helped the young assistant with filling out the mapping sheets. The first days, the mapping was conducted under guidance of the hydrogeological team. As soon as the local women assistants were familiar with the procedure they were doing the work by themselves.

Fig. 58: The local young woman assistant from Khara Kuaa during the mapping of the water infrastructure in her area in November 2016. With a GPS and a mapping sheet she is recording a tap of the public water supply system in KK.

Results

It took seven days à three to four hours to map all local water points. In total, 173 water line connections of whom 35 were not working anymore, nine hand pumps of whom five were broken, one non-functioning bore well and two dry dug wells were mapped. The results were then put on a map by the hydrogeologist and brought back to the local assistants in order to discuss the findings and decide on possible water sampling points.

Conclusion

This study shows that the local women were able to carry out the mapping independently after a well-founded introduction. Furthermore, the study confirms that the mix of an older respected woman, who knows the area very well, together with a younger woman, who can read and write, is a meaningful approach. Another remarkable finding is that it was important during the mapping to emphasize the fact that the team does not belong to the government. Many inhabitants of Khara Kuaa are unsatisfied with the service provided by the responsible authorities regarding their water supply. A limitation of this approach is that the hydrogeologist was creating the map of the area with the results from the mapping. However, in future, the map preparation should be fulfilled by the local organization, e.g. MHT, as the women from the community do not have access to maps nor are used working with maps.

3.4.2 Participatory Water Sampling

Based on the results from the mapping, the monitoring points were chosen together with the local women assistants (Fig. 59).

Fig. 59: Discussing the water monitoring points together with the local women assistants in Khara Kuaa, Jaipur 2017.

The following criteria have to be considered for the decision:

1) The best option is to have monitoring points where it is possible to measure both, water quantity and quality. However, in practice this is not always possible;

2) Accessibility: Is the monitoring point easily accessible, also during monsoon season? If it is a private local water point be sure that the owner agrees with a regular sampling;
3) Usage: The local water point should be used by many people. In most cases, it will not be possible to monitor all water sources in a community, therefore, the most important wells should be included into the monitoring network;
4) Distribution: The monitoring points should be well distributed over the community in order to cover the area as best as possible. If shallow and deep wells are present in your area take samples from both;
5) Diversity: Covering different water sources (e.g. groundwater, piped water from the waterlines);
6) Land use: Covering different locations (e.g. near industries, near agricultural areas).

The main motivation behind this approach is that the quality of the groundwater used by the community should be subject to a regular monitoring in order to determine current quality problems and to detect possible changes in time. To do so, a cost-effective and reliable water testing equipment is needed. It should have a clear step-by-step manual enabling non-scientists to conduct the testing by themselves. Furthermore, is should provide the possibility to test various parameters.

The selection of parameters for the participatory sampling has to be carefully considered. It is advisable to choose as few parameters as possible for the regular testing to take into account the time restrictions from the local women assistants. But at the same time, it is very important to cover the most important parameters. A common approach for a new area with unknown water composition is to start with a wide range of parameters. After the first measurements the range of parameters can be adjusted based on the results, i.e. if a parameter remains below detection limit (or remains within the requirements of the Indian standard drinking water specifications) it can be excluded from the further monitoring. In order to give a decision support, a table was developed indicating the parameters necessary for different types of water resources (Tab. 16).

Tab. 16: Selection of parameters for different water sources

Parameter	Groundwater	Surface water	Piped water
Color	✓	✓	✓
Odor	✓	✓	✓
pH	✓	✓	✓
Turbidity	✓	✓	✓

Temperature	✓	✓	✓
TDS/EC	✓	✓	✓
Hardness	✓	✓	✓
Chloride	✓	✓	✓
Nitrate	✓	✓	✓
Dissolved oxygen	✓	✓	-
Ammonia	✓	✓	-
Iron	✓	-	-
Benthic diversity	-	✓	-
Phosphorous	-	✓	-
Residual chlorine	-	-	✓
Fluoride	*	-	-
Arsenic	*	-	-
Coliform bacteria	*	*	*

*✓: always   - : not necessary   * : if applicable*

Implementation

Within this project, the Jal TARA Water Testing Kit produced by Development Alternatives, an Indian organization based in Delhi, proved to be a good option (TARA - Technology and Action for Rural Advancement, -). It gives the possibility to test the following parameters:

1) Physicochemical: pH, temperature, turbidity;
2) Chemical: arsenic, fluoride, ammonia, nitrate, iron, hardness, chloride, dissolved oxygen, phosphorous, residual chlorine;
3) Biological: coliform bacteria, benthic diversity.

The following parameters were chosen for this study: pH, temperature, turbidity, fluoride, ammonia, iron, hardness, chloride, dissolves oxygen, residual chlorine (for water line supply), coliform bacteria. In addition, TDS was measured with an extra device and smell and color was determined by visual observation.

The sampling was conducted with the water testing kit, a TDS meter and the prepared sampling protocols (Appendix A14). Before the work with the local women assistants could start, a meeting with the women to teach them how to take a water sample with the kit took place. During the first 2-3 sampling campaigns the hydrogeologist accompanied the women. As soon as they were familiar and confident with the testing procedure, they were doing the sampling by themselves together with the *auto-wallah*.

Results

The results of this study show that at the beginning a sampling interval of one month was necessary to consolidate the new capacity and knowledge about the sampling procedure. After 2-3 months, the interval of sampling was changed to two months and finally to a pre- and post-monsoon interval. The local women assistants were able to conduct the regular water sampling at four monitoring points with a maximum of two samplings per day. All results are listed in Appendix A16

Conclusion

This study has found that generally the women have no problems to follow the instructions given in the step-by-step guideline and to take the water samples. However, it is, especially at the beginning a very time intensive process for both sides, for the local women as well as for the "water expert". Therefore, it is important to tell the local women assistants at the beginning that this is going to be a long-term project and that they should work on it on a permanent basis. The women should be aware of this so that they can decide if they want to be involved in the project or not.

Within this project it turned out that it is advisable to always go to the field with the same *auto-wallah*. With an auto, it was possible to transport the water sampling equipment easily and to reach every monitoring point. Furthermore, the back of the auto was used to conduct the tests (Fig. 60).

Fig. 60: The back of an auto as a mobile laboratory: The local women assistants of Khara Kuaa testing the water quality of their community, Khara Kuaa, Jaipur 2017.

The biggest challenge that arose after a few months were other people in the community who asked about the sense of regular testing if there is no change in the current situation (see Chapter 3.7).

3.4.3 Participatory Groundwater Level Measurement

After the women were confident with the water sampling procedures, the depth-to-groundwater measurements started. Based on the field mapping, important local water points were considered to monitor the evolution of groundwater levels. Following criteria were applied to select monitoring points for the participatory monitoring network:

1) Accessibility: The local water point should be easily accessible, also during monsoon season. If it is a private local water point, the agreement of the owner with a regular measuring is necessary;
2) Distribution: The monitoring points should be well distributed over the community in order to cover the area as best as possible;
3) Diversity: Different local water points (e.g. surface water, groundwater) in the area should be measured regularly in order to understand the dynamics and the interaction between the different water sources.

Unequipped wells that are not affected by pumping of any nearby wells are the best places for groundwater level measurements as they better represent natural conditions. Therefore, observation wells constructed under such considerations would be the ideal points for a monitoring network. However, as these does not exist in the area of interest abandoned dug wells or broken hand pumps can be used to determine the groundwater level.

Due to time restrictions, the participatory groundwater level measurement was only conducted in Nai Ki Thari at two broken hand pumps. The local women assistants of Nai Ki Thari easily understood the principle and procedure of the measurement which was also due to knowledge they gained during the water workshops. The main challenge for the measurements was with the hand pumps themselves. Several times the water level meter got stucked inside the well probably due to parts of the broken pump inside the well.

Being limited to few measurements with only one of the pairs of local women assistants this part of the study lacks a sufficient basis for further interpretation.

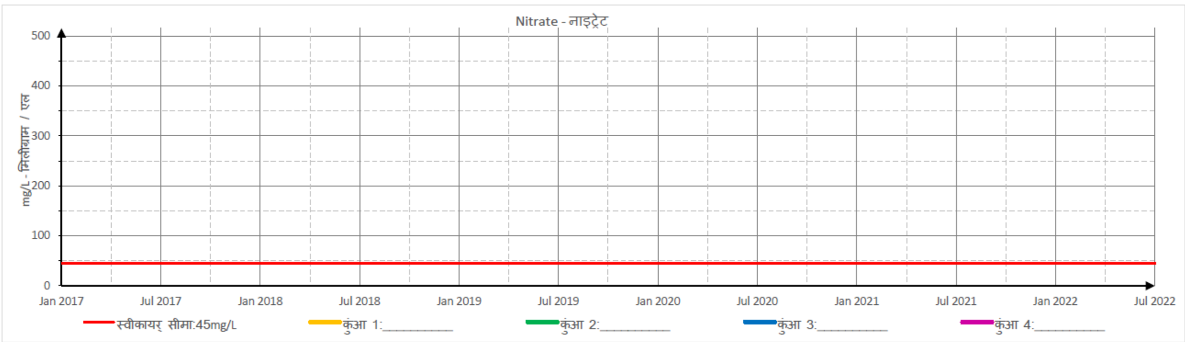
3.4.4 Participatory Data Management and Interpretation

The active involvement part does not stop with data collecting but it continues with data evaluation and interpretation. The aim was that the local women assistants will be enabled to plot the data collected by them in a clear and simple way. This enhances the understanding of the collected data and is necessary for the following interpretation. Without a proper data management, the previous work will be more or less useless as it is not possible to make a sound conclusion on the basis of countless single data points. Furthermore, good data management makes it possible for other users to understand and evaluate the data obtained by the local women assistants.

Implementation

In frame of the project, a booklet was developed in which all water quality data could be displayed (part of Appendix A18). It was designed in a way that also non-scientist can easily use it and that it shows at a glance the development of a certain parameter and if it exceeds the Indian standard. It starts with training graphs (Fig. 61) followed by one sheet per parameter where the results from the participatory sampling of all wells can be inserted (Fig. 62). Every well should be presented by another color. In this way, the water quality of every well in regard to a certain parameter can be easily compared which each other.

Example 1 – उदाहरण 1

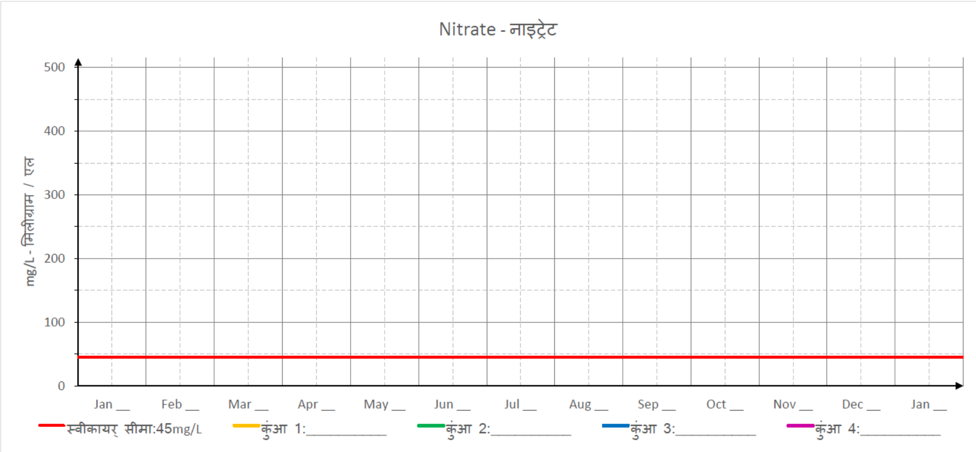


Date	Jan 17	Apr 17	Jul 17	Jan 18	Jul 18	Oct 18	Jan 19	Oct 19	Jan 20	Apr 20	Jan 21	Jul 21	Oct 21	Jan 22	Apr 22	Jul 22
Nitrate [mg/L]	<45	45-100	45-100	45	>100	>100	>100	>100	45	45	<45	45	<45	<45	45	45-100

तिथि	Jan 17	Apr 17	Jul 17	Jan 18	Jul 18	Oct 18	Jan 19	Oct 19	Jan 20	Apr 20	Jan 21	Jul 21	Oct 21	Jan 22	Apr 22	Jul 22
नाइट्रेट [मिलीग्राम/एल]	<45	45-100	45-100	45	>100	>100	>100	>100	45	45	<45	45	<45	<45	45	45-100

Fig. 61: Excerpt from the Water Quality Record Sheets. In the beginning of the assessment booklet, the work with the assessment sheets can be trained by the help of an exemplary result table (in this case for nitrate, and an empty graph).

After about three months of sampling, the data management and interpretation part started with the local assistants from Khara Kuaa. Together with an intern from a local university, the assessment sheets were explained to the women during a first meeting. They were taught how to work with the sheets with the help of the examples given at the beginning where the women transferred the values from the example tables to the example charts (one for Nitrate and one for TDS). Afterwards, the characteristics of each parameter, like source, health impact and drinking water limits were explained again in detail. During a second meeting, the transferring of the results from the sampling protocols to the record sheets started.



Health Concerns: Excessive nitrate intake can result in diarrhea or methaemoglobinaemia (blue-baby syndrome) in infants

Sources: Chemical fertilizers; animal matter; domestic effluents; sewage sludge disposal; industrial discharge

Fig. 62: Excerpt from the Water Quality Record Sheets showing the nitrate graph. For every parameter the Indian Standard is displayed in red at the graph and information regarding related health concerns and possible sources of the parameter are given below.

Conclusion

With the use of the Water Quality Record Sheets the women should be enabled to understand the quality development of the groundwater in their area and, in the best case, relate it to changes in rainfall patterns, construction of new wells or land uses.

One of the findings to emerge from this study is that it was advisable to take enough time with every new parameter to explain again its characteristics. The repetition of the new information was important for the local women assistants to be able to keep it in mind. Another finding was that the local women assistants should transfer the results to the Water Quality Record Sheet after every sampling campaign. This makes it possible to detect changes in time. Furthermore, an understanding of the range and rate of possible changes can be achieved.

While it was shown with this study that the women were able to grasp the system and the goal of the charts and transfer the results of the sampling sheets to them, it was not possible to assess if the women were able to interpret the results since the project duration was too short. Therefore, the study is limited to the first steps of the data management and interpretation part.

3.5 Evaluation and Upscaling

The main overarching goal of the participatory work is to achieve sustainable outputs. Because the common way of scientific communication would not reach the target groups of the project (local communities, NGOs, water experts) it was seen to be necessary to apply innovative approaches. Moving within the usual framework would mean once again encountering boundaries that often stand in the way of sustainable change and innovation. The collaboration with a documentary filmmaker led to the production of one cinematic documentation and one short educational movie. The films enable the upscaling of the project's impact by transferring the results to other places and people. The cooperation added a further level to the interdisciplinary research project, which turns the project into a transdisciplinary project (see Chapter 3.1 *Interdisciplinarity and Transdisciplinarity*).

3.5.1 Filmic Methods in Science

Filmic methods are being used in science in various ways, e.g. documentary, educational film, filming very fast processes which otherwise would not be seen, filming long-term processes. To use filmic methods in a scientific way, several preconditions have to be fulfilled. The film has to be embedded in a scientific discourse, the transparency of the methods and sources has to be given and the access to the sources used has to be guaranteed (Schaedler, 2010).

In regard to the first precondition, this work deals with the questions how to transfer scientific (groundwater) knowledge to people without any background education, how to motivate local people to participate at a groundwater project on a long-term basis, how to increase the awareness and knowledge of groundwater and how to reach a wide audience within the science community to highlight the importance of including social sciences into their work. These questions are getting more and more important in the light of population growth connected to an increasing demand in food and water as well as to urbanization trends, climate change impacts, industrialization in emerging economies leading to on the one hand groundwater contamination and on the other hand an increasing demand on water.

The second precondition regarding transparency is fulfilled by the openly accessible final project report "Pani Check & Pani Doctors - A documentary film project about an interdisciplinary hydrogeological project in Jaipur, India" (Frommen & Ambrus, 2019). Furthermore, in Chapter 3.5.3 the research design of the films is explained in detail. During the production all involved persons were informed about the concept and the goal of the films. All sources are mentioned in the film credits with what the last precondition, access to sources, is given.

When using filming as a scientific tool, especially in other cultures and countries it is crucial to be aware of its constraints. Oester (2010) discusses how film and photography was used in the past and nowadays by different sciences. She distinguished between four approaches, starting with the rationalist approach, where pictures are only used to illustrate texts. In contrast, the empiricist approach, with its height at the turn of the 19th century, understands film and photography as a tool for an objective and exact documentation of reality. This approach was later heavily criticized as racist, discriminating and misogynic by the former objects, like women and people from the colonized countries. This results in the conventionalist approach, which unmasked the apparent objective view as ethnocentric, sexist and male. Therefore, the conventionalist approach states that all production of scientific knowledge is culturally rooted. The last approach is the so-called modellistic approach. This concept assumes that human imagination is involved in the production of scientific knowledge and that human fantasy is, next to critical scientific reasoning, an important part in the process of appropriating reality.

For the present work the last two approaches play a role. During all phases of the film, pre-production, production as well as post-production, it is necessary to critically reflect the own view on another culture, which is on this case a modern western view on a traditional, religious society. Hohenberger (1988) identified five realities within a documentary film beginning with the non-filmic reality and ending with the post-filmic reality. The first reality, the non-filmic one, includes all possible pictures of the historic, cultural, religious and politic setting from which a filmmaker then chose his/her own pictures. Hohenberger argues that this selection process is based on the cultural, political and ideological background of the respective filmmaker. The same applies for the level "reality film", in which a large part of the material is discarded during editing and only selected scenes ultimately flow into the end product, the finished film, and, therefore, is a subjective process, which can make the result look quite different. This was particularly interesting for the hydrogeologist in comparison to scientific work, where all data is evaluated equally and objectivity is necessary for good scientific practice. To sum up, that means that (natural) scientists who are new in the field of documentary should understand that an objective representation of reality is not possible. However, coming back to the modellistic approach defined by Oester (2010) the subjective view on the world as well as the esthetic and artistic perception on it, can contribute to an understanding of reality. With this, the camera can be seen not only for visualization purposes but as a scientific tool itself able to generate knowledge.

3.5.2 Intentions of the Filmic Approach

Film has, due to its visual and emotional qualities, the unique opportunity to reach many people who would never read a scientific publication or a project report. Particularly regarding hydrogeology, this is of great importance, since groundwater related research and work has always also a target group or an "affected group" that does not come from the scientific community (Frommen & Ambrus, 2019). The particular intention was to:

1) help increasing the impact of the Jaipur case study on two levels: It would make it easier to transfer the idea to other low-income areas, and it could be used to educate scientists and NGOs about the positive effects of linking social sciences and hydrogeology.

2) create a professional presentation of the project to reach a broad audience. Furthermore, it could be of interest to traditional media and could be easily shared on social media.

3) increase the women's commitment and give them the feeling that they do important work.

4) help the team to evaluate the project and to assess the impact.

3.5.3 Research Design of the Filmic Approach

The design of the films changed several times during the preparation and the implementation phase as the development of the film formats was an iterative process. The reasons for this lie primarily in the project and the uncertain, because new workflows themselves. Moreover, the cooperation was new for both sides (hydrogeologist and filmmaker) regarding the personal as well as the professional parts, which led, among others, to an underestimating of the financial and time resources necessary to produce the films on the scientist's side. The final format consists of two films, one 52-minute long documentary "Pani Check – The Sisterhood of Water" and a 10-minute long educational film "Pani Doctors – Join the Sisterhood of Water" (Appendix A15). Furthermore, a short version (2-3 minutes) of the documentary is planned, but not produced yet.

The research design is mainly made up of three visits of the filmmaker at the project side. The first visit took place at the beginning of the field work in Jaipur in November 2016, the second in the middle in July 2017 and the third 9 months after the field work was finished in October 2018. Each of the visits last between 15-20 days. With this design, it was possible to depict the progress of the project by staying in the frame of the limited financial resources.

Important to highlight is that the film project was not a classical documentary, e.g. a film about the hydrogeologist by the filmmaker, but a close cooperation between the hydrogeologist and the filmmaker where the hydrogeologist was, of course, part of the film itself but also part of the producer team. The films evolved through a constant exchange between the hydrogeologist and the filmmaker regarding the format as well as the content.

Documentary

Main goals of the documentary are the filmic evaluation of the project, to motivate the local women assistants to participate in the project and to make a following transferability possible. The target groups are local NGOs, local community groups as well as the science community. This divers target group was another aspect why the formats of the films changed during the project as it was a challenge for the filmmaker to create a film who works for illiterate Indian women but also for scientists with various cultural and professional backgrounds and on different stages of their carrier.

The methods applied by the filmmaker for the documentary were unstructured interviews with all important stakeholders (local women assistants, MHT staff, water supplier, hydrogeologists), participatory observations of the main protagonists (three women assistants), observing and filming the hydrogeological and the participatory work of the hydrogeological team, documenting the water supply system and the wastewater situation of the city, shooting general pictures of the city and, finally, developing and shooting the moderation of the film which was conducted by the scientist.

By the help of the interviews and the participatory observations, it is possible for the filmmaker to survey and analyze the environment of the local women assistants and how they behave within it. Based on this, it is possible to create a portrait of the local women assistants by filmic tools. The interviews should further serve as a possibility for the local women assistants to express their thoughts about the project, it aims, it progresses as well as possible challenges. It is supposed that these will help to evaluate the success of the project from a local perspective. Finally, the sum of all the methods together will help to make the results of the project transferable.

Educational Film

Main goals of the educational film are to generate a support for future similar projects, to be able to transfer the knowledge and experience of this project and to motivate women with similar background to participate in groundwater projects. Here, the target group are mainly Indian women community groups.

This film is a special challenge because the people in India have completely different viewing habits than the people in Europe. The film industry in India is almost exclusively characterized by Bollywood productions that live from music and dance. Furthermore, Indian viewers are used to interpret, to elaborate and to engage with the movie during the screening (Srinivas, 1998; Tirumala, 2009). So the question was how a film should be designed women from low-income areas in India are not only attracted by but are also able to identify with. Therefore, it was necessary to understand the conventions of representation and to apply the codes of language and culture Indians are able to read (Hall, 1997). As this would have been impossible to achieve by cultural outsiders within the given short timeframe the idea developed by the filmmaker was to involve the women in the making of the film and to develop a script together. It was also assumed, that for the project it would be more effective to tell significant parts of the educational film from the perspective of the local women assistants, because at that time they would have already gone through the learning process and, therefore, would know best how to convey the contents to other Indian women. An additional aspect would be that in this way the women would learn something new, that is about film making, and they would get even more motivation to share their knowledge. Finally, also further learning effects for the hydrogeologists as well as the filmmaker were expected.

3.5.4 Discussion and Conclusion

In this chapter the outcome of the films itself as well as of the transdisciplinary cooperation between the hydrogeologist and the filmmaker will be summarized, discussed and assessed.

Evaluation of the Filmic Approach

The intention of the documentary and the educational short film was to facilitate a transfer of the results and the idea to other low-income areas as well as using it to educate scientists and NGOs about the positive effects of linking social sciences and hydrogeology, to reach a broad audience consisting of different target groups, to increase the motivation of the local women assistants to participate in the project, and, at last, to enable another perspective on the project which would allow an additional evaluation of it.

Regarding the first two goals, the communication and distribution of the results, only preliminary findings can be discussed. The premiere in India itself, where an evaluation part is planned, and the following distribution of the films via MHT and other Indian organizations, is yet to come. However, with two screenings in Germany, a private test screening and the official premiere in Berlin in May 2019, a first conclusion can already be drawn. With a highly interdisciplinary audience consisting of hydrogeologists, various social scientists, film professionals, Indians and India connoisseurs, as well as persons who have no points of contact with any of the areas the films received an almost consistently positive feedback. In addition, especially the test screening was followed by long and intensive discussions not only regarding water issues, but also regarding a wide range of topics from camera settings over women's rights in India to the critical reflection of Western organizations working in developing and emerging countries. To show the impact the film had on people with different backgrounds, two quotes which aroused after the official premiere were chosen to be presented here:

> "Es war ein tolles und abwechslungsreiches Programm und jeder einzelne Teil war sehr interessant und packend [...] Ich finde es richtig gut, dass du in deiner Arbeit diesen Schwerpunkt auf Kommunikation gelegt hast, nicht nur mit den Frauen in Indien, sondern auch mit uns hier […] Du hast uns dadurch einen ehrlichen Einblick in die Entwicklung des Forschungsprojekts aber auch in deine persönliche Entwicklung im Verlauf des Projekts gegeben […] Ich glaube, dass viele WissenschaftlerInnen in der Feldforschung auf große Herausforderungen stoßen, dass sie schwere Entscheidungen treffen müssen und sich Fehler eingestehen. Das gehört alles dazu aber dennoch sprechen sehr wenige darüber und haben vielleicht Angst davor. Deine Geschichte macht Mut, selbst auch die eigene Geschichte so anzunehmen wie sie ist und sie damit zum Guten zu verwenden."
>
> *"It was a great and varied program and every single part was very interesting and gripping [...] I think it's really good that you put this emphasis on communication in your work not only with the women in India, but also with us here […] You gave us an honest insight into the development of the research project but also into your personal development in the course of the project [...] I believe that many scientists in field research face great challenges, that they have to make difficult decisions and admit mistakes. That's all part of it, but very few talk about it and are perhaps afraid of it. Your story encourages to accept your own story as it is and to use it for good."*
>
> (Lebek, 2019)

Karen Lebek is a doctoral researcher at the interdisciplinary IRI THESys Institute at Humboldt University Berlin with a background in geo-ecology. Her feedback points out on the one hand that the results shown within the film have a wide applicability inside the science community and that they will be helpful for other scientists in similar situations. On the other hand, she highlights the importance of communication not only among scientists but also with the society.

Fabian Hecht has a background in hydrogeology and works for the Senate of Berlin where he is responsible for the communication with citizens who face problems with the Berlin water works (Round Table Groundwater).

> „…das war ein sehr interessanter Abend gestern! Eine Frage: was habt ihr außer der Tour in Indien mit den Filmen vor? Genauer: wird es die auf DVD zu kaufen, zu

> leihen geben um sie z.B. an Hochschulen, Schulen, Wassernetzwerkern etc. zeigen zu können?“
>
> *„…that was a very interesting evening last night! A question: what are you going to do besides the tour in India with the movies? More precisely: will there be DVDs to buy, to rent and to show at universities, schools, water networks, etc.? “*
>
> (Hecht, 2019)

Hechts feedback indicates that there is a huge need for and interest on formats like the films with which you can reach a wide range of people to emphasize the importance of including social science aspects into groundwater research and work not only in developing countries but also in industrialized countries like Germany.

The third goal, to increase the motivation of the participating women, was achieved as well. The widespread interest in movies, filming and in being filmed in India generates a general positive atmosphere (Fig. 63). All protagonists were open to participate in the films and felt appreciated for their meanings and thoughts about the project. This was also due to the layout of the documentary with in-depth interviews, where the women had time to explain in detail their current and past live, their hopes and thoughts concerning the project but also concerning their general situation. Furthermore, the fact that the filmmaker was coming a second and a third time, as was told at the beginning, increased the trust into the whole project.

Fig. 63: The filmmaker during a shooting in July 2017 in Jaipur. The camera attracts a high number of people.

