Low-cost household water treatment: A techno-behavioural intervention for local sustainable development in Afghanistan

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Low-cost household water treatment: A techno-behavioural intervention for local sustainable development in Afghanistan

A thesis submitted to the Department of Earth Sciences at Durham University in partial fulfilment of the requirements for the Degree of Doctor of Philosophy.

Mohammad Daud Hamidi

June 2023

Dedication

To my family.

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Declaration

I declare that no part of this thesis has been previously submitted, in whole or in part, to any university or institution for a degree. The work presented in this thesis is the result of my own, except where states otherwise by reference or acknowledgement.

Mohammad Daud Hamidi

Durham University

June 2023

Abstract

Access to safe drinking water is a critical global challenge, in remote rural areas and urban centres alike. A pressing concern within this challenge lies in the sustainability of groundwater and the livelihoods reliant on it. However, a comprehensive study of such a complex issue as water insecurity requires a multidisciplinary approach that can synthesize perspectives from the natural and social sciences. With the overarching aim of studying and developing means to rectify water insecurity in low-income settings, this thesis pursues such an approach and contributes insights to the broader global dialogue through the case of the conflict-affected urban context of Kabul – where groundwater and livelihood challenges are driven especially by the contamination and rapid depletion of the local aquifers.

The multidisciplinary study begins with a geo-hydrology perspective that explores the sources of groundwater and the factors contributing to groundwater contamination. Additionally, it explores the potential of using clay disc filters for household water treatment from an earth sciences perspective. Complementing these natural science perspectives, the research also incorporates the COM-B framework, which draws from psychology and behavioural science. By leveraging anthropological techniques with a firm grounding in development research, the thesis further adopts a bottom-up approach to inform survey research.

Translating this multidisciplinary approach into the empirical research underlying this thesis, firstly, the groundwater recharge sources and groundwater dynamics in aquifers of Kabul city were explored relying on the analysis of the stable isotopic composition ($\delta^{18}O$ and $\delta^{2}H$) of groundwater and surface water from the Upper Kabul River and Logar River. The results showed that precipitation was the primary source of recharge in the Central Kabul sub-basin, while mixed recharge from the river, precipitation, and irrigation return flow governed recharge in the Logar sub-basin. In the Paghman and Lower Kabul, and Upper Kabul sub-basins, increased rainfall input was also observed. The contribution of river water to groundwater recharge decreased from an average of over 60% in 2007 to less than 50% in 2020. Also, substantial groundwater level depletion was documented in the Central Kabul sub-basin and western parts of the city.

In addition to examining recharge sources and rates, the bacteriological and chemical characteristics of Kabul's groundwater were analyzed. In Kabul, 4.1 million people rely on groundwater, making it critical to understand its contamination trends in the face of rapid development and social changes. The results showed an increase in *E. coli* and NO_3^-, indicating anthropogenic impacts on shallow groundwater quality. The Water Quality Index revealed that less than 35% of shallow groundwater samples had good quality. To address these issues, the implementation of point-of-use water purification was proposed as a temporary solution for reducing the occurrence of waterborne diseases.

Moreover, a qualitative study, based on 68 semi-structured interviews, explored the factors limiting access to clean drinking water in two peri-urban areas in Kabul. These factors included dysfunctional water supply networks, water price inequalities, uneven development, and aid prioritization. In addition, the stressors and dynamic access to water

such as droughts, contamination, and electricity disruption were documented. Further, this research examined the nature and underlying factors of inter-household water-sharing practices. Water availability, the costs to the donor, the frequency of requests for water, the period over which they operate, and religious beliefs were all found to play key roles in determining water-sharing practices. The added influence of droughts in limiting water-sharing practices further highlighted the dynamics in performing the behaviour.

Furthermore, this research explored the factors that influence household water treatment practices, relied on a comprehensive behaviour change model (i.e., COM-B model). The results of the study showed that reflective and automatic motivation, as well as physical opportunity, had a statistically significant association with the performance of household water treatment behaviour. The findings suggest that socioeconomic, psychosocial, and contextual factors are all important in understanding and promoting household water treatment practices, and should be taken into account to develop interventions that are tailored to the specific needs and obstacles of different communities.

Lastly, the potential of using clay disc filters, frequently termed ceramic water filters, made from locally-sourced clay samples, was explored for removing bacteria from water. The clay discs were produced by mixing clay and sorted sawdust in a ratio of 1:2, and the filtration rate was 1 litre per hour. Clay disc filters have the potential to be a low-cost and locally-sourced solution for improving water quality in Afghanistan, but further research and development is needed to optimize their production, particularly by leveraging the skills of local potters in Kabul.

Overall, the synergistic combination of disciplinary techniques was thus capable of shedding light on the complex interplay between water resources, technology, and human behaviour (i.e., household water treatment) and provided a comprehensive understanding of the challenges and solutions surrounding access to safe drinking water.

Acknowledgements

I had just begun working on my thesis when a global pandemic (COVID-19) disrupted the normal human routine. With the help of incredible people, countries managed to navigate through it. However, just as we were catching our breath, a national crisis struck Afghanistan which made my journey more frustrating than any previous situation. Nevertheless, I consider myself truly lucky to have been able to work through this challenging and fulfilling journey with the support of several key individuals.

First of all, I would like to thank my supervisor Professor Chris Greenwell for this incredible opportunity and for providing me with support and guidance throughout my PhD journey and beyond. I am grateful to Chris Greenwell for sharing his expertise in the field, encouragement, and timely feedback which were crucial for the successful completion of this multidisciplinary research.

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I would like to extend my gratitude to the participants of this research, who generously gave their time and effort to contribute to this research. I would like to thank the local potters for sharing their stories, and friendly discussions on the pottery arts in Kabul.

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Chapter 1

1 Introduction

1.1 Rationale

Access to safe drinking water is a basic human right – and is enshrined in the government's policies as well as the UN Sustainable Development Goals or UN-SDGs (UN 2016; MoE 2020). Kabul is one of the most water-stressed cities in the world, with an average per capita water supply of 16 litres per capita per day (lpcd), compared to a desirable level of a minimum of 80 lpcd (World Bank 2010). However, the lack of a reliable water supply leaves almost two-thirds of the city's urban population without sustainable access to safe drinking water. Households in peri-urban Kabul rely on groundwater as a primary source of drinking water (Mack et al. 2013; Hamdard et al. 2015). However, the chemical and microbial status of groundwater has been poorly investigated since the extensive analyses carried out in 2007 by Mack et al. (2010) - these parameters are crucial for assessing the health risks of disease resulting from poor water quality (Graham and Polizzotto 2013). Furthermore, there is a limited understanding of groundwater recharge sources, and surface and groundwater interaction. Gaining insight into these components is very important for sustainable water resource management in this densely populated city (Georg et al. 2003).

Waterborne diseases have a substantial role in the high rate of child mortality in Afghanistan, where 97 out of every 1000 children born die before the age of five (Rasooly et al. 2014). Due to the lack of water supply networks, and lack of wastewater networks, the need for household water treatment is critical to reducing the risks of water-borne diseases (Nath et al. 2006; Bielefeldt et al. 2009). Although household water treatment has the potential to be advantageous, there are obstacles to its adoption. Cost and accessibility of appropriate water treatment technology are major concerns, especially in low-and middle-income countries where resources may be limited (Sobsey et al. 2008). However, the local natural-based solutions and the factors determining household water treatment in the context of Afghanistan have been poorly investigated.

Therefore, this thesis investigates surface and groundwater interaction, access to water, and groundwater quality. It explores developing a low-cost water treatment solution for households in Kabul, Afghanistan to promote sustainable development and increase access to safe drinking water which is essential for the health and well-being of communities. Considering the recognized importance of various socio-psychological factors in determining the adoption and utilization of household water treatment technology, this research involves behavioural elements such as analysis of the social and behavioural factors that influence the adoption and use of household water treatment technologies in the study area.

1.2 Research aims

The aims of this research are summarized as (Figure 1.1):

1. **To quantify** the interaction between surface and groundwater sources in the Kabul aquifer system, and the ramifications of aquifer recharge in the future.
2. **To measure** water quality in Kabul and identify vulnerable neighbourhood areas.
3. **To investigate** factors influencing household water treatment practices.
4. **To design** a low-cost household water treatment method, using locally sourced materials, that local communities can fabricate for the provision of cleaner water for cooking and drinking.
5. **To implement** a behaviour change intervention for encouraging the communities for the sustainable use of the low-cost household water treatment method.

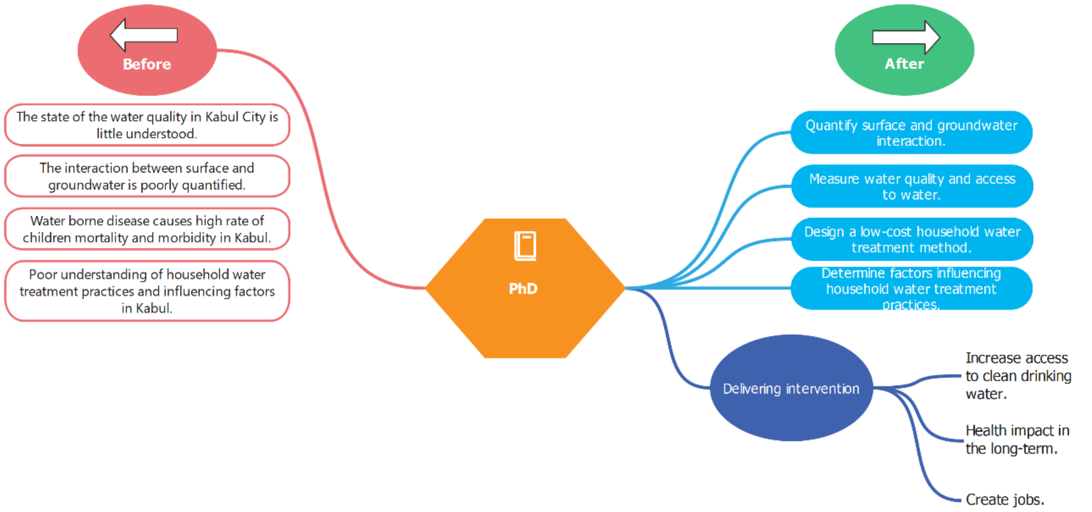

Figure 1.1. The PhD research aims at the outset of the study and the drivers for them.

This research will seek to address the following questions:

1. What are the sources contributing to groundwater recharge in the aquifers of Kabul City?
2. What are the spatial and temporal variability of groundwater levels in Kabul city?
3. How do the chemical and biological characteristics of groundwater vary in Kabul city?
4. What are the mechanisms controlling groundwater hydrogeochemistry in the aquifers of Kabul city?
5. What are the health risks of bacteriological contamination of the groundwater in Kabul city?
6. What are the realities and challenges faced by residents in accessing water in Kabul city?
7. How do the residents in Kabul city perceive the quality of drinking water?
8. What are the factors influencing inter-household water-sharing practices?
9. What factors determine household water treatment practices in Kabul city?
10. How do socioeconomic, psychosocial, and contextual factors influence household water treatment practices?
11. How effective are clay disc filters in removing bacteria from household water?
12. What is determining the optimum filtration rate and microbial removal efficiency of clay disc filters?
13. How can local potters contribute to the design and production of clay disc filters that are culturally acceptable and accessible to the residents of Kabul city?
14. How does the behaviour change intervention impact the actual usage of clay disc filters among households in Kabul city?

1.3 Research approach

The research approach for this multidisciplinary study involves a combination of methodologies from different disciplines that collectively contribute to achieving the research aims:

To begin, conduct the stable isotope analysis of water samples (H and O), to understand the interaction between surface and groundwater sources in the Kabul aquifers.

Next, analyse major cations and anions, and quantify groundwater samples for bacteriological contamination (*E. Coli*) to assess the spatial status of water quality in Kabul city. Steps 1 and 2 above helps identify the neighbourhoods vulnerable to water scarcity and poor water quality in Kabul City.

Then, using insights from steps 1 and 2 above, conduct qualitative semi-structured interviews to identify challenges in access to water, gaps in infrastructure and policy, and determine public perception of water quality, as well as factors influencing household water treatment practices.

Utilize insights from step 3, and administer a quantitative survey to investigate factors determining household water treatment.

Design a clay disc filter, in consultation with local potters, and deliver filtration rate and microbial removal tests on clay disc filters.

Lastly, utilize the insights from steps 1 to 5 to design and implement a behaviour-change intervention to promote the use of clay disc filters for household water treatment in Kabul city.

1.4 Thesis structure

The chapters of this multidisciplinary thesis are structured to resemble the style of the journal articles, which seek to address one or more of the research questions mentioned in Section 1.2. To navigate the complex terrain of this multidisciplinary research, I have relied on the guidance of a team including my primary supervisor and co-supervisors from various disciplines, each of whom has provided invaluable expertise and support throughout my work. It is for this reason that I mention the names of these individuals in each chapter, as a way of acknowledging their contributions to the success of this research. The following is the thesis outline:

Chapter 1 - Introduction

The introduction chapter provides the rationale and aims of this multidisciplinary research. Furthermore, it outlines the thesis structure and a brief introduction to each chapter.

Chapter 2 - Literature review

This chapter builds on a comprehensive review of the literature related to water quality in Kabul City. Specifically, the chemical and biological contaminants present in the city's groundwater. This literature review provides an overview of point-of-use (POU) household water treatment techniques and their effectiveness in removing microbial contaminants. Additionally, I explore the concepts of behaviour change in the context of Water, sanitation and hygiene (WASH), with a focus on delivering interventions to promote household water treatment technologies.

Chapter 3 - Investigating groundwater recharge using hydrogen and oxygen stable isotopes in Kabul city, a semi-arid region

This chapter presents a thorough understanding of the groundwater recharge processes in the Kabul city region and the sources of groundwater recharge. Furthermore, It presents the groundwater dynamics in the aquifer system, for instance, the distribution of groundwater levels within the aquifer. Overall, this chapter provides insights on the groundwater system in the Kabul city region which informs decision-making regarding the management and sustainable use of water resources.

Chapter 4 - Spatial estimation of groundwater quality, hydrogeochemical investigation, and health impacts of shallow groundwater in Kabul city, Afghanistan

This chapter presents the suitability of shallow groundwater for drinking purposes in Kabul City using the Water Quality Index (WQI) and Geographic Information System (GIS). I present the analysis of chemical and biological parameters of shallow groundwater which helps determine the quality and suitability for human consumption. Furthermore, the shallow groundwater characteristics, water type, and the mechanisms controlling groundwater hydrogeochemistry in the study area are presented. In this chapter, the trend of bacteriological contamination in groundwater and its potential health risks across Kabul City is documented. Lastly, I investigate the potential impact of anthropogenic activities on groundwater pollution in Kabul City. Overall, the findings of this study provide valuable information on the state of groundwater in Kabul City.

Chapter 5 - Access to Water in Kabul, Afghanistan: A Qualitative Study

The aim of this qualitative chapter is to enrich the understanding of water access challenges in Kabul by taking an exploratory approach, to achieve two main objectives. The first objective, I explore the grounded realities and identify the key factors that contribute to the challenges of accessing clean drinking water in Kabul. The second objective enriches the methodological approaches to measuring access to water in this setting by examining and critiquing existing methodologies. Further, this chapter proposes an integrated approach that is more sensitive to the complexities and nuances of access to water. Overall, this qualitative chapter provides a deeper and more nuanced understanding of the challenges of access to safe drinking water in Kabul City, and establishes a base to develop more effective methods for measuring and monitoring access to water.

Chapter 6 - Water-Sharing Practices in Kabul, Afghanistan: A Qualitative Study

This chapter relied on a qualitative approach to investigate water-sharing practices and the factors that influence these practices between households. The open-ended exploratory approach allowed for exploring the nuances and complexities of water-sharing practices, rather than imposing pre-determined assumptions or hypotheses. Through in-depth interviews and observations, this chapter presents insights into the motivations, challenges, and opportunities that shape inter-household water transferring practices.

Chapter 7 - Factors Determining Household Water Treatment in Kabul, Afghanistan: A Qualitative Study

This chapter is designed to gain a deeper understanding of the local realities of household water treatment practices from two peri-urban settings by conducting 68 semi-structured interviews. In addition to providing valuable information about the local context, this chapter also aimed to challenge and expand upon the dominant psychological perspectives on Water, sanitation and hygiene (WASH) behaviour change approaches that are often found in the research literature. By adopting a grounded approach, this chapter provides a more nuanced and comprehensive understanding of the factors that influence household water treatment decision-making in low-and-middle income settings. This chapter will inform interventions and policies that aim to improve access to safe drinking water by promoting household water treatment technologies in settings with similar characteristics.

Chapter 8 - Determinants of Household Safe Drinking Water Practices in Kabul, Afghanistan: A Quantitative Survey Study

This chapter investigates various socio-economic, psychosocial, and contextual factors that influence household water treatment behaviour. The quantitative survey was conducted in two peri-urban areas, which allowed to gain a comprehensive picture of the range of factors that may impact household water treatment behaviour in these communities. Although the direct comparison of the two sampling sites is not the primary focus of this chapter, their specific characteristics are likely to play an important role in understanding the contextual variability underlying household water treatment behaviour. By taking a multi-faceted approach that considers a wide range of factors, this chapter provides valuable insights on the interconnected factors that shape household water treatment behaviour in Kabul City. The implications of this chapter include informing interventions and policies aimed at targeting household water treatment practices.

Chapter 9 - Low-cost Household Drinking Water Treatment using Clay Disc

This chapter examines the characteristics of clay sourced from two deposits in Kabul and explores the potential for developing affordable clay disc filters for household water treatment. Clay disc filters are effective at removing bacteria from water, making them a viable option for improving the quality of drinking water. Next, the chapter explores the development of affordable clay disc filters that can maximize bacterial removal efficacy. By using these filters, Kabul residents can replace the need for imported water treatment technology and support the income of local potters. Importantly, affordable solutions to contaminated groundwater ensure that the broader population gain access to safe drinking water.

Chapter 10 - Conclusions

This chapter provides a summary of the main findings and conclusions of the thesis. I begin by summarizing the key points covered in previous chapters and highlighting the main contributions of my research. I then present recommendations for future research as well as policy recommendations based on my research findings. I suggest areas where further research is needed to build on the insights gained from my work and address remaining questions and challenges.

1.5 The COVID-19 impact statement

The restrictions placed due to COVID-19 health and safety regulations caused a delay in the collection of essential field data in Kabul, Afghanistan. Second, the restrictions delayed the delivery of analyses on groundwater samples in the lab. Lastly, the COVID-19 measures and security situation in Afghanistan did not permit the delivery of all phases of intervention as initially planned. However, the cross-sectional quantitative and qualitative data collection provided a substantial contribution to the theory and established a solid foundation for designing and delivering future interventions in low and middle-income countries - particularly in Kabul, Afghanistan.

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Chapter 2

2 Literature Review

Approximately 785 million worldwide people lack even a basic drinking water service, including 144 million people who are dependent on surface water (WHO 2022). The Global Burden of Disease approximated that 1.2 million people died prematurely in 2017 as a result of unsafe water (Stanaway et al. 2019). Waterborne diseases account for 7% of the burden of disease in developing countries (Lvovsky 2001). There is a risk of water contamination, which poses threats to both the physical and social health of individuals. Moreover, barriers to implementing water interventions result in people being deprived of access to safe drinking water.

The aim of this literature review was to identify the current state of knowledge on access to safe drinking water in the study area (Kabul City, Afghanistan), gather existing research and information on household water treatment techniques, and identify concepts of behaviour change approaches. The review sought to gather relevant findings and insights from previous studies to gain a deeper understanding of the challenges associated with water quality, accessibility, and the adoption of appropriate technologies for household water treatment. To conduct the literature review, a comprehensive search was performed using academic journals, reports, and other reputable publications.

2.1 Study area

Kabul province is the capital of Afghanistan and has an area of 4523.9 Km^2. The population of the province was 4.5 Million (World Bank 2019), and the average household size was 7.2 people (NSIA 2018). Within Kabul city, there are three main surface water sources. The Kabul river has a catchment area of 1626 km^2 and a mean discharge of 0.002 $m^3s^{-1}km^2$. The Logar river has a catchment area of 9343 km^2 and a mean discharge of 0.0008 $m^3s^{-1}km^2$. Lastly, The Paghman river has a catchment area of 477 km^2 and a mean discharge of 0.001 $m^3s^{-1}km^2$ (Figure 2.1). Generally, these rivers flow only for a few months during seasonal snow melt and rainfall (Saffi 2011). The Kabul River originates from the eastern side of the Paghman Mountains, from the Paghman district, and numerous small streams gather west of Kabul and join the Paghman River near Deh Mazang; some of these streams refill the Qargha reservoir. Logar River drains water from the Day-Mirdad district of Wardak province, flows towards Kabul Province, and joins the Kabul River east of Kabul city (Saffi 2011).