In general, the filmic approach has influenced the project itself and generated knowledge which otherwise would not have been detected. Therefore, it definitely enabled a new way of evaluation of the project. It was also interesting to see that the women with whom the hydrogeologist worked, but also NGO employees or representatives of authorities, reacted quite differently to the filmmaker than to the hydrogeologist. There were various reasons for this. Regarding the women, it was because they had built up a greater relationship of trust with the filmmaker. This led to the result that the relationship the filmmaker had with them was close to friendship whereas the relationship between the hydrogeologist and them were on a much more professional level. This can be explained by the personality of the filmmaker herself, but also by the fact that she was an outsider who neither represented the project nor came from science. Thus, the barrier to talk with her openly about doubts and wishes regarding the project was much smaller, which gave us a more differentiated picture of the opinions and moods of the people involved in the project. Conversely, concerning the contact with the authorities the presence of a camera probably played a greater role, which apparently gave our appearance more importance. The camera acted as a door opener for us, for example at the public water supplier.

Coming back to the interviews, it was a rather remarkable insight into the expectations the local women assistants had on the project at the beginning. Zeenat Begum, the woman from NKT, said at the very first interview with the filmmaker:

> "It's salty water, It's not pure. But we do not know how will she [Theresa Frommen] purify it. How and from where will she make it sweet? We don't know. But I know that Theresa is working on this."
>
> (Ambrus, 2019)

This statement only came to light during the transcription of the interviews at a later stage. At the time in the very beginning of the transdisciplinary cooperation, the film maker was not aware of the significance of this statement. This shows a challenge of transdisciplinary cooperation as a mutual understanding of the respective field of work takes time and a lot of communication. However, the statement induced at the hydrogeologist a critical reflection about her communication with MHT and the local woman assistants regarding the project aims (see 3.7).

Another finding from the documentary, coming completely unexpected, was the visualization of the development in the relationship with the local assistants as well as of the behavior of them. In one of the scenes at the beginning of the documentary the first groundwater sampling with the women community leader from KK participating, is shown. The body language of both, the hydrogeologist as well as the women leader is reserved and uncertain. In contrast to that, the pictures shot at the second visit of the filmmaker eight months later show the women leader taking a groundwater sample by herself, completely naturally and self-evident. That is a visible development which otherwise would not be captured.

The most haunting evidence how the filmic approach changed the project and enabled a completely different evaluation of the participatory work is the history of the young local woman assistant in NKT, whose family received real threats from the village community, after working on the hydrogeological project. What the hydrogeologist did not know when she started working with her, that the young woman had left her husband and returned to her family. Since then she was a complete outsider within the Muslim community. The natural scientist's work thus had a direct influence on the social structure of the community, which was only fully reflected and came to light through the interviews with the filmmaker.

Evaluation of the Transdisciplinary Cooperation

Several indicators can be used to evaluate the cooperation between hydrogeology and filmmaking: the main product, the finished films; the dissemination and communication of the transdisciplinary cooperation; the content of the films; and possible future prospects.

The main products, the first indicator is easy to evaluate as the completed films exists. Somewhat more difficult is to assess the quality and significance of the films and whether they are able to reach the target audience. However, as discussed in the section before, the films already got a first positive feedback

The transdisciplinary cooperation was the main theme at various presentations on national (FH-DGG 2018 in Bochum, HIP Workshop 2019 in Berlin) and international conferences (IAH 2018 in Korea, EGU 2019 in Vienna). This aimed at establishing a far-reaching and diverse representation at scientific events. During these talks, it became clear that, in particular from the hydrogeological but also from the social-scientific side, e.g. South Asian Studies, a huge interest in the way the cooperation was constructed, what experiences were done so far and, of course, on the final movies exists.

Another objective was to identify the perspectives of the local population, to depict them in the film and, at best, to better understand them and thus optimize the project result. As can be seen in the documentary "Pani Check - The Sisterhood of Water", the first two steps, the recognition and presentation, were very successful and the close and personal accompaniment of the protagonists by the filmmaker led to a better, more differentiated and more honest project result. However, a complete understanding was not possible, as the local perspectives are very diverse and culturally too different from the European ones to penetrate the backgrounds of certain behaviors, desires and conflicts. Here, an interdisciplinarity of the project team would have been necessary not only at the Indian level (Chapter 3.2.1), but also at the local level for Jaipur. Nevertheless, the hydrogeologist got an unusual insight into the life reality of the study participants, which trained and changed her view for the practical suitability of her own scientific work. This process becomes clear in the film "Pani Check - The Sisterhood of Water". Finally, the content of the films shows that this transdisciplinary cooperation can lead to insights that would otherwise not have been possible. Being aware of the great discrepancy between the planned and communicated project goals on the one hand and the expectations of the people involved on the other hand can help to adapt the communication strategy and prevent conflicts in the further course of the project.

The final indicator of successful cooperation is the intention of the filmmaker and the hydrogeologist to continue working together in the future and to develop the project further. A film tour through 4-5 Indian cities is planned, including Jaipur of course, accompanied by workshops on the subject of groundwater. In addition to these team-related perspectives for the future, there is also a great deal of interest in this transdisciplinary cooperation on a broader scientific level, which can be seen, for example, in the large attendance at the film premiere, which was framed by lectures and discussions on the subject of socio-hydrogeology and inter- and transdisciplinary work. Film serves as a medium to bring people from different backgrounds together. The participation of numerous students and employees from different faculties is, on the one hand, a sign that a fundamental rethinking is already taking place and, on the other hand, it offers us the opportunity to convey the importance of interdisciplinary research and work to the students in particular.

During the three-year cooperation, four factors have been identified which were crucial to successfully work in a transdisciplinary project.

1) The key factor is that all those who are involved have a fundamental openness to other scientific and non-scientific ways of thinking and working. Prior studies have noted the importance of a willingness to break new ground in conceptual and methodological terms (Bergmann et al., 2005).

2) In addition to the motivation to break new ground, honest communication with one another is another important aspect. One advantage of the cooperation was the small group of participants with only two main characters, the hydrogeologist and the filmmaker, which made a prompt and direct communication possible and which could counter right from the beginning any misunderstandings or conflicts that might arise.

3) The third central factor was the mutual appreciation, not only in the way of communication, but also with regard how to deal with each other. Essential for this is the awareness that the different competences are a personal and professional enrichment and increase the resources the project has at its disposal.

4) The last success factor was the objective and goal-oriented work. The basic question of the work has always been "What is it that we want to achieve and which of our complementary professional skills and personal qualities are best suited to achieve this goal?" There are two reasons for this. Firstly, this transdisciplinary cooperation came about as a result of the recognized need to break new ground in order to achieve the goal, and secondly, it was neither the filmmaker's nor the hydrogeologist's motivation to advance her own career through this project (Frommen & Ambrus, 2019).

3.6 Water and Conflicts[15]

Conflicts about water occur at multiple levels and between different actors. The most dominant conflict, is the situation between the public water supplier and the water users. A huge part of the local population is unwilling to pay for public water supply. This has different reasons. On the one hand, there is little or no confidence in the public sector due to bad experiences in the past and due to the generally strong hierarchization (caste system) of the society. On the other hand, the resource groundwater is considered as a common commodity, which is freely available and, therefore, should be free of costs. As a result, people tend to withdraw water in unlimited quantities and high-income households can afford private wells equipped with strong pumps.

Another problem are the numerous illegal water withdrawals from the water supply network, which represent a management challenge for the water supplier. In addition, the illegal withdrawals often lead to a pressure drop in the pipes, causing higher or more distant households no longer being supplied. However, many households would be unable to meet their daily water needs without the illegal connections, as most of the time, water comes only for about an hour a day. As a result, people choose the path of an additional illegal access and at the same time feel entitled to do so.

A major problem in the peri-urban area is the competition for land and the concomitant competition for groundwater abstraction, as the rights of use of land and groundwater are closely linked (Fröhlich, 2006). Most of Khara Kuaa is residential area, but Nai Ki Thari is characterized by both agricultural and industrial areas. Agricultural and industrial groundwater withdrawals often exceed groundwater recharge. Unsustainable groundwater abstraction results in sinking groundwater levels in the wider area, which can lead to a decrease in the water quality of public wells, less productive wells or even dry wells. Only people who own land and have enough financial resources to install

[15] Frommen (2018)

for example, wells in deeper (possibly less contaminated) aquifers, can thus respond adequately to changes.

The geographical setting of the peri-urban area is related to another level of conflict, which was identified in the context of the project. People in peri-urban Jaipur feel neglected compared to the people living in the city center. As mentioned earlier, infrastructure development is slower than urbanization. In addition, the inhabitants of peri-urban areas have few opportunities to influence the distribution of water, as often they are represented in neither politically nor economically important positions. This results in well-supplied inner-city areas and heavily underserved outlying areas, not only in terms of water (Howard, 2014).

A completely different level of conflicts arises around religion. Here, it is much more difficult to recognize and understand the conflicts as an outsider. For this reason, only three examples are described in the following, one historical and two current cases. The historical example does not describe a conflict, but shows the extent to which religion and water supply are closely linked. In Khara Kuaa, there is a century-old traditional well, from which water was collected from different sides over fixed rollers with buckets. The various sides served to give each caste its own access to the well, which they were allowed to use exclusively. Today, the well is no longer frequented, as it is dry most of the year and also dirty. The current examples are both related to the (mainly) Muslim study area Nai Ki Thari. During an interview with inhabitants of Nai Ki Thari, it turned out that Muslims were not allowed to use a certain well, a hand pump in this case, as it would make the well impure for the Hindu population. The third example is of a general nature: the perception of Muslims in Nai Ki Thari but also in the whole study area is, that their religion is the reason why the public water supply does not reach them.

3.6.1 Observed Conflict Management

In general, two levels of conflict management can be identified. At an informal level, within a local and/or religious community, conflicts are approached by social condemnation and pressure. As a consequence, it depends mainly on the respective social, and thus mostly religious, but sometimes also financial, status of a person -whereby women are in general in a lower position- how far someone can go before he or she get problems with the rest of the community. For example, during the field work in Nai Ki Thari, I too, as a foreign, seemingly important person, was used as a lever. A neighbor, with the help of a small pump, were able to take more water from the well pipeline than the rest of the well users. I was then taken to a visit at her house, where other residents rebuked her.

At the official level, water conflicts are dealt with by laws and regulations. For example, there has been a ban on drilling new wells in Jaipur District for some years, unless someone has an exemption. But the problem is that compliance with the law is not controlled.

3.6.2 Causes of Conflicts from a Hydrogeological Point of View

The previous two subchapters described the situation discovered during the field study. Especially from the perspective of hydrogeology, but also through the close cooperation with the NGO MHT, the following causes of conflicts could be identified.

Groundwater is a "hidden" resource. The local population often has misconceptions about groundwater, which, among other things, makes them unaware that this resource is limited and how and where contamination paths into groundwater can occur. Inadequate groundwater quality does not have to be anthropogenic, but may also have geogenic causes. For example, the groundwater in the study areas shows a high salinity, which is largely due to geogenic causes. On the part of the authorities, inadequate and incomplete data on the status of groundwater are one of the reasons why adapted and sustainable groundwater management cannot be developed. Another important problem is the lack of communication between the public water supplier and the water users. There is only little information available for the users on the strategies or the major challenges of providing a reliable water supply. As a result, unrealistic expectations by the local population towards the water supplier arise and an objective consideration of the situation is hindered. Furthermore, conflicts can arise if the focus of the water supply is only, or mainly, on water quantity and not on water quality. If the quality is inadequate, users do not feel well looked after and lose confidence in the public water supply. This, in turn, can lead to more informal solutions making management on the catchment level again much more complicated and difficult. The last cause of conflicts identified is religion. In the Indian society, where religion plays a key role, water problems are also seen from a religious perspective. This has huge potential for conflicts because in this way the root causes of the problems are not identified and addressed. Hence, the situation will not improve, on the contrary, fronts will be hardened.

3.7 Challenges

The project presented many challenges, which were to be expected as it was an unusual and new approach for the hydrogeological team on the one hand and took place abroad and in a highly interdisciplinary team on the other hand. However, all problems of the project can be traced back to three underlying concepts/reasons: communication, understanding and practices. In the following, these reasons will be explained and discussed by giving examples from the field work.

3.7.1 Communication

It is not surprising that the research has shown that the most difficult part of the participatory and interdisciplinary approach can be summarized under the topic of communication. However, the extent to how the insufficient communication had influenced the project was indeed unexpected. There was an awareness of communication barriers and accordingly a preparation took place, but in the end, the barriers were still underestimated. To illustrate how misunderstandings can happen, even before the project start, an example will be given below (Fig. 64).

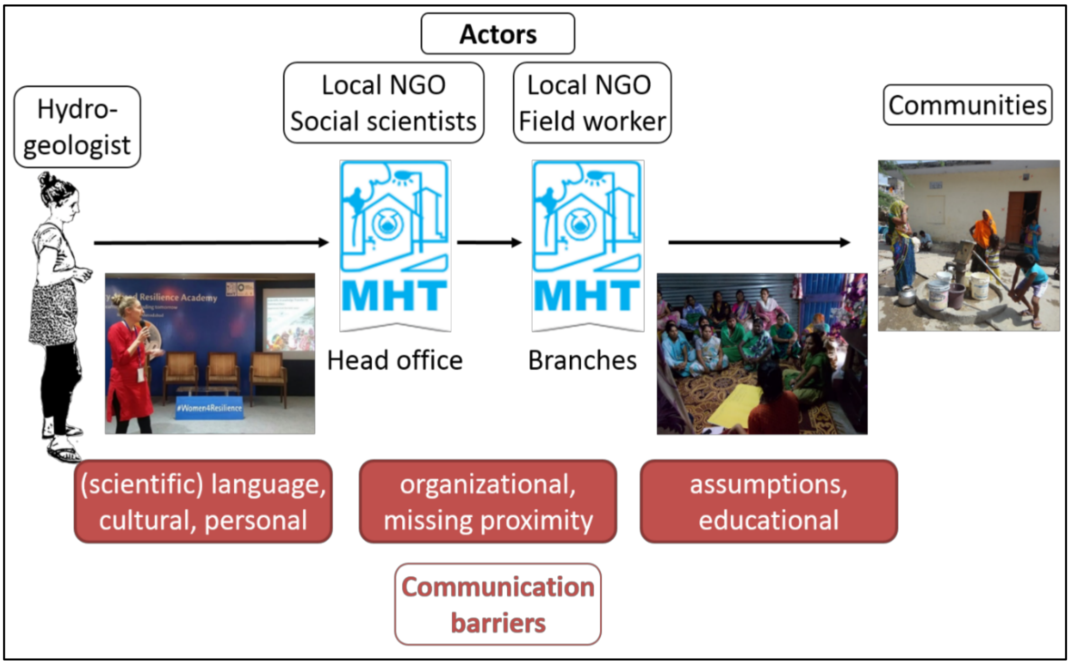


Fig. 64: Communication pathway showing different communication barriers between stakeholders and how misunderstandings can happen even before the project starts officially.

At the beginning of the project, it was explained to MHT (local NGO) by the hydrogeologist what hydrogeology is about and what one can do with it. The whole subject of hydrogeology was new for the mostly social workers and scientists within the head office of MHT. The next step was then by the head office to communicate the planned hydrogeological project to the branch office in Jaipur. MHT's organizational structure is based on a head office with predominantly educated employees and branches in other cities with so-called field-workers. The staff of the Jaipur office then told the women community groups they are working with, about the planned hydrogeological project. These various actors cause communication barriers on different levels. At the first step, next to the more obvious language and cultural barriers also the personal ability to explain a certain topic to outsiders plays a role. The second step is characterized by organizational barriers as there are huge differences between the head and the branch offices in terms of educational background, understanding and commitment. Furthermore, the missing proximity, reducing communication mainly to e-mails and calls, can lead to misunderstandings. During the third step finally, communication barriers are caused on the one hand by the educational background of the local women but on the other hand also by the assumptions the women already have when they come to a meeting with MHT which is about water. As most of them face severe water problems on a daily basis, their expectation on a project about water is that the current situation will be improved in a short-term perspective. In the end, this long communication pathway led to a situation, where, as the project finally starts, the target group -the local women- already had certain expectations to the outcome of the project which did not fit to the project aims (Fig. 65).

Fig. 65: Communication barriers: technical (and foreign) language used by the hydrogeologist and assumptions the women already have in mind.

3.7.2 Understanding

The second main challenge is the understanding common people have of groundwater. During the water workshops the women were asked to draw how they imagine the underground including groundwater. Many women have drawn a groundwater lake or river (Chapter 3.3.1). Their main imagination is an enormous reservoir of water in the underground. It is, therefore, important to keep in mind when working in interdisciplinary or participatory projects that groundwater is a hidden resource. One of the problems arising from this wrong perception is that people expect that hydrogeologist as a so-called "water expert" can solve *all* groundwater problems. This can be illustrated briefly by an incident which happened, after some weeks of field work. People from the study area Nai Ki Thari asked why their groundwater is still salty, although the hydrogeological work is going on for some time already.

3.7.3 Practices

The third finding of the study was that different practices are a challenge for the participatory hydrogeological approach. Practices is a term from social sciences indicating what communities or people from a certain culture are used to. In this study, it turned out that the local people as well as the local NGO are not used to the research approach. This means that they are used to fast solutions, not used to research lasting several years. It is understandable that the women want quick solutions because they are suffering from the current situation. However, this may have nothing to do with a long-term solution. This is certainly true in the case of the suggestions a so-called water expert invited by MHT has given for Nai Ki Thari. After spending about 1 h in the field, he suggested to drill three new bore wells in the community to solve the water problems. But there are already more than 70 bore wells in this area causing decreasing water tables. Additional bore wells would enhance this problem and may show reduced yield or even run dry in the long-term. Furthermore, the groundwater in this area shows extreme high electrical conductivities up to 6200 µS/cm (see Chapter 2.3). However, the local women as well as MHT did not question this suggestion but were happy about it. This shows that they are used to this kind of approach and that, therefore, a yearlong research project is out of their area of experience.

PART 4 Solutions

4.1 Water Management Solutions for Peri-Urban Low-Income Communities in Semi-Arid Climates in India

The basic challenge in this project was the demand for instant improvement by the local population on the one side and the time consuming research work necessary to establish sustainable solutions on the other side. Therefore, it was decided to develop different solution strategies: short- and long-term solutions. Most of the proposed measures are also applicable in other low-income peri-urban areas of India, as many problems are similar and as the two chosen study areas cover a wide range of hydrogeological, social, and infrastructural conditions.

4.1.1 Short-Term Solutions

Khara Kuaa

The investigations on water management have shown that the main part (about two third) of the water supply in Khara Kuaa is provided by the public water lines of PHED with primarily surface water from Bisalpur dam (Chapter 2.4.4). However, this supply is not sufficient. Problems arise through the insufficient pressure on the water line leading to the connection of motor pumps to it through wealthier people and small factories, to illegal connections by many households and, finally, to a lack of water in the pipelines at the upper areas of Khara Kuaa. Furthermore, the water quality does not meet the requirements given by the Indian Standard for Drinking Water and shows great variations with time (see Appendix A16) indicating that there is definitely a significantly mixing of surface water with groundwater at Amer pump house. This shows that the amount of surface water which is available cannot meet the current demand. It will take several years until the supply situation by PHED will improve as the construction of the second pipeline coming from Bisalpur is still in the planning phase (as on July 2017) (Chapter 2.4.2).

In the meantime, it is suggested to use groundwater as an alternative water source to be more independent in times of water scarcity. However, as was shown with the hydrogeological investigations (Chapter 2.3) problems exist in terms of groundwater quality and quantity. Therefore, following measures should be taken:

1) Establishment of a regular water quality monitoring. If one health-related parameter is above the Indian Drinking Water Standard the hand pump should be marked and advice should be given to the users, e.g. in case of high nitrate concentrations that this water is harmful for babies;
2) Cleaning and desilting of the two dug wells by skilled staff and installment of a mesh, which avoids, next to garbage thrown into the well, also pigeons nesting inside it;
3) Construction of groundwater protection zones around hand pumps and dug wells. Protection should be also constructed around broken wells or they should be closed completely;
4) In case of non-operational hand pumps, the responsible authority, in this case PHED, should be informed and the repair of them should be demanded;
5) Establishment of regular water level monitoring to monitor if the water level rises again after monsoon and which hand pumps do not run dry in summer.

Point 1, 4 and 5 could be conducted by the trained local women assistants (see Chapter 3.4). With the new knowledge and capacity which they have gained through this project, they are able to monitor the quality and quantity of groundwater at a fundamental level.

Regarding the groundwater protection zones (Point 3) following issues have to be considered. The fence/wall should stop animals from entering the area close to the well to prevent contamination by them, e.g. by their feces. It is very important to guarantee an outlet for the water from the fenced/walled area in order to prevent water logging at the well surrounding. Furthermore, there must be a gate for people who wants to fetch water from the well and there must be enough space inside the fence/wall for people to be able to fetch water. The fence/wall should be constructed in a manner that the fetching place stays visible from outside in order to prevent people from using the fenced/walled area as a place for open defecation. In addition, the construction should be cost efficient and to prevent vandalism, the material chosen should not be able to break down or to take away easily. To increase the acceptance, there should be a sign outside the fence/wall to explain the reason for it.

After discussion with the community leader in Khara Kuaa and Nai Ki Thari following construction is suggested by them. The material used should be bricks and cement, which is both locally available. At the top of the wall, pieces of broken glass should be attached to prevent animals from climbing it. The women recommended a height of 4 feet (130 cm) and a width of 8 inches (20 cm). They further promote a radius with a minimum of 3 feet (1 m), if possible, however, this may dependent on side specific conditions.

Nai Ki Thari

The water supply of Nai Ki Thari depends nearly completely on groundwater because the area is not yet connected to public water supply via water lines (Chapter 2.4.4). High EC values and declining water tables make the resource unenjoyable and unreliable (Chapter 2.3). Therefore, two third of the population in Nai Ki Thari rely on costly private tanker. The connection to public water supply with surface water will take at a minimum several years. The absence of an official recognition by the municipality in Nai Ki Thari create barriers to legal rights and basic services such as water, sanitation and security of tenure. These problems are faced by about half of Indian slums who are "non-notified" (Subbaraman et al., 2012). However, the new Master Plan by JDA which envisages the year 2025 (JDA - Jaipur Development Authority, 2011a) incorporates an expansion of the current city area. Reclassification as urban area is an important instrument to enable former rural areas in the peri-urban zone to demand for public services. This will make it much easier for the local population to demand a water supply infrastructure and connection to a sewage system.

Until then, following short-term implementations are recommended to prevent a further contamination of the groundwater and a decrease in water tables:

1) Construction of groundwater protection zones around hand pumps, dug wells and bore wells as described in the paragraph above. In Nai Ki Thari, there are many private bore wells. It is suggested to start with public bore wells used by many people.

2) Construction of sewage channels. The missing sewerage coverage leads to widespread water logging and infiltration of water of poor quality. Avoiding contamination by household sewage is a necessary step to protect the groundwater resource many people rely on.

3) Regularly cleaning of septic tanks. The main toilet connection type are septic tanks. Leaky and overflowing septic tanks are a high risk for groundwater quality.

4) Minimizing the construction of new bore wells. The stage of groundwater development is over-exploited and shallow wells regularly run dry. To counteract this development, new wells should not be constructed or at least drastically reduced.

But even if all these measures are taken, the groundwater would still be salty. However, the local population needs water of a sufficient quality. Therefore, following short-term solution is proposed:

5) Bore well connected to a community RO System. Instead of purchasing costly water by private water companies, who are also using only the local groundwater and treat it by RO, it is recommended to establish a community-based system which is under the control of the citizen.

Point 1 and 5 could be places for the involvement of the local women assistants. In regard to the groundwater protection zones they already gave useful hints for the concrete implementation (see previous paragraph). For the community RO system, they could be the manager and regularly check the water quality. RO systems do also have negative aspects as they need electricity, produce a significant amount of highly mineralized wastewater (Ratio about 3:1) and require a costly initial investment. However, pure filtration techniques like slow sand filtration units, who are cheaper and do not waste water, would not remove the high number of dissolved solids. Another low-cost option for demineralization would be solar distillation systems. Main disadvantages which arise with solar stills are the low yield on purified water they produce (1-5 $L/m^2/day$) and its dependence on weather condition which would be a problem during monsoon season. Furthermore, the population of Nai Ki Thari is not used to solar stills but is familiar with treatment via RO. This plays a role in acceptance of a new system and in willingness to invest into and take care of it. This study has shown that people would anyhow buy a household RO system as soon as they could afford it. Therefore, it is suggested to invest into a community-scale RO unit which would reduce the costs per household and enable a regular monitoring of the purified water.

4.1.2 Long-Term Solutions

Even if in the future water demand will be completely covered by surface water supplied through water pipes, it is important to protect and understand the groundwater resource in order to have an alternative water source for times when the official supply does not work, which is likely to occur according to the results of this study.

Khara Kuaa

For Khara Kuaa it is required to identify the exact origins of the high nitrate values in the groundwater and their respective contribution to the total nitrate concentration to be able to implement an adapted prevention and treatment strategy. Another significant aspect to consider is the unreliability of the groundwater resource during summer time. As was shown in Chapter 2.3.4, the hard rock aquifer does not have a high storage capacity which leads to fast declining water tables during the dry season. To increase the reliability of the resource, it is suggested to investigate the possibility of an artificial recharge scheme up-gradient of Khara Kuaa, where uninhabited hillslopes of fractured/weathered quartzite and talus deposits can be found. The current study found that the historical artificial reservoirs located in the neighboring valley at Amer Fort not only lead to stable water tables over the course of the year, but also to an increase in groundwater quality through dilution processes (Chapters 2.3 and 2.4). Further studies need to be carried out in order to investigate the terrain conditions, e.g. size and characteristics of the catchment area, the hydrogeology, e.g. infiltration capacity of the soil, the climatic conditions, e.g. long-term average annual rainfall and its intensity. Then, the best type of the recharge structure has to be chosen. Based on preliminary investigations, a percolation tank seems to be an appropriate measure for this site. A percolation tank is an artificially created surface water body that stops surface run-off so that it percolates into the underground and recharges the aquifer. Barriers in implementation could be the high initial investment costs, the land requirement and the complexity of the construction which requires technical expertise. However, it would be a long-term solution which is already successfully applied in hard rock areas in India (Smet & van Wijk, 2002). Another advantage of this method is the reduction in storm water run-off, which causes regularly damage in Khara Kuaa during monsoon season as reported by the local women. In addition, the operation and maintenance could be community-based, generating an income possibility.

However, the demand for a cheaper, fast and visible measure was high on NGO and community side. Therefore, the suggestion of an artificial recharge structure resulted in a rain water harvesting and well recharge system at a traditional dug well in the lower area of Khara Kuaa.

A further suggestion is to implement a constructed wetland (CW) at the *taalaab* downstream of Khara Kuaa. Constructed wetlands are "engineered systems, designed and constructed to utilize the natural functions of wetland vegetation, soils and their microbial populations to treat contaminants in surface water, groundwater or waste streams" (Mueller et al., 2003). CWs are decentralized waste water treatment options which requires a primary treatment step such as grease traps at HH level and sedimentation tanks. For treatment of greywater, domestic or municipal waste water a substrate of coarse sand is used. The treatment process is based on biological and physical processes such as adsorption, precipitation, filtration, nitrification and decomposition. The best type would be subsurface flow CW. They are favored over surface flow CW as they avoid mosquito problems. Horizontal flow beds are favored over vertical flow beds because less technology, maintenance and energy is required for this type (Hoffmann et al., 2011). Further research would be necessary to study aspects of technical feasibility, e.g. land availability, expected hydraulic and organic load, design aspects, local plants and reuse options, of social acceptance, e.g. willingness to provide land for construction and taking over responsibility for maintenance, and of the economic feasibility, e.g. planning, construction and maintenance costs. Barriers in implementation could be high investment costs, necessary maintenance and land limitations. Alternatively, a conventional STP could be installed. Even if the sewage treatment will not directly benefit Khara Kuaa, it would be to the advantage of the local groundwater resource and ecosystem as well as to the groundwater users down-gradient of the *taalaab*.