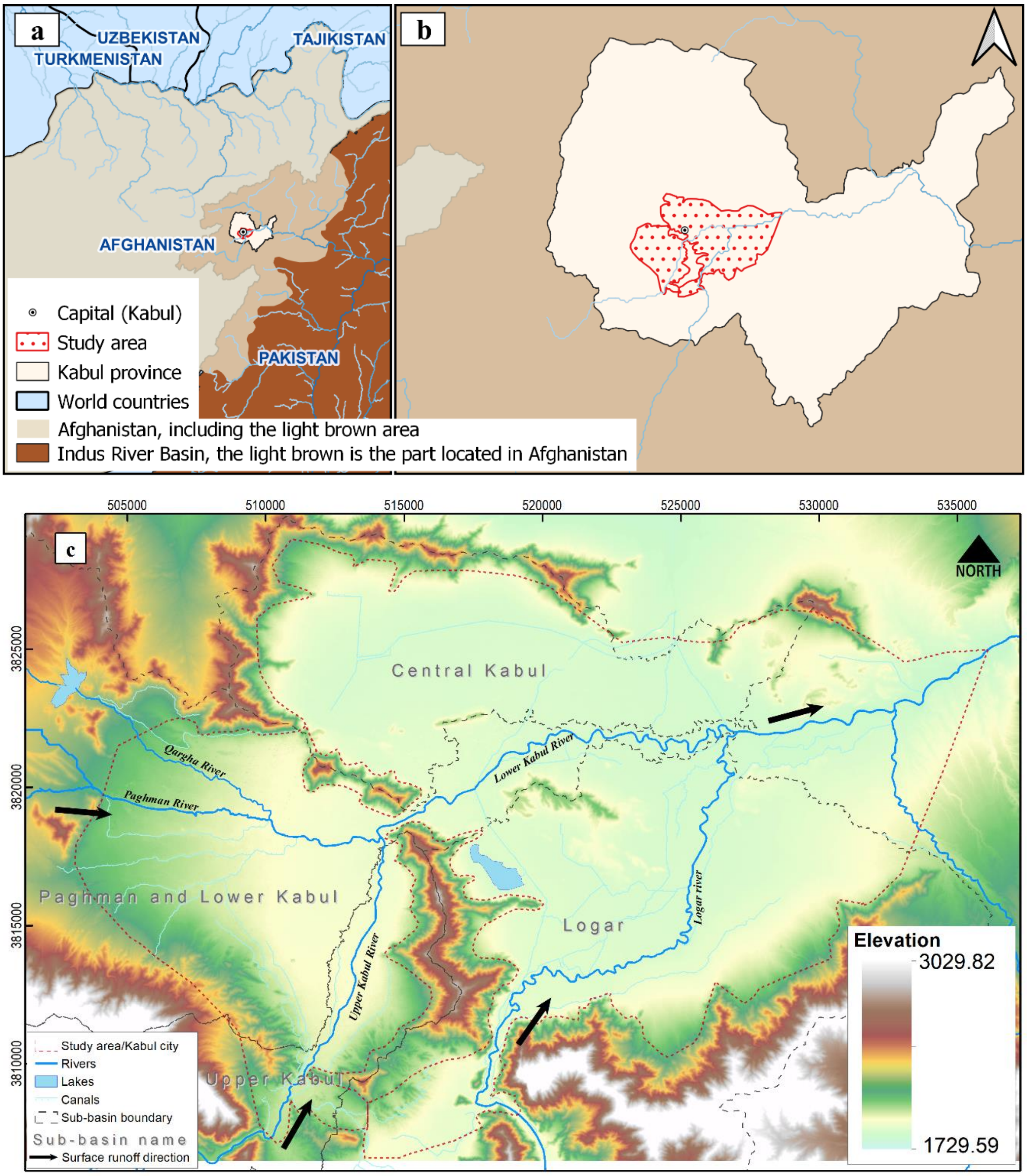

Figure 2.1. Kabul River flows through Kabul province in Afghanistan and toward Pakistan, where it joins the Indus River (a); the study area location (Kabul city) in Kabul province (b); elevation map of the study area (c).

2.2 Water quality in Kabul

The national coverage of access to safe drinking water was 45.5%, as reported by the Ministry of Rural Rehabilitation and Development of Afghanistan in 2015. In the same year, only around 39.4% of the rural population had access to safe drinking water, the coverage of access to sanitation was 8.4 %, and only around 2.4% of the rural population had access to sanitation (Saffi 2019). Merely 12% of Kabul's residents have access to the public water supply system; 50% of households, especially those with low income, relied on private wells dug inside the households (Brati et al. 2019).

The key reason for the lack of accessible safe drinking water in Kabul is that most of the annual rainfall and snowmelt (the main source of water for Kabul city) is not captured for productive use due to a lack of storage infrastructure and flows onward to Pakistan. The absence of storage infrastructure leaves Kabul reliant on groundwater. However, the available groundwater is of poor quality and is deteriorating due to human factors such as leaching, contamination from pit latrines and waste disposal. In the meantime, the groundwater levels are declining due to over-abstraction, particularly in the west of the city (KMARP 2018b). The primary source of municipal water supply systems is groundwater through more than 40 supply wells, and the second is surface water obtained from the Qargha Reservoir in the Paghman Sub-basin (Karim 2018).

The use of fertilizer for agriculture and the existence of landfill sites in high permeability areas causes pollution of groundwater. In 2003, about 32 % of hand-pump wells in the Kabul Basin had nitrate concentration levels exceeding the World Health Organisation (WHO) limit of 50 mg/l (Georg et al. 2003). Groundwater samples from the Kabul Basin had significant amounts of total coliform bacteria, and in almost all samples *E. Coli* was detected (97% of samples); nitrate was found in the range of 3.3–40.2 mg/l, and arsenic was detected in a few samples (Broshears et al. 2005; Mack et al. 2013).

In the Kabul basin, all the samples showed high water hardness (>120 mg/l), and hardness was associated with high carbonate concentrations (Shnizai 2011). The study added that in the Kabul basin approximately more than 50% of samples exhibited Borate levels below the limit set by WHO (0.5 mg/l). However, the levels of borate in the urban areas were much higher (18 mg/l) than in the rural areas.

Considerable anthropogenic emissions are identifiable in the urban area of Kabul, which has a serious impact on the natural groundwater quality, e.g., through massive input of nutrients and bacteria from sewage and uncontrolled waste disposal (Sundem 2014).

Since there is no systematic sewage treatment or refuse collection, the shallow groundwater is affected by considerable contamination (Sundem 2014), and the sampled water from Kabul Airport indicated a potential health risk from elevated levels of boron, magnesium, manganese and sodium.

Almost 60 % of tested water samples (1,758 water samples) from the water points in the Groundwater Monitoring Network System exceeded the WHO guideline of zero colony forming unit (CFU) per 100 ml (Saffi and Kohistani 2013). The total coliforms are considered to be a general indicator of potential contamination from a wide range of sources. In contrast, faecal coliforms originate only from human and animal waste and are therefore an indicator of sewage contamination and potential health risks from the presence of hazardous bacteria (e.g., *Escherichia coli* (*E. Coli*). A study by Kabul Managed Aquifer Recharge Project (KMARP) concluded that all samples of both surface water and groundwater contained copious quantities of coliforms, often at levels too numerous to count (KMARP 2018b).

2.3 Household drinking water treatment using ceramic filters

Household water treatment and safe storage (HWTS) systems have been associated with marked drinking water quality improvement and disease reduction. However, time-consuming operation and maintenance, aesthetic concerns, limited effectiveness, high costs of existing technologies, and lack of consideration of consumer preferences have limited the scale-up of HWTS systems (Sandec 2011). There are different household water treatment techniques used in the world such as boiling, chlorination and bio-sand filtration (Clasen 2005). The aforementioned water treatment techniques are used to diminish waterborne disease by filtering microorganisms or reducing the turbidity of the source water. However, the mentioned techniques are expensive, if applied continuously, and also reduce the quality of water, for example, using chlorination as a household water treatment reduces or changes the taste of water. Alternatively, ceramic filters are affordable, sustainable and don’t require energy sources. The ceramic filters are made from clay and combustible material (e.g., sawdust and rice husk). For this purpose, a clay mixture was prepared by mixing sawdust and clay that are screened using a 0.5 mm sieve (Zereffa and Bekalo 2017; Bulta and Micheal 2019). The decontamination mechanism in ceramic filters is governed by pore capture and silver disinfection. When the contaminated water is poured into the ceramic filter, the tiny pores inside the ceramic pot act as a filter that traps most particles and debris along with larger parasites and bacteria (Palmateer et al. 1999). Clay minerals are hydrous aluminosilicates broadly defined as those minerals that make up the colloid fraction (<2μm) of soils, sediments, rocks and water (Pinnavaia 1983), and may be composed of mixtures of fine-grained clay minerals and clay-sized crystals of other minerals such as quartz, carbonate and metal oxides (Bhattacharyya and Gupta 2008).

Ceramic flower pots also known as ceramic filters are a mixture of clay powder and burn-out material that are, sometimes, painted with a special solution of silver that kills bacteria (Zereffa and Desalegn 2019). Ceramic pots were used for centuries in Afghanistan for the purpose of water storage but recently more plastic is used due to durability and ceramic usage has been undermined (Istalifi 2020).

2.3.1 *E. Coli* removal

Different methods were used in the past for household water purification in different regions of the world based on flocculation or coagulation, as mentioned by Madsen and Schlundt (1989) "for some hundred years or more, the women in the rural communities along the Nile valley have been employing local water purification methods to remove turbidity, several natural flocculating or coagulating agents of plant and soil origin existed, and their distribution and local use were extensively reviewed by Jahn (1977, 1981)". The authors further elaborated that the techniques used were based on flocculating properties of a certain clay type called "Rauwaq (clarifier)" which was found in certain sites and varying qualities at the river banks (Madsen and Schlundt 1989). Furthermore, it was highlighted that "the preliminary investigation by Jahan (1976) indicated some removal of coliforms took place during the purification process, where the turbidity reduction was paralleled by a bacterial reduction of approximately 1-1.5 log units (90-96.9%) for *Salm. Typhimurium, Shig. Sonnei* and *Str. Faecalis,* and almost 3 log units (99.9%) for *E. Coli* within the first hour" (Madsen and Schlundt 1989). However, regrowth of *E. Coli* was observed after the first hour and indicated the importance of the time factor, and the treated water should, if possible, be consumed in the first hours of purification (Madsen and Schlundt 1989).

Point of Use (POU) technologies such as ceramic and bio-sand filters are promising for being effective and affordable ways to achieve sustained access to sufficient quantities of safe drinking water for those people worldwide who most need it (Sobsey et al. 2008). In their study, Mwabi et al. (2012), investigated the removal of *E. coli* through several household water treatment methods.

Table 2.1 Average percentage of *E. Coli* removal efficiency, also present as Log Reduction Value or LRV from tested water samples, adapted from Mwabi et al. (2012)

Devices	Surface water with a low turbidity LRV (%) *n* = 18	Surface water with a high turbidity LRV (%) *n* = 18	Groundwater with a low turbidity LRV (%) *n* = 18	Groundwater with a high turbidity LRV (%) *n* = 18
Biosand filter-standard (BSF-S)	2.4 (99.4)	3.1 (> 99.9)	1.6 (96)	> 3.7 (100)
Ceramic candle filter (CCF)	1.8 (98)	3.2 (> 99.9)	>2.5 (99.5)	2.9 (99.8)
Silver-impregnated porous pot (SIPP)	> 3.5 (100)	> 4.0 (100)	> 2.5 (100)	> 3.7 (100)

The experiments were delivered on the surface and groundwater samples, and included devices such as a Silver-impregnated porous pot (SIPP) which was mentioned as the best device, among others, as the average removal of *E. Coli* from environmental water samples was > 99.99 %. Biosand filter-standard (BSF-S) and Ceramic candle filter (CCF) efficacy in *E.*Coli removal ranged between 96 % to 99.9 %. The average removal of *E. Coli* ranged between 1.6 to 4 Log Reduction Value (LRV) or 96% to 100% for BSF-S and 1.8 to > 3.2 LRV or 98 % to 99.9 % for CCF (Table 2.1).

In their experiments, Varkey and Dlamini (2012), made porous pots from terracotta clay and sawdust. The clay and sawdust were grounded and sieved using 300 µm, 600 µm and 900 µm sieves, and were mixed in the ratios 1:1 and 1:2 to make the pots. The produced pots were then dried and fired in an electric furnace at 850 ^{o}C (Varkey and Dlamini 2012). The pots were suspended inside plastic receptacles to make clay pot water filters (CPWFs) for point-of-use (POU) application, the filters were tested for their ability to purify raw water obtained from local rivers where the 600 µm filter (with a filtration rate of 110 ml/h) yielded water that was completely free of *E. Coli* (the *E. coli* level was as high as 9600 CFU per 100 mℓ), and reduced the total coliform concentration by 99.3 % (Varkey and Dlamini 2012). It is worth noting that the accepted level for potable water quality is zero CFU per 100 mℓ for coliforms, the presence of *E. Coli* or thermotolerant coliform bacteria and Total coliform bacteria must not be detectable in any 100-ml sample of all waters intended for drinking purpose (WHO 2017). The presence of *E. coli* indicates that the water could have been contaminated with animal or human waste and could cause waterborne diseases such as diarrhoea, which often lead to deaths, particularly among children (Rayner et al. 2013). Because of the potential disease-causing characteristics of certain *E. Coli*, the removal of *E. Coli* from raw water was a major step in all water purification systems (Bielefeldt et al. 2009; van der Laan et al. 2014).

According to Zereffa and Bekalo (2017), the ceramic filters manufactured from 15 % sawdust, 80 % clay, and 5 % grog (fired clay) that were fired at 950 °C or 1000 °C showed better microbial and ion removal efficiency compared to those fired a lower firing temperature (900 °C). Figure 2.2 indicates the *E. coli* removal efficiency of ceramic filters produced in Ethiopia at different firing temperatures, adapted from Zereffa and Bekalo (2017).

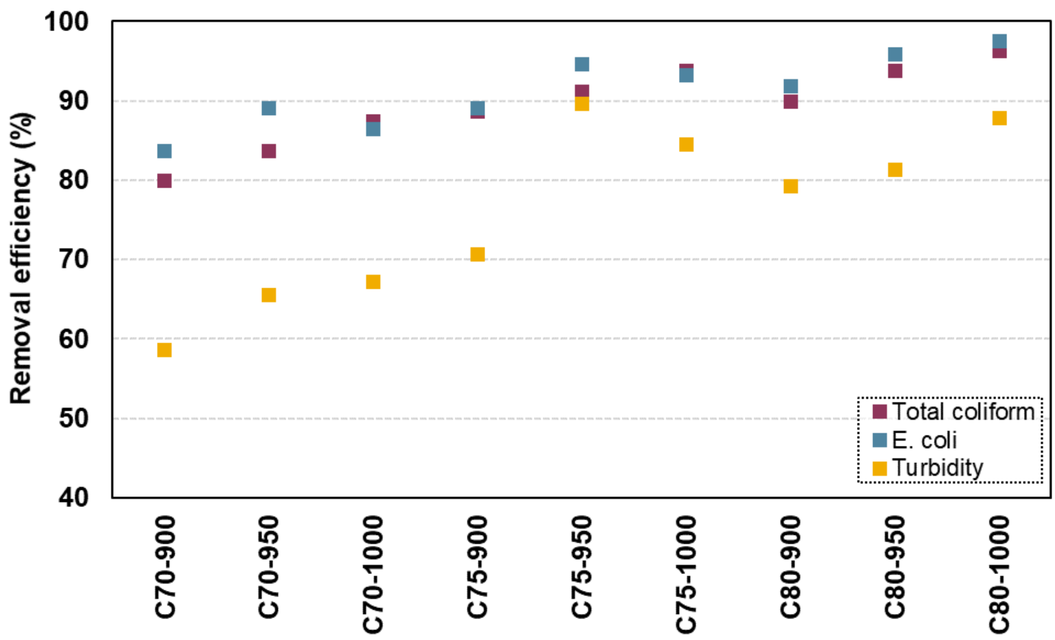

Figure 2.2 *E. Coli* removal efficiency of different mixtures of ceramic filters sintered at 900º C, 950º C and 1000º C, adapted from Zereffa and Bekalo (2017).

2.4 Perception of poor quality water health risks, and use of household water treatment

While ceramic water filters and other point-of-use water filters can be effective at improving the quality of drinking water, their adoption and use are not always guaranteed and are influenced by a range of factors such as availability, cost, and cultural and social norms. A measurement of the use of household water filters in Ethiopia showed that water filters were more or less consistently used in rural communities where they have been distributed free but the use was limited for a portion of the household's water consumption needs (Sandec 2011). As highlighted in the report by Sandec (2011), respondents reported filling their water filters on average 2.1 times a day, which compared to the average of 1.8 recorded by the data loggers. However, the data loggers indicated that daily consumption was on average 12.5 litres, compared to self-reports of 19.4 litres (Sandec 2011). When divided by the number of people living in each household, the average consumption of water from the filters was 2.0 litres per person per day; This amount of water was likely sufficient for drinking, but not for cooking. Additionally, the survey participants indicated that they mainly used filters for drinking water rather than for cooking (Sandec 2011).

In order to deliver successful intervention on household water treatment techniques, in a survey in Kenya, the residents were proposed questions about the design of water filters (Johnston et al. 2012). The responses revealed that most respondents preferred cubic and cylindrical shapes, as they were perceived to be stable, familiar and not take up too much space (Johnston et al. 2012). Furthermore, regardless of wealth, respondents overwhelmingly chose blue over other colours, and complex patterns including traditional African prints were not as well liked as solid colours (Johnston et al. 2012).

2.4.1 Health risks of poor water quality

It has been estimated that in Afghanistan around 30–40% of all reported diseases and deaths are due to poor water quality. Moreover, the leading cause of death in infants and children up to 10 years of age as well as a mortality rate of 1,600 per 100,000 live births was reportedly due to diarrhoea (Karim 2018). Estimates of the under-5 mortality rate in Afghanistan indicate that, per 1,000 live births, 161 children die before they reach their fifth birthday; in 23% of the cases, the deaths may be directly attributed to causes related to poor water and sanitation. On average, Afghan children undergo six episodes of diarrhoeal disease each year (KMARP 2018a).

The Kabul Managed Aquifer Recharge Project (KMARP) conducted health surveys and found that the incidence of potential waterborne diseases in Kabul was generally high and was distributed according to groundwater levels and increasing with time (KMARP 2018a). These diseases are mainly caused by water quality issues, although food is often the main cause of several of the illnesses used as an indicator. The report also indicated that there was a negligible reported incidence of mosquito-borne diseases in Kabul, but there was a clear link between water-borne diseases and shallow groundwater levels in eastern Kabul, particularly in areas populated by internally displaced persons(KMARP 2018a). The empirical data available indicate that there was conclusive evidence that shallow groundwater was currently causing health impacts in eastern and central Kabul, dysentery was almost ubiquitous, regardless of depth to groundwater (KMARP 2018a).

Monitoring of over 100 boreholes by the Ministry of Energy and Water (MEW) and Ministry of Health (MOH) showed that almost all boreholes were contaminated with *E. coli*, and four locations had visible sewage contamination or an odour of sewage (KMARP 2018a). In the aforementioned reports, faecal coliforms were used to indicate sewage contamination of groundwater and surface waters. The results showed that there was attenuation of faecal coliforms in the subsurface with concentrations four orders of magnitude lower than in foul water drains (KMARP 2018a). There was a clear spatial pattern of contamination with the highest results occurring in the east of the city (KMARP 2018a).

2.4.2 Religion and water

Religious beliefs can play a significant role in the decision-making to use ceramic water filters for household water treatment. In Islam, as highlighted by Zaharuddin and Sabri (2005), the Prophet discouraged the selling of water and even forbade the sale of excess water. He also encouraged Othman to buy the well at Ruma and give away its water for free, these examples reflect the prophet’s desire for the poor and weak to have access to water (Zaharuddin and Sabri 2005). In Qur'an (2:11), the command to believers is ‘‘*make not mischief on earth.*’’, this means that people cannot spoil or degrade natural resources. The Prophet Mohammad, very sensibly, forbade urination into stagnant water and advised guarding against this practice, showing how Islam has underlined that water sources should be guarded against any contempt that can pollute the source (Zaharuddin and Sabri 2005).

The recognition of water as a vital resource, to which everyone has the right to a fair share which effectively makes water a community resource to which all, rich or poor, have a right is emphasized by the following hadith: ‘‘Muslims have a common share in three things, pasture, water, and fire’’, as narrated by Abu Daud (Zaharuddin and Sabri 2005). In addition, Islam proclaims water conservation, and it is considered a fixed concept of Islamic teaching, a Muslim is ordered to be economical with water even if he is taking his water from a fast-flowing river. The Prophet said not to overdo it even in worshipping Allah; for instance, he used only a handful of water in taking his ablution (Zaharuddin and Sabri 2005).

2.5 Behaviour change intervention: Household water treatment

Household water treatment technology can help reduce the risk of waterborne diseases (Sobsey et al. 2008). However, getting people to adopt and consistently use these technologies can be a challenge. It is important to study the factors that influence the adoption and consistent use of household water treatment methods to inform the development of effective intervention strategies (Martin et al. 2018; McGuinness et al. 2020b). A behaviour-change intervention, based on emotional drivers, was effective in significantly increasing the prevalence of handwashing with soap in villages in rural India, the intervention seems to have been both effective in making people switch from handwashing with water to handwashing with soap and also in making people wash their hands when previously they did not (Biran et al. 2014).

The dominant behaviour change models in the household water treatment landscape include the RANAS model which stands for Risk beliefs, Attitudinal beliefs, Normative beliefs, Ability beliefs, and Self-regulation (Mosler 2012). The RANAS model emphasizes that changes could take place in households on their own, without addressing larger societal or environmental changes at the institutional, economic, or political levels (Arriola et al. 2020). The presented model can be useful in situations where households have the ability to make changes to their daily routines without needing assistance from external sources, such as government institutions. If public health practitioners decide to focus on individual behaviour change, the model can serve as a comprehensive approach (Mosler 2012). The RANAS behaviour change model was delivered in order to increase safe water consumption in Bangladesh and Ethiopia (Sandec 2011). The RANAS model is proposed to be effective in delivering interventions at the household level, while there have been several studies utilizing RANAS in delivering WASH interventions by primarily focusing on psychological factors, the research overlooked delivering a comprehensive approach in determining factors influencing household water treatment from a more comprehensive perspective.

Michie et al. (2011) presented that the most parsimonious way of designing an intervention is to represent the whole classification system in terms of a behaviour change wheel (BCW) with three layers (Figure 2.3). This is not a linear model where components within the behaviour system interact with each other as do the functions within the intervention layer and the categories within the policy layer (Michie et al. 2011).

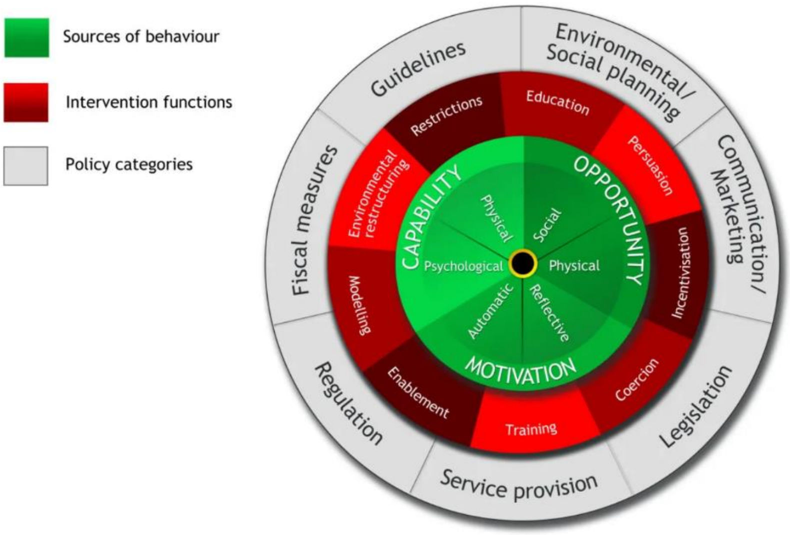

Figure 2.3. Behaviour Change Wheel, adapted from Michie et al. (2011).

The wheel consists of components that are arranged circularly to represent the interconnectedness of the different factors that can influence behaviour change (Michie et al. 2011). The centre of BCW is the Source of Behaviour which provides the simplest and most inclusive definition of behaviour suggested by Michie et al. (2011) and requires three conditions for behaviour to take place, namely Capability (physical and psychological), Opportunity (physical and social), and Motivation (reflective and automatic). In my study, the main focus is on the Source of Behaviour and implementing an intervention at this level. Specifically, I utilize the framework to explore the factors determining household water treatment, and promoting the use of clay disc filters for household water treatment by targeting the identified determinants. The components at the source level include:

> *Capability:* the individual's ability to perform the desired behaviour, including their physical, mental, and emotional abilities,
>
> *Opportunity:* the availability of resources, such as time, money, and support, that makes it possible for the individual to engage in the desired behaviour,
>
> *Motivation:* the individual's reasoning for engaging in performing or not performing the desired behaviour, including their beliefs, attitudes, and values,
>
> *Behaviour:* the behaviour that the individual is being asked to change.

2.6 Conclusion

The literature review highlighted the critical issue of inadequate access to safe drinking water and the burden of waterborne diseases which pose a significant threat in developing countries. The review also pointed out the critical water quality and accessibility challenges in Kabul, Afghanistan, the study area. For instance, the reliance on groundwater, which has been contaminated due to leaching and waste disposal, coupled with declining groundwater levels, exacerbates the issue. High levels of nitrate, and coliform bacteria were observed in the groundwater of Kabul city. The limited coverage of the water supply network adds to the problem, with many households relying on private wells.

Additionally, the review brought attention to ceramic filters as an affordable and sustainable option in the context of Kabul. These filters, made from clay and combustible materials, effectively trap particles and bacteria. These gravity-based clay-made filters offer advantages over other techniques like boiling or chlorination which can be costly and affect water taste. Studies have demonstrated the efficiency of clay-made filters in removing *E. coli* from water, making them a promising point-of-use technology.

Moreover, the review underscored that the perception of poor water quality and associated health risks remains a challenge. While household water treatment methods are available, their usage remains limited. Efforts to promote the adoption of household water treatment methods need to consider factors such as maintenance, cost, and consumer preferences and the technology must be accompanied by behaviour change interventions. The review highlighted a recently developed behaviour change approach (COM-B) which is useful to explore factors influencing household water treatment from a comprehensive perspective considering socioeconomic, psychosocial, and contextual factors.

Chapter 3

At the time of submitting the thesis, this chapter was submitted with slight modifications to the *Journal of Hydrology:*

Mohammad Daud Hamidi, Darren R. Gröcke, Suneel Kumar Joshi, H. Chris Greenwell

Mohammad Daud Hamidi was responsible for conceptualization, data collection, analysis, methodology, visualization, writing original draft, review and editing. DRG: Contributed to the Sample Analysis, Discussion of the results, Review and editing, Funding acquisition. SKJ: Contributed to the setup of the methodology through discussions with the lead author, Contributed to the discussion of the results, Review and editing. HCG: Supervision (my primary supervisor), Resources, Funding acquisition, Review and editing. As the main author, I would like to thank the co-authors for their helpful discussions and priceless suggestion throughout the process.

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3 Investigating groundwater recharge using hydrogen and oxygen stable isotopes in Kabul city, a semi-arid region

Abstract

There are significant concerns about the sustainability of groundwater and the livelihoods that depend on it due to the rapid groundwater depletion from the shallow alluvium aquifers in Kabul city. Sustainable groundwater management in Kabul requires understanding the sources and rates of groundwater recharge. This study aims to understand groundwater recharge processes, examine the interaction between surface water and groundwater, and explore groundwater dynamics in the aquifers of Kabul city. In this study, the stable isotopic composition ($\delta^{18}O$ and $\delta^{2}H$) of groundwater and surface water from the Upper Kabul River and Logar River was examined. Utilizing the hydrograph separation approach, the contribution of river water to groundwater was assessed, including the uncertainty analysis of its estimation. The isotopic analysis demonstrated that precipitation was the primary source of groundwater recharge in the Central Kabul sub-basin. Mixed recharge from the river, precipitation and irrigation return flow governed groundwater recharge in the Logar sub-basin. In Paghman and Lower Kabul, and Upper Kabul sub-basins, more rainfall input was observed besides the river contribution to groundwater recharge. Substantial spatial and depth-related variation in the contribution of the river water to groundwater recharge was noted. The river water contribution (fraction contribution) to groundwater recharge has changed from over 60±5 % (on average) in 2007 to less than 50±5 % (on average) in 2020. Significant groundwater level depletion was documented in the Central Kabul sub-basin and western parts of Kabul city (Paghman and Upper Kabul sub-basins).

3.1 Introduction

More than two billion people rely on groundwater around the globe for drinking, hygiene and irrigation (Jasechko et al. 2017), with groundwater the largest reserve of freshwater currently available on the planet (Opie et al. 2020). Groundwater constitutes the primary source of drinking water in semi-arid and arid regions, it is an essential component of the water cycle in alluvial aquifer systems where the depletion of groundwater is a major issue and surface water often recharges groundwater (Alley et al. 2002; Gleeson et al. 2015). Therefore, for water management, it is important to understand the spatio-temporal interactions between surface and groundwater, mainly at an appropriate local and regional scale (Joshi et al. 2018).

Approximately 4.4 million people residing in the Kabul city region rely on groundwater as a primary source of drinking water (Broshears et al. 2005; Hossaini 2019). Kabul city has undergone rapid unplanned urbanization, increasing water demand over the past 20 years (Noori and Singh 2021; Zaryab et al. 2022a). Meldebekova et al. (2020) observed 5.3 cm/year subsidence in the land surface above the Upper Kabul aquifer, which was highly correlated to groundwater level decrease - doubts persist regarding water level data. (2020)Based on the Representative Concentration Pathway (RCP 4.5) climate model, precipitation projections indicate a decline in winter precipitation in the Kabul River Basin between 2020 and 2079 (Ghulami et al. 2022). Surface runoff modelling projections for Afghanistan suggest a 20 % to 30 % decrease from 2041 to 2060 due to climate change (Milly et al. 2005). Landsat-based analysis of glacier lakes in Hindu Kush Himalaya, including Afghanistan, indicates the trend is decreasing (Maharjan et al. 2018). Furthermore, surface runoff modelling for the Upper Kabul River estimates a 4.2 % decrease by 2030 due to climate impact under RCP 4.5 (Akhtar et al. 2021). Groundwater level monitoring from the drinking water wells network indicates a rapid decline in Kabul city (Saffi 2011; Mack et al. 2013; Saffi 2014; Brati et al. 2019; Saffi 2019; Noori and Singh 2021). Observations of river flow and nearby groundwater wells estimated that the majority of groundwater recharge takes place from October to May (Sadid 2020). Moreover, Masoom (2018) suggested artificial groundwater recharge from excess Kabul River flow during the rainy season could be used as a sustainable management approach for the basin. Geographic Information System (GIS) and remote sensing data have been utilized to assess groundwater recharging zones and indicate excellent potential for groundwater recharge in Kabul city (Nasir et al. 2021; Hussaini et al. 2022; Mahdawi et al. 2022; Singh and Noori 2022). However, there remains a limited understanding of groundwater sources, the interaction between surface and groundwater, and recharge processes in the Kabul city region.

Stable isotopes of hydrogen and oxygen (δ^2H and δ^{18}O) contained in water molecules serve as natural tracers for quantifying groundwater recharge dynamics and sources (Clark and Fritz 1997; Joshi et al. 2018; Jasechko 2019; Kumar et al. 2021), and the interaction between surface water and groundwater (Davisson et al. 1999; Jasechko 2019; Xie et al. 2022). Isotopic values such as δ^{18}O and δ^2H follow predictable patterns in natural systems, and are influenced by atmospheric, geological, and biological processes (Gat 1996; Clark 2015; Rai et al. 2021). Changes in δ^{18}O and δ^2H values primarily occur due to due to phase changes, mixing, and temperature variations (Clark and Fritz 1997; Jeelani et al. 2013; Keesari et al. 2017; Scheihing et al. 2017). High-temperature water-rock interactions increase δ^{18}O values, while low-temperature interactions decrease δ^{18}O values, resulting in lower or higher d-excess values, respectively (Giggenbach 1992; Kloppmann et al. 2002). Factors such as high-temperature alterations of the parent groundwater and evaporation prior to or during infiltration contribute to the enrichment of isotopic values (Giggenbach 1992; Jasechko 2019). Groundwater samples with higher δ^{18}O and δ^2H values than amount-weighted precipitation indicate recharge by local precipitation modified by evaporation (Joshi et al. 2018). A low intercept value suggests that groundwater may be affected by evaporation or mixed with evaporated water (Bowen et al. 2018).

The only study hitherto on stable isotopes of groundwater in the Kabul city region was conducted between 2004 to 2007 (Mack et al. 2010): an intriguing conclusion was that no groundwater samples indicated substantial evaporation in this arid basin. Due to a lack of historical isotopic data of groundwater and surface water, Mack et al. (2010) could not investigate the long-term change in the isotopic signature of the groundwater. To the author’s knowledge, no attempt has taken place since 2007 to investigate the spatio-temporal characteristics of δ^2H and δ^{18}O in groundwater in the alluvial aquifer systems in the Kabul city region. In this study, the focus is on the δ^2H and δ^{18}O analysis of surface water and groundwater samples that are compared to groundwater level dynamics between 2007 and 2020 to understand groundwater recharge sources. The aims of this study focused on Kabul city region are: (1) understanding of groundwater recharge processes; (2) understanding the interaction between surface water and groundwater; and (3) understanding groundwater dynamics in the aquifer system.

3.2 Study area

The study covers 450 km^2 of the Kabul city area with a population of 4.4 million (NISA 2020). The elevation of the city is 1800 m above mean sea level (Favre and Kamal 2004). Kabul's climate is semi-arid, with more than 300 mm of average annual rainfall and potential evapotranspiration is 1600 mm, annually (Zaryab et al. 2017). Low rainfall and a high evaporation rate significantly impact surface water and groundwater storage, water quality, and community health (Sheikhi et al. 2020).

The average minimum daily air temperature between 2000 to 2020 was –15.6 ºC and the average maximum daily air temperature was 27.8 ºC (POWER-Project 2022). Kabul city has four sub-basins, and the city lies at the intersection of the Kabul River (Upper Kabul River and Lower Kabul River), Logar River, and Paghman River (Figure 3.1). In the west of the city, the Paghman River joins the Kabul River near the Deh Mazang area and then flows east toward its confluence with the Logar River (Saffi 2019). These seasonal river beds are connected by clay-like loess and sandy soils that are responsible for a significant amount of water transfer into the shallow aquifer (Broshears et al. 2005; Hossaini 2019).

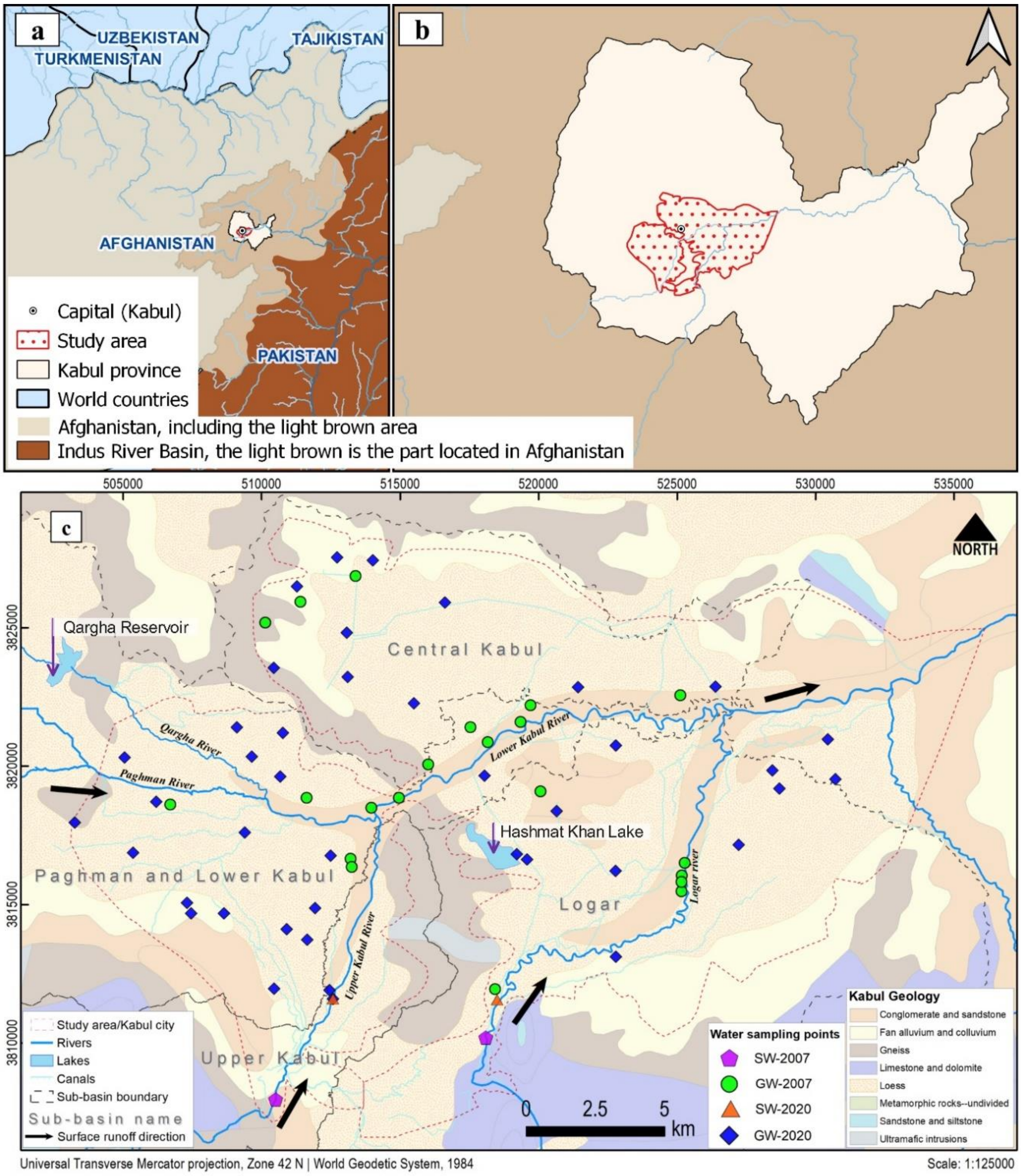

Figure 3.1. Map of countries sharing Indus River Basin (a), location of the study area in larger Indus River Basin (b), and spatial distribution of water sampling locations superimposed on geological settings of the study area (c). The pentagons and triangles show surface water sampling locations, and circles and diamonds show groundwater sampling locations for 2007 and 2022, respectively. *Data source*: Geology from Bohannon and Turner (2007), Lindsay et al. (2005). Sample locations for 2007 (Mack et al. 2010).

3.3 Methods

3.3.1 Data sources

Historical isotope data consisted of 21 groundwater and 3 surface water sampling points located in the study area: these were collected between December 2006 to mid-July 2007, as described by Mack et al. (2010). As part of this study, groundwater samples for isotopic analyses were collected in January 2020 from 41 piezometric wells and 2 samples from rivers in the study area (Figure 3.1). It is important to note that water levels were accurately recorded in all piezometers. The depth to the water level in sampled wells ranged from 2 to 90 metres below ground level (m bgl) in the study area.

For groundwater sampling, the piezometers were purged for more than 30 minutes prior to sampling for each location, and two samples were collected from each location in 50 ml sterile Falcon centrifuge tubes. pH and Electrical Conductivity (EC) were measured onsite during water collection. The collected water samples were transported by air in polystyrene containers to the UK and subsequently stored in a refrigerator, until isotopic analysis could be performed in the Stable Isotope Biogeochemistry Laboratory (SIBL) at Durham University.

3.3.2 Water δ^2H and $\delta^{18}O$ analyses

Stable isotope analysis of water was performed after filtering the water at 0.25µm, using a Los Gatos Liquid-Water Isotope Analyzer (LWIA) DLT-100. Each water sample was analysed 10 times but the first 3 injections were discarded due to memory effects. All analyses were then processed using LWIA software to achieve higher precision using the remaining 7 injected samples. IsoAnalytical water standards (see Supplementary Material 3.1) were analysed as a group with separated by de-ionised water samples. The same analytical procedure was performed on the standards, and each group of standards was analysed every 8 samples. The results are expressed in standard delta (δ) notation as per mil (‰) values in relation to VSMOW or Vienna Standard Mean Ocean Water (Sharp 2017). The average standard deviation for the samples was <0.4 ‰ (1s) for δ^2H, and <0.2 ‰ (1s) for $\delta^{18}O$.

To investigate the recharge process and groundwater dynamics deuterium excess (D-excess) values of the river (surface water) and groundwater samples were calculated. D-excess was calculated following Dansgaard (1964): D-excess = $\delta^2H - 8 \times \delta^{18}O$. D-excess is a key parameter for tracking the impact of evaporation on the isotopic composition of precipitated water before groundwater recharge (Clark and Fritz 1997). Fluctuations in D-excess depend on relative humidity and evaporation in precipitation, as well as the change in wind speed and ocean surface temperature (Gat 1983; Clark and Fritz 1997). The global mean value of D-excess is +10 ‰, indicating 85 % relative humidity (Merlivat and Jouzel 1979; Clark and Fritz 1997). To understand the dynamics of δ^2H and $\delta^{18}O$ values for precipitation (i.e., the dominant water source), the data from the Karizimir station located at Kabul International Airport was used.