Nai Ki Thari

The situation in Nai Ki Thari is worse than in Khara Kuaa. The groundwater has higher EC values and the geomorphology does not provide the same opportunities as at the hill side in Khara Kuaa. In the long-term, the water supply by PHED (with surface water from Bisalpur reservoir) is the only solution. To meet the demand, the surface water could be mixed with local groundwater, however, by doing so, the quality has to be checked regularly in order to adapt mixing ratios. This is currently not the case, as the results from the participatory water testing of public water supply samples in Khara Kuaa have proved (Chapter 3.4.2, Appendix 16). In addition, connecting any household with a water meter along with a fair pricing system could get people to save water, thus helping to meet the demands of all users.

To avoid the widespread water logging, the *nallah* flowing through Nai Ki Thari could be reactivated to drain the area. Currently, the *nallah* is partly used as solid waste disposal site. Together with sewer lines and a CW, as described in the paragraphs above, this could enhance the health conditions in the area and prevent further groundwater contamination by infiltrating grey water. The advantage in Nai Ki Thari as opposed to Khara Kuaa, is the available space as it is not yet as densely urbanized as the area around Khara Kuaa. A preferable location for a CW would be in the southeast of Nai Ki Thari. On the one hand, the natural gradient would lead the grey water there and on the other hand there is enough barren land.

This study has found that generally it is of utmost importance to protect the recharge areas and the areas with still pristine groundwater in the peri-urban space. Furthermore, for NGO projects working in such areas it is significant to know the official plans for the respective area. Otherwise, a lot of effort can be wasted as some solutions are not possible due to the regulatory situation.

City Level

India's and Jaipur's authorities do know about the numerous problems and they do recommend a wide range of measures, e.g. mandatory provision of rain water harvesting in plots more than 300 m² area, recharging groundwater with treated wastewater or implementation of modern agriculture management techniques (CGWB, 2013; CPCB - Central Pollution Control Board, 2009; JDA - Jaipur Development Authority, 2011a, 2011b). Especially, the JDA Master Plan lists many measures in detail which should be followed to reach a sustainable development of Jaipur city in terms of social, environmental and economic aspects (JDA - Jaipur Development Authority, 2011a). However, Jaipur city was not the focus of this study and therefore, it will not be discussed here in detail as it would be mainly a repetition of already well-known facts. Rather, some thoughts on the general perspective on peri-urban low-income communities within a city framework will be given.

The peri-urban space should get more attention in a sense that it should be seen as a chance for innovative urban planning which is inclusive and participatory by giving the local population real power in decision-making (see Chapter 1.3.3). In contrast to densely populated inner city centers the peri-urban space offers more opportunities for sustainable transition. That does not apply for all areas as some of the peri-urban zones may already be densely inhabited or occupied by industry.

The peri-urban zone should be seen as a precious ecosystem which fulfills important services the city relies on, e.g. food production. In the surrounding of Nai Ki Thari many small-scale farmers produce food which they deliver on a daily or weekly basis to the city. At the same time, the peri-urban zone of Jaipur is used as a dustbin. Untreated wastewater is led out of the city to wetlands located between Khara Kuaa and Nai Ki Thari (Chapter 2.3.3) and solid waste is dumped at a huge landfill (~12 hectares) 2 km southwest of Nai Ki Thari directly next to the river bed of the easterly tributary of Kanota dam (Chapter 2.1.1).

The needs of the poor population in peri-urban communities should be known and taken seriously. A lack of communication between citizen and responsible authorities lead to misunderstandings, mistrust and conflicts. One incident illustrates this point clearly. During interviews with PHED officials in Amer they complained about the numerous illegal connections to the water lines which represent a management challenge for the water supplier. However, at interviews with the local women they argued that many households would be unable to meet their daily water needs without the illegal connections, as most of the time, water comes only for about an hour a day. As a result, they choose the path of an additional illegal access and at the same time feel entitled to do so.

4.2 Concluding Remarks

The aim of the present research was to examine how participatory groundwater management in peri-urban low-income communities in India can be established. In the following paragraphs, this question will be answered by first referring back to the specific questions stated in Chapter 1.2.2 followed by a discussion of the limitations of the study. Finally, an outlook is given.

4.2.1 Knowledge Transfer within Participatory Projects

The set of questions was concerned with knowledge transfer, which is a significant part of the participatory approach.

The study showed that the chosen content of the water workshops – hydrological cycle, basics about groundwater and related quality and quality issues – were suitable for achieving a basic understanding of groundwater among the participants (Chapter 3.3, Appendix 18). It enabled the local women assistants, together with the knowledge of groundwater mapping and sampling gained during the active involvement part (Chapter 3.4), to investigate their groundwater resource and make a simple assessment of it. However, if this knowledge is enough so that the women are able to develop adapted solution strategies could not be studied during this work due to time constraints. Nevertheless, the local women assistant of Khara Kuaa did take actively part in the planning and construction of the RWH and well recharge system which was implement as a result of this project (Chapter 4.1.2).

One unanticipated finding was that the local women assistants were capable to conduct the water mapping and testing after a well-founded introduction independently and that they showed a good understanding of hydrogeological principles, especially the local woman assistant of Khara Kuaa. During the preparations for the educational short movie, she came up with a lot of ideas how to display her learnings of the last two years in a clear and vivid way. Overall, these results indicate that more technical knowledge can be transferred to non-experts as one may expect.

The way how knowledge is transferred influences the outcome significantly. Using interactive and demonstrative tools were central when giving the workshops. They helped to transfer the knowledge and, at the same time, kept the motivation and concentration of the participants at a high level. This was important, as most of the participants were not used to concentrate for a long time (Chapter 3.3). The way how the outcomes of the projects are transferred and upscaled, is important for a long-term impact. Therefore, a media portfolio consisting of various formats and adapted to the target group of local NGOs and, in large parts, uneducated poor women were developed. Components of this are the two films (Chapter 3.5), the training manual (Chapter 3.3, 3.4; Appendix 18), the physical groundwater model (Chapter 3.3.2, Appendix 17) and the water workshops. Except for the films, all other materials were already handed over to MHT.

These results add to the expanding field of participatory and socio-hydrogeological research in groundwater management and they show that this approach can contribute to raising awareness of groundwater among local population and NGOs working in the field of water management.

4.2.2 Limitations of the Study

While this study showed that it is definitely possible to teach non-experts how to map their area, to take a water sample by themselves and to make a first basic assessment of the groundwater situation of their area, the concrete outcomes in terms of an improvement of the current situation were not satisfying. The main challenge in forming the developed solution strategies into real implementations were the numerous barriers on official side, e.g. municipal institutions, water supplier. It is unfortunate that the study did not include a detailed stakeholder analysis. Furthermore, a crucial lack of the project was that the branch office of MHT in Jaipur is not as strong and not as connected within the city as the head office in Ahmedabad. However, a strong local partner is necessary when it comes to implementation of measures which often require the cooperation with public authorities. The lack of visible implementations led to a demotivation among the local women assistants and to a decrease in acceptance of the hydrogeological work by the wider community. Therefore, it is recommended for future similar projects, even if it is a research project, to always have a strong focus on implementation.

Further issues that were not adequately addressed in this study, is the existing traditional knowledge and practice in regard to water management. In future projects, it would be advisable to focus on these aspects and to establish a knowledge exchange rather than a knowledge transfer.

4.2.3 Outlook

In August 2017, the MHT office of Jaipur asked for a workshop for the staff members on how to use the water testing kit. Instead of doing it by herself, the hydrogeologist asked the two local women assistants of Khara Kuaa, if they would like to do this. At that time, they worked for approximately nine months within the participatory project. They agreed and as a result, they were given a sound workshop to people who normally teach them (Fig. 66).

Fig. 66: The two local assistants of Khara Kuaa (second and third person from the left) teach the staff members of MHT Jaipur how to take a water sample with the water testing kit in a correct way and how to fill out the sampling sheet with all necessary information. August 2017, Jaipur.

The role of socio-hydrogeology within hydrogeological research and work is likely to increase in future and it will not only be of great importance in developing countries but also in Europe. In 2019, at an international geology conference, a French hydrogeologist was given a talk about the planned construction of drinking water production wells outside a big city in France, where the executing institution is facing severe problems with a citizen action group protesting heavily against these wells. This is only one example of many, where a missing communication and a missing participation of the society led to huge problems. Participatory approaches are neither restricted to developing countries nor to the specific approach presented in this study. On this background, further research could focus on developing a methods catalogue of socio-hydrogeology which can be used by hydrogeologists in order to 1) understand the people they are working with or for, 2) to be able to communicate with them and 3) to include them and their perspectives into groundwater research and work. The methods catalogue could be developed by collecting and categorizing, in a first step, the methods already established in related disciplines and approaches like socio-hydrology and IWRM (see Chapter 1.3.3). In a second step, all currently available information on socio-hydrogeology projects, with a focus on the methods used and their success or failure could be collected. The third step would then be the comparison of the methods and, based on this, the development of a summary of useful methods which can be applied in groundwater-related work. Additionally, the education of hydrogeologists, which is often based purely on natural sciences, could be adapted. A lecture series including standard methods in social sciences, communication strategies and examples from case studies would enable future hydrogeologists to look on water problems in a holistic way.

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Appendix

Eidesstattliche Erklärung

Ich erkläre hiermit, dass ich diese Dissertation selbstständig ohne Hilfe Dritter und ohne Benutzung anderer als der angegebenen Quellen und Hilfsmittel verfasst habe. Alle den benutzten Quellen wörtlich oder sinngemäß entnommenen Stellen sind als solche einzeln kenntlich gemacht.

Diese Arbeit ist bislang keiner anderen Prüfungsbehörde vorgelegt worden und auch nicht veröffentlicht worden.

Ich bin mir bewusst, dass eine falsche Erklärung rechtliche Folgen haben wird.

Berlin, den 01.02.2021, Theresa Frommen

Ort, Datum, Name

A 1 Details of the field tests.

Parameter	Unit	Method	Measuring range	Error	Test number (Merck)
HCO_3^-	mmol/L	titrimetric with titration pipette	0.1 - 10	±0.2	111109
NH_4^+	mg/L	colorimetric with color-disk comparator	0.2 - 8.0	semiquantitatively	114750
	mg/L	colorimetric with color-card comparator	0.025 - 0.4	semiquantitatively	114428
NO_2^-	mg/L	colorimetric with color card and sliding comparator	0.025 - 0.5	semiquantitatively	108025
NO_3^-	mg/L	colorimetric with color card and sliding comparator	10 - 150	semiquantitatively	111170
	mg/L	colorimetric with test strips	10 - 500	semiquantitatively	110020
S_2^-	mg/L	colorimetric with color card and comparator block	0.02 – 0.025	semiquantitatively	114416

A2 Hydrochemical Results.

Well ID	Sub-group	Date	T [°C]	EC [µS/cm]	pH	ORP [mV]	O2 [mg/l]	NO2 [mg/l]	NH4 [mg/l]	Na [mg/l]	K [mg/l]	Ca [mg/l]	Mg [mg/l]	NO3 [mg/l]	SO4 [mg/l]	Cl [mg/l]	HCO3 [mg/l]	Sr [mg/l]	SiO2 [mg/l]	Br [mg/l]	CBE [%]
KK_HP01	Amer Hillside	11/14/16	28,4	3.400	6,71	120	4,25	0,025	0	150	14,0	345	95	368	156	586	519	1,7	-	0,0	-3,47
KK_HP16	Amer Hillside	11/16/16	28	2.290	6,47	76	1,97	0,6	0,5	90	6,0	270	64	272	92	327	415	1,4	-	0,7	1,07
KK_HP15	Amer Hillside	12/27/16	26,5	3.600	6,72	14	2,14	0,5	0,15	109	15,0	350	107	455	145	580	476	3,6	-	1,0	-4,74
KK_HP04	Amer Hillside	12/27/16	26,4	2.690	6,93	47	2,89	3	0	135	22,0	210	59	125	116	450	519	2,0	-	0,9	-8,13
KK_HP10	Amer Hillside	12/28/16	26,7	4.060	6,82	65	2,41	0,3	2	265	32,0	346	125	325	168	715	744	2,8	-	1,1	-1,49
KK_BW03	Amer Hillside	12/28/16	27,9	3.410	6,51	305	2,28	0	0	122	26,0	325	93	480	128	486	458	2,2	-	0,5	-2,88
KK_HP24	Amer Hillside	4/3/17	27,6	3.980	7	57	27,90	3,75	0	251	8,2	257	137	200	290	740	830	3,5	-	1,0	-10,78
KK_HP04	Amer Hillside	4/4/17	28	2.420	7,27	39	2,51	0,4	0	127	22,0	203	55	141	118	446	506	2,0	-	0,8	-10,50
KK_HP10	Amer Hillside	4/4/17	28	3.800	7,14	69	2,32	0,075	4,5	219	44,0	274	104	337	165	695	793	2,9	-	1,1	-11,55
KK_BW03	Amer Hillside	4/4/17	29,1	3.110	6,45	222	1,68	0	0	73	10,0	160	40	460	130	490	513	1,0	-	0,8	-37,49
KK_HP15	Amer Hillside	4/5/17	28,3	3.120	6,88	43	2,32	6	4,5	105	15,0	306	108	311	152	617	452	3,2	-	1,0	-6,24
KK_HP01	Amer Hillside	4/5/17	28,7	3.420	6,6	60	2,88	0,3	0,05	136	24,0	334	96	425	160	615	537	2,5	-	1,0	-7,76
KK_HP02	Amer Hillside	4/5/17	28,9	2.790	6,83	73	3,07	1	0,025	135	15,0	281	88	366	120	460	500	2,9	-	0,8	-3,60
KK_HP16	Amer Hillside	4/6/17	28,8	2.370	6,49	83	2,21	0,3	0,8	88	7,5	277	67	300	100	360	458	2,0	-	0,6	-2,54
KK_HP01	Amer Hillside	10/11/17	29,3	2.590	7,04	91	3,89	-	-	217	16,0	260	70,8	328	142	478	513	1,5	43,7	0,8	-2,52
KK_HP15	Amer Hillside	10/12/17		3.271	6,93	228	2,12	1,5	0,4	187	9,5	348	107,0	447	159	579	506	2,8	38,8	1,0	-0,87
KK_HP10	Amer Hillside	10/12/17	28,8	3.180	7,11	95	2,24	0,6	3	365	47,6	242	98,1	240	185	593	787	2,1	46,6	1,0	-0,14

Well ID	Sub-group	Date	T [°C]	EC [µS/cm]	pH	ORP [mV]	O2 [mg/l]	NO2 [mg/l]	NH4 [mg/l]	Na [mg/l]	K [mg/l]	Ca [mg/l]	Mg [mg/l]	NO3 [mg/l]	SO4 [mg/l]	Cl [mg/l]	HCO3 [mg/l]	Sr [mg/l]	SiO2 [mg/l]	Br [mg/l]	CBE [%]
KK_HP24	Amer Hillside	10/12/17	28,2	3.310	7,02	114	3,27	0,3	0,025	406	5,4	239	126,0	244	281	607	781	2,5	50,3	0,9	0,48
KK_HP04	Amer Hillside	10/13/17	28,4	2.393	7,07	99	2,84	-	-	207	13,1	216	59,6	149	116	409	513	1,6	32,3	0,7	0,54
KK_BW03	Amer Hillside	10/13/17	28,8	2.710	6,57	270	1,65	0,025	0,025	204	16,9	298	83,8	440	134	448	513	1,8	48,8	0,7	0,24
KK_HP02	Amer Hillside	10/14/17	30,2	2.582	7,11	96	2,48	1,5	0,05	170	9,9	279	82,0	306	122	433	488	2,1	37,1	0,7	1,12
KK_HP16	Amer Hillside	10/14/17	29,2	1.945	6,7	60	2,13	1	0,1	106	4,8	224	55,5	238	86,9	284	397	1,2	54,2	0,5	0,79
KK_HP24	Amer Hillside	12/20/17	25,8	3.130	6,97	130	2,44	0,4	0	381	8,0	216	114	210	250	615	818	2,3	-	1,0	-3,15
KK_HP16	Amer Hillside	12/21/17	28,2	1.521	6,85	31	2,80	0,6	0,05	105	6,5	196	50	273	82	236	323	1,1	-	0,4	1,53
KK_HP10	Amer Hillside	12/21/17	26,6	2.178	6,99	31	2,88	0,6	3	243	31,0	156	60	185	136	393	494	1,3	-	0,6	-1,86
KK_HP01	Amer Hillside	12/21/17	29,1	2.480	6,91	66	2,19	0,15	0,05	194	17,0	250	72	349	118	445	482	1,6	-	0,8	-2,26
KK_HP04	Amer Hillside	12/21/17	26,3	2.240	7	80	2,75	1,5	0,075	201	18,5	227	63	157	116	442	543	1,8	-	0,8	-1,13
KK_HP15	Amer Hillside	12/21/17	26,7	3.380	6,86	114	2,93	1,5	0,2	200	14,5	380	115	555	281	717	513	3,1	-	1,0	-7,33
KK_BW03	Amer Hillside	12/21/17	28	2.550	6,75	254	1,76	0	0	194	23,0	286	78	421	120	433	513	1,6	-	0,7	-0,31
KK_HP02	Amer Hillside	12/22/17	27	2.770	6,84	28,40	2,76	3	0	166	13,5	279	78	308	114	445	488	2,3	-	0,8	0,03
NKT_BW01	Amer Plain	11/3/16	26,5	4.560	7,03	157	3,70	0	0	510	2,5	93,2	104	170	164	935	812	-	-	0,0	-12,76
NKT_BW01	Amer Plain	11/12/16	26,3	4.520	7,04	180	3,45	0	0	510	3,5	91,0	108	169	165	944	830	3,0	-	2,5	-13,02
NKT_BW06	Amer Plain	12/25/16	27,7	5.240	7,73	139	2,91	0	0	611	1,0	101	108	235	175	1.020	946	2,5	-	2,7	-12,11
NKT_BW09	Amer Plain	12/25/16	27,6	4.990	6,94	173	2,12	0	0	500	2,0	118	147	97	214	1.034	903	4,0	-	3,5	-11,36
NKT_BW15	Amer Plain	12/26/16	26,7	4.930	7,21	195	3,50	-	-	575	1,0	138	103	214	174	1.007	921	2,6	-	2,5	-11,19

Well ID	Sub-group	Date	T [°C]	EC [µS/cm]	pH	ORP [mV]	O2 [mg/l]	NO2 [mg/l]	NH4 [mg/l]	Na [mg/l]	K [mg/l]	Ca [mg/l]	Mg [mg/l]	NO3 [mg/l]	SO4 [mg/l]	Cl [mg/l]	HCO3 [mg/l]	Sr [mg/l]	SiO2 [mg/l]	Br [mg/l]	CBE [%]
KK_HP20	Amer Plain	12/27/16	27,2	3.740	7,48	105	2,73	0,15	4,5	250	55,0	178	102	190	165	670	732	2,6	-	1,1	-11,71
PHED03	Amer Plain	12/28/16	23,5	4.830	6,82	259	4,99	-	-	558	2,0	343	223	190	255	1.360	702	7,0	-	3,5	1,32
KK_BW09	Amer Plain	12/30/16	26	6.060	6,74	219	1,72	0	0	683	6,0	231	178	145	400	1.250	873	4,9	-	3,1	-3,60
PHED01	Amer Plain	12/30/16	27	3.530	6,82	240	4,51	0	-	230	11,0	124	135	77	170	735	574	2,7	-	1,4	-11,73
NKT_BW06	Amer Plain	4/2/17	29,9	5.220	8,01	207	4,26	-	-	690	4,2	58,0	92	255	194	990	879	2,4	-	3,1	-10,86
NKT_BW09	Amer Plain	4/2/17	29,3	3.750	6,95	240	2,49	0,025	0	519	5,8	96,0	114	108	215	1.000	879	3,6	-	3,7	-13,92
NKT_BW01	Amer Plain	4/3/17	29,1	4.580	7,06	177	5,20	-	-	487	6,0	86,0	101	174	167	998	818	3,5	-	2,9	-16,99
PHED03	Amer Plain	4/3/17	29,4	3.260	7,16	245	6,07	-	-	214	20,0	174	90	140	138	735	488	3,7	-	1,8	-13,31
PHED01	Amer Plain	4/3/17	30	3.350	6,93	246	5,42	-	-	217	31,0	232	71	80	170	735	555	2,5	-	1,5	-11,25
KK_HP20	Amer Plain	4/4/17	27,7	3.870	6,87	109	2,35	0,2	4,5	295	67,0	160	92	258	185	720	787	301,0	-	1,3	-15,59
KK_BW09	Amer Plain	4/5/17	28,4	5.840	6,82	212	3,41	-	-	668	5,3	225	177	167	400	1.490	848	5,0	-	3,3	-9,81
NKT_BW15	Amer Plain	10/10/17	28,3	4.320	7,21	227	2,37	0,025	0	887	3,2	73,0	77,8	225	181	923	934	2,2	24,4	2,3	-0,02
NKT_BW01	Amer Plain	10/10/17	28,3	4.170	7,09	250	4,90	-	-	773	3,2	93,5	109,0	172	171	1.017	818	3,3	27,1	3,2	-1,13
NKT_BW09	Amer Plain	10/10/17	28,6	4.030	7,28	217	3,37	0,025	0	741	3,0	91,6	109,0	106	216	917	866	3,3	28,1	3,5	-0,46
PHED03	Amer Plain	10/14/17	28	3.310	7,31	252	3,51	-	-	602	2,7	79,1	108,0	111	185	664	885	2,4	30,2	1,3	0,28
KK_BW09	Amer Plain	10/14/17	29,4	5.630	7,07	240	4,22	-	-	930	2,1	195	168,0	159	362	1.412	885	3,8	39,2	2,9	-0,29
PHED01	Amer Plain	10/14/17	29,6	2.980	6,99	205	3,69	-	-	395	15,8	202	68,1	74,8	182	696	531	2,2	40,0	1,4	-0,09
KK_HP20	Amer Plain	10/14/17	28,4	3.220	7,21	143	2,71	0,075	4,5	434	75,8	150	86,4	567	193	566	818	2,3	59,3	1,1	-9,13

Well ID	Sub-group	Date	T [°C]	EC [µS/cm]	pH	ORP [mV]	O2 [mg/l]	NO2 [mg/l]	NH4 [mg/l]	Na [mg/l]	K [mg/l]	Ca [mg/l]	Mg [mg/l]	NO3 [mg/l]	SO4 [mg/l]	Cl [mg/l]	HCO3 [mg/l]	Sr [mg/l]	SiO2 [mg/l]	Br [mg/l]	CBE [%]
NKT_BW09	Amer Plain	12/20/17	28,7	4.040	7,05	160	3,24	-	-	729	6,5	84,0	105	114	197	916	891	2,9	-	3,0	-1,83
KK_HP20	Amer Plain	12/21/17	27,7	3.170	7,09	196	2,59	0,1	8	436	66,0	150	87	246	161	554	903	2,3	-	0,8	-3,35
NKT_BW06	Amer Plain	12/22/17	28	4.740	7,34	187,20	3,46	-	-	947	5,5	56,0	95	250	197	984	793	2,3	-	3,0	3,03
PHED01	Amer Plain	12/22/17	28,9	2.840	6,89	197,70	4,85	-	-	394	24,5	192	66	68	178	776	464	2,2	-	1,4	-2,26
NKT_BW15	Amer Plain	12/22/17	27,7	4.270	7,24	202,80	2,95	0,05	0	891	8,0	88,0	97	221	175	978	842	2,2	-	2,3	2,74
KK_HP03	Amer Valley	12/27/16	26,8	1.681	7	82	4,22	-	-	90	37,0	113	35	95	66	203	439	0,7	-	0,4	-8,39
KK_HP19	Amer Valley	12/27/16	27,6	1.951	7	105		-	-	106	34,0	136	43	81	94	278	445	0,8	-	0,6	-7,60
KK_DW03	Amer Valley	12/27/16	26,7	987	7,17	254	6,07	-	-	70	29,0	67,0	24	52	37	95	342	0,5	-	0,2	-4,13
KK_HP23	Amer Valley	12/28/16	26,1	1.893	6,91	101	3,73	0,15	0	98	33,0	140	41	100	76	245	458	0,9	-	0,5	-6,47
KK_BW02	Amer Valley	12/28/16	25,3	1.743	6,91	250	4,45	-	-	98	33,0	120	37	108	70	212	433	0,8	-	0,5	-7,03
KK_HP03	Amer Valley	4/4/17	27,3	1.263	7	60	3,85	-	-	102	30,0	86,0	27	71	55	145	391	0,5	-	0,3	-4,34
KK_HP23	Amer Valley	4/4/17	27,8	1.970	6,86	66	4,35	-	-	147	2,6	155	48	170	128	354	445	1,0	-	0,6	-11,13
KK_BW02	Amer Valley	4/4/17	28,3	1.332	6,97	218	5,23	-	-	106	27,5	92,0	28	83	56	164	366	0,7	-	0,4	-3,64
KK_HP19	Amer Valley	10/11/17	28,7	787	7,8	129	4,38	-	-	105	14,3	35,5	11,6	23,6	34,0	83,4	281	0,2	27,2	0,2	-2,43
KK_HP03	Amer Valley	10/11/17	27,3	1.217	7,08	58	4,62	-	-	131	23,8	78,4	24,0	60,4	44,4	142	403	0,5	32,7	0,3	-1,25
KK_BW02	Amer Valley	10/13/17	27,9	1.259	6,84	270	3,89	-	-	130	22,0	89,1	26,2	77,7	49,8	149	372	0,5	32,9	0,3	0,89
KK_HP23	Amer Valley	10/13/17	27,7	1.519	7,03	53	4,45	0,2	0,025	147	25,7	111	32,6	93,9	69,7	204	397	0,6	33,7	0,4	0,18
KK_HP03	Amer Valley	12/21/17	27,2	1.127	7,07	221	3,85	-	-	123	28,0	71,0	23	61	45	120	372	0,4	-	0,3	0,42