3.3.3 Two-component mixing model

To evaluate the contribution of surface water (i.e., river water) to groundwater recharge in the study area, a tracer-based two-component mixing model was employed (Clark and Fritz 1997; Clark 2015). In the tracer-based study, many researchers have used δ^2H and $\delta^{18}O$ values of water from three different sources (see Herrmann and Stichler, 1980; Joshi et al., 2018). The present study uses $\delta^{18}O$ values of groundwater, surface water (river water), and precipitation (amount weighted average precipitation, or AWAP) to understand the surface water and groundwater interaction and its fraction contribution using Eq. (1):

$$f_c = \frac{(C_g - C_p)}{(C_r - C_p)} \quad (3.1)$$

Where C_r is the $\delta^{18}O$ value of river water, C_g is the $\delta^{18}O$ value of groundwater, C_p is the $\delta^{18}O$ value of precipitation (AWAP), and f_c is the contribution of river water to groundwater.

3.3.4 Uncertainty analysis

The first-order Gaussian error propagation method was employed following Uhlenbrook and Hoeg (2003) to evaluate uncertainty in the two-component mixing model. The measurement errors in $\delta^{18}O$ values of surface water, groundwater, and precipitation were ±0.1 ‰. The degree of uncertainty was calculated using the following equation:

$$\Delta f_x = \sqrt{(\frac{\partial z}{\partial c_1}\Delta c_1)^2 + (\frac{\partial z}{\partial c_2}\Delta c_2)^2 + \cdots + (\frac{\partial z}{\partial c_n}\Delta c_n)^2} \quad (3.2)$$

Where:

Δf_x : Uncertainty in the contribution,

c_1, c_2 ... c_3 : variables,

$\Delta c_1, \Delta c_2$ ... Δc_3 : measurement error in each variable, and

$\frac{\partial z}{\partial c_1}, \frac{\partial z}{\partial c_2}$ ... $\frac{\partial z}{\partial c_n}$: partial differentiation of factor equations for each variable for the two-component mixing model.

3.3.5 Groundwater storage change

The water table fluctuation (WTF) method was employed to estimate the groundwater storage change rate in the study area, Eq. (3):

$$R = S_y \, {}^{\Delta h}/_{\Delta t} \quad (3.3)$$

Where *Sy* is the specific yield, and Δ*h*/Δ*t* is the water table fluctuation over time (Healy and Cook 2002; Bhanja et al. 2019; Beg et al. 2022). The specific yield values were adapted from Sadid (2020), and the spatial distribution of map specific yield was produced for Kabul city (Figure S3.2).

3.4 Results and Discussion

3.4.1 Spatio-temporal patterns of groundwater level

The spatio-temporal distribution of groundwater level maps for 2007 and 2020 were prepared to understand the groundwater system of Kabul city. The inverse distance weighting (IDW) interpolation algorithm was used in ArcGIS (ESRI 2019) to prepare the groundwater level surface. Figures 3.2a and 3.2b demonstrate the spatial distribution of groundwater levels for 2007 and 2020, respectively. The spatial distribution of the groundwater level shows marked variation across Kabul city. The groundwater level in 2007 varied between 3.2 and 57.5 m bgl. However, the range of groundwater levels has drastically changed to lie between 2.7 and 90.1 m bgl at the time of this present study (i.e., 2020), indicating a spatially declining trend in groundwater levels of the study area.

Shallower groundwater levels (<25 m) were observed in most of the study area (except for two locations in the Central Kabul sub-basin) in 2007 (Figure 3.2a). In 2020, the groundwater level map shows a deeper level (>35 m) in the Central Kabul and Paghman sub-basins (Figure 3.2b) compared to 2007. In contrast, shallow groundwater levels were observed in the Lower Kabul and Logar sub-basins indicating very less drawdown between 2007 and 2020.

Furthermore, the water table fluctuation map was generated from 2007 to 2020 based on the difference between 2007 and 2020 groundwater level data (Figure 3.2c). The Kabul central basin experienced substantial groundwater depletion between 2007 and 2020; the range of water depletion was between 35 and 55 m. In the same period, western parts of Kabul city (Paghman and Upper-Kabul sub-basins) also experienced groundwater depletion, where the range of depletion was between 15 and 35 meters. However, in the Logar sub-basin and parts of the Lower Kabul sub-basin, the groundwater level hasn’t observed considerable depletion from 2007 to 2020, and the range was almost stable. Groundwater depletion in parts of Kabul city is linked to the growth of population and rapid, unplanned urbanization that has led to over-utilisation of groundwater (Jawadi et al. 2020; Noori and Singh 2021; Zaryab et al. 2022a), and changes in land use and landcover between 2005 and 2020 (Figure S3.1).

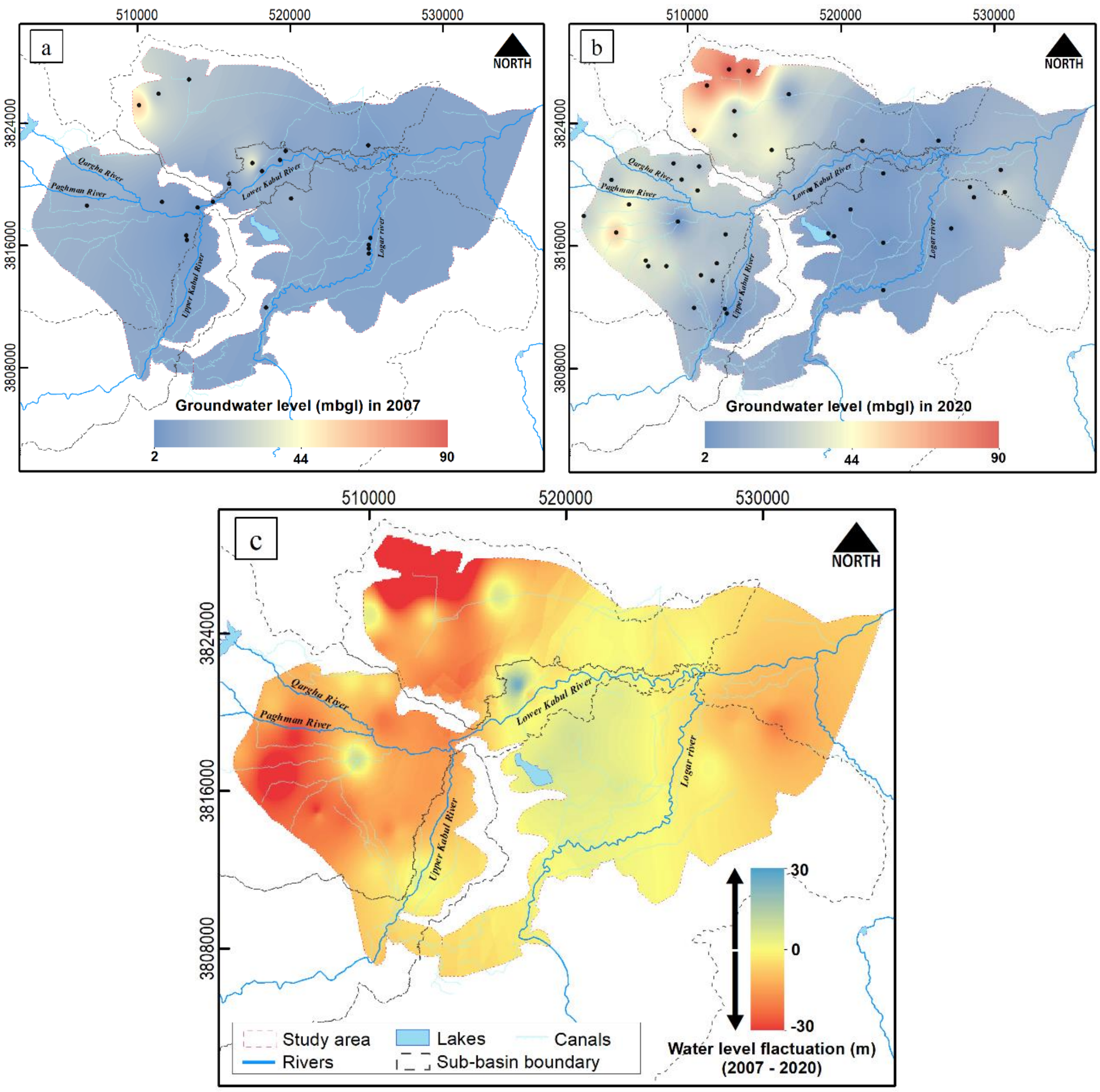

Figure 3.2. Spatial distribution of depth to water level maps: (a) 2007; (b) 2020; and (c) the groundwater level difference between 2007 and 2020. The black points in (a) and (b) are sampling locations.

The spatial distribution of the groundwater storage change rate was estimated based on the WTF approach (Figure 3.3). Spatially, the amount of water rising rate in the Logar and lower Kabul sub-basins were the highest (approximately 0.25 m/year). The Central Kabul sub-basin had the highest water declining rate in the study area, while Paghman and Lower Kabul sub-basin illustrated a mixed trend of rising and declining rates of groundwater storage change. The considerable variability in groundwater storage rates was mainly associated with the aquifer properties and infiltration rate. The positive rates in the Logar region indicated a rising trend in groundwater storage rate between 2007 and 2020, suggesting that the groundwater is being replenished due to excess surface water available for infiltration from the Logar River.

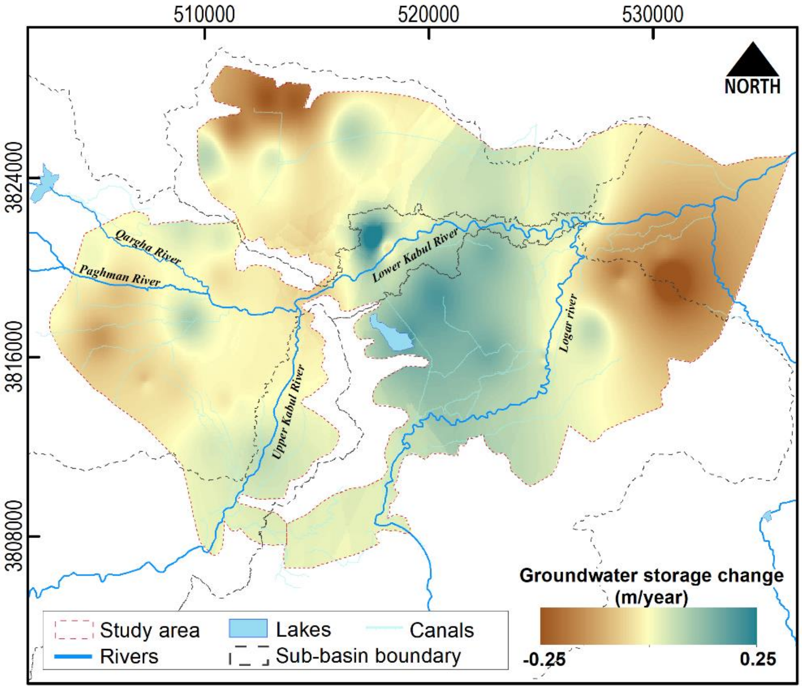

Figure 3.3. Groundwater storage change rate of Kabul city region.

3.4.2 Isotopic characterization of precipitation, surface water and groundwater

a. *Precipitation*

The isotopic composition of precipitation was collected between January 1962 to September 1989 by the International Atomic Energy Agency (IAEA/WMO 2022). The δ^2H value of precipitation varies from -103.0 ‰ to +33.0 ‰ (mean: -33.2 ‰ ± 7.2 ‰, n = 86), $\delta^{18}O$ from -16.0 ‰ to +3.5 ‰ (mean: -6.0 ‰ ± 1.0 ‰, n = 86), and D-excess from -9.7 ‰ to +40.6 ‰ (mean: +14.6 ‰ ± 3.7 ‰, n = 86). The isotopic and D-excess values of precipitation, showing a wide range in the study region, can be attributed to the westerly moisture source for precipitation. In addition, following Clark and Fritz (1997) and Hughes and Crawford (2012), AWAP isotopic values have been estimated for IAEA precipitation data in Kabul utilizing isotopic values of individual events using Eq. (4):

$$AWAP\ (\delta^{18}O) = \sum_1^n \delta_i P_i \,/\, \sum_1^n P_i \qquad (3.4)$$

Where δ_i is the isotopic value of an individual event with a precipitation amount of P_i. The AWAP values of δ^2H and $\delta^{18}O$ were (-36.0 ‰ ± 8.5 ‰) and (-7.15 ‰ ± 1.13 ‰), respectively.

A cross-plot between δ^2H and $\delta^{18}O$ values is shown in Figure 3.4. The regression line in Figure 3.4 represents the local meteoric water line (LMWL): $\delta^2H = 7.33 \times \delta^{18}O + 12.37$. The LMWL was compared with the global meteoric water line (GMWL), defined by Terzer et al. (2013). The slope in LMWL is less than the GMWL, indicating isotopic enrichment during the precipitation event. In comparison, the intercept value of LMWL is higher than the GMWL, which is directly related to the evaporation rate of the local precipitation (Clark 2015).

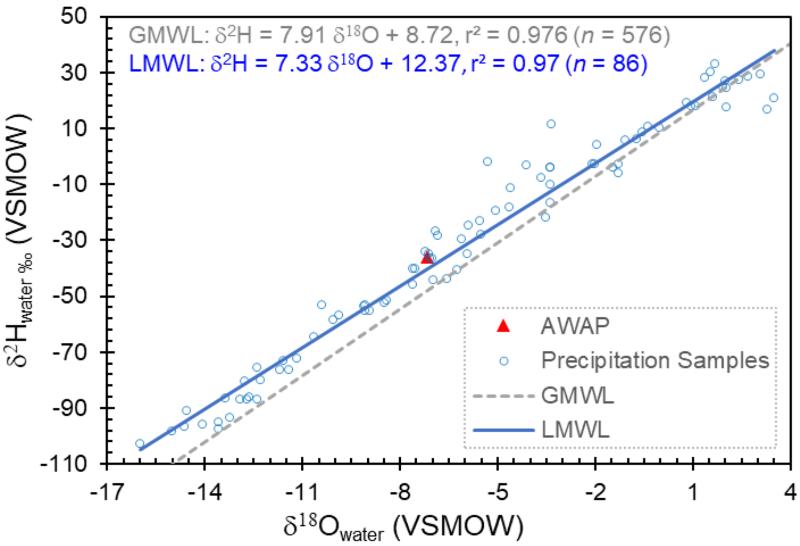

Figure 3.4. Cross plot between δ^2H and $\delta^{18}O$ values of precipitation. *Data source*: Precipitation data from (IAEA/WMO 2022).

b. *Surface water*

The $\delta^{18}O$, δ^2H and D-excess values of the water from the Logar and Upper Kabul rivers in the study area for 2007 and 2020 are presented in Table 3.1 (see Figure 3.1 for spatial location of Logar and Upper Kabul Rivers). The difference in isotopic composition (on average $\delta^{18}O$ = -0.23 ‰, $\delta^{2}H$ = -6.79 ‰, D-excess = +4.95 ‰) between the Logar and Upper Kabul basin river waters could potentially be due to the distance travelled and the larger catchment area of Logar sub-basin compared to Upper Kabul sub-basin. Surface water observations in California showed -21 ‰ distance-related depletion in $\delta^{2}H$ for every 100 km of the river (Williams and Rodoni 1997). The Logar River consists of 6 tributaries, before entering Kabul city and the flow distance from upstream is approximately 250 km. The Upper Kabul River consists of 3 tributaries before entering Kabul city and the flow distance from upstream is approximately 100 km. The water from the Logar River is used for irrigation in the upstream region before entering Kabul city (Sadid 2020). Furthermore, the isotopic composition of the Logar River samples shows depleted values relative to the AWAP in 2007 and 2020. Similarly, the isotopic composition of the Upper Kabul River shows depleted values relative to the AWAP and values fell on LMWL in 2007 and above LMWL in 2020. This can be attributed to the different sources of water contributing to the river water, such as higher altitude water (snow/ice), and/or precipitation (Rai et al. 2009; Semwal et al. 2020).

The range in river water $\delta^{18}O$ in 2007 was between -9.2 ‰ to -9.0 ‰, whereas in 2020 it ranged between -8.3 ‰ and -8.1 ‰. Meanwhile, the range in river water $\delta^{2}H$ in 2007 was between -61.5 ‰ to -54.3 ‰, whereas in 2020 it ranged between -52.4 ‰ to -46.1 ‰. The average decrease in river water D-excess between 2007 and 2020 was 1.5 ‰.

Table 3.1. Average river water $\delta^{18}O$, $\delta^{2}H$, and D-excess between 2007 and 2020.

River	**2007**			**2020**		
	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	D-excess	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	D-excess
Logar	-9.2	-61.5	+12.4	-8.3	-52.4	+14.1
Upper Kabul	-9.0	-54.3	+17.5	-8.1	-46.1	+18.8

Note: The data source for 2007. (Mack et al. 2010).

The possible reasons behind elevated $\delta^{18}O$ and $\delta^{2}H$ values of river water, and a decrease of D-excess between 2007 and 2020 could be directly related to a different source (snow or rainfall), temperature effect, and/or amount effect (Gat 1983). Observations from other rivers in the larger Indus basin point to analogous variations in $\delta^{18}O$, $\delta^{2}H$, and D-excess values, as reported by Ahmad et al. (2003).

The enrichment in the isotopic composition of river water was investigated by employing the hydrometeorological datasets from 2000 to 2020. Precipitation and temperature variation in Kabul were utilized to explore the reason behind the variation in isotopic characteristics of surface water between 2007 and 2020. Figure 3.5a illustrates historical daily precipitation and temperature data from 2000 to 2020 for Kabul city, obtained from the NASA Langley Research Center (POWER-Project 2022). Kabul city has periodically experienced dry years (Baig et al. 2020). Figure 3.5a highlights, on average, the amount of precipitation was very low between 2000 and 2005 (average annual rainfall ≤ 200 mm), while an increase was observed in the average amount of precipitation between 2006 and 2016 (average annual rainfall ≥ 320 mm). The city experienced extreme drought in 2018, while the average precipitation significantly increased in 2020. These annual and long-term changes in temperature and precipitation contribute to and impact the isotopic characteristics of surface water. Figures 3.5b - c show the precipitation and temperature before the river water sampling campaigns in 2007 and 2020.

The total amount of precipitation in December 2006 was 74.88 mm with an average temperature of -1.8 ºC; the total amount of precipitation in January 2007 was 9.44 mm with an average temperature of -0.3 ºC (Figure 3.5b). However, in 2020 December was warmer with an average temperature of 2.7 ºC, and significantly less precipitation (9.2 mm) than in December 2006. January 2020 was colder with a temperature average of -4.1 ºC and significantly higher precipitation (51.5 mm) in comparison to January 2007 (Figure 3.5c). Thus, the lower amount of rain and higher temperature in January 2007, compared to the higher amounts of rain and lower temperature in January 2020 illustrates the difference in source and mixing from precipitation and snow/ice. There is a negative association between mean $\delta^{18}O$ values and monthly precipitation amount, known as the amount effect (Clark 2015). The relationship between the surface temperature and the isotopic composition of meteoric water is particularly strong at high latitudes where water vapour condenses close to the ground (Sharp 2017).

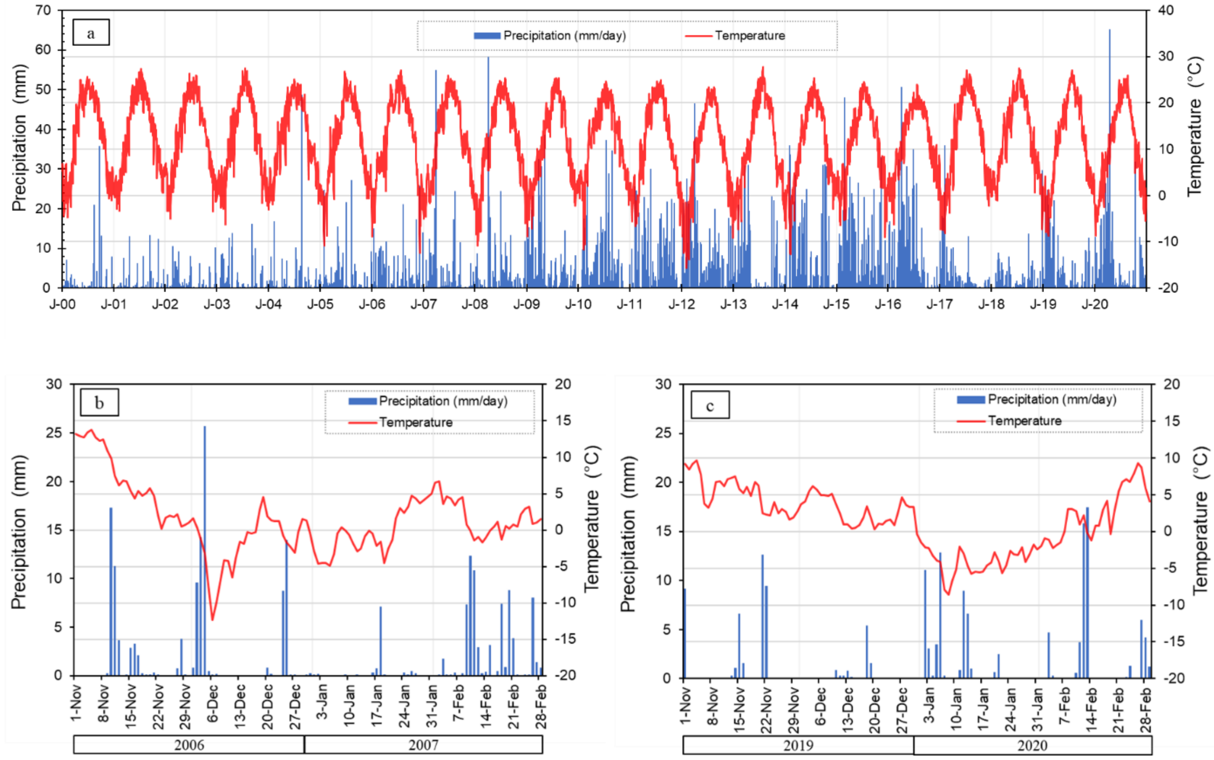

Figure 3.5. Precipitation and temperature trends in Kabul city: 2000 – 2021 (a), November 2006 to February 2007 (b), and November 2019 to February 2020 (c). *Data source*: NASA's POWER-Project.

c. *Groundwater*

The isotopic composition of groundwater in Kabul city for δ^2H varied from -64.5 ‰ to -32.3 ‰ (mean: -49.3‰ ± 7.2 ‰, n = 62), $\delta^{18}O$ from -9.6 ‰ to -4.9 ‰ (mean: -7.9 ‰ ± 1 ‰, n = 62), and D-excess from +5.3 ‰ to +24.4 ‰ (mean: 14.2 ‰ ± 3.6 ‰, n = 62). The average groundwater $\delta^{18}O$, δ^2H and D-excess values in the study area for 2007 and 2020 are presented in Table 3.2. Central Kabul is the only sub-basin in Kabul city without a river running through it. All other sub-basins contain a river, and hence may explain why the groundwater in the Central Kabul sub-basin is generally lower in $\delta^{18}O$ both in 2007 and 2020 compared to the other sub-basins in Kabul city.

Overall, the data presented in Table 3.2, illustrate that the groundwater samples are elevated in $\delta^{18}O$, δ^2H and D-excess between 2007 and 2020. Figure 3.6 illustrates the cross plots of $\delta^{18}O$ and δ^2H of the groundwater samples from all sub-basins in the study area, including groundwater lines (GWL). Figure 3.6a highlights that the groundwater samples for 2007 fall below the LMWL, while in 2020, besides enrichment, some samples fall above LMWL. The GWL for the Central Kabul sub-basin ($\delta^2H = 6.64 \times \delta^{18}O + 4.37$, $R^2 = 0.65$) has a lower slope and intercept than the LWML, indicating evaporation in groundwater samples and/or mixing during the recharge processes. However, precipitation is the primary contributing source to groundwater in the Central Kabul basin.

Table 3.2. Analysis results of groundwater samples for $\delta^{18}O$, δ^2H, and D-excess in 2007 and 2020.

Sub-basin	2007			2020		
	$\delta^{18}O$ (‰)	δ^2H (‰)	D-excess	$\delta^{18}O$ (‰)	δ^2H (‰)	D-excess
Central Kabul	-9.2 (*n* = 4)	-60.5 (*n* = 4)	+13.2 (*n* = 4)	-8.2 (*n* = 10)	-48.9 (*n* = 10)	+17.0 (*n* = 10)
Logar	-8.5 (*n* = 6)	-56.5 (*n* = 6)	+11.6 (*n* = 6)	-7.1 (*n* = 12)	-44.8 (*n* = 12)	+12.2 (*n* = 12)
Paghman and Lower Kabul	-8.8 (*n* = 11)	-55.4 (*n* = 11)	+14.8 (*n* = 11)	-7.4 (*n* = 17)	-44.3 (*n* = 17)	+14.7 (*n* = 17)
Upper Kabul				-7.1 (*n* = 2)	-43.0 (*n* = 2)	+13.7 (*n* = 2)

The isotopic composition of groundwater samples from the Logar sub-basin experienced an increased both in $\delta^{18}O$ and δ^2H between 2007 and 2020 while all the samples fall below the LMWL (Figure 3.6b). The slope and intercept of GWL for the Logar sub-basin ($\delta^2H = 6.15 \times \delta^{18}O - 2.01$, $R^2 = 0.86$) were below the LMWL. This indicates the groundwater samples were more evaporative in the Logar sub-basin, possibly due to evaporation before recharge, mixing during recharge, and/or irrigation return flow. The isotopic composition of water that has evaporated or been mixed with evaporated water typically shows a lower slope than the GMWL, or LMWL (Clark and Fritz 1997).

The GWL for Paghman, Lower Kabul and Upper Kabul sub-basins (Figure 3.6c) is closest to the LMWL compared to other sub-basins ($\delta^2H = 7.04 \times \delta^{18}O + 7.16$, $R^2 = 0.88$). The isotopic composition of the groundwater samples from the Paghman, Lower Kabul and Upper Kabul sub-basins showed less influence due to evaporation, or had more rainfall input. Near mountains, the $\delta^{18}O$ values of well water are frequently lower than those of AWAP (Kebede et al. 2005).

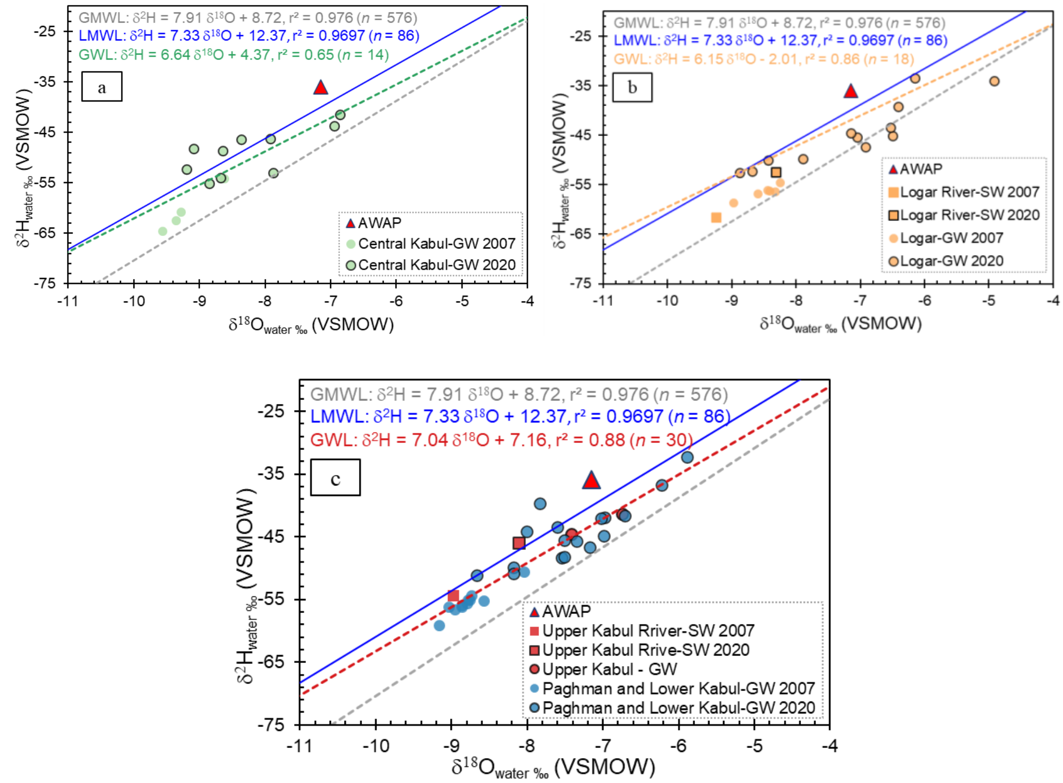

Figure 3.6. Cross plots of groundwater δ^2H and $\delta^{18}O$ for Central Kabul (a), Logar (b), and the Upper Kabul and Paghman/Lower Kabul (c).

3.4.3 Interaction between surface water and groundwater

The interaction between groundwater and surface water was investigated using the isotopic composition of river water, precipitation and groundwater for 2007 and 2020. Cross-plots of D-excess vs. $\delta^{18}O$ values for the groundwater and river water samples for 2007 and 2020 are shown in Figures 3.7a and 3.7b, respectively. Kabul periodically experiences droughts, and the residence time of groundwater is reported to be 15, and 20 years in the study area, based on a few samples (Mack et al. 2010). In this semi-arid region, the observation of Mack et al. (2010) that none of the analysed groundwater samples showed substantial evaporation is unusual. Groundwater samples in 2007 exhibited active recharge conditions since the values closely resembled that of river water, particularly in Paghman and Lower Kabul sub-basins (2010)(Figure 3.7a). Overall, 11 groundwater samples show mixed recharge conditions. In general, the groundwater and surface water samples during 2007 featured depleted isotopic composition compared to the AWAP value ($\delta^{18}O$ = -7.2 ‰ and D-excess = +16.9 ‰), which indicates the primary recharge source was from a higher altitude region. In contrast, a few groundwater samples in Logar sub-basin had lower D-excess than the river, which is likely due to mixing from various sources and/or irrigation return.

However, Figure 3.7b illustrates the groundwater and surface water samples in 2020. The groundwater samples in 2020 had observed enrichment, indicating a change in recharge mechanism between 2007 and 2020. The groundwater recharge in 2020 was dominated by mixing during recharge and evaporative enriched samples. This indicates local factors, such as evaporation during recharge processes and/or irrigation return, play an important role in modifying the isotopic composition of groundwater in the study area.

The D-excess value is an indicator of evaporation's impact on the physical-chemical properties of water; as a result, as the water evaporates, the D-excess declines (Joshi et al. 2021). Figure 3.7 illustrates that the relation between the D-excess and $\delta^{18}O$ was negative in the study area. The majority of water samples in the study area had a value of D-excess of more than 10 ‰, both in 2007 and 2020. The high D-excess values (>10 ‰) in groundwater and surface water samples of the Himalayan region were associated with moisture sources brought by western disturbance (Jeelani et al. 2021; Beg et al. 2022). The NOAA's HYSPLIT atmospheric transport and dispersion modelling system was utilized (Stein et al. 2015), to investigate the air mass trajectory. Figure S3.3 highlighted that the majority of the winter air mass, in Kabul city, constituting the maximum precipitation period is governed by westerly winds.

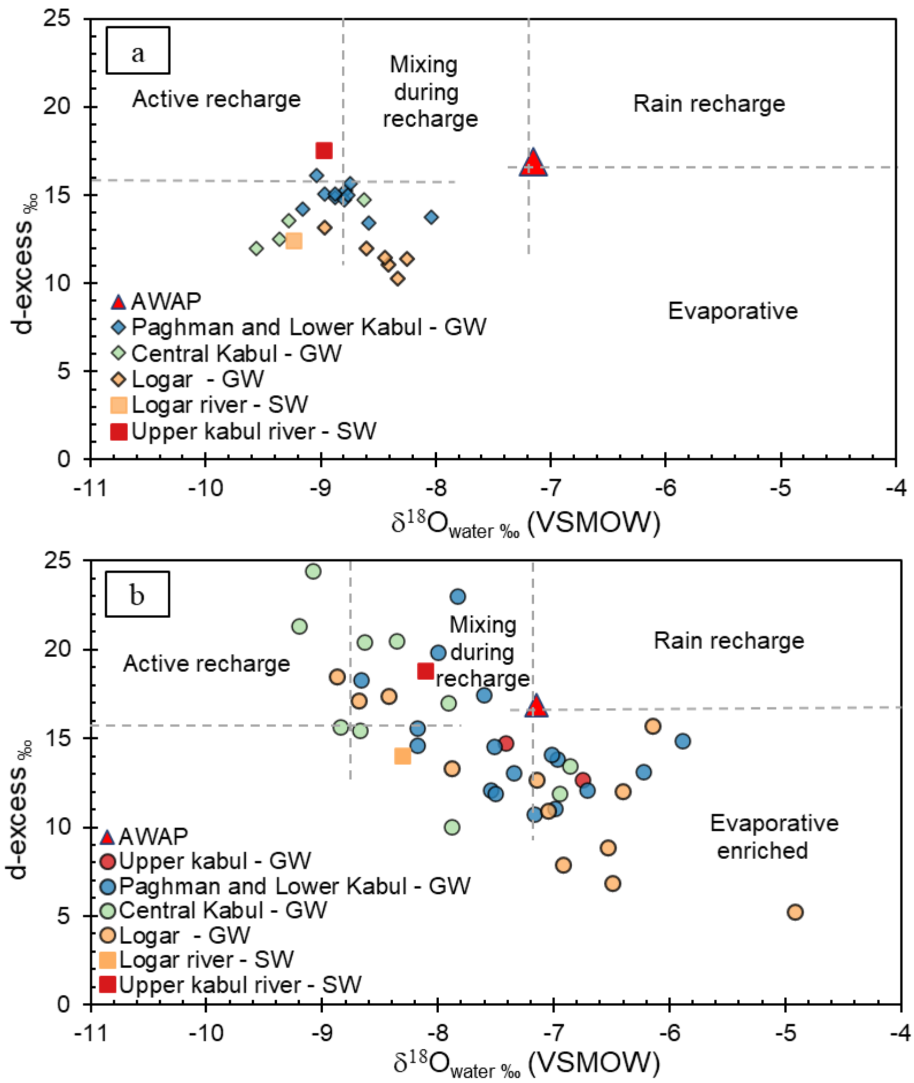

Figure 3.7. Cross plot of $\delta^{18}O$ values and d-excess: (a) 2007, and (b) 2020. The cross plot indicates a change in surface water and groundwater interaction in the study area between 2007 and 2020.

3.4.4 Spatial variation in isotopic characteristics of groundwater

The abundance of $\delta^{18}O$, D-excess is spatially varied in the study area (Figure 3.8). The Central Kabul sub-basin has not observed significant changes in the depleted $\delta^{18}O$ samples between 2007 and 2020 (Figure 3.8a). However, the D-excess values highlight an increasing trend and a few samples have observed 10 ‰ increases between 2007 and 2020 (Figure 3.8b). The samples of groundwater that have a depleted isotopic signature may be due to recharge from precipitation.

In Paghman, and the Upper-Kabul and Lower Kabul sub-basins, the changes of $\delta^{18}O$ in groundwater samples located near the rivers followed the river path; in this mainly alluvial system, elevated $\delta^{18}O$ can be observed as the river flows downstream, which also indicates the greater influence of river water recharge. However, the samples located in other parts of the aforementioned sub-basins show variation in isotopic characteristics, potentially indicating a higher contribution of precipitation and/or canal water in groundwater recharge. Elevated $\delta^{18}O$ values of groundwater samples were noted close to the Qargha reservoir ($\delta^{18}O$: -5.9 ‰ and -6.2 ‰), potentially indicating evaporative enrichment (Figure 3.8a).

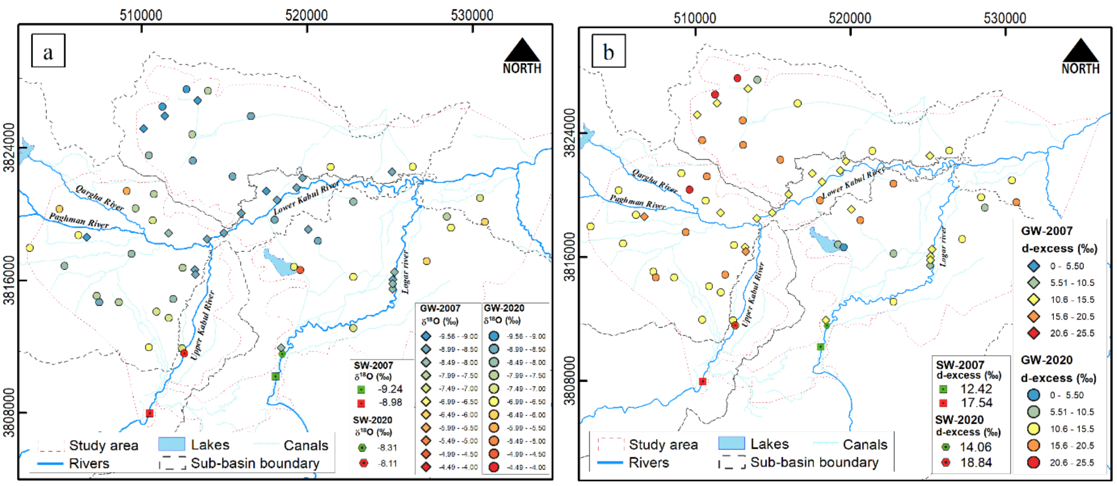

Figure 3.8. Spatial distribution of $\delta^{18}O$ (a) and D-excess (b) values of surface water and groundwater for 2007 and 2020.

Similarly, in the Logar sub-basin, the $\delta^{18}O$ for groundwater samples located near the rivers, significantly elevated as moving downstream, suggesting that local factors, such as irrigation return, play an important role in modifying the isotopic characteristic of groundwater. The spatial map (Figure 3.8a) highlights a significantly elevated groundwater sample near Heshmat Khan Lake ($\delta^{18}O$: -4.9 ‰), a clear indicator of evaporative enrichment. Spatial differences in groundwater isotope compositions may be caused by the mixing of groundwater of various origins and histories (Sharp 2017).

Figure 3.8a and Figure 3.8b illustrated that no significant pattern was observed in the isotopic composition of groundwater samples in 2007 and 2020, likely due to the intermixing during the recharge processes. Interestingly, the isotopic values of groundwater samples were more depleted than the AWAP, suggesting recharge could be from the higher altitude region during the study period.

3.4.5 Sources of groundwater recharge

Aquifer systems, surface topography, lithology, soil characteristics, and subsurface geometry are primarily responsible for interactions between surface water and groundwater in any given basin (Taylor and Howard 1996). In the present study, a two-component mixing model was used to evaluate mixing during the recharge processes and measure the fraction contributions of surface water and precipitation in the groundwater samples using $\delta^{18}O$ values. One of the main conditions for employing the two-component mixing model is that the values of $\delta^{18}O$ for groundwater samples should fall between rainfall and surface water values of $\delta^{18}O$. The river water samples from upstream of two major rivers (Upper Kabul and Logar) constituted one end-member. And, precipitation AWAP was the other end-member component.

Figures 3.9a and 3.9b highlighted the contribution of river recharge to groundwater relative to depth. The fraction contribution (%) and $\delta^{18}O$ were spatially different between 2007 and 2020 in all sub-basin. During 2007, the groundwater samples showed higher recharge contribution from the river, and the Upper Kabul, Paghman and Lower Kabul sub-basins received maximum recharge from the river water (fraction contribution: 85 ± 5 % to 92 ± 5 %, n = 7). In contrast, the groundwater samples from Upper Kabul, Paghman and Lower Kabul sub-basins revealed less contribution from the river in 2020 (2 ± 5 % to 40 ± 5 %, n = 7), which may be related to a shift in recharge pattern; as a result, the groundwater level in the study area showed depletion (see Figure. 3.2c). Similarly, in the Logar sub-basin, the groundwater samples showed higher recharge contribution from the river in 2007 (59 ± 5 % to 76 ± 5 %, n = 5) compared to 2020 (64 ± 5 %, n = 2). It is important to note that the average values for both years (in the Logar sub-basin) are almost within the range of uncertainties, indicating a relatively consistent trend.

Figures 3.9c and 3.9d indicated that the isotopic composition of groundwater was depleted in 2007 and enriched in 2020, exhibiting a distinct evaporative signature in 2020. This may be consistent with the spatial rise in groundwater storage change rates (see

Figure 3.3), enriched groundwater infiltration resulted in an increased concentration of $\delta^{18}O$ in groundwater.

The present study also noted site-specific variations in the isotopic composition of groundwater due to depth or increasing distance from upstream of the basin and river. Similarly, utilizing remotely sensed data, Tani and Tayfur (2021) and Mahdawi et al. (2022) suggested that the recharge condition in Kabul city was highly suitable for managed aquifer recharge. The present study unequivocally demonstrated that active recharging was occurring in Kabul City, however, the recharge process was local, and intermediate flow patterns have been observed.