Well ID	Sub-group	Date	T [°C]	EC [µS/cm]	pH	ORP [mV]	O2 [mg/l]	NO2 [mg/l]	NH4 [mg/l]	Na [mg/l]	K [mg/l]	Ca [mg/l]	Mg [mg/l]	NO3 [mg/l]	SO4 [mg/l]	Cl [mg/l]	HCO3 [mg/l]	Sr [mg/l]	SiO2 [mg/l]	Br [mg/l]	CBE [%]
KK_BW02	Amer Valley	12/21/17	27,2	963	7,22	266	4,85	-	-	106	21,5	62,0	19	52	42	105	299	0,4	-	0,0	1,42
KK_HP19	Amer Valley	12/21/17	28,3	760	7,55		4,40	-	-	107	18,0	33,0	11	26	36	90	250	0,2	--	0,2	-0,70
KK_HP23	Amer Valley	12/22/17	27,2	1.393	7,04	100,90	5,07	0,4	0	144	30,0	93,0	30	86	66	167	372	0,5	-	0,4	2,05
KK_LAKE02	Historic Reservoir	10/12/17	25,3	1.457	7,74	224	1,77	0,025	0,8	143	40,0	58,0	66,0	0,0	160	190	391	10,5	-	0,4	1,56
NKT_BW42	NKT East	12/26/16	27,8	3.950	6,91	220	4,90	-	-	235	9,0	206	131	86	93	1.000	421	5,1	-	3,3	-9,89
NKT_BW25	NKT East	12/26/16	28	3.900	7,18	276	5,76	-	-	324	8,0	194	123	87	124	945	574	4,2	-	3,2	-8,01
NKT_BW42	NKT East	4/3/17	28,8	3.930	7,69	252	5,50	-	-	235	7,1	207	132	88	101	1.000	427	5,5	-	3,5	-10,14
NKT_BW25	NKT East	4/3/17	29,1	4.030	7,64	263	6,64	-	-	332	7,1	157	93	88	132	936	574	3,9	-	3,5	-14,07
NKT_BW25	NKT East	10/10/17	29,3	3.500	6,96	276	3,89	-	-	526	4,1	156,0	92,5	86,6	135	898	567	3,5	28,0	3,4	-0,59
NKT_BW42	NKT East	10/10/17	29,7	3.300	7,01	215	5,19	-	-	373	4,3	193,0	123,0	90,0	96,9	937	421	4,6	29,3	3,4	-0,98
NKT_BW42	NKT East	12/23/17	28,5	3.280	6,94	199,30	7,37	-	-	358	8,0	192	123	94	100	977	409	4,8	-	3,4	-3,24
NKT_BW41	NKT North	12/26/16	27,1	5.100	6,81	242	4,42	-	-	570	1,0	234	205	201	209	1.380	781	6,0	-	4,1	-5,28
NKT_BW41	NKT North	4/2/17	29,1	5.250	7,2	255	4,84	-	-	580	8,7	185	160	213	215	1.353	671	6,0	-	4,3	-8,79
NKT_BW41	NKT North	10/12/17	29,4	5.680	6,87	171	5,11	-	-	899	4,9	206	179,0	214	234	1.612	653	5,9	29,1	4,9	-0,20
NKT_BW41	NKT North	12/24/17	27,6	5.850	6,75	209,10	4,70	-	-	866	8,7	204	175	210	220	1.550	525	-	-	4,6	1,78
NKT_HP01	NKT West	12/25/16	26,5	6.200	7,42	40	2,44	5	0,05	611	3,0	188	196	100	255	1.350	866	5,0	-	5,0	-6,32
NKT_BW49	NKT West	12/25/16	28,3	5.700	7,55	52	2,53	0,1	0	611	5,0	120	162	173	185	1.150	848	3,7	-	3,7	-7,03
NKT_BW13	NKT West	12/25/16	26,7	5.950	7,46	207	4,92	-	-	710	1,0	86,0	127	153	265	1.050	1.025	2,9	-	3,6	-8,75

Well ID	Sub-group	Date	T [°C]	EC [µS/cm]	pH	ORP [mV]	O2 [mg/l]	NO2 [mg/l]	NH4 [mg/l]	Na [mg/l]	K [mg/l]	Ca [mg/l]	Mg [mg/l]	NO3 [mg/l]	SO4 [mg/l]	Cl [mg/l]	HCO3 [mg/l]	Sr [mg/l]	SiO2 [mg/l]	Br [mg/l]	CBE [%]
NKT_BW47	NKT West	12/25/16	26,5	5.500	7,35	248	4,67	0	0	743	1,0	40,5	81	150	205	1.000	1.263	1,9	-	3,0	-15,12
NKT_HP04	NKT West	12/26/16	26,8	4.130	7,02	5	3,05	0,3	0,025	410	7,0	117	111	159	141	890	775	3,6	-	2,2	-13,52
NKT_BW03	NKT West	12/26/16	25,6	5.520	7,18	218	3,53	0	0	720	8,0	80,0	98	179	205	963	1.037	2,5	-	3,2	-8,15
NKT_HP01	NKT West	4/2/17	28,7	5.850	7,56	119	2,76	1	0,05	645	9,0	148	150	114	266	1.307	833	4,5	-	5,1	-9,33
NKT_HP04	NKT West	4/2/17	29,7	4.190	7,33	129	3,08	0,2	0	454	6,1	105	98	164	152	884	732	3,6	-	2,4	-12,56
NKT_BW47	NKT West	4/2/17	28,8	5.180	7,69	249	4,23	-	-	763	3,5	31,0	63	165	212	960	1.141	1,7	-	3,0	-13,83
NKT_BW03	NKT West	4/3/17	27,9	5.450	7,71	239	1,73	0	0,025	711	4,0	64,0	78	205	216	1.011	988	2,5	-	3,2	-12,75
NKT_BW49	NKT West	4/3/17	29	5.440	7,12	255	4,74	-	-	596	7,1	101	125	193	197	1.260	787	3,6	-	3,9	-14,65
NKT_BW03	NKT West	10/9/17	29,7	4.730	7,65	306	2,97	0	0	1.008	2,9	19,0	73,1	200	224	1.027	1.025	2,0	23,6	3,0	-2,65
NKT_BW13	NKT West	10/9/17	28,6	4.750	7,64	316	6,04	-	-	953	3,7	83,2	91,5	164	232	1.076	1.025	2,4	25,0	3,6	-1,29
NKT_BW49	NKT West	10/9/17	29,4	5.020	7,53	287	3,18	-	-	877	3,0	103	138,0	204	191	1.244	812	3,5	26,2	3,9	-0,85
NKT_HP01	NKT West	10/9/17	27,9	5.010	7,43	118	2,75	-	-	839	3,8	143	151,0	110	240	1.273	805	3,9	27,6	4,5	0,25
NKT_HP04	NKT West	10/9/17	27,4	4.040	7,54	151	3,36	-	-	699	3,3	110	101,0	168	158	924	738	3,3	28,2	2,5	0,14
NKT_BW47	NKT West	10/10/17	28,4	4.570	7,48	185	4,10	-	-	1.046	1,7	34,1	64,9	164	220	924	1.178	1,6	23,2	2,8	0,00
NKT_HP04	NKT West	12/20/17	27,5	4.040	7,11	70	3,83	-	-	677	7,0	102	98	165	150	970	726	3,1	-	2,0	-2,58
NKT_BW47	NKT West	12/20/17	27,3	4.560	7,41	189	4,22	-	-	1.004	4,5	34,0	63	195	210	950	1.153	1,4	-	3,0	-2,45
NKT_HP01	NKT West	12/22/17	27,4	5.290	7	136,70	3,43	0,75	0,025	872	10,0	141	153	129	251	1.200	763	4,1	-	4,9	3,73
NKT_BW03	NKT West	12/22/17	26,8	4.590	7,21	236,70	2,75	-	-	978	7,0	56,0	73	197	213	910	940	1,9	-	2,8	2,84

Well ID	Sub-group	Date	T [°C]	EC [µS/cm]	pH	ORP [mV]	O2 [mg/l]	NO2 [mg/l]	NH4 [mg/l]	Na [mg/l]	K [mg/l]	Ca [mg/l]	Mg [mg/l]	NO3 [mg/l]	SO4 [mg/l]	Cl [mg/l]	HCO3 [mg/l]	Sr [mg/l]	SiO2 [mg/l]	Br [mg/l]	CBE [%]
NKT_BW49	NKT West	12/23/17	28,1	5.070	6,99	199,80	2,62	0	0	966	7,0	98,0	144	216	180	1.163	641	3,5	-	3,8	7,68
NKT_HP12	Outlier (Amer Inflow)	10/14/17	29,8	576	7,82	217	3,23	-	-	50	2,1	44,2	21,9	20,4	15,1	21	329	0,6	22,8	0,1	-3,03
NKT_HP12	Outlier (Amer Inflow)	12/23/17	27,6	575	7,44	160,30	4,04	-	-	54	2,6	43,0	21	17	14	22	305	0,6	-	0,0	0,83
KK_BW08	Outlier (Amer Plain)	12/30/16	26,1	7.630	6,59	159	2,29	0,05	0	713	44,0	374	165	270	530	1.600	653	0,0	-	4,4	-5,04
KK_BW08	Outlier (Amer Plain)	4/3/17	29,7	7.470	6,99	216	2,34	0,025	0	688	52,0	425	183	274	559	1.860	641	5,0	-	4,8	-7,85
KK_BW08	Outlier (Amer Plain)	10/13/17	29,3	7.450	6,57	168	2,21	0,05	0,05	1.029	45,1	452	193,0	229	564	2.133	653	4,5	40,1	5,0	-1,14
KK_BW08	Outlier (Amer Plain)	12/22/17	28,2	7.680	6,63	201,80	2,96	-	-	1.050	51,0	443	192	222	543	1.964	592	4,4	-	4,7	2,97
KK_OBS02	Outlier (Amer Pz.)	12/28/16	29	1.909	8,57	-192	0,16	0	3	210	5,0	16,0	44	0	1	536	122	0,1	-	0,7	-11,22
KK_OBS02	Outlier (Amer Pz.)	4/7/17	30,5	1.849	8,46	-190	0,20	0	2	171	20,0	121	38,0	0,2	0,5	541	146	0,5	-	1,0	-1,61
NKT_DW02	Outlier (NKT Dug well)	11/12/16	26,8	4.650	7,1	267	7,14	0,025	0	485	4,0	169	119	140	165	1.000	751	3,7	-	2,5	-7,91
NKT_DW02	Outlier (NKT Dug well)	4/3/17	28,1	4.510	7,43	255	6,69	-	-	427	6,4	122	105	144	162	960	732	4,0	-	2,7	-14,45
Rain	Rain	1/26/17	16,9	53	6,23	293	8,99	-	-	0,5	0,0	2,7	0	5	11	2	12	0,0	-	0,0	-50,40
KK_LAKE01	Taalaab	11/14/16	23,8	1.321	9,54	182	12,73	0	-	120	30,0	40,0	34	2	43	250	238	0,5	-	0,0	-4,86
KK_LAKE01	Taalaab	10/14/17	27,2	843	11,04	44	20,62	0	0,05	112	22,0	30,0	6,7	1,1	23,0	140	159	0,3	-	0,1	3,01

A 3 Results from stable water isotopes analysis used for interpretation.

Well ID	Sub-group	Date	$\delta^{18}O_{VSMOW}$ [‰]	sd $\delta^{18}O$ [‰]	δ^2H_{VSMOW} [‰]	sd δ^2H [‰]	DE	T [°C]	T_{air} [°C]	Altitude [masl]
KK_HP04	Amer Hillside	8/24/17	-3.39	0.07	-26.88	0.06	0.22	28.3	28.9	465
KK_HP01	Amer Hillside	8/24/17	-4.18	0.04	-30.58	0.14	2.85	30.1	29.3	414
KK_HP10	Amer Hillside	8/24/17	-3.05	0.11	-25.76	0.30	-1.35	28.6	30.7	409
KK_HP01	Amer Hillside	8/31/17	-3.28	0.15	-25.74	0.55	0.50	28.8	27.3	414
KK_HP04	Amer Hillside	8/31/17	-3.40	0.08	-27.00	0.21	0.21	27.6	26.4	465
KK_HP10	Amer Hillside	8/31/17	-3.25	0.05	-25.62	0.28	0.37	27.4	26.4	409
KK_HP01	Amer Hillside	9/7/17	-3.41	0.05	-27.71	0.13	-0.46	29.2	27.8	414
KK_HP04	Amer Hillside	9/7/17	-3.48	0.11	-27.79	0.54	0.03	28.4	28.6	465
KK_HP10	Amer Hillside	9/7/17	-3.13	0.06	-26.21	0.47	-1.19	28.3	28.5	409
KK_HP01	Amer Hillside	9/14/17	-3.36	0.13	-27.09	0.73	-0.24	28.6	26.6	414
KK_HP04	Amer Hillside	9/15/17	-3.22	0.05	-27.03	0.33	-1.26	31.1	38.7	465
KK_HP10	Amer Hillside	9/15/17	-3.14	0.02	-26.26	0.12	-1.17	29.9	36.5	409
KK_HP01	Amer Hillside	9/22/17	-3.33	0.16	-27.47	0.76	-0.82	28.8	28.5	414
KK_HP04	Amer Hillside	9/22/17	-3.33	0.04	-27.27	0.12	-0.66	29.8	30	465
KK_HP10	Amer Hillside	9/22/17	-3.10	0.14	-25.80	0.66	-0.99	29.6	31.7	409
KK_HP01	Amer Hillside	9/29/17	-3.31	0.11	-27.57	0.55	-1.06	28.9	29.1	414
KK_HP04	Amer Hillside	9/29/17	-3.22	0.09	-27.39	0.17	-1.62	27.9	29.6	465
KK_HP10	Amer Hillside	9/29/17	-3.12	0.15	-25.80	0.62	-0.84	28.4	29.4	409
KK_HP01	Amer Hillside	10/11/17	-3.44	0.15	-27.90	0.67	-0.38	29.3	29.5	414
KK_HP15	Amer Hillside	10/12/17	-4.25	0.07	-32.16	0.73	1.88	-	28.9	412
KK_HP10	Amer Hillside	10/12/17	-3.10	0.08	-25.16	0.59	-0.34	28.8	29.6	409
KK_BW03	Amer Hillside	10/13/17	-4.07	0.07	-29.55	0.32	3.03	28.8	27.3	419
KK_HP04	Amer Hillside	10/13/17	-3.40	0.07	-27.87	0.67	-0.68	28.4	28.8	465
KK_HP16	Amer Hillside	10/14/17	-4.80	0.08	-33.91	0.57	4.46	29.2	28.9	423
KK_HP02	Amer Hillside	10/14/17	-4.75	0.04	-33.12	0.62	4.85	30.2	25.5	405
KK_HP01	Amer Hillside	11/1/17	-4.21	0.12	-29.87	0.36	3.77	29.2	31	414
KK_HP10	Amer Hillside	11/1/17	-3.30	0.06	-25.96	0.71	0.47	28.2	30.3	409
KK_HP04	Amer Hillside	11/1/17	-3.55	0.07	-27.65	0.22	0.72	27.8	29.3	465
KK_HP01	Amer Hillside	11/11/17	-3.96	0.17	-29.98	0.76	1.72	28.7	27.1	414
KK_HP04	Amer Hillside	11/11/17	-3.34	0.14	-27.57	0.43	-0.88	28.1	28.2	465
KK_HP10	Amer Hillside	11/11/17	-3.27	0.07	-27.17	0.22	-1.02	27.7	27.3	409
KK_HP01	Amer Hillside	11/16/17	-4.04	0.10	-29.66	0.84	2.69	-	26.8	414
KK_HP04	Amer Hillside	11/16/17	-3.57	0.13	-27.76	0.71	0.84	28.4	30.4	465
KK_HP10	Amer Hillside	11/16/17	-3.39	0.06	-27.18	0.31	-0.04	27.4	27	409
KK_HP01	Amer Hillside	12/1/17	-3.98	0.02	-29.83	0.19	2.04	27	18.3	414
KK_HP04	Amer Hillside	12/1/17	-3.47	0.02	-27.42	0.21	0.35	28.5	30.2	465
KK_HP10	Amer Hillside	12/1/17	-3.39	0.07	-26.97	0.32	0.17	27.5	26.3	409
KK_HP01	Amer Hillside	12/7/17	-4.09	0.03	-30.12	0.32	2.63	27.5	21.6	414
KK_HP04	Amer Hillside	12/7/17	-3.48	0.03	-27.55	0.32	0.26	27.1	18.9	465
KK_HP10	Amer Hillside	12/7/17	-3.34	0.02	-27.68	0.12	-0.97	26.4	20.1	409
KK_HP24	Amer Hillside	12/20/17	-3.19	0.02	-25.37	0.05	0.14	25.8	18.7	385
KK_BW03	Amer Hillside	12/21/17	-3.66	0.01	-28.49	0.23	0.75	28	24.4	419
KK_HP02	Amer Hillside	12/22/17	-4.37	0.04	-31.54	0.28	3.40	27	21.4	405
KK_HP24	Amer Hillside	10/12/17	-3.60	0.07	-26.95	0.15	1.88	28	-	385
KK_HP01	Amer Hillside	11/14/16	-3.28	0.04	-27.21	0.22	-0.99	28.4	-	414
KK_HP16	Amer Hillside	11/14/16	-4.94	0.08	-35.10	0.14	4.38	28.8	-	423
KK_HP10	Amer Hillside	10/10/18	-2.45	0.07	-21.90	0.47	-2.29	28.3	30.1	409
NKT_BW42	NKT East	10/10/17	-4.58	0.11	-33.72	0.74	2.95	29.7	28.6	384
NKT_BW25	NKT East	10/10/17	-4.41	0.08	-33.79	0.59	1.52	29.3	28.4	381
NKT_BW42	NKT East	11/8/16	-4.52	0.05	-33.36	0.28	2.83	28.7	-	384
NKT_BW25	NKT East	11/8/16	-4.63	0.06	-33.95	0.20	3.07	27.2	-	381
KK_HP03	Amer Valley	8/24/17	-3.56	0.12	-29.04	0.48	-0.57	27.8	27.6	415
KK_HP19	Amer Valley	8/24/17	-3.49	0.17	-29.51	0.40	-1.60	29.2	27.6	394
KK_HP03	Amer Valley	8/31/17	-3.60	0.10	-28.84	0.22	-0.05	27.5	27.4	415
KK_HP19	Amer Valley	8/31/17	-3.45	0.09	-28.73	0.10	-1.12	28.3	26.6	394

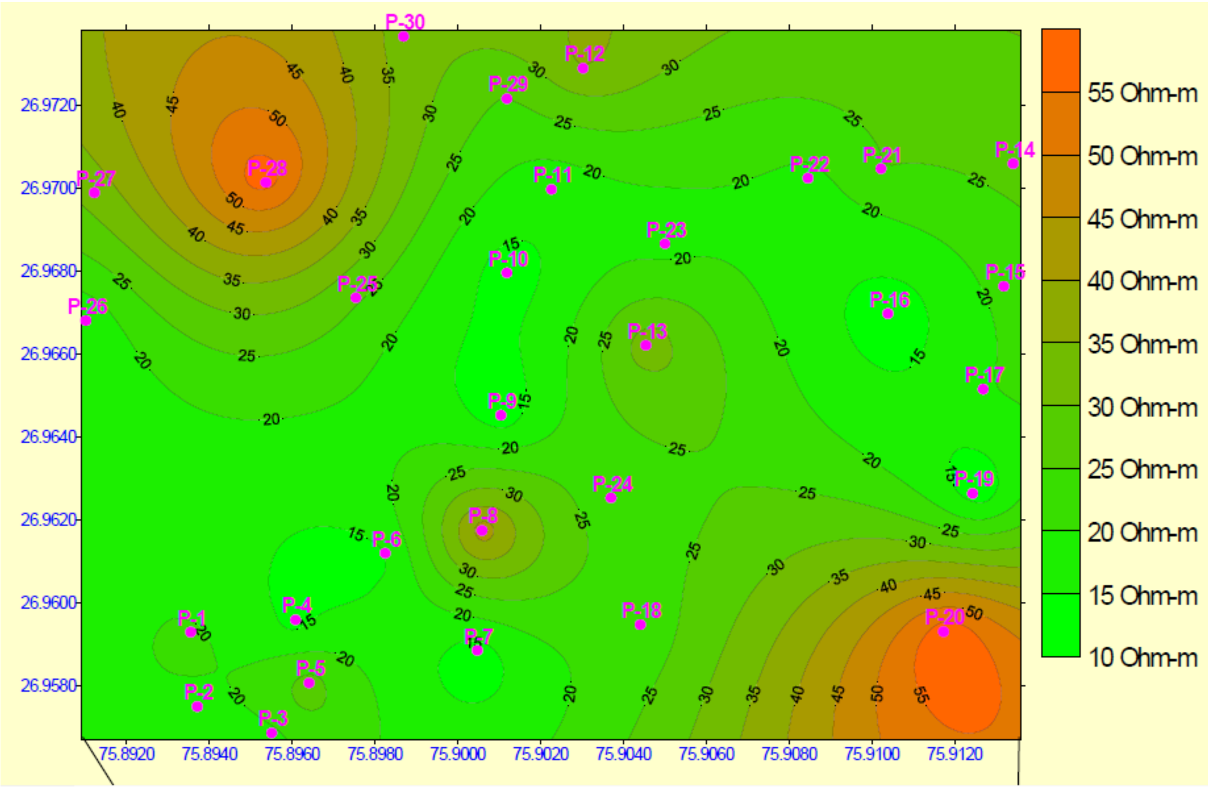
Well ID	Sub-group	Date	$\delta^{18}O_{VSMOW}$ [‰]	sd $\delta^{18}O$ [‰]	$\delta^{2}H_{VSMOW}$ [‰]	sd $\delta^{2}H$ [‰]	DE	T [°C]	T_{air} [°C]	Altitude [masl]
KK_HP03	Amer Valley	9/7/17	-3.54	0.04	-28.27	0.29	0.03	27.9	27.5	415
KK_HP19	Amer Valley	9/7/17	-3.36	0.02	-29.75	0.14	-2.87	28.3	27.6	394
KK_HP03	Amer Valley	9/14/17	-3.64	0.10	-28.88	0.25	0.25	27.4	26.5	415
KK_HP19	Amer Valley	9/14/17	-3.18	0.20	-29.08	0.64	-3.65	28.2	26.5	394
KK_HP03	Amer Valley	9/22/17	-3.57	0.05	-29.17	0.10	-0.58	27.9	27.2	415
KK_HP19	Amer Valley	9/22/17	-3.21	0.13	-28.87	0.65	-3.17	28.8	27.7	394
KK_HP03	Amer Valley	9/29/17	-3.51	0.04	-29.08	0.17	-0.99	27.5	28	415
KK_HP19	Amer Valley	9/29/17	-3.19	0.17	-28.33	0.64	-2.83	28.9	28.8	394
KK_HP03	Amer Valley	10/11/17	-3.37	0.02	-28.95	0.08	-2.00	27.3	30.6	415
KK_HP19	Amer Valley	10/11/17	-3.35	0.18	-29.30	0.74	-2.47	28.7	27.7	394
KK_BW02	Amer Valley	10/13/17	-3.25	0.06	-28.33	0.29	-2.30	27.9	26.3	394
KK_HP19	Amer Valley	11/1/17	-3.51	0.02	-29.75	0.36	-1.71	28	28.5	394
KK_HP03	Amer Valley	11/1/17	-3.70	0.09	-28.95	0.64	0.61	27.4	27.6	415
KK_HP03	Amer Valley	11/11/17	-3.35	0.12	-28.45	0.45	-1.63	27.5	27.1	415
KK_HP19	Amer Valley	11/11/17	-3.28	0.08	-29.78	0.17	-3.50	28.1	26.6	394
KK_HP03	Amer Valley	11/16/17	-3.36	0.16	-27.78	1.00	-0.92	26.9	22.7	415
KK_HP19	Amer Valley	11/16/17	-3.41	0.10	-29.06	0.64	-1.78	27.4	25.1	394
KK_HP19	Amer Valley	12/1/17	-3.42	0.01	-29.85	0.19	-2.49	27.5	25.1	394
KK_HP03	Amer Valley	12/1/17	-3.35	0.05	-28.34	0.52	-1.50	27.1	25.4	415
KK_HP03	Amer Valley	12/7/17	-3.29	0.02	-27.90	0.25	-1.60	26.1	21.7	415
KK_HP19	Amer Valley	12/7/17	-3.40	0.06	-29.96	0.56	-2.77	27.2	21.5	394
KK_HP23	Amer Valley	10/13/17	-3.31	0.08	-27.66	0.19	-1.14	28	-	383
KK_HP03	Amer Valley	10/10/18	-2.60	0.06	-24.21	0.34	-3.40	27.9	30	415
PHED01	Amer Plain	10/14/17	-4.69	0.14	-32.34	0.55	5.19	29.6	28.5	394
NKT_BW01	Amer Plain	10/10/17	-3.38	0.04	-28.44	0.06	-1.41	28	-	384
NKT_BW09	Amer Plain	10/10/17	-4.38	0.05	-32.93	0.13	2.14	29	-	382
NKT_BW15	Amer Plain	10/10/17	-3.38	0.04	-28.37	0.43	-1.35	28	-	392
KK_HP20	Amer Plain	10/14/17	-3.90	0.08	-29.46	0.23	1.72	28	-	399
PHED03	Amer Plain	10/14/17	-2.75	0.03	-23.35	0.23	-1.33	28	-	383
KK_BW09	Amer Plain	10/14/17	-3.27	0.05	-26.70	0.26	-0.53	29	-	388
NKT_BW01	Amer Plain	11/8/16	-3.54	0.05	-28.61	0.18	-0.32	27.9	-	384
NKT_BW06	Amer Plain	11/9/16	-4.00	0.07	-31.40	0.22	0.59	27.8	-	380
NKT_BW15	Amer Plain	11/9/16	-3.34	0.09	-28.06	0.12	-1.31	27.7	-	392
NKT_BW01	Amer Plain	11/12/16	-3.55	0.03	-29.17	0.24	-0.80	26.3	-	384
NKT_BW41	NKT North	10/12/17	-3.11	0.05	-27.33	0.16	-2.45	29.4	28.3	385
NKT_BW41	NKT North	12/24/17	-3.23	0.06	-27.40	0.53	-1.52	27.6	23.5	385
NKT_BW41	NKT North	11/8/16	-3.26	0.03	-27.37	0.13	-1.33	27.6	-	385
NKT_BW41	NKT North	11/20/17	-3.26	0.04	-27.38	0.14	-1.32	-	-	385
NKT_BW03	NKT West	10/9/17	-3.39	0.12	-28.54	0.76	-1.40	29.7	33.1	374
NKT_BW47	NKT West	10/10/17	-3.28	0.13	-28.13	0.51	-1.87	28.4	26.8	379
NKT_HP04	NKT West	10/9/17	-3.23	0.09	-27.08	0.37	-1.24	27	-	382
NKT_HP01	NKT West	10/9/17	-4.30	0.06	-32.80	0.12	1.58	28	-	388
NKT_BW13	NKT West	10/9/17	-3.88	0.05	-31.09	0.17	-0.06	29	-	384
NKT_BW49	NKT West	10/9/17	-4.33	0.09	-32.58	0.34	2.03	29	-	381
NKT_HP04	NKT West	11/8/16	-3.29	0.11	-26.88	0.11	-0.57	28.8	-	382
NKT_BW03	NKT West	11/8/16	-4.61	0.04	-33.59	0.21	3.27	30.8	-	374
NKT_BW03	NKT West	11/9/16	-3.39	0.13	-28.71	0.16	-1.59	27.8	-	374
NKT_BW49	NKT West	11/9/16	-4.37	0.05	-32.89	0.16	2.03	29.2	-	381
NKT_BW13	NKT West	11/9/16	-3.79	0.04	-30.22	0.10	0.08	28.1	-	384
KK_LAKE02	Historic Reservoir	8/24/17	5.78	0.14	19.44	0.67	-26.80	-	-	430
KK_LAKE03	Historic Reservoir	8/24/17	5.85	0.23	15.85	1.01	-30.93	29.6	28.7	465
KK_LAKE02	Historic Reservoir	8/31/17	3.65	0.17	9.61	0.35	-19.61	27.9	27.6	430
KK_LAKE03	Historic Reservoir	8/31/17	4.78	0.07	11.62	0.45	-26.64	28.4	27.6	465
KK_LAKE02	Historic Reservoir	9/7/17	3.40	0.11	7.76	0.36	-19.47	28	27.5	430
KK_LAKE03	Historic Reservoir	9/7/17	4.65	0.05	11.16	0.23	-26.02	28.1	26.6	465
KK_LAKE02	Historic Reservoir	9/14/17	3.69	0.09	8.69	0.91	-20.84	28.8	27.7	430
KK_LAKE03	Historic Reservoir	9/14/17	4.98	0.05	12.21	0.06	-27.59	28.7	27	465

Well ID	Sub-group	Date	$\delta^{18}O$ VSMOW [‰]	sd $\delta^{18}O$ [‰]	$\delta^{2}H_{VSMOW}$ [‰]	sd $\delta^{2}H$ [‰]	DE	T [°C]	T_{air} [°C]	Altitude [masl]
KK_LAKE02	Historic Reservoir	9/22/17	4.00	0.10	9.99	0.45	-22.03	27.2	27.5	430
KK_LAKE03	Historic Reservoir	9/22/17	5.16	0.07	12.66	0.21	-28.60	27.5	26.5	465
KK_LAKE02	Historic Reservoir	9/29/17	4.20	0.10	10.48	0.20	-23.10	26.5	26.6	430
KK_LAKE03	Historic Reservoir	9/29/17	5.32	0.17	13.17	0.64	-29.35	27.2	27.3	465
KK_LAKE02	Historic Reservoir	10/12/17	4.71	0.23	13.36	0.77	-24.31	25.3	24.1	430
KK_LAKE02	Historic Reservoir	11/1/17	5.14	0.12	15.83	0.55	-25.25	22.6	30.3	430
KK_LAKE03	Historic Reservoir	11/2/17	6.74	0.07	19.57	0.68	-34.32	-	-	465
KK_LAKE02	Historic Reservoir	11/11/17	5.33	0.25	16.91	0.31	-25.74	20.7	25.7	430
KK_LAKE03	Historic Reservoir	11/11/17	6.90	0.05	21.47	0.34	-33.75	22	25	465
KK_LAKE02	Historic Reservoir	11/16/17	5.65	0.05	16.60	0.44	-28.61	19.4	25.8	430
KK_LAKE03	Historic Reservoir	11/16/17	7.21	0.09	22.20	0.16	-35.50	20.3	24.1	465
KK_LAKE02	Historic Reservoir	12/1/17	6.00	0.06	18.35	0.69	-29.68	15.6	19.7	430
KK_LAKE02	Historic Reservoir	12/7/17	6.07	0.05	18.90	0.48	-29.65	20.7	25.6	430
KK_LAKE03	Historic Reservoir	12/7/17	7.77	0.05	24.53	0.53	-37.63	18.9	23.4	465
KK_LAKE02	Historic Reservoir	10/10/18	0.00	0.03	-12.29	0.81	-12.31	23.7	29.5	430
KK_LAKE03	Historic Reservoir	10/10/18	2.86	0.07	-0.28	0.50	-23.17	23.1	28.9	465
KK_LAKE01	Taalaab	10/14/17	0.90	0.12	-10.20	0.54	-17.44	27.2	31.2	394
KK_LAKE01	Taalaab	10/14/17	1.19	0.14	-8.91	0.21	-18.43	27.2	31.2	394
KK_LAKE01	Taalaab	11/14/16	0.21	0.08	-16.54	0.08	-18.23	23.8	-	394
KK_Nallah	KK_Nallah	10/31/17	-2.38	0.19	-22.86	0.68	-3.83	21.5	-	-
KK_smallNallah	KK_Nallah	10/31/17	-2.88	0.14	-25.64	0.31	-2.62	-	-	-
NKT_HP12	Outlier (Amer Inflow)	12/23/17	-5.39	0.08	-37.75	0.24	5.41	27.6	24.7	382
NKT_HP12	Outlier (Amer Inflow)	10/14/17	-5.52	0.03	-38.01	0.41	6.14	30	-	382
KK_HP08	Outlier (Amer Inflow)	10/10/18	-5.84	0.03	-38.84	0.63	7.91	30.3	35.7	418
NKT_HP12	Outlier (Amer Inflow)	10/15/18	-5.63	0.07	-37.38	0.14	7.69	28.6	-	382
KK_BW08	Outlier (Amer Plain)	10/13/17	-3.80	0.09	-28.03	0.81	2.34	29.3	30.9	387
NKT_DW02	Outlier (NKT Dug well)	11/8/16	-3.42	0.06	-27.88	0.11	-0.50	26.9	-	384
NKT_DW02	Outlier (NKT Dug well)	11/12/16	-3.31	0.06	-28.61	0.28	-2.11	26.8	-	384
KK_HP26	KK_HP26	10/10/18	5.73	0.06	17.31	0.52	-28.57	26.7	25.6	429
Rain	Rain	1/26/17	-4.84	0.04	-22.47	0.21	16.21	-	-	-
Rain	Rain	1/26/17	-1.60	0.05	0.28	0.10	13.10	-	-	-
Rain	Rain	1/26/17	-0.75	0.06	3.81	0.28	9.80	-	-	-
Rain	Rain	3/10/17	2.35	0.06	34.11	0.18	15.34	-	-	-
Rain	Rain	7/29/17	-14.12	0.03	-102.11	0.23	10.84	-	-	-
Rain	Rain	7/29/17	-14.14	0.04	-101.11	0.60	12.02	-	-	-
Rain	Rain	7/29/17	-14.16	0.07	-102.22	0.26	11.03	-	-	-
Rain	Rain	8/31/17	-12.83	0.03	-91.13	0.21	11.48	-	-	-
Rain	Rain	9/6/17	-1.71	0.11	-7.53	0.34	6.17	-	-	-
Rain	Rain	9/12/17	1.48	0.11	13.80	0.32	1.97	-	-	-
Rain	Rain	9/13/17	-0.29	0.23	8.70	0.52	11.03	-	-	-
Rain	Rain	12/11/17	1.23	0.06	12.4	0.29	2.55	-	-	-

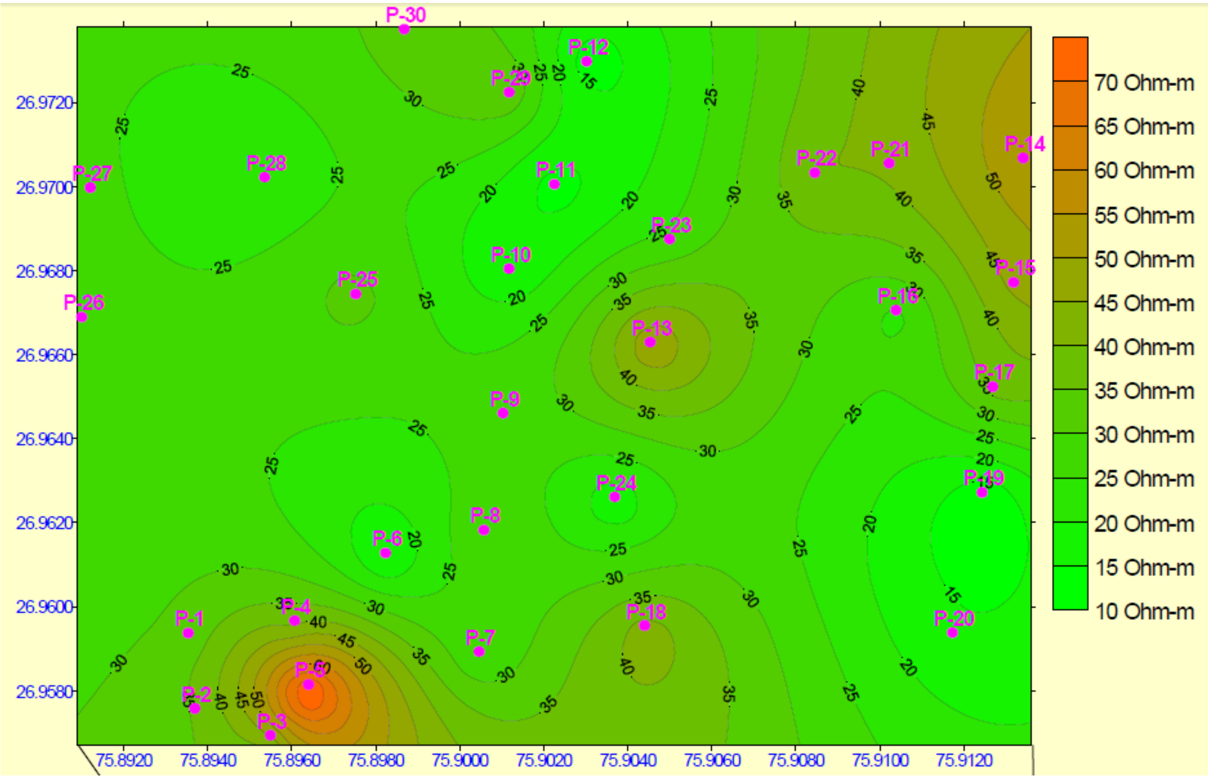
A 4 Results from stable nitrate isotopes analysis. $\delta^{18}O$ was measured for nine samples.

Well ID	Sub-group	Date	$\delta^{15}N_{AIR}$ [‰]	sd $\delta^{15}N$ [‰]	$\delta^{18}O_{VSMOW}$ [‰]	sd $\delta^{18}O$ [‰]
NKT_BW27	-	11/12/16	13.99	0.13	-7.98	1.10
NKT_BW36	-	11/12/16	15.52	0.15	-5.54	0.70
NKT_HP05	-	11/12/16	14.57	0.09	-6.72	1.17
KK_HP01	Amer Hillside	11/14/16	14.61	0.16	-11.77	0.03
KK_HP16	Amer Hillside	11/14/16	16.29	0.20	-10.22	0.02
KK_HP01	Amer Hillside	10/11/17	14.15	0.13	-	-
KK_HP10	Amer Hillside	10/12/17	17.34	0.08	-	-
KK_HP15	Amer Hillside	10/12/17	16.86	0.05	-	-
KK_BW03	Amer Hillside	10/13/17	14.88	0.02	-	-
KK_HP02	Amer Hillside	10/14/17	17.66	0.35	-	-
KK_HP16	Amer Hillside	10/14/17	16.20	0.02	-	-
NKT_BW01	Amer Plain	11/12/16	14.12	0.08	-7.00	0.36
PHED01	Amer Plain	10/14/17	15.03	0.05	-	-
KK_HP03	Amer Valley	10/11/17	15.10	0.06	-	-
KK_HP19	Amer Valley	10/11/17	13.46	0.03	-	-
KK_BW02	Amer Valley	10/13/17	14.81	0.06	-	-
KK_LAKE02	Historic Reservoir	10/12/17	-	-	-	-
NKT_BW25	NKT East	10/10/17	15.08	0.06	-	-
NKT_BW42	NKT East	10/10/17	12.99	0.06	-	-
NKT_BW41	NKT North	10/13/17	16.14	0.10	-	-
NKT_BW03	NKT West	10/9/17	13.39	0.14	-	-
NKT_BW47	NKT West	10/10/17	12.84	0.08	-	-
KK_BW08	Outlier (Amer Plain)	10/13/17	17.52	0.06	-	-
NKT_DW02	Outlier (NKT Dug well)	11/12/16	15.91	0.03	-6.06	0.85
KK_LAKE01	Taalaab	11/14/16	4.40	0.01	8.44	1.42
KK_LAKE01	Taalaab	10/14/17	6.54	0.01	-	-
Public Water Line	-	11/11/16	10.12	0.17	-14.25	0.32
Wastewater	-	10/10/17	-	-	-	-
Wastewater	-	10/31/17	-	-	-	-
Dung	-	-	12.29	0.22	-	-
UREA	-	-	-0.21	0.06	-	-

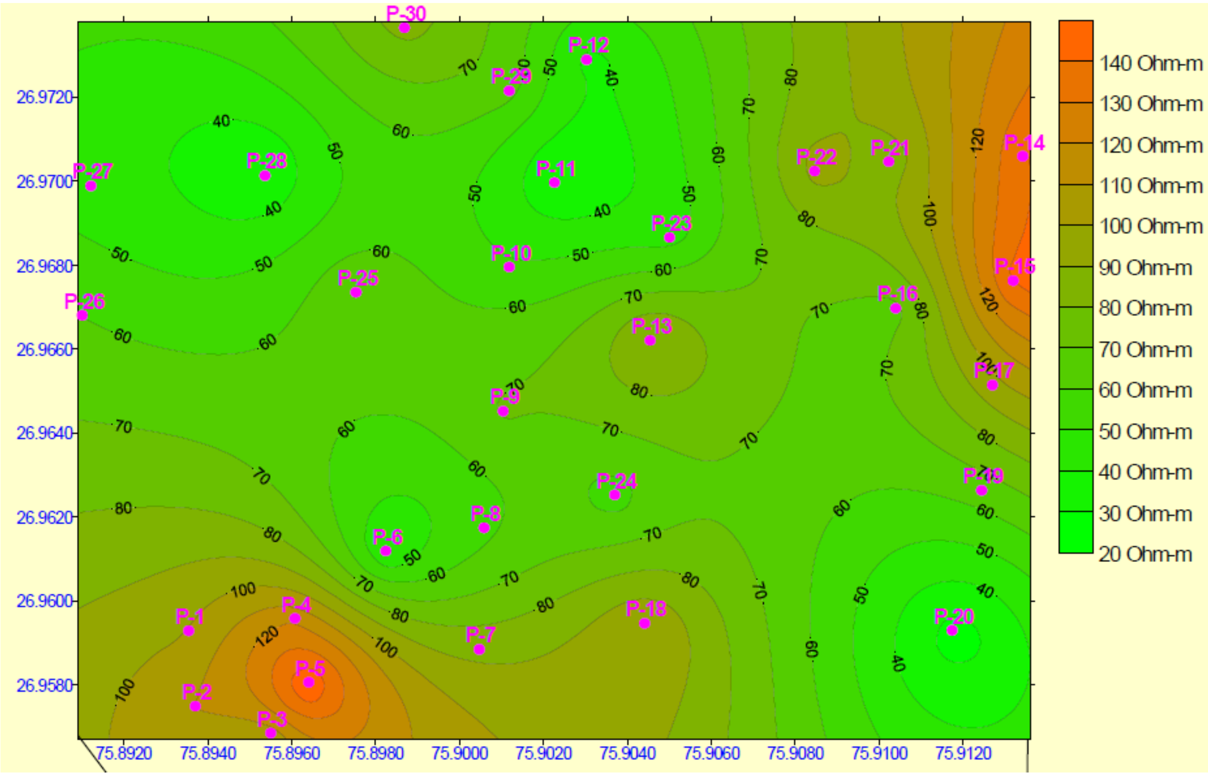
A 5 Geoelectrical Resistivity Soundings



ISO resistivity section at 20 m depth. Purple points show locations of geoelectrical resistivity soundings.



ISO resistivity section at 40 m depth. Purple points show locations of geoelectrical resistivity soundings. Attention: Scale is different to 20 m section.



ISO resistivity section at 60 m depth. Purple points show locations of geoelectrical resistivity soundings. Attention: Scale is different to 20 and 40 m section.

A 6 Depth to water measurements

Well ID	Date	Longitude	Latitude	Altitude GPS [m a.s.l]	Water Table [m a.s.l]	Depth to Water [m]	Altitude DGPS [m a.s.l]
KK_DW01	7/5/15	75,862117	26,990117	405			397,172
KK_DW06	7/5/15	75,850450	26,992417	436			
KK_DW01	9/26/15	75,862117	26,990117	405			397,172
KK_DW02	9/26/15	75,860133	26,989317	404	390	14	399,272
KK_DW06	9/26/15	75,850450	26,992417	436	424	12	
KK_OBS03	9/26/15	75,850450	26,992417	436			
KK_SW03	10/19/16	75,862317	26,985833	410	399	11	395,872
KK_DW03	10/19/16	75,856333	26,988733	415	403	12	404,574
KK_DW09	10/19/16	75,854400	26,986850	421			408,587
KK_DW04	10/19/16	75,851483	26,990617	414			413,699
KK_DW08	10/19/16	75,851533	26,989283	432			415,360
KK_BW06	10/19/16	75,850633	26,992267	423	413	10	
KK_DW05	10/19/16	75,851117	26,991050	422	412	10	
KK_DW06	10/19/16	75,850450	26,992417	436	424	12	
KK_DW07	10/19/16	75,850733	26,989117	428			
KK_SW01	10/19/16	75,851117	26,991050	422			
KK_SW02	10/19/16	75,859633	26,987633	418			
NKT_BW13	10/25/16	75,901933	26,960333	384	358	26	
NKT_DW02	10/25/16	75,900917	26,968700	384	350	34	
KK_DW10	10/26/16	75,862967	26,985700	405	394	11	
KK_DW11	10/26/16	75,861900	26,986917	404	393	11	
KK_OBS01	10/26/16	75,863033	26,985100	406	395	11	
NKT_BW16	11/4/16	75,902267	26,965317	386	359	27	
KK_SW03	11/16/16	75,862317	26,985833	410	398	12	395,872
KK_DW12	11/16/16	75,861350	26,988900	401	389	12	397,056
KK_DW01	11/16/16	75,862117	26,990117	405	392	13	397,172
KK_DW01	12/3/16	75,862117	26,990117	405	391	14	397,172
KK_DW09	12/6/16	75,854400	26,986850	421	410	11	408,587
KK_DW04	12/6/16	75,851483	26,990617	414			413,699
KK_DW07	12/6/16	75,850733	26,989117	428			
KK_DW09	12/16/16	75,854400	26,986850	421	410	11	408,587
KK_DW04	12/16/16	75,851483	26,990617	414	405	9	413,699
KK_DW08	12/16/16	75,851533	26,989283	432	419	13	415,360
KK_BW06	12/16/16	75,850633	26,992267	423	413	10	
KK_DW05	12/16/16	75,851117	26,991050	422	412	10	
KK_DW06	12/16/16	75,850450	26,992417	436	419	17	
KK_DW07	12/16/16	75,850733	26,989117	428	412	16	
KK_DW17	12/16/16	75,864800	26,982600	408	387	21	
KK_OBS03	12/16/16	75,850450	26,992417	436			
KK_DW18	12/17/16	75,870933	26,991167	390	373	17	389,132
KK_SW07	12/17/16	75,869217	26,989117	393	374	19	391,495
KK_DW19	12/17/16	75,871567	26,990917	400	382	18	
KK_DW20	12/17/16	75,869750	26,988917	393	375	18	

Well ID	Date	Longitude	Latitude	Altitude GPS [m a.s.l]	Water Table [m a.s.l]	Depth to Water [m]	Altitude DGPS [m a.s.l]
KK_DW22	12/22/16	75,865667	26,995167	405	390	15	391,556
KK_DW21	12/22/16	75,864433	26,992150	403	387	16	
KK_DW12	12/27/16	75,861350	26,988900	401	390	11	397,056
KK_HP18	12/27/16	75,862500	26,990533	408	389	19	397,663
KK_DW13	12/27/16	75,862817	26,992300	408	389	19	402,221
KK_HP12	12/27/16	75,861867	26,991917	410	377	33	406,269
KK_OBS02	12/28/16	75,873467	26,992033	408	390	18	388,511
KK_DW02	12/28/16	75,860133	26,989317	404	392	12	399,272
KK_DW10	12/28/16	75,862967	26,985700	405	391	14	
KK_SW05	12/30/16	75,866133	26,979800	391	369	22	389,583
KK_DW25	12/30/16	75,871500	26,975100	393	374	19	
NKT_BW02	1/19/17	75,900917	26,963733	380	356	24	
KK_OBS02	2/25/17	75,873467	26,992033	408			388,511
KK_DW18	2/25/17	75,870933	26,991167	390	372	18	389,132
KK_DW22	2/25/17	75,865667	26,995167	405	389	16	391,556
KK_DW12	2/25/17	75,861350	26,988900	401	390	11	397,056
KK_DW01	2/25/17	75,862117	26,990117	405	391	14	397,172
KK_DW02	2/25/17	75,860133	26,989317	404	392	12	399,272
KK_DW13	2/25/17	75,862817	26,992300	408	389	19	402,221
KK_DW03	2/25/17	75,856333	26,988733	415	403	12	404,574
KK_DW09	2/25/17	75,854400	26,986850	421	410	11	408,587
KK_DW04	2/25/17	75,851483	26,990617	414	404	10	413,699
KK_DW08	2/25/17	75,851533	26,989283	432	419	13	415,360
KK_DW05	2/25/17	75,851117	26,991050	422	412	10	
KK_DW07	2/25/17	75,850733	26,989117	428	412	16	
KK_DW19	2/25/17	75,871567	26,990917	400	381	19	
KK_DW21	2/25/17	75,864433	26,992150	403	385	18	
KK_DW30	2/26/17	75,870917	26,968383	391	387	4	380,351
KK_DW29	2/26/17	75,868867	26,964817	387	380	7	381,926
KK_DW28	2/26/17	75,867750	26,976400	394	374	20	385,896
KK_SW05	2/26/17	75,866133	26,979800	391	367	24	389,583
KK_SW07	2/26/17	75,869217	26,989117	393	372	21	391,495
KK_SW04	2/26/17	75,866150	26,983133	407	384	23	391,731
KK_SW03	2/26/17	75,862317	26,985833	410	395	15	395,872
KK_DW11	2/26/17	75,861900	26,986917	404	390	14	
KK_DW17	2/26/17	75,864800	26,982600	408	385	23	
KK_DW20	2/26/17	75,869750	26,988917	393	374	19	
KK_DW25	2/26/17	75,871500	26,975100	393	372	21	
KK_SW06	2/26/17	75,863783	26,988900	401	377	24	
KK_SW09	2/26/17	75,869317	26,965533	393	386	7	
NKT_DW08	2/28/17	75,873950	26,974883	388	368	20	
NKT_DW09	2/28/17	75,879067	26,977233	390	370	20	
NKT_DW10	2/28/17	75,876683	26,972883	390	374	16	
NKT_DW11	3/2/17	75,869833	26,961583	395	391	4	380,541

Well ID	Date	Longitude	Latitude	Altitude GPS [m a.s.l]	Water Table [m a.s.l]	Depth to Water [m]	Altitude DGPS [m a.s.l]
KK_DW36	3/2/17	75,870033	26,979100	398	373	25	387,051
KK_DW31	3/2/17	75,864450	26,983717	400	378	22	
KK_DW32	3/2/17	75,863533	26,984067	403	382	21	
KK_DW33	3/2/17	75,864433	26,980750	399	376	23	
KK_DW35	3/2/17	75,868800	26,980533	391	367	24	
KK_DW37	3/2/17	75,869600	26,976183	398	377	21	
NKT_DW12	3/2/17	75,882350	26,964417	376	370	6	
NKT_DW20	3/4/17	75,892817	26,960383	376	363	13	369,735
NKT_DW23	3/4/17	75,890333	26,953817	384	361	23	375,282
NKT_DW19	3/4/17	75,879883	26,955100	386	370	16	377,003
NKT_DW17	3/4/17	75,877067	26,950883	391	372	19	381,149
KK_DW38	3/4/17	75,874900	26,991683	394	374	20	386,797
NKT_DW14	3/4/17	75,875683	26,990800	389	366	23	
NKT_DW21	3/4/17	75,896483	26,960050	400	380	20	
NKT_DW22	3/4/17	75,888367	26,952517	386	360	26	
NKT_DW24	3/4/17	75,887783	26,957900	382	360	22	
KK_OBS02	4/7/17	75,873467	26,992033	408	386	22	388,511
KK_DW29	4/18/17	75,868867	26,964817	387	380	7	381,926
KK_DW28	4/18/17	75,867750	26,976400	394	373	21	385,896
KK_SW05	4/18/17	75,866133	26,979800	391			389,583
KK_DW22	4/18/17	75,865667	26,995167	405			391,556
KK_SW04	4/18/17	75,866150	26,983133	407	381	26	391,731
KK_SW03	4/18/17	75,862317	26,985833	410			395,872
KK_DW12	4/18/17	75,861350	26,988900	401	388	13	397,056
KK_DW01	4/18/17	75,862117	26,990117	405	388	17	397,172
KK_HP18	4/18/17	75,862500	26,990533	408	384	24	397,663
KK_DW02	4/18/17	75,860133	26,989317	404	390	14	399,272
KK_DW13	4/18/17	75,862817	26,992300	408			402,221
KK_DW03	4/18/17	75,856333	26,988733	415	403	12	404,574
KK_HP12	4/18/17	75,861867	26,991917	410	388	22	406,269
KK_DW09	4/18/17	75,854400	26,986850	421	409	12	408,587
KK_DW04	4/18/17	75,851483	26,990617	414	404	10	413,699
KK_DW08	4/18/17	75,851533	26,989283	432	418	14	415,360
KK_DW05	4/18/17	75,851117	26,991050	422	411	11	
KK_DW07	4/18/17	75,850733	26,989117	428	411	17	
KK_DW11	4/18/17	75,861900	26,986917	404	388	16	
KK_DW17	4/18/17	75,864800	26,982600	408			
KK_DW21	4/18/17	75,864433	26,992150	403			
KK_DW31	4/18/17	75,864450	26,983717	400			
KK_DW32	4/18/17	75,863533	26,984067	403	380	23	
KK_DW33	4/18/17	75,864433	26,980750	399	374	25	
KK_SW06	4/18/17	75,863783	26,988900	401			
KK_SW09	4/18/17	75,869317	26,965533	393	384	9	
KK_DW30	4/19/17	75,870917	26,968383	391	386	5	380,351

Well ID	Date	Longitude	Latitude	Altitude GPS [m a.s.l]	Water Table [m a.s.l]	Depth to Water [m]	Altitude DGPS [m a.s.l]
NKT_DW11	4/19/17	75,869833	26,961583	395	391	4	380,541
KK_DW38	4/19/17	75,874900	26,991683	394	372	22	386,797
KK_DW36	4/19/17	75,870033	26,979100	398	372	26	387,051
KK_OBS02	4/19/17	75,873467	26,992033	408	384	24	388,511
KK_DW18	4/19/17	75,870933	26,991167	390	370	20	389,132
KK_SW07	4/19/17	75,869217	26,989117	393	370	23	391,495
KK_DW19	4/19/17	75,871567	26,990917	400	378	22	
KK_DW20	4/19/17	75,869750	26,988917	393	370	23	
KK_DW25	4/19/17	75,871500	26,975100	393	372	21	
KK_DW35	4/19/17	75,868800	26,980533	391			
KK_DW37	4/19/17	75,869600	26,976183	398			
KK_HP25	4/19/17	75,875383	26,984300	398			
NKT_DW08	4/19/17	75,873950	26,974883	388	369	19	
NKT_DW14	4/19/17	75,875683	26,990800	389	363	26	
NKT_HP10	4/19/17	75,875633	26,983350	389			
NKT_HP11	4/19/17	75,873650	26,979200	394	370	24	
NKT_DW20	4/21/17	75,892817	26,960383	376	363	13	369,735
NKT_DW26	4/21/17	75,883833	26,962317	379	370	9	374,300
NKT_DW23	4/21/17	75,890333	26,953817	384	360	24	375,282
NKT_DW19	4/21/17	75,879883	26,955100	386	369	17	377,003
NKT_DW17	4/21/17	75,877067	26,950883	391	375	16	381,149
NKT_DW25	4/21/17	75,882950	26,962967	382	375	7	
KK_HP18	4/29/17	75,862500	26,990533	408	382	26	397,663
NKT_DW30	5/7/17	75,891967	26,975700	386			378,664
KK_DW39	5/7/17	75,887117	27,034083	399	386	13	
NKT_DW27	5/7/17	75,909033	27,021333	408			
NKT_DW28	5/7/17	75,906617	27,025533	411			
NKT_DW29	5/7/17	75,892000	27,024250	399			
NKT_DW31	5/9/17	75,919100	26,970983	374	326	48	
NKT_DW32	5/9/17	75,919000	26,951900	373	348	25	
NKT_HP07	5/11/17	75,903450	26,968167	388	357	31	373,629
NKT_OBS01	5/11/17	75,890900	27,000267	381	343	38	379,502
KK_DW12	7/15/17	75,861350	26,988900	401			397,056
KK_DW01	7/15/17	75,862117	26,990117	405			397,172
KK_HP18	7/15/17	75,862500	26,990533	408			397,663
KK_DW02	7/15/17	75,860133	26,989317	404			399,272
KK_DW03	7/15/17	75,856333	26,988733	415	404	11	404,574
KK_DW09	7/15/17	75,854400	26,986850	421	411	10	408,587
KK_DW04	7/15/17	75,851483	26,990617	414	405	9	413,699
KK_DW08	7/15/17	75,851533	26,989283	432	419	13	415,360
KK_DW05	7/15/17	75,851117	26,991050	422	412	10	
KK_DW07	7/15/17	75,850733	26,989117	428	411	17	
NKT_DW20	7/16/17	75,892817	26,960383	376	363	13	369,735
NKT_DW26	7/16/17	75,883833	26,962317	379	370	9	374,300