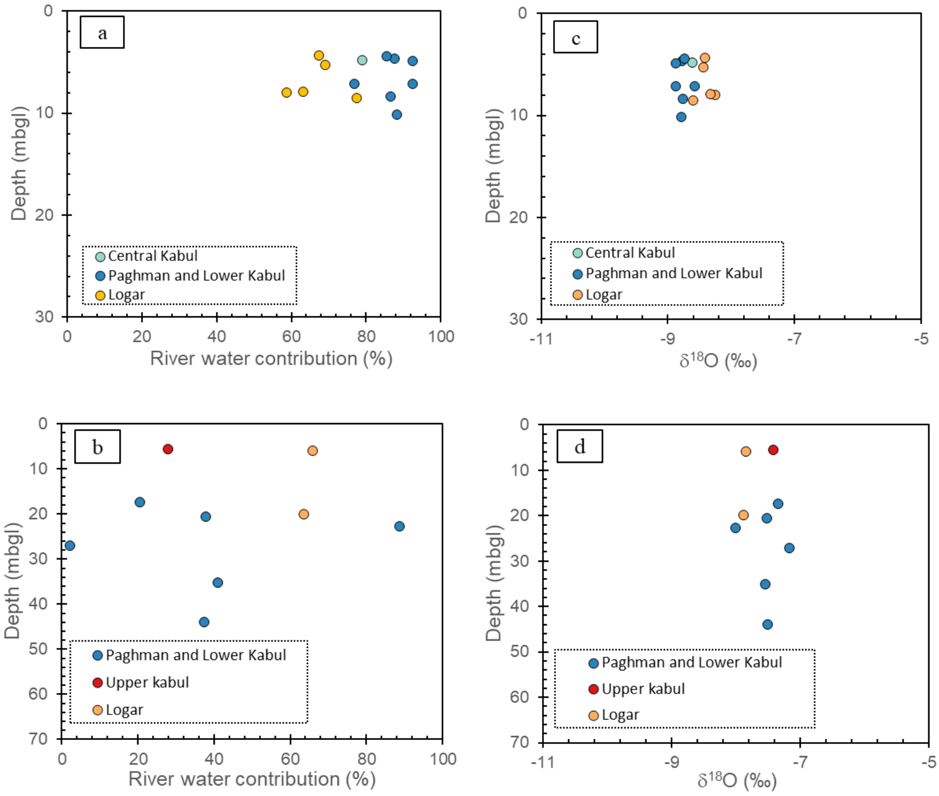

Figure 3.9. Depth-wise river water contribution to groundwater for 2007 (a), and 2020 (b); depth-wise variation of water to $\delta^{18}O$ values for 2007 (c), and 2020 (d).

Figure 3.10 was generated to explore further the spatial variance of river water contribution to groundwater. Several groundwater samples (n = 18) located near rivers had recharge sources from the river water. The groundwater samples near the river showed a higher recharge rate in 2007. Only one sample in 2020 illustrates above 80 % contribution of the river to groundwater; the sample is located in the compound of the National Water Affairs Regulation Authority (NWARA) near a rainwater harvesting pilot project which could have affected the bias toward higher contribution from river water.

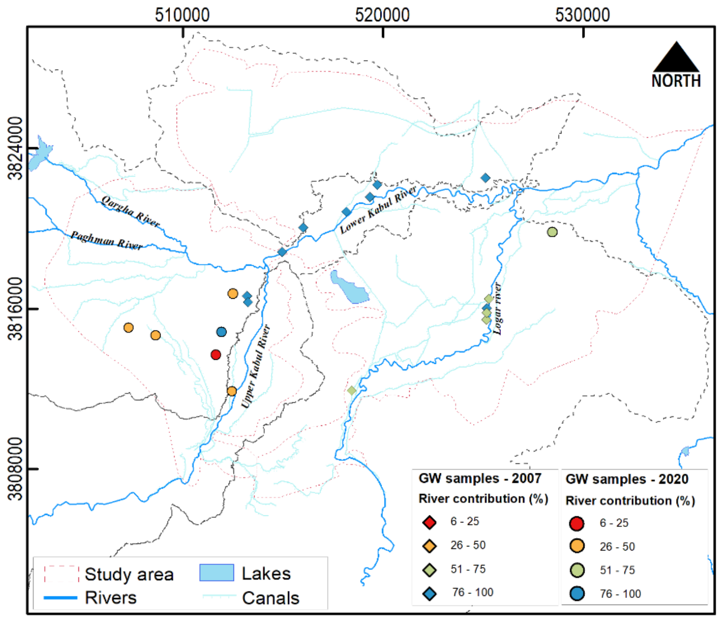

Figure 3.10. The spatial variation of the river water contribution to groundwater recharge.

The Logar River has a higher inflow into Kabul city compared to the inflow of rivers to other sub-basins. Besides the direct water transfer through the canals, the extensive irrigation activities in the Logar sub-basin shape the environment for a river water contribution (over 50 %) in groundwater recharge. However, in the Upper Kabul sub-basin, the contribution of the river to groundwater was spatially different, with an average of below 50 %.

3.4.6 The conceptual model for representing the geohydrological process

As presented in previous sections, the geohydrological processes taking place in the sub-basins located in the Kabul city region are varied. The spatial variance in depth of water level and recharge rate appears to be influenced by complex sub-surface sedimentary architecture. Figure 3.11 illustrates a conceptual model representing the geohydrological process governing the sub-basin located in Kabul city. The conceptual model was built on the water table data, spatial variability of δ^2H, δ^{18}O and D-excess values, and river water contribution to groundwater recharge.

The heterogeneity sub-surface sedimentary structure is thought to impact the spatial variation of depth to water level and recharge rate. Figure 3.11 depicts a conceptual model for the geohydrological process governing the sub-basins located in Kabul city.

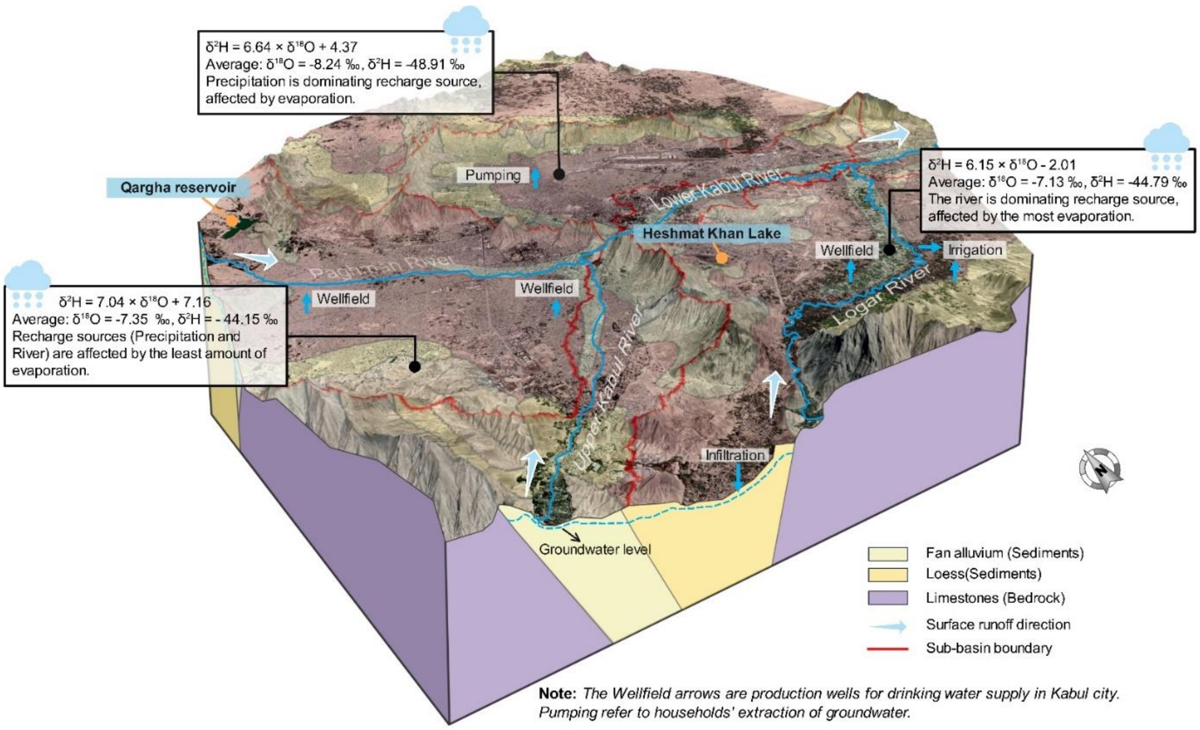

Figure 3.11. The conceptual model for groundwater sources in Kabul City, indicates the groundwater (GW) line, δ^{18}O and δ^2H, and the source of groundwater recharge. *Data source*: Geology from Bohannon and Turner (2007), and Lindsay et al. (2005). Imagery and topography from Google Earth (2022).

With the use of this conceptual model, the understanding of the lateral and vertical fluctuations of δ^2H, δ^{18}O and D-excess values in groundwater enhanced, which is ascribed to the uneven distribution of aquifer-and non-aquifer-related sediments in the subsurface. Furthermore, as illustrated in the conceptual model depicted in Figure 3.11, the basins located in the study area were distinct in several ways, including the depth of water, geology, land use, and surface water flow. For instance, the Logar River plays a significant role in the groundwater of the Logar basin, and irrigation plays a critical role in shaping the isotopic characteristics of groundwater. However, in the Central Kabul sub-basin, the groundwater levels were very low and the only source of recharge appears to be precipitation.

3.5 Conclusions

This study revealed that the changes in groundwater levels in Kabul city are spatially different. The Central Kabul sub-basin experienced substantial groundwater depletion between 2007 and 2020 (between 35 and 55 m). The western parts of Kabul city (Paghman and Upper-Kabul sub-basins) have also experienced groundwater depletion, where the range of depletion is between 15 and 35 m. However, in the Logar sub-basin and parts of the Lower Kabul sub-basin, the groundwater level hasn't observed significant depletion from 2007 to 2020 and the range is almost stable. Groundwater level fluctuations can be connected both spatially and temporally with the geological heterogeneity of the aquifer system, which in turn depends on the composition of the alluvial stratigraphy that lies beneath the study area.

The findings suggest that the main sources of groundwater recharge in the Kabul city region are local precipitation, river water, and irrigation return flow. These recharge sources vary spatially, the main source of groundwater recharge appeared to be precipitation in Central Kabul sub-basin. The influence of river water to recharge is most apparent in the Logar and Lower Kabul sub-basin. However, the spatial variability in δ^2H and δ^{18}O values in the western parts of Kabul city (Paghman and Upper-Kabul sub-basins) reflects limited lateral connectivity of the aquifer due to the heterogeneity of aquifer material. However, the variance of δ^{18}O with depth demonstrates the impact of averaging the isotopic composition of diverse groundwater sources at different depths.

The spatial variability of the stable isotopic data is controlled by local recharge and mixing between surface water and groundwater. The river water contribution to groundwater recharge was, on average over 60 % in 2007 while the contribution has changed on average to less than 50 % in 2020, with notable variations related to depth and spatially. The finding of this study suggests that river water serves as an important source of groundwater recharge in the Kabul city region.

To link the findings of this study with the sustainable groundwater management scenarios, a potential implication of the present study is for groundwater management in Kabul city by enhancing the understanding of the local water cycle. The present study used isotopic and groundwater level data to describe the local and regional flow system. The findings of this study provided important insights for projects aimed at sustainable groundwater management, including the Kabul Managed Aquifer Recharge pilot project and follow-up schemes. Furthermore, the findings of this study provided valuable inputs on understanding water level, surface and groundwater interaction, and groundwater source, which are crucial in designing and implementing strategic plans for the region, namely the Kabul Urban Framework Plan and Sanitation Concept Study project. It is essential to acknowledge a limitation of this study, which is the reliance on two cross-sectional groundwater sampling campaigns. This limitation mainly restricts the conclusions drawn from the two-component mixing model. However, besides the analysis of groundwater level changes, the most considerable contribution of this study lies in highlighting the high rate of enrichment observed in the groundwater samples. This finding directly challenges the unusual observation made by Mack et al. (2010), who reported no substantial evaporation in any of the analyzed groundwater samples in this semi-arid region.

Supplementary material

Supplementary material 3.1 Details on standards used during the stable isotope analysis of samples:

The standard deviation for the standards was <0.4 ‰ (1s) for δ^2H, and <0.2 ‰ (1s) for δ^{18}O during the analysis of the samples. Iso-Analytical standards used:

IA-R063 δ^2H VSMOW = +11.26 ‰, δ^{18}O VSMOW = -0.41 ‰

IA-R064 δ^2H VSMOW = -98.32 ‰, δ^{18}O VSMOW = -12.34 ‰

IA-R065 δ^2H VSMOW = -269.07 ‰, δ^{18}O VSMOW = -33.57 ‰

Supplementary material 3.2 Land use and land cover in Kabul city

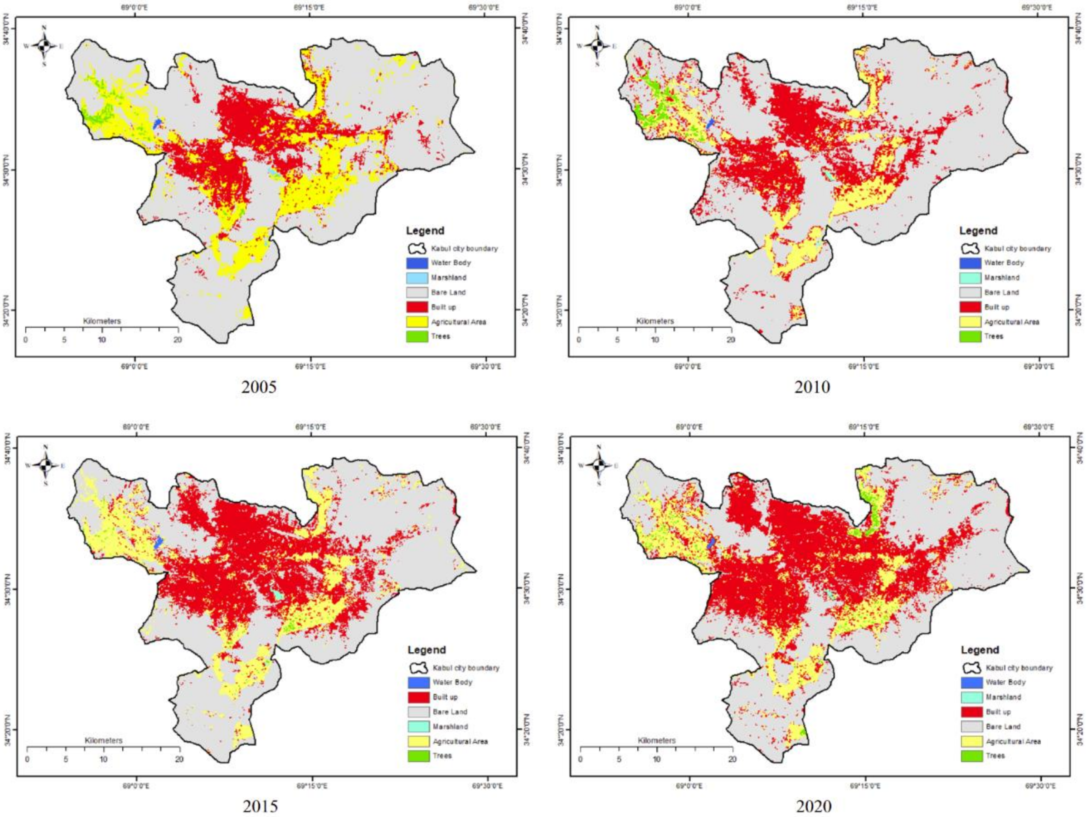

Figure S3.1 Land use and land cover changes in Kabul city between 2005 and 2020, adapted from Noori and Singh (2021).

Supplementary material 3.3 Specific yield map for Kabul city.

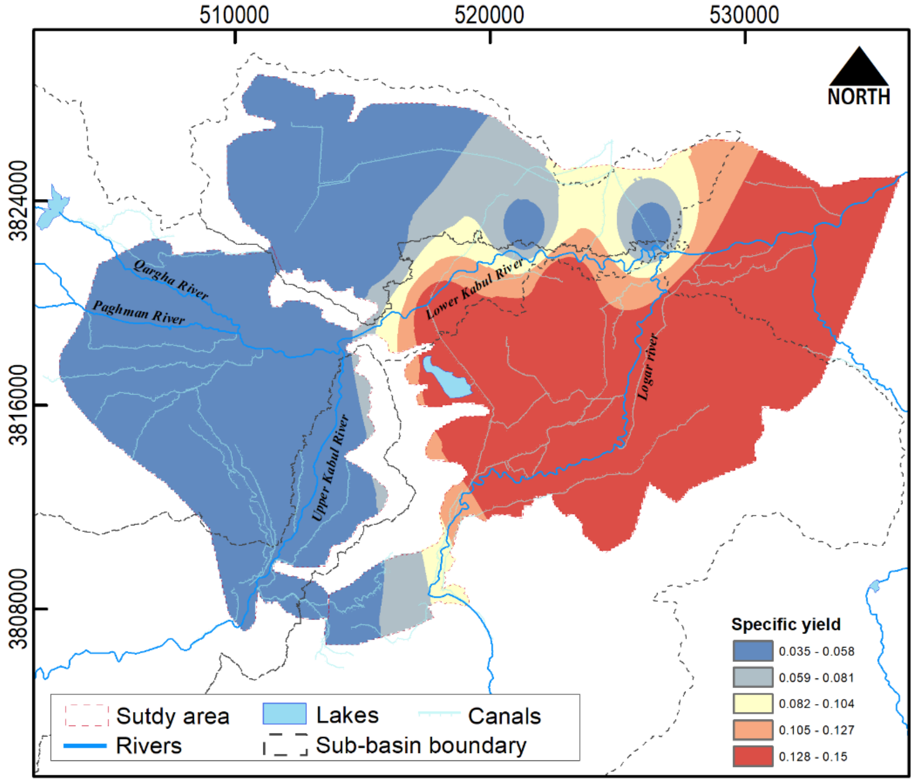

Figure S3.2 Distributed specific yield in Kabul city, values adapted from (Sadid 2020).

Supplementary material 3.4 Air mass trajectory for Karizmir Station in Kabul city (2006-07 and 2019-20).

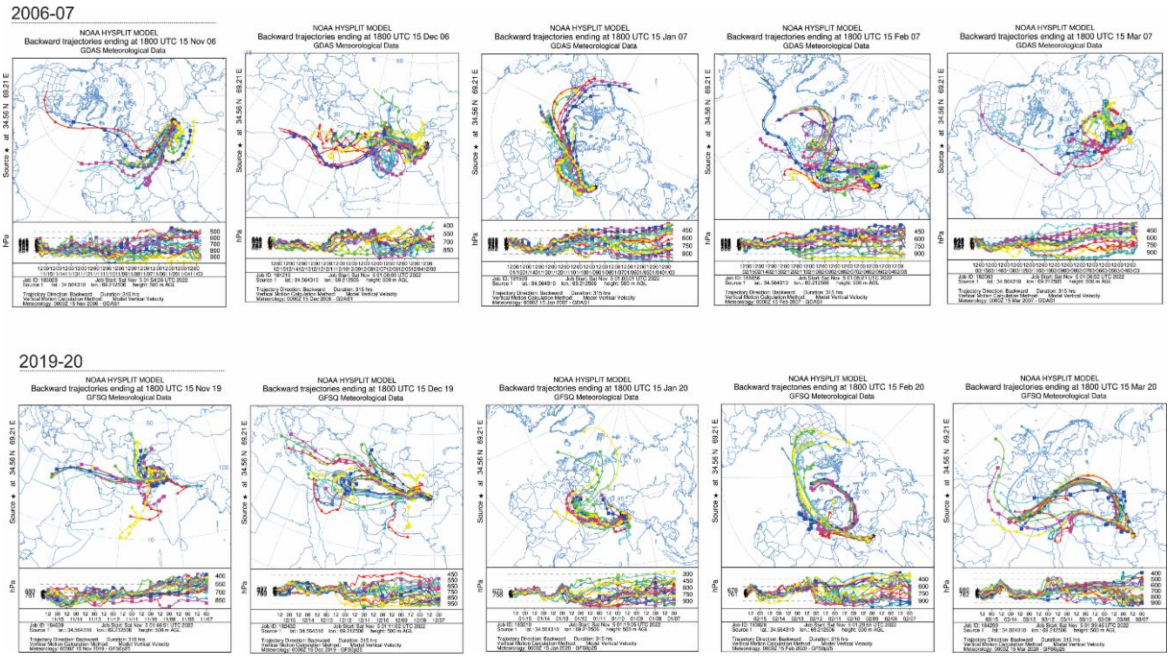

Figure S3.3 Air mass trajectory for Karizmir Station in Kabul city (2006-07 and 2019-20). *Data source*: HYSPLIT model (Stein et al. 2015).

Chapter 4

At the time of submitting the thesis, this chapter was published with slight modifications in the *Sustainable Water Resources Management*:

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Mohammad Daud Hamidi was responsible for conceptualization, data collection, analysis, methodology, visualization, writing original draft, review and editing. SK led the sampling campaign in Kabul and contributed to reviewing and editing. AAB and ST contributed to analysing major anions, and reviewing and editing. AKQ and JS contributed to reviewing and editing. HCG contributed through supervision (my primary supervisor), resources, review and editing. As the main author, I would like to thank the co-authors for their helpful discussions and priceless suggestion throughout the publishing process.

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4 Spatial estimation of groundwater quality, hydrogeochemical investigation, and health impacts of shallow groundwater in Kabul city, Afghanistan

Abstract

The management of groundwater in densely populated areas with no centralised water treatment is critical for the prevention of diseases and maintaining sanitation. Here, the bacteriological and chemical characteristics of groundwater are determined in Kabul city, a resource that 4.1 million individuals rely on. Groundwater samples were analysed from 41 newly established piezometric wells across Kabul, and data were compared with the last detailed study, undertaken in 2007, to understand contamination trends in an area that has undergone significant development and social changes. Piper diagrams, Gibbs diagrams, correlation analysis, and bivariate plots examine the hydrogeochemical and naturally occurring processes of groundwater. The average concentration of cations followed the order $Na^+ > Mg^{2+} > Ca^{2+} > K^+$, and anions $HCO_3^- > NO_3^- > Cl^- > SO_4^{2-} > F$ with Gibbs diagrams indicating mainly rock weathering influences groundwater chemistry. An increase in nitrate (NO_3^-) and *E. coli* indicates anthropogenic activities impacting the shallow groundwater quality, with significantly elevated nitrate (over 50 mg/L) and *E. coli* (up to 250 CFU/100 ml). The increasing presence of *E. coli* and NO_3^- in the shallow groundwater of Kabul city in turn suggests problematic links to the prevalence of waterborne diseases. Additionally, the Water Quality Index (WQI) was used to assess groundwater quality, and rank its suitability for drinking purposes. The WQI analysis showed that less than 35% of shallow groundwater samples had good water quality. The findings of this study are crucial for the development and sustainable management of groundwater in the city. In the short term, interventions such as point-of-use (POU) water purification are proposed which may offer temporary respite for waterborne disease prevention. Kabul city requires immediate attention to developing sustainable groundwater management policies, expansion of the water supply network, groundwater quality monitoring, and wastewater management.

4.1 Introduction

Water is one of the most valuable natural resources on Earth, yet in many areas is categorised as vulnerable. Water quality is of concern to humanity through its direct relationship to health, development and social prosperity (Milovanovic 2007; Singh et al. 2012). Under the United Nations Sustainable Development Goal (UN SDG) 6, targets 6.1 and 6.3 seek to ensure sustainable access to clean drinking water (UN 2015). Subterranean aquifers are vital bodies of fresh water and, in many urban areas in developing economies, are relatively safe compared to surface watercourses, which are invariably polluted by anthropogenic sewage and other waste sources (Christopher and Mohd 2011). As such, groundwater is widely used for different purposes and is the primary source of drinking water in many regions, especially in arid and semi-arid regions (Yu et al. 2014). The determining factor for the safe use of groundwater in different uses, including drinking, agriculture and industry, is the groundwater's chemical and biological composition (Kumar et al. 2010; Davraz and Özdemir 2014; Mallick et al. 2018). The physical and chemical characteristics of groundwater are influenced by natural processes such as climatic conditions, aquifer lithology, and interaction between surface water and aquifer, as well as anthropogenic activities including infiltration of agricultural fertilisers and wastewater, over-exploitation of groundwater, urbanization, industrialization, and population growth (Guo et al. 2017; Abbasnia et al. 2018; Jehan et al. 2019).

A common method of assessing the suitability of water quality for drinking purposes is by using the water quality index (WQI). The WQI is a dimensionless number that expresses water quality in a straightforward manner and is useful for decision-making for sustainable groundwater management when combined with GIS to demonstrate spatial variation in water quality and identification of vulnerable sites (Badeenezhad et al. 2020; Verma et al. 2021). Horton created a WQI in 1965 based on eight water quality parameters. Later, various WQIs have been established, including the National Sanitation Foundation WQI (Wills and Irvine 1996), the Canadian WQI (Davies 2009), and the Oregon WQI (Lumb et al. 2011). WQI is used to demonstrate groundwater suitability for drinking purposes (Ramakrishnaiah et al. 2009; Adimalla et al. 2018; Badeenezhad et al. 2020; Udeshani et al. 2020).

Afghanistan is classified as one of the extremely high water stress countries with a water stress of more than 80% (WRI 2015), based on a baseline water stress measure which is the ratio of total withdrawals to total renewable supply. Afghanistan's capital city, Kabul, is almost entirely reliant on groundwater owing to the seasonality of river water availability and a lack of water storage infrastructure for utilizing surface water supplies. Meldebekova et al. (2020) quantified a mean annual 5.3cm/year in the land surface above the Upper Kabul aquifer, which was highly correlated to groundwater level decrease. Kabul is one of the fastest-growing cities in the world, the mean annual population growth rate was 2.96 % between 2004 to 2020 (UN 2019), during which time the Kabul city population increased from 2.6 million to 4.1 million (CIESIN 2018; NISA 2020). Research suggests that rapid urbanization and population growth have an adverse impact on groundwater quantity and quality (Singh et al. 2012; Badeenezhad et al. 2020). Though groundwater is the main source of drinking water in Kabul, there are considerable water quality problems due to the lack of a municipal waste collection network, population growth and the consequence of decades of conflict prevented sustainable management in Kabul city (Broshears et al. 2005; Mack et al. 2013; Saffi 2019; Zaryab et al. 2022b). In their study, Jawadi et al. (2020) used WQI to assess the groundwater quality of the Kabul basin in Afghanistan; however, their work has been mostly restricted to limited samples (15 sampling points) located inside Kabul City, the general applicability of the published research is problematic due to diversity in land use, geology, water use practices, and population density.

Nevertheless, little is known about the natural mechanisms that govern the chemical composition of groundwater, bacterial contamination, and the impact of anthropogenic activities on groundwater quality in Kabul city. A network of pre-existing groundwater wells were identified by the United States Geological Survey (USGS) and Japan International Cooperation Agency (JICA) for monitoring groundwater levels and quality in Kabul city (Houben et al. 2009) and was handed over to the Hydrogeology Department of the Ministry of Energy and Water in Kabul in 2011. However, this network was not optimal for monitoring groundwater due to private ownership, limited access and corroded pumps installed in the wells. In addition, there has not been regular monitoring of water level and quality since (KMARP 2018b). In 2018, findings of the Kabul Managed Aquifer Recharge Project (KMARP 2018b) suggested the establishment of a network of piezometers in Kabul dedicated to sustainable water level and quality monitoring which was operationalized in 2019.

The present study is the first of its kind in 14 years aimed at a detailed assessment of groundwater in Kabul city, relying on the analysis of groundwater samples from the recently established network of piezometric wells. The objectives of this study are: a detailed assessment of shallow groundwater suitability for drinking purposes in Kabul city using WQI and GIS (a), evaluate the shallow groundwater characteristics, water type, and the mechanisms controlling groundwater hydrogeochemistry in the study area (b), explore the current trend of bacteriological contamination in groundwater and its health risk across Kabul city (c), and investigate the potential impact of anthropogenic activities on groundwater pollution (d). The findings of this study are crucial for the development and sustainable management of groundwater in Kabul city including the Kabul Managed Aquifer Recharge pilot project and follow-up schemes.

4.2 Materials and methods

4.2.1 Study area and data sources

The study covers 450 km^2 of the Kabul urban and peri-urban area with a population of 4.1 million, excluding internally displaced people and nomads (NISA 2020). The elevation of the city is 1800 m above mean sea level (Leslie 2019). The climate of Kabul is defined as a continental, cold semi-arid climate according to (Peel et al. 2007) with approximately 300 mm average annual rainfall and evapotranspiration at 1600 mm, annually. Low rainfall, combined with a high evaporation rate, has a significant impact on groundwater storage and water quality, as well as community health (Sheikhi et al. 2020). Furthermore, Multi-model ensemble precipitation projections for Kabul province by World Bank (2021) suggest little to no increase in the near future and an increase in the far future under Shared Socioeconomic Pathways (SPP)2 – 4.5, relative to the baseline period 1995 - 2014. The precipitation projections under different scenarios by World Bank (2021) as in (Figure S4.1) and Sidiqi et al. (2018) predict an increase. These studies indicate that climate change is intensifying the existing obstacles to sustainable access to groundwater in Kabul city.

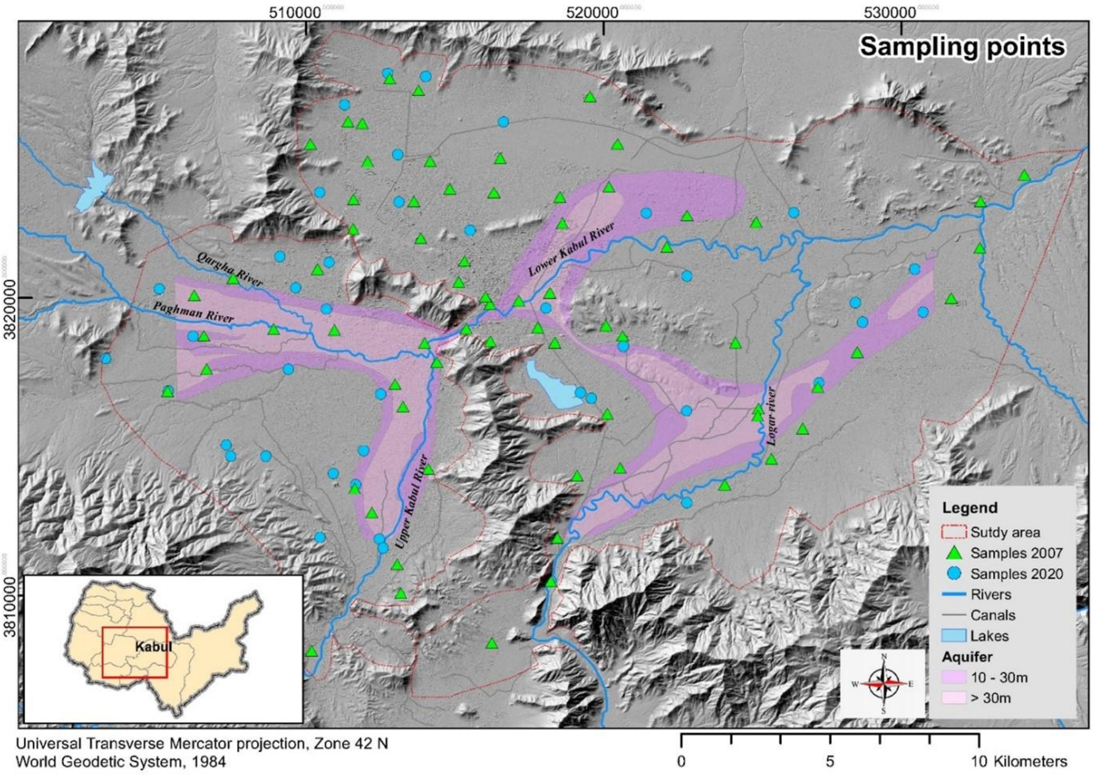

Figure 4.1 Groundwater sampling points in 2007 and 2020, the water flows from west to east; the city is divided into east and west catchments by the mountains.

Kabul city is divided into east and west sub-basins by mountains. The city lies at the intersection of the Kabul River, Logar River, and Paghman River (Figure 4.1). In the west of the city, the Paghman river joins the Kabul River near Deh Mazang area and then flows east toward its confluence with the Logar River (Saffi 2019). In the alluvial Kabul, the seasonal river beds are connected by loess and sandy soils that are responsible for a significant amount of discharge to the shallow aquifer (Broshears et al. 2005; Hossaini 2019; Zaryab et al. 2022b).

The historic data consisted of 75 groundwater sampling points located in the study area, which were collected from May 2006 through to June 2007 as described by Mack et al. (2010). As part of the present study, groundwater samples for chemical analyses were collected in January 2020 from 41 piezometric wells in the study area (Figure 4.1). From each sampling point, two samples were collected: 50 ml (0.20 µm filtered onsite) in sterile Falcon tubes and 500 ml in polythene containers. The pH and electrical conductivity were measured onsite by CHECKER1 pH Meter. The 500 ml sample was autoclaved (121 °C for 20 minutes) at the Central Veterinary Diagnostic and Research Laboratory of the Ministry of Agriculture, Irrigation and Livestock in Kabul. The collected and pretreated samples were transported in a cool box by air to Durham University, UK. Samples for major cation analyses were delivered to Durham Geochemistry Centre. Water samples for major anion analysis were sent to the High-performance Analytical Hub at the Centre for Agroecology, Water and Resilience (CAWR) at Coventry University, UK. The water samples for dissolved inorganic carbon (DIC) analysis were sent to the James Hutton Institute, Aberdeen, UK.

4.2.2 Analytical methods

The groundwater samples were analysed for *E. coli* counts at the Central Veterinary Diagnostic and Research Laboratory of the Ministry of Agriculture, Irrigation and Livestock in Kabul. The APHA (2017, pt.9216) standard for the direct total microbial count was used to analyse water samples. All groundwater samples were analysed for major cations (Na^{+}, Mg^{2+}, Ca^{2+} and K^{+}) according to the United States Environmental Protection Agency (EPA) (1994) using inductively coupled plasma-optical emission spectrometry (ICP-OES Thermoscientific ICAP 6000). The analysis of major anions (NO_3^-, SO_4^{2-}, Cl^-, Br^- and F^-) were delivered using ion chromatography on a Thermo Scientific™ Integrion™ system. The total hardness (TH) was calculated and expressed as an equivalent of calcium carbonate using Equation 1, as described by the American Public Health Association (APHA) (2017, sec.2340: Hardness) and the total dissolved solids (TDS) was calculated using Equation 2, as described by APHA (2017, sec.1030 E.):

$$Total\ Hardness, mg\ equivalent\ CaCO_3/L = 2.497\ [Ca, mg/L] + 4.118\ [Mg, mg/L] \quad (4.1)$$

$$\text{Total Dissolved Solids} = 0.6\ (\text{alkalinity as } CaCO_3) + Na^+ + K^+ + Ca^{2+} + Mg^{2+} + Cl^- + SO_4^{2-} + SiO_3^{2-} + NO_3^- + F^- \quad (4.2)$$

Dissolved Inorganic Carbon (DIC) analysis was used on for calculating the bicarbonate and carbonate concentrations in groundwater samples. The DIC was measured by pipetting 0.5 ml of water into a 12 ml Exetainer® vial and capped. The vials were flushed with N_2 gas using a Gas-bench II (Thermo Finnigan, Bremen, Germany). 0.1 ml of 1.3 M

H_3PO_4 was injected through the septa of the cap into the sample and left overnight. The concentration released into the headspace of the Exetainers® was analysed using a Gas-bench II connected to a DeltaPlus Advantage isotope ratio mass spectrometer (both Thermo Finnigan, Bremen, Germany). Through the use of the Valco valve and a sample loop within the gas bench and the instrument Isodat NT software version 2.0, each Exetainer® was sampled eight times of which the last four values were averaged to give a single sample value. Concentration values were based on the "area all" of the m/z (mass to charge ratios) 44, 45 and 46 of the samples compared with similarly treated DIC standards of 0, 25, 50 and 100 ppm. Bicarbonate and carbonate concentrations were calculated from DIC and pH using Equation 3 and Equation 4 as described by Clark (2015):

$$\boldsymbol{m}_{\mathrm{HCO}_3^-} = \frac{K_1 \times m_{DIC}}{a_{H^+} \times \gamma_{\mathrm{HCO}_3^-} + K_1} \tag{4.3}$$

$$\boldsymbol{m}_{CO3^{2-}} = \frac{K_2 \times m_{DIC} \times \gamma_{\mathrm{HCO}_3^-}}{a_{H^+} \times \gamma_{CO3^{2-}} + K_2 \times \gamma_{\mathrm{HCO}_3^-}} \tag{4.4}$$

Where K_1 and K_2 are the first and second dissociation constants for H_2CO_3 and HCO_3^- with values $10^{-6.38}$ and $10^{-10.38}$, respectively, considering the temperature of the water as 20 ºC; m_{DIC} is the concentration of dissolved inorganic carbon. $\gamma_{\mathrm{HCO}_3^-}$ and $\gamma_{CO3^{2-}}$ are 0.89 and 0.63 respectively; and, a_{H^+} is $10^{-\mathrm{pH}}$ as described by Clark (2015). The Piper diagram was used, developed by Piper (1944), to investigate the types of water, the chemical analysis was plotted on a Piper diagram, using AquaChem software (Waterloo 2021). To differentiate the mechanisms governing the hydrogeochemical compositions of groundwater in the study area, Gibbs diagrams was used, proposed by Gibbs (1970). Gibbs diagram is primarily used for surface water. However, researchers applied it in alluvial regions where rivers and aquifers are well-connected (Chintalapudi et al. 2017; Singh et al. 2018). The sources of rock-weathering in relation to the hydrochemical properties of groundwater in the study area was characterized using end-member diagrams following Pradhan et al. (2022) and Roy et al., (2020), and as suggested by Gaillardet et al. (1999).

4.2.3 Water quality index

There are three steps in calculating the WQI (Ramakrishnaiah et al. 2009). Considering the relative significance of the groundwater quality for drinking purposes and health impact in the study area, 12 parameters were selected and a weight (w_i) scale of 1-5 was assigned (Table 4.1). TDS and nitrate are having the highest influence on the groundwater quality of Kabul city, with a maximum weighting of 5 and the lowest weighting of 1 was assigned to F^-. The relative weight was calculated using Equation 5:

$$\boldsymbol{W_i} = {}^{\boldsymbol{w_i}}\!/\!{}_{\sum_{i=1}^{n} \boldsymbol{Wi}} \qquad (4.5)$$

W_i represents the relative weight, w_i is the weight assigned and n is the number of parameters (Vasanthavigar et al. 2010).

Table 4.1 Relative weight of each parameter considering WHO and ANDWQS guidelines

Parameter	WHO/ ANDWQS guideline	Weight (w_i)	Relative weight (W_i)
TDS	1000 mg/1	5	0.128
NO_3^-	45 mg/1	5	0.128
Total hardness	500 mg/1	4	0.103
pH	6.5 - 8.5	4	0.103
SO_4^{2-}	250 mg/1	4	0.103
Ca^{2+}	200 mg/1	3	0.077
Mg^{2+}	150 mg/1	3	0.077
Na^+	200 mg/1	3	0.077
Cl^-	250 mg/1	3	0.077
K^+	12 mg/1	2	0.051
HCO_3^-	500 mg/1	2	0.051
F^-	1.5 mg/1	1	0.026
		$\Sigma w_i = 39$	$\Sigma W_i = 1.00$

A relative quality rating (*qi*) was assigned for each measured parameter in each sample using Equation 6:

$$\boldsymbol{qi = \frac{Ci}{Si} \times 100} \quad (4.6)$$

Where *Ci* is the amount of measured parameter in a sample and *Si* is the respective standard value based on World Health Organisation and Afghanistan National Drinking Water Quality Standard (ANDWQS 2012).

A sub-index (*SIi*) is determined for each chemical parameter using Equation 7; and, the sum of *SIi* is the value of WQI for each sample, as given in Equation 8:

$$\boldsymbol{SIi = Wi \times qi} \quad (4.7)$$

$$\boldsymbol{WQI = \sum SIi} \quad (4.8)$$

Where *Wi* is the relative weight; *qi* is the relative quality rate of the parameter and *WQI* is the water quality index. In this study, the WQI is calculated for 2007 and 2020 for each sampling point. Interpolation and maps were created using Inverse Distance Weighting (IDW) in ArcGIS software (Esri 2019), as described by Sardoo and Azareh (2017).

4.3 Results and Discussion

4.3.1 Statistical results of hydro-chemical parameters

The analysis results of measured parameters for 41 groundwater samples are presented in Table 4.2, with and without two identified locations as hotspots. The two hotspots were located in areas where all the measured parameters were anomalously high both in 2007 and 2020 (see Section 4.3.2). The statistical analysis results are illustrated with the corresponding box and whisker plots in Figure 4.2.

The measured pH varied from 7.04 to 8.22 suggesting a weakly alkaline association. TDS concentrations varied from 173 mg/L to 1430 mg/L. This indicates distributed water quality in the basin and could be due to a variety of factors (e.g., aquifer heterogeneity and anthropogenic activities). The TDS value in several cases in the northeast and southeast of Kabul city is higher than the permissible level for drinking (1000 mg/L) set by WHO (2017) and ANDWQS (2012). The results also indicate that the total hardness

(TH) values vary between 93 to 828, which also confirms that the distribution of water quality is varied in Kabul City.

Nitrate (as NO_3^-) concentration ranges between 17.6 to 494 mg/L. The maximum allowable limit for NO_3^- in drinking water is 50 mg/L (as NO_3^-), set by WHO (2003) and ANDWQS (2012). Due to the lack of nitrate in most geologic formations, elevated NO_3^- concentrations are commonly representative of water pollution by anthropogenic sources such as animal waste, and fertilizer (Adimalla and Qian 2019). Over 86% of the households in Kabul dispose of sewage via a simple pit latrine or cesspit without any further wastewater treatment (Houben et al. 2009).