Well ID	Date	Longitude	Latitude	Altitude GPS [m a.s.l]	Water Table [m a.s.l]	Depth to Water [m]	Altitude DGPS [m a.s.l]
NKT_DW23	7/16/17	75,890333	26,953817	384	361	23	375,282
NKT_DW19	7/16/17	75,879883	26,955100	386	370	16	377,003
NKT_OBS01	7/16/17	75,890900	27,000267	381	341	40	379,502
KK_DW30	7/16/17	75,870917	26,968383	391	386	5	380,351
NKT_DW11	7/16/17	75,869833	26,961583	395	392	3	380,541
NKT_DW17	7/16/17	75,877067	26,950883	391	375	16	381,149
KK_DW29	7/16/17	75,868867	26,964817	387	380	7	381,926
KK_DW28	7/16/17	75,867750	26,976400	394	372	22	385,896
KK_DW36	7/16/17	75,870033	26,979100	398	371	27	387,051
KK_OBS02	7/16/17	75,873467	26,992033	408	379	29	388,511
KK_DW18	7/16/17	75,870933	26,991167	390			389,132
KK_SW07	7/16/17	75,869217	26,989117	393			391,495
KK_SW04	7/16/17	75,866150	26,983133	407			391,731
KK_DW03	7/16/17	75,856333	26,988733	415	404	11	404,574
KK_HP12	7/16/17	75,861867	26,991917	410	380	30	406,269
KK_DW09	7/16/17	75,854400	26,986850	421	411	10	408,587
KK_DW04	7/16/17	75,851483	26,990617	414	404	10	413,699
KK_DW08	7/16/17	75,851533	26,989283	432	419	13	415,360
KK_DW05	7/16/17	75,851117	26,991050	422	412	10	
KK_DW06	7/16/17	75,850450	26,992417	436	422	14	
KK_DW11	7/16/17	75,861900	26,986917	404			
KK_DW25	7/16/17	75,871500	26,975100	393	371	22	
KK_DW33	7/16/17	75,864433	26,980750	399	374	25	
KK_SW09	7/16/17	75,869317	26,965533	393	386	7	
NKT_DW02	7/16/17	75,900917	26,968700	384	352	32	
NKT_DW08	7/16/17	75,873950	26,974883	388	368	20	
NKT_DW12	7/16/17	75,882350	26,964417	376			
NKT_DW32	7/16/17	75,919000	26,951900	373	347	26	
NKT_OBS01	8/2/17	75,890900	27,000267	381	341	40	379,502
KK_BW01	8/24/17	75,862217	26,990117	403	362	41	
NKT_DW20	9/13/17	75,892817	26,960383	376	363	13	369,735
NKT_HP07	9/13/17	75,903450	26,968167	388	357	31	373,629
NKT_DW26	9/13/17	75,883833	26,962317	379	371	8	374,300
NKT_DW23	9/13/17	75,890333	26,953817	384	361	23	375,282
NKT_DW19	9/13/17	75,879883	26,955100	386	372	14	377,003
NKT_DW30	9/13/17	75,891967	26,975700	386			378,664
NKT_DW11	9/13/17	75,869833	26,961583	395	392	3	380,541
NKT_DW17	9/13/17	75,877067	26,950883	391	376	15	381,149
NKT_DW02	9/13/17	75,900917	26,968700	384	353	31	
NKT_DW31	9/13/17	75,919100	26,970983	374	327	47	
NKT_DW32	9/13/17	75,919000	26,951900	373	347	26	
NKT_OBS02	9/13/17	75,897017	26,969283	372	342	30	
KK_OBS02	9/14/17	75,873467	26,992033	408	383	25	388,511
KK_DW12	9/14/17	75,861350	26,988900	401	388	13	397,056

Well ID	Date	Longitude	Latitude	Altitude GPS [m a.s.l]	Water Table [m a.s.l]	Depth to Water [m]	Altitude DGPS [m a.s.l]
KK_DW01	9/14/17	75,862117	26,990117	405	384	21	397,172
KK_DW02	9/14/17	75,860133	26,989317	404	392	12	399,272
KK_DW13	9/14/17	75,862817	26,992300	408			402,221
KK_DW03	9/14/17	75,856333	26,988733	415	404	11	404,574
KK_HP12	9/14/17	75,861867	26,991917	410	386	24	406,269
KK_DW09	9/14/17	75,854400	26,986850	421	411	10	408,587
KK_DW04	9/14/17	75,851483	26,990617	414	406	8	413,699
KK_DW08	9/14/17	75,851533	26,989283	432	419	13	415,360
KK_BW01	9/14/17	75,862217	26,990117	403	379	24	
KK_DW05	9/14/17	75,851117	26,991050	422	411	11	
NKT_OBS01	9/15/17	75,890900	27,000267	381	342	39	379,502
KK_DW30	9/15/17	75,870917	26,968383	391	387	4	380,351
KK_DW29	9/15/17	75,868867	26,964817	387	383	4	381,926
KK_DW28	9/15/17	75,867750	26,976400	394	372	22	385,896
KK_DW38	9/15/17	75,874900	26,991683	394	369	25	386,797
KK_DW36	9/15/17	75,870033	26,979100	398	372	26	387,051
KK_DW18	9/15/17	75,870933	26,991167	390			389,132
KK_SW05	9/15/17	75,866133	26,979800	391	369	22	389,583
KK_SW07	9/15/17	75,869217	26,989117	393	371	22	391,495
KK_DW22	9/15/17	75,865667	26,995167	405	389	16	391,556
KK_SW04	9/15/17	75,866150	26,983133	407	385	22	391,731
KK_SW03	9/15/17	75,862317	26,985833	410			395,872
KK_DW10	9/15/17	75,862967	26,985700	405			
KK_DW11	9/15/17	75,861900	26,986917	404			
KK_DW17	9/15/17	75,864800	26,982600	408	388	20	
KK_DW19	9/15/17	75,871567	26,990917	400			
KK_DW20	9/15/17	75,869750	26,988917	393	372	21	
KK_DW21	9/15/17	75,864433	26,992150	403	385	18	
KK_DW25	9/15/17	75,871500	26,975100	393	372	21	
KK_DW32	9/15/17	75,863533	26,984067	403	385	18	
KK_DW33	9/15/17	75,864433	26,980750	399	379	20	
KK_DW35	9/15/17	75,868800	26,980533	391			
KK_DW37	9/15/17	75,869600	26,976183	398	376	22	
KK_SW06	9/15/17	75,863783	26,988900	401			
KK_SW09	9/15/17	75,869317	26,965533	393	389	4	
NKT_DW08	9/15/17	75,873950	26,974883	388	369	19	
KK_OBS02	10/18/17	75,873467	26,992033	408	379	29	388,511
NKT_HP07	11/4/17	75,903450	26,968167	388	357	31	373,629
NKT_BW06	11/4/17	75,897133	26,963567	380	359	21	
NKT_OBS02	11/4/17	75,897017	26,969283	372	341	31	
NKT_DW20	11/15/17	75,892817	26,960383	376	362	14	369,735
NKT_DW26	11/15/17	75,883833	26,962317	379	370	9	374,300
NKT_DW23	11/15/17	75,890333	26,953817	384	361	23	375,282
NKT_DW19	11/15/17	75,879883	26,955100	386	372	14	377,003

Well ID	Date	Longitude	Latitude	Altitude GPS [m a.s.l]	Water Table [m a.s.l]	Depth to Water [m]	Altitude DGPS [m a.s.l]
NKT_DW11	11/15/17	75,869833	26,961583	395	391	4	380,541
NKT_DW17	11/15/17	75,877067	26,950883	391	377	14	381,149
KK_DW29	11/15/17	75,868867	26,964817	387	380	7	381,926
KK_SW09	11/15/17	75,869317	26,965533	393	387	6	
NKT_DW02	11/15/17	75,900917	26,968700	384	350	34	
NKT_DW31	11/15/17	75,919100	26,970983	374	327	47	
NKT_DW32	11/15/17	75,919000	26,951900	373	347	26	
KK_DW30	11/16/17	75,870917	26,968383	391	387	4	380,351
KK_DW28	11/16/17	75,867750	26,976400	394	372	22	385,896
KK_DW38	11/16/17	75,874900	26,991683	394	366	28	386,797
KK_DW36	11/16/17	75,870033	26,979100	398	372	26	387,051
KK_OBS02	11/16/17	75,873467	26,992033	408	379	29	388,511
KK_DW18	11/16/17	75,870933	26,991167	390			389,132
KK_SW05	11/16/17	75,866133	26,979800	391			389,583
KK_SW07	11/16/17	75,869217	26,989117	393	369	24	391,495
KK_DW22	11/16/17	75,865667	26,995167	405			391,556
KK_SW04	11/16/17	75,866150	26,983133	407	380	27	391,731
KK_DW12	11/16/17	75,861350	26,988900	401			397,056
KK_DW01	11/16/17	75,862117	26,990117	405			397,172
KK_DW02	11/16/17	75,860133	26,989317	404	389	15	399,272
KK_DW13	11/16/17	75,862817	26,992300	408			402,221
KK_DW03	11/16/17	75,856333	26,988733	415	403	12	404,574
KK_HP12	11/16/17	75,861867	26,991917	410			406,269
KK_DW09	11/16/17	75,854400	26,986850	421	410	11	408,587
KK_DW04	11/16/17	75,851483	26,990617	414	404	10	413,699
KK_DW08	11/16/17	75,851533	26,989283	432	418	14	415,360
KK_BW01	11/16/17	75,862217	26,990117	403	355	48	
KK_DW05	11/16/17	75,851117	26,991050	422	412	10	
KK_DW17	11/16/17	75,864800	26,982600	408	384	24	
KK_DW19	11/16/17	75,871567	26,990917	400			
KK_DW21	11/16/17	75,864433	26,992150	403			
KK_DW25	11/16/17	75,871500	26,975100	393	372	21	
KK_DW32	11/16/17	75,863533	26,984067	403	380	23	
KK_DW33	11/16/17	75,864433	26,980750	399	375	24	
NKT_DW08	11/16/17	75,873950	26,974883	388	368	20	
KK_HP18	11/25/17	75,862500	26,990533	408	360	48	397,663
NKT_OBS01	12/4/17	75,890900	27,000267	381	341	40	379,502
NKT_HP07	12/14/17	75,903450	26,968167	388	357	31	373,629
NKT_OBS02	12/14/17	75,897017	26,969283	372	341	31	
NKT_DW26	12/20/17	75,883833	26,962317	379	370	9	374,300
NKT_DW11	12/20/17	75,869833	26,961583	395	391	4	380,541
KK_DW29	12/20/17	75,868867	26,964817	387	380	7	381,926
KK_SW09	12/20/17	75,869317	26,965533	393	384	9	
KK_DW02	12/21/17	75,860133	26,989317	404	390	14	399,272

Well ID	Date	Longitude	Latitude	Altitude GPS [m a.s.l]	Water Table [m a.s.l]	Depth to Water [m]	Altitude DGPS [m a.s.l]
KK_DW03	12/21/17	75,856333	26,988733	415	403	12	404,574
KK_DW09	12/21/17	75,854400	26,986850	421	410	11	408,587
KK_DW04	12/21/17	75,851483	26,990617	414	404	10	413,699
KK_DW08	12/21/17	75,851533	26,989283	432	418	14	415,360
KK_BW01	12/21/17	75,862217	26,990117	403			
KK_DW05	12/21/17	75,851117	26,991050	422	412	10	
KK_DW30	12/22/17	75,870917	26,968383	391	387	4	380,351
KK_DW38	12/22/17	75,874900	26,991683	394			386,797
KK_DW36	12/22/17	75,870033	26,979100	398	372	26	387,051
KK_SW07	12/22/17	75,869217	26,989117	393			391,495
KK_DW25	12/22/17	75,871500	26,975100	393	372	21	
NKT_DW08	12/22/17	75,873950	26,974883	388	368	20	
NKT_DW32	12/22/17	75,919000	26,951900	373	347	26	
NKT_DW20	12/23/17	75,892817	26,960383	376	363	13	369,735
NKT_HP07	12/23/17	75,903450	26,968167	388	357	31	373,629
NKT_DW23	12/23/17	75,890333	26,953817	384	361	23	375,282
NKT_DW19	12/23/17	75,879883	26,955100	386	372	14	377,003
NKT_OBS01	12/23/17	75,890900	27,000267	381	340	41	379,502
NKT_DW17	12/23/17	75,877067	26,950883	391	377	14	381,149
KK_DW28	12/23/17	75,867750	26,976400	394	372	22	385,896
KK_OBS02	12/23/17	75,873467	26,992033	408	380	28	388,511
KK_SW04	12/23/17	75,866150	26,983133	407			391,731
KK_DW17	12/23/17	75,864800	26,982600	408			
KK_DW32	12/23/17	75,863533	26,984067	403			
KK_DW33	12/23/17	75,864433	26,980750	399	374	25	
NKT_DW02	12/23/17	75,900917	26,968700	384	352	32	
NKT_DW31	12/23/17	75,919100	26,970983	374	326	48	
NKT_OBS02	12/23/17	75,897017	26,969283	372	341	31	
KK_DW22	10/10/18	75,865667	26,995167	405	389	16	391,556
KK_DW12	10/10/18	75,861350	26,988900	401	388	13	397,056
KK_DW01	10/10/18	75,862117	26,990117	405	383	22	397,172
KK_HP18	10/10/18	75,862500	26,990533	408	365	43	397,663
KK_DW02	10/10/18	75,860133	26,989317	404	392	12	399,272
KK_DW13	10/10/18	75,862817	26,992300	408			402,221
KK_DW03	10/10/18	75,856333	26,988733	415	404	11	404,574
KK_DW04	10/10/18	75,851483	26,990617	414	404	10	413,699
KK_DW08	10/10/18	75,851533	26,989283	432	422	10	415,360
KK_DW05	10/10/18	75,851117	26,991050	422	412	10	
KK_DW21	10/10/18	75,864433	26,992150	403	385	18	
KK_SW09	10/10/18	75,869317	26,965533	393	382	11	
NKT_DW20	10/11/18	75,892817	26,960383	376	363	13	369,735
NKT_DW26	10/11/18	75,883833	26,962317	379	371	8	374,300
NKT_DW23	10/11/18	75,890333	26,953817	384	359	25	375,282
NKT_DW19	10/11/18	75,879883	26,955100	386	372	14	377,003

Well ID	Date	Longitude	Latitude	Altitude GPS [m a.s.l]	Water Table [m a.s.l]	Depth to Water [m]	Altitude DGPS [m a.s.l]
KK_DW30	10/11/18	75,870917	26,968383	391	387	4	380,351
NKT_DW11	10/11/18	75,869833	26,961583	395	392	3	380,541
NKT_DW17	10/11/18	75,877067	26,950883	391	377	14	381,149
KK_DW29	10/11/18	75,868867	26,964817	387	378	9	381,926
KK_DW25	10/11/18	75,871500	26,975100	393	371	22	
KK_SW09	10/11/18	75,869317	26,965533	393	385	8	
NKT_DW02	10/11/18	75,900917	26,968700	384	346	38	
NKT_DW08	10/11/18	75,873950	26,974883	388	363	25	
NKT_DW31	10/11/18	75,919100	26,970983	374	331	43	
NKT_DW32	10/11/18	75,919000	26,951900	373	347	26	
NKT_OBS02	10/11/18	75,897017	26,969283	372			
NKT_OBS01	10/15/18	75,890900	27,000267	381			379,502
KK_DW28	10/15/18	75,867750	26,976400	394	372	22	385,896
KK_DW38	10/15/18	75,874900	26,991683	394			386,797
KK_DW36	10/15/18	75,870033	26,979100	398	371	27	387,051
KK_SW07	10/15/18	75,869217	26,989117	393	369	24	391,495
KK_SW04	10/15/18	75,866150	26,983133	407	383	24	391,731
KK_SW03	10/15/18	75,862317	26,985833	410	388	22	395,872
KK_DW11	10/15/18	75,861900	26,986917	404			
KK_DW17	10/15/18	75,864800	26,982600	408	388	20	
KK_DW32	10/15/18	75,863533	26,984067	403	385	18	
KK_DW33	10/15/18	75,864433	26,980750	399	379	20	
NKT_BW06	10/10/07	75,897133	26,963567	380	359	21	

A7 Interview Data from MHT (MHT, 2016)

Row number	Slum_Name	FullTime_Earning_members	PartTime_Earning_members	DomesticWork	ConstructionWorkLabourMason	StitchingTailoring	VendingVegetableFishFruits	Embroidery	Officehelp	DriversLMVHMV	SchoolHospitalsupportstaff	GovernmentJob	GovtInformalWorkANWMidDayMealetc	ShopGroceryStationeryHardwareOtherConsumables	BrickKilnworker	PapadMaking	Hadiyacountryliquormaking	Notworking
1	KK	5	0	Yes	No	No	No	Yes	No	No	No	No	No	No	No	No	No	
2	KK	1	0	No	Yes	No	No	No	No	No	No	No						
3	KK	1	1	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No
4	KK	1	1		Yes													
5	KK	1	0		Yes													
6	KK	3	0										Yes	Yes				
7	KK	2	0	No	Yes	No	No	Yes	No	No								
8	KK	2	0	No	No	No	No	No	No	No	No	No						
9	KK	2	0	No	Yes	No	No	No	No	Yes	No	No	No	No				
10	KK	1	2	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No
11	KK	1	0	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No
12	KK	1	1		Yes													
13	KK	3	0		Yes													
14	KK	1	0				Yes											
15	KK	1	0									Yes						
16	KK	3	0															
17	KK	2	2															
18	KK	1	0		Yes													
19	KK	1	0															
20	KK	1	0	No	Yes													
21	KK	3	0		Yes													
22	KK	3	0		Yes						Yes							
23	KK	1	0															
24	KK	1	0	Yes	No	No	No	Yes	No	No	No	No	No	No	No	No		
25	KK	1	0	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
26	NKT	1	1	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	
27	NKT	1	1	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	
28	NKT	2	0							Yes								
29	NKT	2	0					Yes										
30	NKT	1	0							Yes								
31	NKT	2	0		Yes	Yes												
32	NKT	2	0							Yes								
33	NKT	2	0							Yes								
34	NKT	1	0	Yes	No	No	No	No	No	No	No							
35	NKT	1	0	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	
36	NKT	1	0	Yes	No	No	No	No	No	No	No							
37	NKT	3	3	Yes	No	No	No	No	No	No	No							
38	NKT	3	2	No	Yes													
39	NKT	2	2	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	
40	NKT	1	1		Yes													
41	NKT	1	0	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No
42	NKT	2	0			Yes								Yes				
43	NKT	1	0							Yes								
44	NKT	1	0							Yes								
45	NKT	1	0															
46	NKT	3	0			Yes		Yes		Yes								
47	NKT	2	0		Yes				Yes									
48	NKT	1	0							Yes								
49	NKT	1	1															
50	NKT	1	1											Yes				
51	NKT	2	2	Yes	No	No	No	No	No	No	No							

Row number	Others	Family_Income_PM	Who_Fetch_Water	TimeSpend_CollectWater_General	TimeSpend_CollectWater_BreakDown	Discontinuity_Water_forMoreThan_2days	Number_Of_Times	Is_waterQuantity_Adequate_Summer
1		Between 5000 to 10000	Adult female	10 to 20 minutes	20 to 30 minutes	Yes	3	Yes
2		Below 5000	Adult female	20 to 30 minutes	20 to 30 minutes	Yes	4	No
3	No	Below 5000	Adult female	20 to 30 minutes	20 to 30 minutes	Yes	4	Yes
4	conductor in bus	Between 5000 to 10000	Adult female	10 to 20 minutes	20 to 30 minutes	No	0	Yes
5		Below 5000	Adult female	20 to 30 minutes	10 to 20 minutes	No	0	Yes
6	private teacher	Between 5000 to 10000	Adult female	20 to 30 minutes	20 to 30 minutes	Yes	3	No
7		Between 5000 to 10000	Adult female	10 to 20 minutes	20 to 30 minutes	Yes	4	No
8		Between 5000 to 10000	Adult female	Available within premises	20 to 30 minutes	Yes	0	No
9		Between 5000 to 10000	Adult female	Available within premises	20 to 30 minutes	Yes	4	No
10	No	Between 5000 to 10000	Adult female	20 to 30 minutes	20 to 30 minutes	No	0	No
11	No	Between 5000 to 10000	Adult female	20 to 30 minutes	20 to 30 minutes	Yes	4	No
12		Below 5000	Adult female	Less than 10 minutes	Less than 10 minutes	No	0	Yes
13	nagina worker	Below 5000	Adult male	20 to 30 minutes	20 to 30 minutes	No	0	No
14		Below 5000	Girl Child	10 to 20 minutes	20 to 30 minutes	Yes	20	No
15		Between 5000 to 10000	Adult female	20 to 30 minutes	Available within premises	No	0	Yes
16	nagina worker	Below 5000	Adult female	Less than 10 minutes	Less than 10 minutes	No	0	No
17	works at domiNos	Between 5000 to 10000	Adult female	Available within premises	Available within premises	Yes	3	No
18		Between 5000 to 10000	Adult female	10 to 20 minutes	20 to 30 minutes	No	0	No
19	nagina worker	Below 5000	Adult female	10 to 20 minutes	20 to 30 minutes	No	0	No
20		Between 5000 to 10000	Adult female	20 to 30 minutes	10 to 20 minutes	No	0	Yes
21	nagina worker	Below 5000	Adult male	20 to 30 minutes	20 to 30 minutes	No	0	No
22	nagina worker	Between 5000 to 10000	Adult female	10 to 20 minutes	20 to 30 minutes	Yes	10	No
23	open labour	Between 5000 to 10000	Adult female	20 to 30 minutes	20 to 30 minutes	Yes	2	Yes
24		Between 10000 to 20000	Adult female	Available within premises	20 to 30 minutes	Yes	4	Yes
25	Gardening	Between 5000 to 10000	Adult female	Available within premises	Available within premises	No	0	Yes
26		Between 5000 to 10000	Adult female	Available within premises	10 to 20 minutes	Yes	8	No
27		Between 5000 to 10000	Adult female	Available within premises	Available within premises	Yes	8	No
28	make kites	Between 5000 to 10000	Adult female	20 to 30 minutes	20 to 30 minutes	Yes	5	No
29	brokerage	Between 5000 to 10000	Adult female	20 to 30 minutes	Available within premises	Yes	20	No
30		Between 5000 to 10000	Adult female	20 to 30 minutes	20 to 30 minutes	No	0	No
31		Between 5000 to 10000	Adult female	20 to 30 minutes	10 to 20 minutes	Yes	15	No
32	nagina worker	Between 5000 to 10000	Adult female	20 to 30 minutes	Available within premises	No	0	No
33	nagina worker	Between 5000 to 10000	Adult female	20 to 30 minutes	Available within premises	No	0	No
34		Between 5000 to 10000	Adult female	Available within premises	Available within premises	Yes	0	No
35		Between 5000 to 10000	Adult female	Available within premises	Available within premises	Yes	0	No
36		Between 5000 to 10000	Adult female	Available within premises	Available within premises	Yes	0	No
37		Between 5000 to 10000	Adult female	20 to 30 minutes	20 to 30 minutes	Yes	0	No
38		Between 10000 to 20000	Adult female	Available within premises	Available within premises	Yes	4	No
39	property	Between 5000 to 10000	Adult female	Available within premises	Available within premises	Yes	4	No
40		Below 5000	Adult female	Available within premises	20 to 30 minutes	Yes	4	No
41		Below 5000	Adult female	20 to 30 minutes	20 to 30 minutes	Yes	4	No
42		Between 5000 to 10000	Adult male	Available within premises	20 to 30 minutes	No	0	No
43		Below 5000	Adult male	20 to 30 minutes	20 to 30 minutes	Yes	15	No
44		Below 5000	Adult male	20 to 30 minutes	20 to 30 minutes	Yes	15	No
45	nagina worker and open labour	Below 5000	Adult female	10 to 20 minutes	Available within premises	No	0	No
46	nagina woker	Between 10000 to 20000	Adult male	20 to 30 minutes	Available within premises	No	0	No
47		Between 5000 to 10000	Adult female	20 to 30 minutes	Available within premises	No	0	No
48		Between 5000 to 10000	Adult female	10 to 20 minutes	Available within premises	No	0	No
49	open labourer	Below 5000	Adult female	20 to 30 minutes	20 to 30 minutes	Yes	10	No
50	works at a grocery shop	Between 5000 to 10000	Adult female	20 to 30 minutes	Available within premises	Yes	5	No
51	Diamond work	Between 5000 to 10000	Adult female	Available within premises	Available within premises	Yes	6	No

Row number	Have_ENoughWater_Bathing_Summer	Discontinuity_Water_for MoreThan_2days_2015	WhathappensinawatersupplybreakdownDescribe	Do_You_Purchase_Water	If_Yes_When	Amount_spentPM_for_Water	Practice_Water_Purification
1	No	Yes	unable to bath and do daily activities	Yes	Only sometimes during breakdowns	350	Straining with cloth
2	No	Yes	unable to prepare food and bath	Yes	Only sometimes during breakdowns	350	Straining with cloth
3	No	Yes	unable to bath and do daily activities	Yes	Only sometimes during breakdowns	350	Straining with cloth
4	No	No		Yes	Only sometimes during breakdowns	100	Straining with cloth
5	No	No		Yes	In summers for drinking and domestic use	300	Straining with cloth
6	No	Yes	fill from government tank ,Now even that is closed	Yes	Daily for drinking and domestic	300	Straining with cloth
7	No	Yes	unable to bath,people fight for water	Yes	Only sometimes during breakdowns	350	Straining with cloth
8	No	Yes		Yes			Purification drops
9	No	Yes	unable to bath and daily activities	Yes	Daily for drinking and domestic	600	Straining with cloth
10	No	No		Yes	Daily for drinking and domestic	600	Straining with cloth
11	No	Yes	unable to bath,people fight for water	Yes	Only sometimes during breakdowns	350	Straining with cloth
12	Yes	No		No			Straining with cloth
13	No	Yes	buy tankers from nagar nigam at a high price	Yes	Only sometimes during breakdowns	25.	Dont do anything
14	No	No Idea	bring from neighbouring areas	No			Straining with cloth
15	Yes	Yes	had to call tanker in 2015	No			Water Purifier
16	No		No Idea	No			Dont do anything
17	No	Yes	they doNot recieve supply water	Yes	Daily for drinking and domestic	400	Straining with cloth
18	No	No		No			Straining with cloth
19	No	Yes	bring from public post 1 km away	No			Dont do anything
20	Yes	No		Yes	Only sometimes during breakdowns		Straining with cloth
21	No	Yes	buy tankers from nagar nigam at a high price	Yes	Only sometimes during breakdowns	25.	Dont do anything
22	No	Yes	bring water on bike from hand pump 1\\2 km away	No			Dont do anything
23	Yes	No Idea	fill from tank of nagar nigam 1 km away	Yes	Only sometimes during breakdowns	150	Straining with cloth
24	Yes	Yes	we are unable to drink water and do other work	No			Water Purifier
25	Yes	No		No			Dont do anything
26	No	Yes		Yes	Only sometimes during breakdowns		Purification drops
27	No	Yes		Yes	Only sometimes during breakdowns		Purification drops
28	No	Yes	bring from nearby public water tap	Yes	Daily for drinking and domestic	150	Straining with cloth
29	No	No Idea	bring from the public stand postc	Yes	Daily for drinking and domestic	150	Dont do anything
30	No	Yes	30.	Yes	Daily for drinking and domestic	150	Dont do anything
31	No	No	bring tanker or from public taps	Yes	Daily for drinking and domestic	200	Straining with cloth
32	No	No		Yes	Daily for drinking	150	Dont do anything
33	No	No		Yes	Daily for drinking	150	Dont do anything
34	Yes	Yes		Yes			Purification drops
35	Yes	Yes		Yes			Purification drops
36	Yes	Yes		Yes			Purification drops
37	No	Yes		Yes			Purification drops
38	No	Yes	unable to cook food and do daily activities	Yes	Daily for drinking and domestic	600	Straining with cloth
39	No	Yes	unable to do daily work	Yes	Daily for drinking and domestic	600	Dont do anything
40	No	Yes	unable to drink water,we have to survive with sour water	Yes	Daily for drinking and domestic	600	Dont do anything
41	No	Yes	unable to bath for 3-4 days	Yes	Daily for drinking and domestic	600	Straining with cloth
42	No	No		Yes	Daily for drinking and domestic	150	Dont do anything
43	No	Yes	call the tanker	Yes	Daily for drinking	600	Straining with cloth
44	No	Yes	call the tanker	Yes	Daily for drinking	600	Straining with cloth
45	No	No		Yes	Daily for drinking	150	Dont do anything
46	No	Yes	use water judiciously and bring from public tap	Yes	Daily for drinking and domestic	150	Straining with cloth
47	No	Yes	bring from near by areas	Yes	Daily for drinking	150	Dont do anything
48	No	Yes	bring from local public tap and use drinking water as domestic use	Yes	Daily for drinking and domestic	150	Dont do anything
49	No	Yes	public tap	Yes	Only sometimes during breakdowns	300	Dont do anything
50	No	No	dont have any option other than calling the tanker	Yes	Daily for drinking and domestic	200	Dont do anything
51	No	No		Yes	Daily for drinking and domestic	600	Dont do anything

Row number	Haveyoueverlostworkduetowaterstress	Sanitation_Facility	Sanitation_Facility_Other	Toilet_Flush_Type	Toilet_Connection
1	No	Open space/field			
2	Yes	Own toilet within dwelling		Pour-flush	Not connected to anything
3	No	Open space/field			
4	No	Own toilet within dwelling		Pour-flush	Piped sewer system
5	No	Own toilet within dwelling		Pour-flush	Piped sewer system
6	No	Own toilet within dwelling		Pour-flush	Pit latrine with slab
7	Yes	Own toilet within dwelling		Pour-flush	Not connected to anything
8	Yes	Own toilet within dwelling			
9	Yes	Own toilet within dwelling		Pour-flush	Not connected to anything
10	No	Own toilet within dwelling		Pour-flush	Not connected to anything
11	Yes	Own toilet within dwelling		Pour-flush	Not connected to anything
12	No	Own toilet within dwelling		Pour-flush	Piped sewer system
13	Yes	Own toilet within dwelling		Pour-flush	Piped sewer system
14	Yes	Own toilet near dwelling		Pour-flush	Septic tank
15	No	Own toilet within dwelling		Pour-flush	Piped sewer system
16	No	Own toilet within dwelling		Pour-flush	Piped sewer system
17	No	Own toilet within dwelling		Pour-flush	Piped sewer system
18	Yes	Own toilet within dwelling		Pour-flush	Piped sewer system
19	No	Own toilet within dwelling		Pour-flush	Piped sewer system
20	No	Own toilet near dwelling		Pour-flush	Piped sewer system
21	Yes	Own toilet within dwelling		Pour-flush	Piped sewer system
22	Yes	Own toilet near dwelling		Pour-flush	Piped sewer system
23	Yes	Shared toilet (with extended family)		Pour-flush	Piped sewer system
24	Yes	Own toilet within dwelling		Pour-flush	Piped sewer system
25	No	Own toilet within dwelling		Pour-flush	Not connected to anything
26	No	Shared toilet (with extended family)			
27	No	Shared toilet (with extended family)			
28	No	Own toilet within dwelling		Pour-flush	Septic tank
29	No	Own toilet near dwelling		Pour-flush	Septic tank
30	Yes	Own toilet within dwelling		Pour-flush	Septic tank
31	No	Own toilet within dwelling		Pour-flush	Septic tank
32	No	Own toilet within dwelling		Pour-flush	Septic tank
33	No	Own toilet within dwelling		Pour-flush	Septic tank
34	Yes	Shared toilet (with extended family)			
35	Yes	Shared toilet (with extended family)			
36	Yes	Shared toilet (with extended family)			
37	No	Own toilet near dwelling			
38	Yes	Own toilet within dwelling		Pour-flush	Not connected to anything
39	No	Own toilet within dwelling			
40	No	Own toilet within dwelling		Pour-flush	Not connected to anything
41	No	Own toilet within dwelling		Pour-flush	Not connected to anything
42	No	Own toilet near dwelling		Pour-flush	Piped sewer system
43	Yes	Own toilet within dwelling		Pour-flush	Septic tank
44	Yes	Own toilet within dwelling		Pour-flush	Septic tank
45	No	Own toilet within dwelling		Pour-flush	Septic tank
46	No	Own toilet within dwelling		Pour-flush	Septic tank
47	No	Own toilet within dwelling		Pour-flush	Septic tank
48	No	Own toilet within dwelling		Pour-flush	Septic tank
49	No	Own toilet within dwelling		Pour-flush	Septic tank
50	No	Own toilet near dwelling		Pour-flush	Septic tank
51	Yes	Own toilet within dwelling		Pour-flush	Not connected to anything

A 8 Completed Questionnaires – Women

Interviewer: Theresa Frommen (hydrogeologist)
Translator: Srishti Singh (MHT staff)
Date and Place: 23rd-24th September 2015, Jaipur

GENERAL

1. Who do you live with?

Function	Answer	Notes
Community leader, KK	6: husband (labor work), 4 children (all adult), father-in-law	my impression was, that there were also grandchildren living there, at least 1 Baby
CAG member, KK	5: son + daughter-in-Law + 2 (grand-) children, son of other married daughter	
Community leader, NKT	10: 2 sons+2 daughter-in-laws + 3 (grand-) children, 2 daughters, husband	
CAG member, NKT	4: husband, father-in-law+wife,1 son	I've written mother-in-law + wife, but this doesn't make sense
Community leader, Bhanda Basti	5: 1 daughter, 3 sons, husband	

2. Do your children go to school?

Function	Answer	Notes
Community leader, KK	yes (in the past)	
CAG member, KK	yes	
Community leader, NKT	Yes	
CAG member, NKT	Yes	
Community leader, Bhanda Basti	yes	

3. Where do they go?

Function	Answer	Notes
Community leader, KK	5 km away; 1 daughter has Master of Arts	
CAG member, KK	2 km, governmental school	
Community leader, NKT	New Sir Syed Public School; 2-3 km	Private school?
CAG member, NKT	New Sir Syed Public School; 2-3 km	
Community leader, Bhanda Basti	governmental school, very near: 0.5 km	

4. What are you doing for living?

Function	Answer	Notes
Community leader, KK	MHT → work with/as community leader; agent for Sahara India scheme: give deposits to other people, employs other women → bring fabrics/raw material and the other women make clothes, jewelry, saris of it etc. then she takes it back and sells it	
CAG member, KK	maid in a private school	
Community leader, NKT	sari making /stones	
CAG member, NKT	she makes holes in pearls for necklaces	

Community leader, Bhanda Basti	sari work and jewelry, MHT work: taking loans	she is also intermediary for 4 other organizations which give loans for business

5. How are your friendships in your community?

Function	Answer	Notes
Community leader, KK	very good friendships with other women (she also gives work to them)	question was not understood in the way I understood it
CAG member, KK	good, normal	"
Community leader, NKT	good terms	"
CAG member, NKT	good friendships	"
Community leader, Bhanda Basti	very good	"

6. Draw something that would make you happier (extra sheet).

Function	Answer	Notes
Community leader, KK	likes her work, her house, flowers	
CAG member, KK	flowers, temple	very shy, at the beginning didn't want to draw anything
Community leader, NKT	supply water to all the community, sari, house	she's smiling, doesn't start, a lot of discussion, daughter is doing the drawing, then she continues
CAG member, NKT	her machine on which she is working	she is laughing and saying if here family is happy, she is happy too; she smiles while drawing
Community leader, Bhanda Basti	design she is doing on the saris and her name	she is smiling and starting; her daughter is also drawing something

7. Imagine how your family looks in 5 years.

Function	Answer	Notes
Community leader, KK	her family be happy; everything she achieved and her family should achieve more (build on this)	
CAG member, KK	happy, bigger house, children are educated and become something in live	
Community leader, NKT	bigger house, well educated children, that they can earn enough for living	
CAG member, NKT	well educated children; house is completely done; happy family	
Community leader, Bhanda Basti	happiness; her family should not go through what she was going through	

COMMUNITY

8. What do you like about your community/area where you live?

Function	Answer	Notes
Community leader, KK	behavior of women towards her; motivating them, giving them work; that they are motivated to work with her	
CAG member, KK	her own house, her school	
Community leader, NKT	open spaces, no fight/tension within the community	

CAG member, NKT	love and affection in the community; no fights; exchange of love, they have for other people despite many problems there is a common	
Community leader, Bhanda Basti	now: the cleanness inside her house, before it was very muddy and dirty; road which has be done now	

9. Why?

Function	Answer	Notes
Community leader, KK	-	
CAG member, KK	she is affectionate towards it (school)	
Community leader, NKT	she feels relaxed	
CAG member, NKT	-	
Community leader, Bhanda Basti	-	

10. What would you like to change?

Function	Answer	Notes
Community leader, KK	garden for children to play; school nearby; good education	
CAG member, KK	water supply; road	
Community leader, NKT	some livelihood options for women, because there is no option to work here at the moment; create a space where they can come together	
CAG member, NKT	roads; water lines	
Community leader, Bhanda Basti	toilet with soak pits → they want a sewerage line	

11. Why?

Function	Answer	Notes
Community leader, KK	it makes her happy to give children good education to build their future, make them happy	
CAG member, KK	because it is important, daily live; electricity → no connection	
Community leader, NKT	because prices are increasing she wants to secure family income. Now, only husband is earning. Better: if there are many options to share the income demand	
CAG member, NKT	dirty roads; no pavements	
Community leader, Bhanda Basti	when rainfalls comes it fills up the soak pit → very difficult then	

12. How many women do you meet at the well and what do you talk about?

Function	Answer	Notes
Community leader, KK	3-4km away bore well: 40-50 women, huge queue, talking about water issues	well nearby has dried up
CAG member, KK	doesn't go out for water, what is coming is sufficient	
Community leader, NKT	now: 1km at the road, 40-50 women, huge lines, fights because of water issues, sim card systems in meters since 4 days, before water was free, only if recharge sim card they have access to water	
CAG member, NKT	200 people (men+ women): about livelihood options, diseases among children, problems	
Community leader, Bhanda Basti	HH individual connection	

13. Can you tell me something about the social groups in your community?

Function	Answer	Notes
Community leader, KK	MHT community based group; during festival there are social groups, not registered, collect money for worship, cultural activities	question understanding was wrong
CAG member, KK	CBOs take all women, don't have this differentiated thinking in mind; no discrimination in this place	
Community leader, NKT	all the same community	
CAG member, NKT	all of one	Srishti did not ask this question
Community leader, Bhanda Basti	all the same community	

DAY-TO-DAY LIVING

14. Where do you go shopping/buying food?

Function	Answer	Notes
Community leader, KK	daily: 1-2 km away local market near Amer Fort; shopping: Jaipur city	
CAG member, KK	goes to Amer, local market	
Community leader, NKT	husband brings everything, she doesn't go out	
CAG member, NKT	goes to main city (for all, vegetable etc.), once a week on Saturday	
Community leader, Bhanda Basti	local market: 0.5 km away	

15. How do you cook?

Function	Answer	Notes
Community leader, KK	cook stove → takes more consumption of LEG; wood stove outside the house (chapattis)	
CAG member, KK	gas stove and wood stove	her daughter-in-law has to cook
Community leader, NKT	summer: gas stove; winter: wood stove	
CAG member, NKT	gas stove	
Community leader, Bhanda Basti	gas stove	

16. How do you spend your free time?

Function	Answer	Notes
Community leader, KK	making sari + jewelry	
CAG member, KK	stitching of clothes	
Community leader, NKT	sari work; if there are any issues in the community she goes there	
CAG member, NKT	no free time, always engaged in work	
Community leader, Bhanda Basti	no free time (makes MHT work, Sari)	

17. How do you entertain yourself/your family?

Function	Answer	Notes
Community leader, KK	goes out with friends; TV/music/computer for family	
CAG member, KK	spends time with the children; no TV watching, but there is one	
Community leader, NKT	TV	TV was on when we arrived at the house

CAG member, NKT	not much time for entertainment, only a little bit TV	
Community leader, Bhanda Basti	TV sometimes; whenever someone calls she send her daughter	

18. What is your favorite movie and why?

Function	Answer	Notes
Community leader, KK	spiritual films, local language films	
CAG member, KK	doesn't know about movies	
Community leader, NKT	Geet Gaya Patharon ne (old movie: Song sung by the stones); Generally, she likes family movies with HH activities shown there, she feels very affected with this	wikipedia: The Rocks Sang a Melody
CAG member, NKT	no movie, no interest in movies	
Community leader, Bhanda Basti	Sanam bewafa (Hindi movie)	1991, German: Ein verratener Geliebter

19. What is the biggest problem you're facing every day?

Function	Answer	Notes
Community leader, KK	cooking for big family → takes much time; water	
CAG member, KK	road; street lights → get dark early, feels insecure	
Community leader, NKT	water	
CAG member, NKT	unemployment; water issues	
Community leader, Bhanda Basti	no problem as such	

EXISTING KNOWLEDGE OF WATER

20. Where do you think the water comes from and goes to?

Function	Answer	Notes
Community leader, KK	if raining: from the mountains water come and percolate into the soil/underground, ground sucks it	question was not understood in the way I understood it
CAG member, KK	percolation from the ground; goes into the ground	"
Community leader, NKT	groundwater, comes and goes into ground again	"
CAG member, NKT	water comes from ground, goes back into the ground	"
Community leader, Bhanda Basti	from ground; first it goes to the nallahs then to bigger nallahs then in agriculture, then into ground	"

21. How do you determine if the water quality is good or bad?

Function	Answer	Notes
Community leader, KK	1) through drinking 2) visually observation: thin film of creamy layer → bad 3) stomach upset → bad	
CAG member, KK	visual observation (if there is white powder on water → bad)	
Community leader, NKT	through testing	
CAG member, NKT	visual observation → yellow/brown, or are there any particles inside, dirt settled down at the bottle	

Community leader, Bhanda Basti	visual and odor	

22. What do you think are the reasons for the water problems in this area?

Function	Answer	Notes
Community leader, KK	because of very low rainfall, past 15-20 years due to low rainfall	
CAG member, KK	no/low rainfall	
Community leader, NKT	no governmental scheme, it had not reached here; no water line, no sewer line	husband is talking…
CAG member, NKT	no individual water connection and no governmental action to apply it	
Community leader, Bhanda Basti	because of wastage of water in lower area people in upper side don't get enough water	

WATER USAGE

23. Where do you get your water from?

Function	Answer	Notes
Community leader, KK	PHED: in the morning 4-5:30am 30-40 min water line supply	
CAG member, KK	individual connection from PHED	
Community leader, NKT	-	
CAG member, NKT	tanker	
Community leader, Bhanda Basti	PHED (legal: pressure very low: only ½ bucket filled)	

24. Is it sufficient?

Function	Answer	Notes
Community leader, KK	no, it is too less	
CAG member, KK	yes	
Community leader, NKT	if it is not sufficient → tanker, 4000 L → 300 Rs	
CAG member, NKT	yes, 4000 L→ 350 Rs → enough for 15-20 days	
Community leader, Bhanda Basti	it's only sufficient with illegal connection (only 1 hour/day) but pressure is better (2-3 buckets get filled)	

25. How often do you go per day to get water from the well?

Function	Answer	Notes
Community leader, KK	1 tanker comes daily for 20 HHs, she takes 5-7 buckets, every bucket 12-20 L	
CAG member, KK	-	
Community leader, NKT	5-6 rounds	
CAG member, NKT	3-4 times	
Community leader, Bhanda Basti	-	

26. How much time do you spend for water issues every day?

Function	Answer	Notes
Community leader, KK	min. 2 hours, can go up to 4-5 hours, if they have to wait for morning tanker	
CAG member, KK	-	

Community leader, NKT	4-5 hours	
CAG member, NKT	5-6 hours	
Community leader, Bhanda Basti	2 hours	

27. How many people are using the well?

Function	Answer	Notes
Community leader, KK	-	
CAG member, KK	earlier she goes to the well, but not now	
Community leader, NKT	1000s of people	I would say 100s of people
CAG member, NKT	1000-2000 people	
Community leader, Bhanda Basti	-	

28. Where do you store your water? Can you show it to me?

Function	Answer	Notes
Community leader, KK	in a tank behind the house, underground	see pictures
CAG member, KK	1 tank, within the house, underground; black tank at the roof	
Community leader, NKT	buckets and tank → beneath courtyard	
CAG member, NKT	buckets, pots	
Community leader, Bhanda Basti	buckets + black tank (500 L) +200 L tank: ~1000 L	

29. How much water does your household use?

Function	Answer	Notes
Community leader, KK	100-150 L	
CAG member, KK	50-60 L	
Community leader, NKT	500 L/day	they have also animals (3 goats I think)
CAG member, NKT	100-150 L	
Community leader, Bhanda Basti	1000 L/day (wash house twice a day with water)	

30. What do you use the water for and how much for each activity (drinking/washing..)?

Function	Answer	Notes
Community leader, KK	washing clothes (max), bathing, cooking, drinking, toilet	
CAG member, KK	bathing, washing clothes, cooking, drinking, toilet	
Community leader, NKT	cooking, washing, toilet, animal washing	
CAG member, NKT	washing, cleaning, cooking, drinking	
Community leader, Bhanda Basti	drinking etc.	

31. How much water or liquids do you drink per day?

Function	Answer	Notes
Community leader, KK	3-4 L (RO), before RO installed → 2 L (it was very salty)	cooking rice with this water → got yellow
CAG member, KK	2 L	
Community leader, NKT	5 L	
CAG member, NKT	2 L	
Community leader, Bhanda Basti	5 L	

WATER PROBLEMS

32. What is frustrating for you when you think of water in your community?

Function	Answer	Notes
Community leader, KK	most of HHs do not have a toilet → go out to forest	(she has one)
CAG member, KK	diseases she is getting from the water	
Community leader, NKT	bring water from such a he distance; fights happen	
CAG member, NKT	water quality, salty water → get throat ache; taste is so bad you can already feel it in your throat	
Community leader, Bhanda Basti	not everybody get access to water because of wastage of water	

33. What do you do when there's a scarcity? How do you rearrange your consumption?

Function	Answer	Notes
Community leader, KK	water must be there for drinking/cooking! tries to reuse water → washing water reuse for toilet	
CAG member, KK	reuse water: washing water → stored → use for toilet	she was listening what community leader (KK) has said in her interview
Community leader, NKT	for some days if there is not enough water, she is waiting with washing clothes etc. until there is water again, but then there is a huge water use on this day	
CAG member, NKT	tries to use less quantity of water in all parts; doesn't take a bath	
Community leader, Bhanda Basti	doesn't take bath and doesn't clean the house	

34. What are your friends doing when there is a scarcity?

Function	Answer	Notes
Community leader, KK	take less bath; don't go to toilet but open defecation	
CAG member, KK	similar like her	
Community leader, NKT	don't sweep and mop	
CAG member, NKT	similar things	
Community leader, Bhanda Basti	do the same; tanker has to be called	

HOW THEY WOULD SOLVE IT

35. What would be an improvement from your point of view of the water situation?

Function	Answer	Notes
Community leader, KK	make a group go to PHED, PHED: we cannot install water line here, Women: we can contribute some of the amount	
CAG member, KK	community leader is doing everything for improvement	she is very unconfident
Community leader, NKT	government have to support, they cannot do it alone for water lines etc.	
CAG member, NKT	government: that all community members get connection	
Community leader, Bhanda Basti	large water tank for the entire community	

36. Do you feel you can change some part of this by yourself?

Function	Answer	Notes
Community leader, KK	yes!	

CAG member, KK	alone she cannot, but with community leader she can do (not able to think in this line)	
Community leader, NKT	she doesn't feel she can solve it.	
CAG member, NKT	yes	
Community leader, Bhanda Basti	yes	

37. How?

Function	Answer	Notes
Community leader, KK	goes to PHED, if they don't listen, she goes to MHT	
CAG member, KK	-	
Community leader, NKT	if people are coming asking for water, she can help because they have a big tank	
CAG member, NKT	help other if government doesn't	
Community leader, Bhanda Basti	by no wasting water and tell other women also not to waste water	

38. What prevents you?

Function	Answer	Notes
Community leader, KK	people who are jealous of her, because she already achieved so much	
CAG member, KK	my mind is not working in this direction	
Community leader, NKT	her education is preventing her, otherwise she would be able to go the government	
CAG member, NKT	nothing	
Community leader, Bhanda Basti	her daughter is using a lot of water for washing (washing herself 2x a day)	

39. What do you expect from the government?

Function	Answer	Notes
Community leader, KK	no expectation	they are not able to see any of the implementation/service
CAG member, KK	no expectation	
Community leader, NKT	they are expecting something	
CAG member, NKT	expects good things, but they are not doing good things actually	
Community leader, Bhanda Basti	sewer line	

SANITATION

40. Where do you go to toilet?

Function	Answer	Notes
Community leader, KK	HH toilet	through MHT (MSD Foundation)
CAG member, KK	HH toilet	through MHT
Community leader, NKT	HH toilet	through MHT
CAG member, NKT	HH toilet	
Community leader, Bhanda Basti	HH toilet	

41. How often do members of your household get sick?

Function	Answer	Notes
Community leader, KK	only seasonal diseases	
CAG member, KK	yes, every 15-30 days	
Community leader, NKT	she: every 2-3 days	
CAG member, NKT	frequent diseases	
Community leader, Bhanda Basti	no	

42. Which diseases have they had?

Function	Answer	Notes
Community leader, KK	dengue, fever, malaria, diarrhea, conjunctivitis (eye-flu)	
CAG member, KK	fewer, cold, cough, joint pain	
Community leader, NKT	digestion problems, skin diseases, cough, cold	
CAG member, NKT	cold and cough	
Community leader, Bhanda Basti	fever, cold, cough → very seasonal diseases	

43. Which of these diseases are related to water?

Function	Answer	Notes
Community leader, KK	some are related to water; heavy rainfall → different kinds of diseases arise	
CAG member, KK	joint pains	
Community leader, NKT	joint pain → because of the salty water; cold; cough	
CAG member, NKT	cough because of water quality	
Community leader, Bhanda Basti	because of the season, not of the water	

44. Where do you go if you get sick?

Function	Answer	Notes
Community leader, KK	private doctor (0.5 km); never goes to governmental hospital	
CAG member, KK	private doctor, no governmental hospital	
Community leader, NKT	private doctor, there is no governmental doctor nearby	
CAG member, NKT	private doctor, if not solved there they go to the city → governmental doctor	
Community leader, Bhanda Basti	HH level treatment, if not enough, go outside for doctor	

MEDIA

45. Do you have access to Internet? Computer? TV? Radio? Mobile Phone? Smartphone?

Function	Answer	Notes
Community leader, KK	yes, internet only by phone	
CAG member, KK	TV, mobile phone	
Community leader, NKT	TV, mobile phone	
CAG member, NKT	TV, mobile phone	
Community leader, Bhanda Basti	TV, mobile phone, radio	

46. How do you communicate with your friends and family (in the same community, other city?)

Function	Answer	Notes
Community leader, KK	go in person if nearby; far away → mobile phone	
CAG member, KK	mobile phone	

Community leader, NKT	mobile phone	
CAG member, NKT	mobile phone	
Community leader, Bhanda Basti	mobile phone	

END

47. Tell me about the last time you learned something new.

Function	**Answer**	**Notes**
Community leader, KK	to work by herself (other than HH work); to give other women work; to collaborate; to work in a group	
CAG member, KK	in the temple, she learned songs	needed long time to think about it, only with help of Srishti she was able to give an answer
Community leader, NKT	working with saris: putting stones on the sari	
CAG member, NKT	she learned how to use the hole making machine	thought very shortly about the question
Community leader, Bhanda Basti	learned to operate a camera (from MHT)	she's confused, MHT staff has to explain

48. Imagine you can live in any place on earth. Where and why?

Function	**Answer**	**Notes**
Community leader, KK	want to stay at that place, where she want to guide other women to solve their problems	
CAG member, KK	she wants to stay at her place	
Community leader, NKT	Kashmir → there will be no water problems	she is laughing, it was only a joke
CAG member, NKT	doesn't want to go anywhere, has her own place, has everything here	
Community leader, Bhanda Basti	likes to spend time with friends but afterwards she wants to go home again	

49. General Notes

Function	**Notes**
Community leader, KK	
CAG member, KK	very friendly; her room is smaller than Community leader, KKs
Community leader, NKT	2 daughters are also there, then the 2nd interviewee is coming and husband is joining after a while, motor was installed by governmental initiatives, now closed all motors
CAG member, NKT	
Community leader, Bhanda Basti	daughter isn't go to school anymore, because has to do too much HH work→ big discussion with MHT worker and Srishti about this

A9 Questions for the Experts: MHT – Srishti Singh.

Date: 13.09.2015
Interviewers: Theresa Frommen, Anja Urzendowsky

GENERAL

1. What other tools than FGD are you using to educate women and youth in the slums?
We conduct audio/video shows and folk media to spread the relevant information. We also try to interact with them through setting up games, role plays and other group as well individual activities as per the topic of the training, to educate the women and youth in the discussions.

2. Are there any cultural barriers we should be aware of?
No, not exactly.

3. Do you give them any incentives to take action/to apply what they have learned?
Yes, we often give stipend (on a daily wage basis) to the active women leaders who interestingly take part in our activities and who work for us.

4. What do they already know about water and the interaction between water and their behavior?
They are quite aware of the supplier and source of water in their areas. They would not have a detailed understanding about the quality as well as quantity but they could have a rough overview about all the aspects of water in their area.

5. We learned that you are focusing on women. Just to clarify, do the men have any part in the decision-making within the community/household?
MHT focuses on poor women and their empowerment. Generally, men are the decision makers within the household and also within the community but with MHT's initiatives, many women community leaders have been empowered within the course of time (especially in Ahmedabad) and the situation has changed enormously in MHT's operational areas.

6. How do you work with youth/children?
Through this project, we are going to form Community Action Groups (CAGs) in each of the slums ensuring at least 80% leaders being women and 40% youth leaders. The whole idea to involve the young people is to build resilience action plans and make them agents of change for futuristic and long term impacts.

7. What age group are these women?
There is no specific age group that MHT focuses. We work with adolescent girls and women of all age groups.

8. Are there any difficulties when working with government organizations in your project? How cooperative is the government in your requests?
MHT has been working in close collaboration with the government agencies and municipal corporations in all our operating cities. Initially we do face difficulties when we have just begun in a particular state/city. However, once we are known, they cooperate in our requests within their scope.

9. Are there any limitations in your (MHT) work (e.g. financial)?
MHT works on project-basis which has certain financial limitations.

PROJECT

10. Is it okay to ask the women/youth about sanitation? Where do they defecate etc?

Yes, you may ask.

11. Are there (in India) any similar projects we can learn from or connect to?

I don't think a project on building community resilience presently operates in any of the urban areas of India. However, you may find something similar for rural India.

12. What were the successes with this project until now?

As you know, the project was in its pilot phase and now we have recently received the project for implementation. In its pilot phase, we conducted around 50 focus group discussions with the women in the communities and also with the community leaders. Through this, we exposed the women to the sectoral thinking, provided them with a few participatory tools to go back to their communities and understand the nuances and within a fortnight they were back, talking one-on-one terms with the experts, getting them on track if they deviated, suggesting localized/cheaper versions of technical solutions and working towards a common goal of people's "LIVELIHOOD", because that is at stake. There were many solutions as well as demands that came up from the community leaders. For instance, installation of water meters to reduce wastage.

13. Do you know about any governmental efforts in slums in Jaipur?

During my recent visit to Jaipur, I came across new scheme of the government to provide metered water in the slums. In a discussion with PHED officials, I also got to know about the efforts being made to provide good quality water to the slums in Jaipur.

14. What resources (e.g. projector and a screen, meeting room) could we get for education and/or what would be effective?

Audio/visual shows, role plays and folk media are the best ways to transfer relevant information to the wider audience in the community. You would be requiring a projector and screen to manifest them. However, once the community starts recognizing, one to one interviews and FGDs/trainings would be really helpful.

15. Is there any traditional wisdom, we can borrow for our educational project (e.g. beliefs)?

You may try to revive the traditional practices that are directly related to the identified stresses and that have stopped during the course of time due to the excess use of technology, e.g. drinking of refrigerated cold water, rather than the water stored in the earthen pots.

16. How much time can the women and youth dedicate to our educational project? (daily/weekly/monthly)

Twice a month.

Thank you so much for your help and valuable insights!

A10 Summary of the Expert Interview – Amnesty International.

Interview with representatives of Amnesty International-India Co-Group Berlin:
Dr. Michael Gottlob and Bianca Negri

Evgeny Kiverin and Theresa Frommen
16.09.2015, 10-11.30 am, Berlin

Methods:

- Missed Calls
  - Campaign method
  - To sign a petition
  - ai has the contact afterwards to inform about other projects etc.
  - certain numbers for certain campaign
  - is advertised in public spaces, e.g. metro
- Work with pictures!
- Theatre on the road
  - Interactive experience
  - Give pictures to children afterwards
- Movie on the road
  - Small car with screen
  - Goes to slums/villages in the evening, call people together
  - Very short movies
  - Without words/or only few words
  - E.g. to the topics of abortion, plastic bottles
- Plastic bottle project in school: cut the top of the bottle and fill the rest with soil and seed some plants. Every child has to take care of one plant, including watering etc and in the end can take it to its home
  - Children get feeling for water
  - They are proud and happy about their "own" plant which they are allowed to take home
- Do concrete things!
  - Sing
  - demonstrate things
    →interact

Projects:

- North East Indian Forum (Brot für die Welt; Uni Duisburg/Essen)
  - Per Mail am 17.09.:„Zu dem geplanten Nordost-Indien-Seminar unter dem Arbeitstitel "Transboundary Water Management in the Eastern Himalaya (Northeast-India, Bangladesh, Southwest-China, Myanmar) and the Mekong Delta" gibt es noch kein fertiges Programm. Aber hier ist ein AA-Papier zum Kontext: www.adelphi.de/de/publikationen/dok/43463.php?pid=1927 „
- Governmental project: Interlinking of the big rivers in India

- Design: Architectures from University of Bangalore designed water household supply with two taps: one with drinking water quality and the other one for all other purposes
  → Save high quality water and reuse of only slightly polluted water
- Per Mail am 17.09.: „Zur Dignity-Kampagne von ai (Mit Menschenrechten gegen Armut):
  http://www.amnesty-wsk.de/?page_id=133
  https://www.amnesty.de/journal/2009/oktober/fuer-ein-leben-menschenwuerde „

Notes:

- Take a long time to educate
- Be sure of the support of the older women in the slums, they are deciding a lot!
- Problem: Conflicts within the communities, hierarchical structures
  - Caste, religious (Muslims sometimes similar to "untouchables"), political
- In cooperation with officials:
  - Be concrete!
  - Show what you want to do with pictures
  - Make clear who is supposed to do what
  - Ask every time what can be done together
  - Be careful with your expressions/language
    - Do not mention human rights and environmental protection (just think of it ☺) because these points are not liked by many Indian officials because they can lead to economic disadvantages, e.g. Greenpeace got severe problems with working in India…)

Ideas:

- Present our Solution design in Bremen to the local Indian group in order to get a review (Evgeny will be back in Bremen to this time)
- Indian guy (friend of them) dealing with cheap pumps, so that also poor people can afford to buy a pump and extract groundwater → could contact them for us

Others:

- Der Berlinale-Film aus Rajasthan: Lajwanti:
  https://www.berlinale.de/en/archiv/jahresarchive/2014/02_programm_2014/02_Filmdatenblatt_2014_20147056.php#tab=filmStills

A11 Overview of all photos.


Mein
cewe fotobuch
Mein Leben
www.fotoparadies.de
FOTO Paradies
13-Oct-2015
Film No. 744723


Mein
cewe fotobuch
Mein Leben
www.fotoparadies.de
FOTO Paradies
13-Oct-2015
Film No. 744719

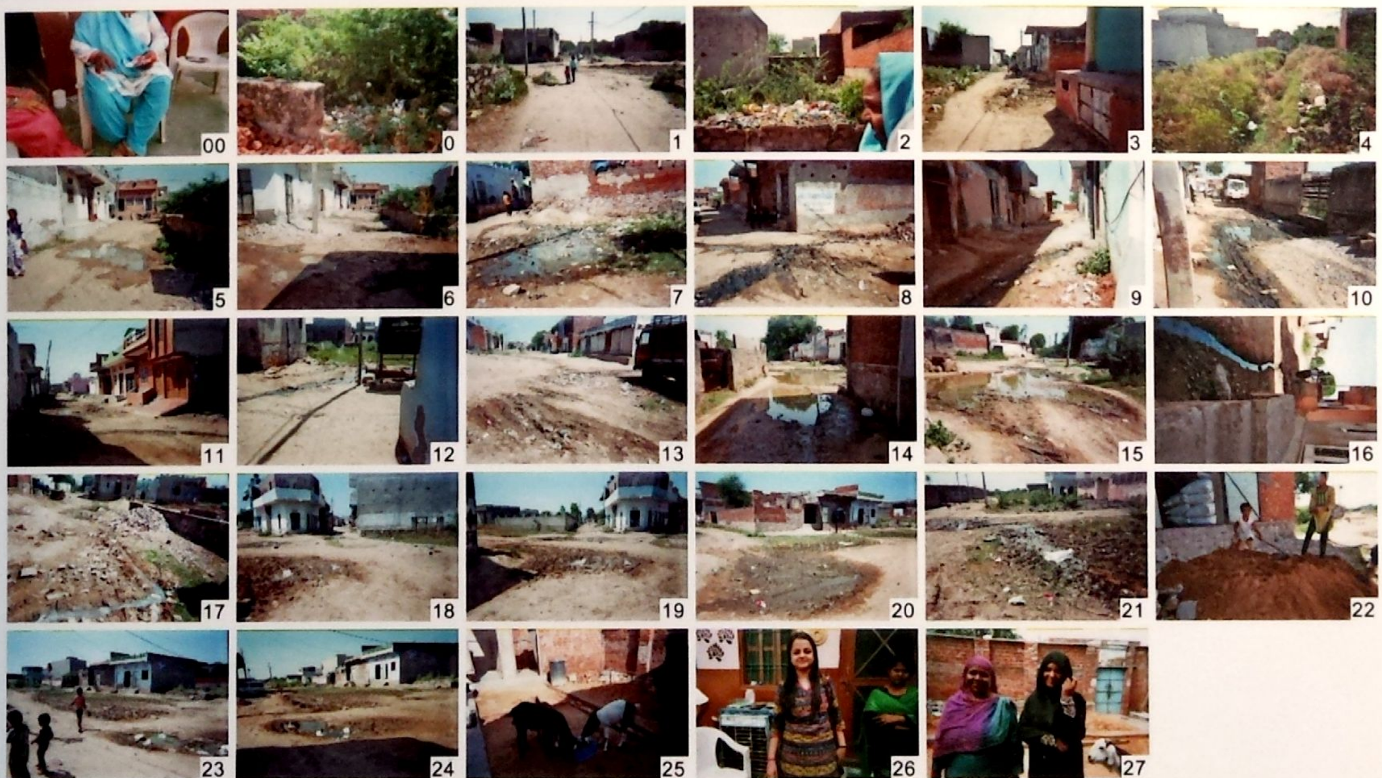
13-Oct-2015

Film No. 744749

Mein cewe fotobuch
Mein Leben
www.fotoparadies.de
FOTO Paradies

13-Oct-2015

Film No. 744721



Global Resilience Partnership | Mahila Housing SEWA Trust (MHT) | Freie Universität Berlin

A12

Water Infrastructure: Mapping Sheet – Water Line

Name of scientist/assistant: ____ Date: _____________

1) General information

Community: ____ ID:__________________

GPS: ________________________Landmarks: ____

2) Connection

Tap: ☐

Open: ☐ Bolt: ☐ Other: ________________________________

3) Use

Drinking: ☐ Irrigation: ☐ Industrial: ☐ Household: ☐ Other: ________________

Private: ☐ Public: ☐ Other: ____

4) Possible water sampling location

Owner agreed: ☐ Many people using it: ☐ Regular water supply: ☐ Easy accessible: ☐

Other:____

5) Supply times

From ______________________ To ______________________ Never: ☐

From ______________________ To ______________________

6) Additional notes

____

____

____

7) Filter system (e.g. RO machine)

Yes: ☐ No: ☐

8) Number of connections

1: ☐ 2: ☐ more: ☐ How many working:______

9) Photos

Number: ____

GLOBAL RESILIENCE PARTNERSHIP

MHT Mahila Housing SEWA Trust

Freie Universität Berlin

A13

Water Infrastructure: Mapping Sheet – Well

Name of scientist/assistant: ____ Date: ____________

1) General information

Community: __________________________Well ID:_________________ Built by:_____________

GPS: ________ Number on well: _____ Landmarks: _______________________________________

2) Type

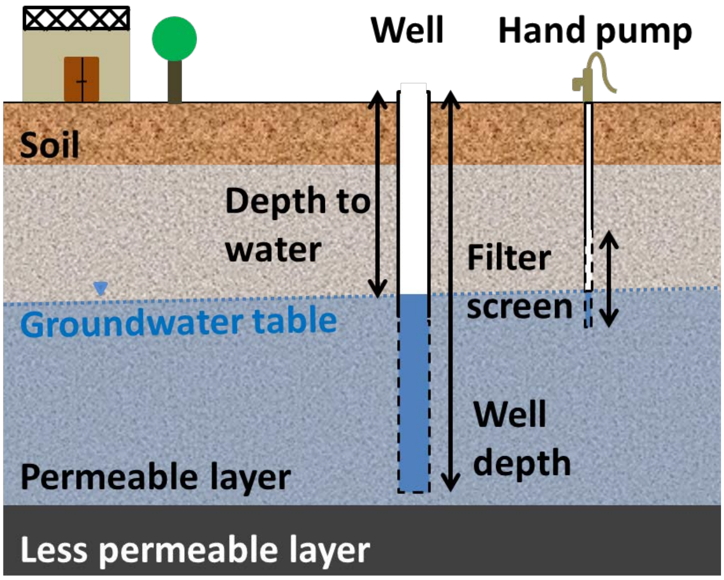
Bore well: ☐ Dug well: ☐ Step well: ☐

Hand pump: ☐ Observation well: ☐

Other: ________________________________

Well depth [ ]: _____ Diameter of well [ ]: ____

Filter screen depth [ ]: _____ - _____



3) Working

Yes: ☐ No: ☐ Reason: _____________________

_________________ Since when: ___________

4) Use

Drinking: ☐ Irrigation: ☐ Industrial: ☐ Household: ☐ Other: _______________

Private: ☐ Public: ☐ Other: ____

5) Condition

Protected: ☐ Unprotected: ☐ Partly protected: ☐

Description:____

____

6) Possible water sampling location

Owner agreed: ☐ Many people using it: ☐ Regular water supply: ☐ Easy accessible: ☐

Groundwater available: ☐ Other:____

7) Additional notes

____

____

____

8) Filter system (e.g. RO machine)

Yes: ☐ No: ☐

9) Photos

Number: ____________________________

A 14
Water Quality Sampling Protocol.

जल गुणवत्ता आंकड़ा

GLOBAL RESILIENCE PARTNERSHIP MHT Freie Universität Berlin

दिनांक: __________ समय: ________ एकत्रण कारने वाले का नाम: ______________________________________

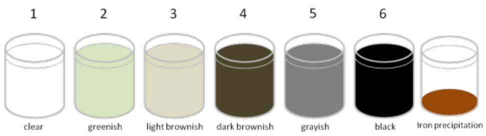
कुंआ संख्या: _______ स्थान: _________________________________ मौसम: ____________________________

नमूना संख्या: _________________ पंमपिग शुरु:______ पंमपिग समाप्त : ______ पंमपिग का समय : ______

परिवेश:

कचरा: ☐ घरेलू व्यर्थ: ☐ पशु: ☐ कृषि: ☐ औद्योगिक व्यर्थ: ☐ धोना: ☐ मल: ☐

रंग:



____

गंध:

नहीं	क्लोरीन	गंधक (सड़े हुए अंडे)	मिट्टी की/ मछली का	पेट्रोल	तेज रासायनिक	अन्य

	P.	पाचल [मिलीग्राम / एल]	निरीक्षण मूल्य	मानक (IS 10500 : 2012) स्वीकार्य सीमा	अनुमेय सीमा	टिप्पणियों
1.		हवा का तापमान [डिग्री सी]		-		
	20	तापमान [डिग्री सी]		-		
2.	18	पी. एच. (इकाइयों)		6.5 - 8.5		
3.	33	फ्लोराइड		1	1.5	
4.	27	धुंधलापन [एन. टी. यू.]		1	5	
5.	42	अमोनिया		0.5		
6.	31	नाइट्रेट		45		
7.	37	लोह तत्व		0.3		
8.	40	कठोरता		200	600	
9.	29	क्लोराइड		250	1000	
10.	-	टी.डी.एस [मिलीग्राम/एल]		500	2000	
	-	विद्युत चालकता [µS/cm]				टी.डी.एस ≈ विद्युत चालकता x 0.65
11.	44	मल प्रदूषण		अनुपस्थित		
12.	22	घुली ऑक्सीजन		-		

टिप्पणियों:

____

____

अंत समय: ________________________

A15 – Details of the films.

A15 – 1 Pani Check – The Sisterhood of Water

Shooting period:	November 2016 – October 2018
Shooting location:	Jaipur, Bisalpur, India
Director:	Katalin Ambrus
Camera:	Katalin Ambrus
Sound:	Katalin Ambrus, Maximilian Nölscher, Paul Königer
Editor:	Lucian Busse
Duration:	52 min

A15 – 2 Pani Doctors – Join the Sisterhood of Water

Shooting period:	October 2018
Shooting location:	Jaipur, India
Director:	Katalin Ambrus
Camera:	Katalin Ambrus
Sound:	Katalin Ambrus, Theresa Frommen
Editor:	Lucian Busse
Duration:	10 min

A16 Participatory water sampling data.

Well ID	Date	Colour	Smell	T Air [°C]	T H_2O [°C]	pH	F [mg/L]	Turbidity [NTU]	NH_3 [mg/L]	NO_3 [mg/L]	Fe [mg/L]	Hardness [mg/L]	Cl [mg/L]	TDS [mg/L]	EC [µS/cm]	Faecal Coliform	DO [mg/L]
KK_HP15	1/31/17	brown	no	-	27	8	1,5	100	1	100	3	816	503,39	-	-	absent	54,8
KK_HP16	2/1/17	light brownish	iron	-	27	7	<0.6	25	<1	45-100	1-3	632	354,5	580	-	absent	0,8
KK_WL126	3/2/17	clear	no	25	24	8	<0.6	<10	<1	45-100	<0.3	384	351	641	-	absent	3,1
KK_HP01	3/3/17	clear	no	22	27	7	<0.6	10	<1	100	0,3	1112	659	804	-	absent	1,2
KK_HP15	3/4/17	-	iron	23	28	7	<0.6	>100	<1	100	3	952	574	789	-	-	2,6
KK_HP16	3/11/17	iron precipitation	-	25	28	7	<0.6	25	<1	100	1	632	362	707	-	-	-
KK_HP01	4/5/17	clear	-	29	29	7	<0.6	<10	<1	45-100	0.3-1	464	539	826	3062	-	-
KK_HP16	4/6/17	clear	no	32	29	7	<0.6	25	<1	45	1	624	340	626	-	-	-
KK_HP15	4/7/17	clear	no	30	28	7	<0.6	50-100	3	100	1	904	532	748	2706	-	-
KK_WL126	4/8/17	clear	no	28	29	8	<0.6	-	<1	45-100	<0.3	640	376	681	-	-	-
KK_HP01	6/5/17	clear	no	38	29	7	0,6	10	<1	45-100	0,3	632	567	736	-	-	1,6
KK_HP16	6/6/17	clear	-	39	25	8	0,6	<10	<1	45-100	1	512	255	726	-	-	0,8
KK_HP15	6/11/17	iron precipitation	-	29	32	8	<0.6	10-25	<1	100	1-3	1088	560	868	-	-	0,1
KK_WL126	6/12/17	clear	-	30	32	7	<0.6	<10	<1	45-100	<0.3	520	341	674	-	-	-
KK_HP01	8/1/17	clear	no	27	29	7	<0.6	<10	<1	45-100	1	568	447	836	2600	-	2
KK_HP16	8/2/17	iron precipitation	-	30	28	7	<0.6	25	<1	45-100	1-3	400	212	613		-	12
KK_WL126	8/12/17	clear	no	31	28	7	<0.6	<10	<1	45-100	<0.3	536	291	765	1962	-	4,8
KK_HP15	8/7/17	iron precipitation	-	29	28	8	<0.6	25-50	<1	100	1-3	904	588	116	-	-	12
KK_HP01	10/11/17	iron precipitation	-	28	29	8	<0.6	25	<1	100	3	476	475	989	-	-	10

Well ID	Date	Colour	Smell	T Air [°C]	T H_2O [°C]	pH	F [mg/L]	Turbidity [NTU]	NH_3 [mg/L]	NO_3 [mg/L]	Fe [mg/L]	Hardness [mg/L]	Cl [mg/L]	TDS [mg/L]	EC [µS/cm]	Faecal Coliform	DO [mg/L]
KK_HP15	10/12/17	iron precipitation	-	29	28	8	<0.6	50-100	<1	100	3	788	553	-	3169	-	6
KK_WL126	11/1/17	-	no	28	27	7	<0.6	10-25	<1	45-100	1	480	397	778	-	-	7
KK_HP16	11/2/17	iron precipitation	iron	32	28	7	0,6	10-25	<1	100	1-3	496	354	1332	2049	-	1,2
KK_HP01	12/2/17	iron precipitation	iron	23	28	7	0,6	10-25	<1	45-100	1	800	432	990	-	-	2,4
KK_HP15	12/3/17	iron precipitation	iron	22	28	7	<0.6	25	<1	45-100	1	720	290	790	-	-	3,2
KK_HP16	12/4/17	iron precipitation	iron	28	28	7	<0.6	25-50	1	100	0,3	1128	631	1170	-	-	2
KK_WL126	12/9/17	clear	no	23	19	7	0,6	10-25	<1	45-100	<0.3	568	248	766	-	-	3,6
KK_WL126	5/8/18	clear	-	29	29	7	<0.6	<10	2	45	<0.3	472	305	1745	-	-	6
KK_HP16	5/11/18	clear	no	39	29	8	0,6	<10	<1	45-100	1	496	220	1518	-	-	2,4
KK_HP15	5/13/18	-	-	38	28	7	<0.6	<10	<1	100	1	1048	638	3625	-	-	-

Well ID	Date	Colour	Smell	T Air [°C]	T H_2O [°C]	pH	F [mg/L]	Turbidity [NTU]	NH_3 [mg/L]	NO_3 [mg/L]	Fe [mg/L]	Hardness [mg/L]	Cl [mg/L]	TDS [mg/L]	EC [µS/cm]	Faecal Coliform	DO [mg/L]
NKT_HP02	05/12/2016	clear	no	-	23	8	0,6	<10	<0.1	-	-	520	872,07	2680	-	absent	-
NKT_HP02	13/12/2016	clear	no	-	24	8	1	-	-	-	-	-	-	-	-	-	-
NKT_HP05	18/01/2017	clear	no	-	26	8	0,6	<10	<1	45-100	0,3	552	808,28	-	-	absent	16,4
NKT_BW23	19/01/2017	clear	no	-	29	7	<0.6	<10	<1	45-100	<0.3	800	1063,5	-	-	absent	2,4
NKT_BW17	22/01/2017	little yellow	no	-	28	7	<0.6	10	<1	45-100	0,3	800	999,69	-	-	absent	2,8
NKT_BW02	03/02/2017	clear	no	-	25	7	<0.6	<10	<1	45-100	<0.3	456	921,7	-	-	absent	2,4
NKT_HP05	22/02/2017	clear	no	-	28	7	<0.6	10-25	<1	45-100	1	640	808,26	2536	3902	-	5,2
NKT_BW23	23/02/2017	-	no	28	28	8	<0.6	<10	<1	45-100	<0.3	648	950,06	2610	4016	-	0,4
NKT_BW17	23/02/2017	clear	no	28	29	8	<0.6	10-25	<1	45-100	0,3	800	964,24	2423	3728	-	0,8
NKT_BW02	28/02/2017	clear	no	26	27	8	<0.6	<10	<1	45-100	<0.3	520	872,07	2672	4110	absent	2,4
NKT_HP05	29/03/2017	clear	no	32	26	7	<0.6	10-25	<1	45	1	616	935,88	2566	3947	-	1,2
NKT_BW23	29/03/2017	clear	no	35	30	7	<0.6	<10	<1	45-100	<0.3	648	772,81	2815	4330	-	2,4
NKT_BW02	01/04/2017	clear	no	31	29	7	<0.6	<10	<1	10	0,3	400	751,54	2613	4020	-	2,4
NKT_BW02	13/06/2017	clear	no	30	29	7	<0.6	<10	<1	45-100	<0.3	400	992,6	2683	4128	-	2,4
NKT_HP05	14/06/2017	-	-	34	29	7	<0.6	10	<1	45-100	0,3	400	907,51	2620	4031	-	10
NKT_BW23	18/06/2017	clear	-	31	29	7	<0.6	<10	<1	45-100	<0.3	800	1035,14	2803	4312	-	5,2
NKT_BW17	19/06/2017	clear	-	34	29	7	<0.6	<10	<1	45-100	<0.3	552	943,236	2371	3648	-	2,4
NKT_BW17	10/08/2017	clear	no	30	28	7	<0.6	10	<1	45-100	0,3	800	992,6	-	-	-	0,4
NKT_BW02	11/08/2017	clear	no	28	29	7	0,6	10	<1	45-100	<0.3	400	740,9	2717	4180	-	2

Well ID	Date	Colour	Smell	T Air [°C]	T H_2O [°C]	pH	F [mg/L]	Turbidity [NTU]	NH_3 [mg/L]	NO_3 [mg/L]	Fe [mg/L]	Hardness [mg/L]	Cl [mg/L]	TDS [mg/L]	EC [µS/cm]	Faecal Coliform	DO [mg/L]
NKT_HP05	25/08/2017	-	no	31	29	7	<0.6	25-50	<1	45-100	<0.3	720	850	465	-	-	0,4
NKT_BW23	26/08/2017	-	no	36	30	7	<0.6	<10	<1	45-100	<0.3	1120	1063	2893	4450	-	0,4
NKT_HP05	23/10/2017	clear	no	27	28	7	<0.6	10	<1	45-100	<0.3	416	957	-	-	-	0,4
NKT_BW02	24/10/2017	clear	no	25	28	7	<0.6	10	<1	45	<0.3	400	716	2661	4094	-	4
NKT_BW23	25/10/2017	clear	no	25	30	7	<0.6	10	<1	45-100	<0.3	800	709	2912	4480	-	4
NKT_BW17	26/10/2017	clear	no	26	29	7	<0.6	10	<1	45-100	<0.3	512	886	2536	3902	-	1,6
NKT_BW02	15/12/2017	clear	no	16	26	7	0,6	<10	<0.1	10-45	<0.3	540	808	1571	2417	-	3,6
NKT_BW17	16/12/2017	clear	no	15	28	7	<0.6	<10	<1	45	<1.0	-	694,82	4025	-	-	8
NKT_HP05	17/12/2017	clear	no	12	28	7	<0.6	<10	<1	45	<0.3	784	1021	4246	-	-	8
NKT_BW23	26/12/2017	clear	no	15	25	7	<0.6	<10	<1	10	<0.3	600	865	4233	-	-	4,4
NKT_BW02	01/05/2018	clear	no	29	32	8	0,6	<10	<1	10	<0.3	504	992,6	3784	-	-	2,4
NKT_BW23	02/05/2018	clear	no	29	34	7	<0.6	<10	<1	45	<0.3	688	815,35	4190	-	-	8,4
NKT_BW17	04/05/2018	clear	no	32	29	7	<0.6	<10	<1	45-100	<0.3	880	857,89	3808	-	-	2,4
NKT_HP05	06/05/2018	clear	no	39	30	7	<0.6	<10	<1	45	<0.3	672	1020,96	4162	-	-	4,8