Table 4.2 Summary statistics of measured parameters of Kabul city shallow groundwater samples from 2020

Parameters	Excluding two hotspots				Including two hotspots			
	Min	Max	Mean	Standard deviation	Min	Max	Mean	Standard deviation
pH	7.04	8.22	7.58	0.32	7.04	8.22	7.58	0.34
TDS (mg/L)	173	1430	611	341	173	11800	1151	2430
TH (mg of $CaCO_3$/L)	93.3	828	345	183	93.3	5630	554	976
Ca^{2+} (mg/L)	4.45	174	30	38.9	4.45	626	50	106
Mg^{2+} (mg/L)	19.9	151	66	40.0	19.9	986	104	178
Na^+ (mg/L)	15.3	452	106	89.2	15.3	2970	219	525
K^+ (mg/L)	1.53	17.8	6	3.42	1.53	22.8	7	4.78
HCO_3^- (mg/L)	43.5	527	208	122	43.5	2200	253	334
SO_4^{2-} (mg/L)	5.93	380	54	74.9	5.93	380	54	74.9
NO_3^- (as NO_3^- mg/L)	19.5	494	125	107	19.5	5630	363	1080
Cl^- (mg/L)	9.97	308	102	82.8	9.97	2410	207	478
F^- (mg/L)	0.01	0.26	0.09	0.08	0.01	0.26	0.07	0.08

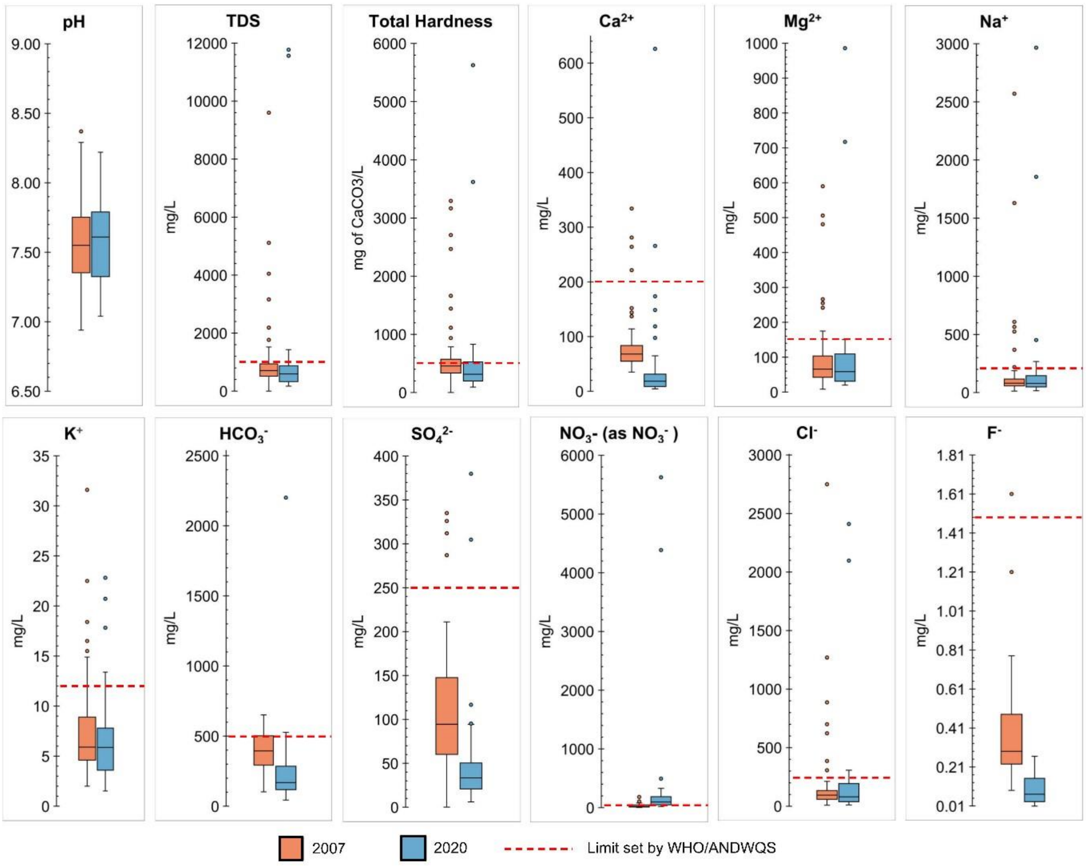

Figure 4.2 Box and whisker plots of measured parameters of groundwater samples for 2007 (n=75) and the new piezometer wells in 2020 (n=41).

4.3.2 Water quality index

The WQI was used to assess the trend and suitability of shallow groundwater quality for drinking purposes in the study area, Kabul city. The classification of the type of water according to the WQI is presented in Table 4.3, following the work of Sheikhi et al. (2020) and Vasanthavigar et al. (2010). The quality of water in shallow aquifers of Kabul city has considerably deteriorated between 2007 and 2020, as illustrated in Figure 4.3a and Figure 4.3b, respectively. In the east of the city, it is illustrated that in 2007 the quality of shallow groundwater was excellent to good water except in two spots (Figure 4.3a). While in 2020, the quality of shallow groundwater is poor to unsuitable for drinking purposes except for the very few wells with good quality (Figure 4.3b). In the west of the city, the water quality has also deteriorated from most of the area having excellent water in 2007 to good water in 2020. Because of their sandy to gravel composition and related high permeabilities, the aquifers in the Kabul Basin provide a little barrier to the spread of pollutants (Houben et al. 2009).

Table 4.3 WQI based classification of water type (Vasanthavigar et al. 2010; Sheikhi et al. 2020)

Range	Type of water
<50	Excellent water
50-100	Good water
100-200	Poor water
200-300	Very poor water
>300	Unsuitable for drinking purposes

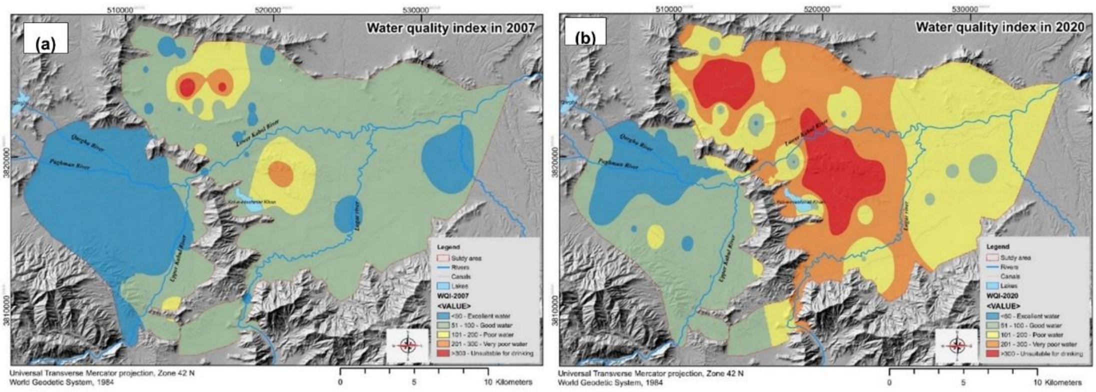

Figure 4.3 Spatial distribution of water quality index in Kabul city (a) 2007, and (b) 2020.

The two hotspots illustrated in Figure 4.4a and Figure 4.4b highlight high WQI values for drinking water quality. In both locations, the water quality ranked as unsuitable for drinking purposes. The two hotspots are located in the vicinity of surface wastewater collection and inundation control canals. In both areas, the WQI was classified as very poor water quality in 2007, while contamination has spread in the area and the quality index increased to unsuitable for drinking purposes by 2020. As illustrated in Figure 4.4a, the area is densely populated besides industrial activities taking place. The sampled piezometer well (Figure 4.4a) is located near a perennial canal that takes surface and wastewater to the Logar River. Similarly, a sampled piezometer well located 3.5 km downstream of the canal also indicates WQI over 100, poor water quality. The second hotspot illustrated in Figure 4.4b shows the sampled piezometer well located in an area near a perennial and an intermittent canal used for surface wastewater collection and inundation control.

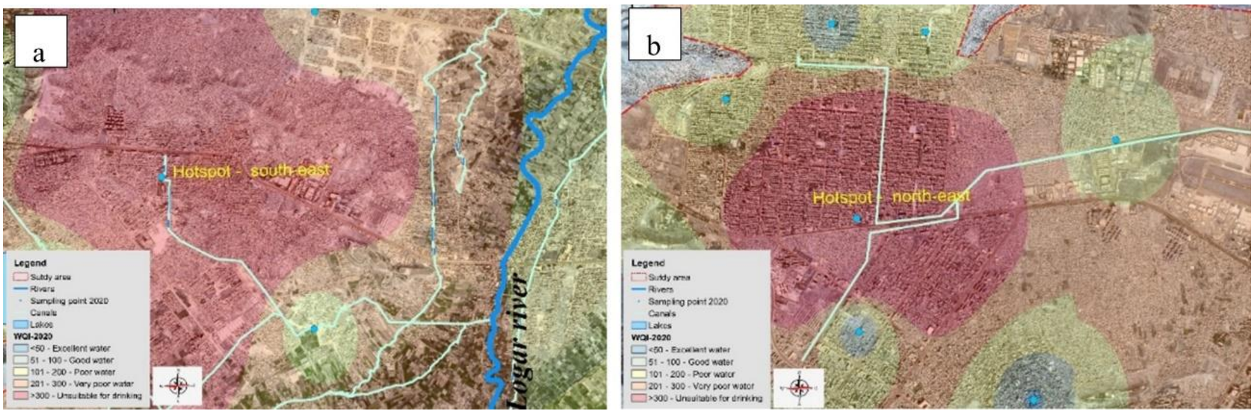

Figure 4.4 The two hotspots with high WQI, unsuitable for drinking water (a) south-east of Kabul city, and (b) north-east of Kabul city.

4.3.3 Groundwater hydrochemical type

To observe changes and to classify the groundwater type or hydrochemical facies of shallow groundwater in Kabul city, the cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and anions (Cl^-, HCO_3^-, SO_4^{2-}) composition were plotted on Piper trilinear diagrams for 2007 (Figure 4.5a) and 2020 (Figure 4.5b).

The water types for the study area are presented in four groups based on the geographic location of sampled wells. The group of samples located in the northeast were mainly Ca-HCO_3 and Mixed water type (Ca-Mg-Cl) in 2007 (Figure 4.5a). Other groups of samples located in the southeast, northwest, and southwest were mainly Ca-HCO_3 water type in 2007 (Figure 4.5a). However, the analysis of sampled piezometric wells in 2020 highlighted some changes in water type compared to 2007. For instance, in the northeast of the city, more samples were Ca-Na- HCO_3 besides other water types including Ca-HCO_3 and Mixed water type (Ca-Mg-Cl). In the southeast of the city, more samples illustrated mixed water type (Ca-Mg-Cl) beside the Ca-HCO_3 water type. The northwest of the city is the only region where the groundwater hasn’t observed a significant change in water type, the Ca-HCO_3 water type remains unchanged (Figure 4.5b). However, in the southwest of Kabul city, the sampled piezometric wells in 2020 illustrated samples with mixed type water (Ca-Na- HCO_3), Ca- HCO_3, and few samples were Na-Cl water type. The emergence of Na-Cl water type in the southwest of Kabul city could be due to cation exchange and evaporation. The hydro-chemical analysis demonstrated an increase of Na^+, Cl^- and Mg^{2+} in the groundwater of Kabul city between 2007 to 2020. The enrichment of alkali (Na^+) and strong acid anions (Cl^- and SO_4^{2-}) could be a result of pit latrine leachate infiltration (Rao et al. 2013).

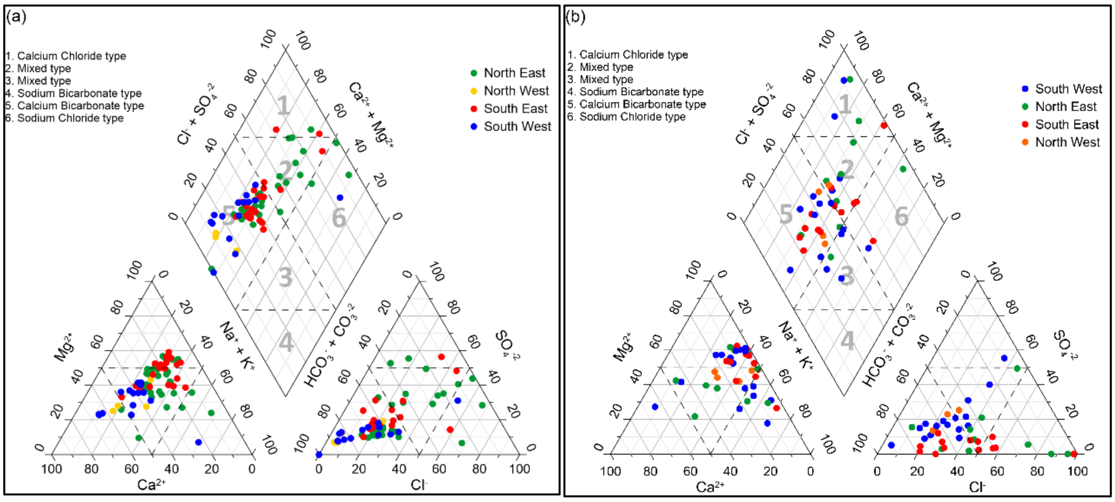

Figure 4.5 Piper diagrams for (a) 2007, and (b) 2020 – an increase in Na^+, Cl^- and Mg^{2+} is observed between 2007 and 2020.

4.3.4 Mechanisms controlling groundwater hydrogeochemistry

The groundwater samples fall mainly in the rock weathering dominance zone, defined by Gibbs (1970), with few samples in the evaporation zone (Figure 4.6), indicating that both rock weathering and evaporation crystallization influence groundwater chemical evolution. As illustrated in Figure 4.6, Na^+ is the major cation in groundwater and a major contributor to high groundwater salinity because the values of $Na^+/(Na^+ + Ca^{2+})$ for the majority of the samples exceed 0.6. Moreover, the variation of $Na^+/(Na^+ + Ca^{2+})$ between 0.08 to 0.96 suggest a strong cation exchange in the groundwater. Cation exchange and interactions with silicates are likely to cause the $Na^+HCO_3^-$ water type (Toran and Saunders 2002; Su et al. 2017; Gao et al. 2019). The ratio of $Cl^-/(Cl^- + HCO_3^-)$ in the majority of the groundwater samples is below 0.6 (Figure 4.6), with an influence of rock-weathering except for some samples spread in evaporation dominance. The rock-weathering processes could be influenced by anthropogenic activities (Marghade et al. 2012; Pradhan et al. 2022). As illustrated in Figure 4.6, none of the groundwater samples falls in the precipitation dominance zone indicating the limited impact of atmospheric participation on the chemical composition of the groundwater of Kabul city. In the semi-arid regions, owing to the semiarid climate conditions, atmospheric precipitation has a limited impact on the chemical composition of groundwater (Feng et al. 2020).

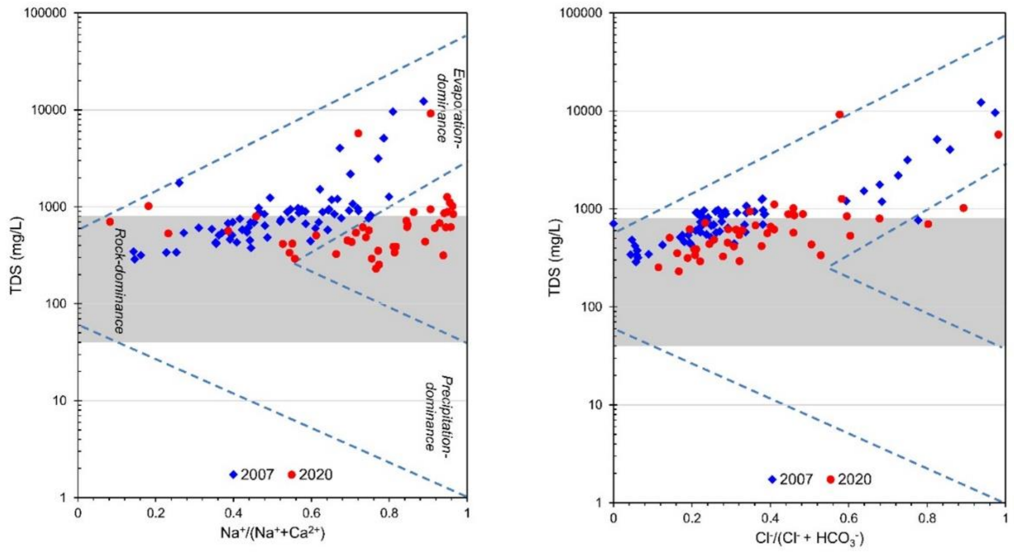

Figure 4.6 Gibbs diagrams of the groundwater samples for 2007 and 2020.

Figure 4.7 shows the chemical composition of groundwater in the study area is primarily between carbonate and silicate, indicating that groundwater chemical composition originates from carbonate and silicate mineral weathering.

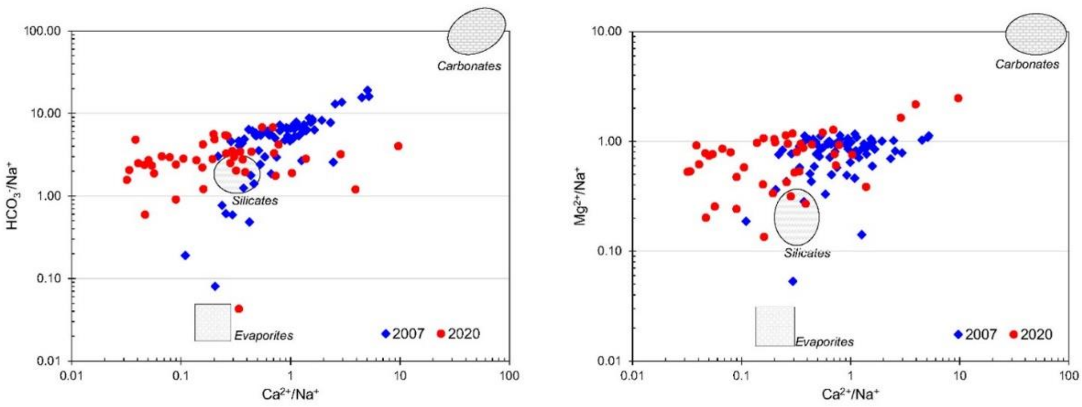

Figure 4.7 End-member diagrams of the groundwater samples for 2007 and 2020.

4.3.5 Nitrate contamination

Long-term nitrate exposure could result in a lack of oxygen delivery to numerous bodily tissues and organs, causing brain damage and, finally, death in infants (Ahada and Suthar 2018). As presented in Section 3.1, nitrate in Kabul city groundwater wells exceeds the WHO guidelines for safe drinking water. The maximum level of nitrate (NO_3^-) contamination recommended by the WHO is 50 mg/L. The results show that 76% of the analysed groundwater samples from Kabul city in 2020 exceeded the limit of 50 mg/L up to ten-fold. Spatially distributed maps of nitrate contamination (as NO_3^-) for Kabul city in 2007 and 2020 are provided as Supplementary Material (Figures S4.2 and S4.3). The present study evaluated NO_3^- connections with physiochemical indices to assess the consequences of anthropogenic activities on groundwater quality in Kabul city. The relationship between NO_3^- and Cl^-, as illustrated in Figure 4.8, shows that the two ions originate from the same source. Because wastewater has a substantial impact on Cl^-, it is plausible to assume that wastewater has a similar impact on NO_3^- (Li et al. 2016). Thus, as illustrated in Figure 4.8, the strong correlation between Cl^- and NO_3^- (R^2 = 0.98 including the two hotspots, R^2 = 0.5 and excluding the two hotspots) suggests a similar source, mainly through anthropogenic activities, happened in Kabul city over time. A statistically significant positive relationship between TDS and (NO_3^- + Cl^-)/HCO_3^- (R = 0.19) was noted. A positive correlation between TDS and ions indicates that human activities influence groundwater chemistry (Jalali 2009).

Nitrate pollution in groundwater and surface water results from sources such as solid waste, leaching from agricultural land, disposal sites, human excreta, or ammonia oxidation (WHO 2003; Rahman et al. 2021). The redox potential measured in Kabul city by Houben et al. (2009) suggested that ammonium nitrification is most likely occurring in the pit latrines and unsaturated zone and to a lesser extent in shallow groundwater. Houben et al. (2009) found that despite its near-surface location, the groundwater in Kabul city exhibits strong signs of oxygen depletion due to the oxygen-consuming processes of nitrification and oxygenation of dissolved organic matter from sewage. However, there are many variables and uncertainties. A substantial increase in urban built-up areas is observed in Kabul between 2007 and 2020 (Noori and Singh 2021). Besides agriculture activities in parts of the city, Kabul is populated with high density, experienced rapid growth of non-standard urbanization, lacks wastewater collection systems, and most houses are accommodated with a pit latrine or cesspit. As a consequence, NO_3^- pollution may regularly occur in the study area and increase over time due to geogenic and anthropogenic activities. In their study, Borchardt et al. (2021), showed that total coliforms at well sites and nitrate were strongly linked to depth-to-bedrock and neighbouring agricultural land use.

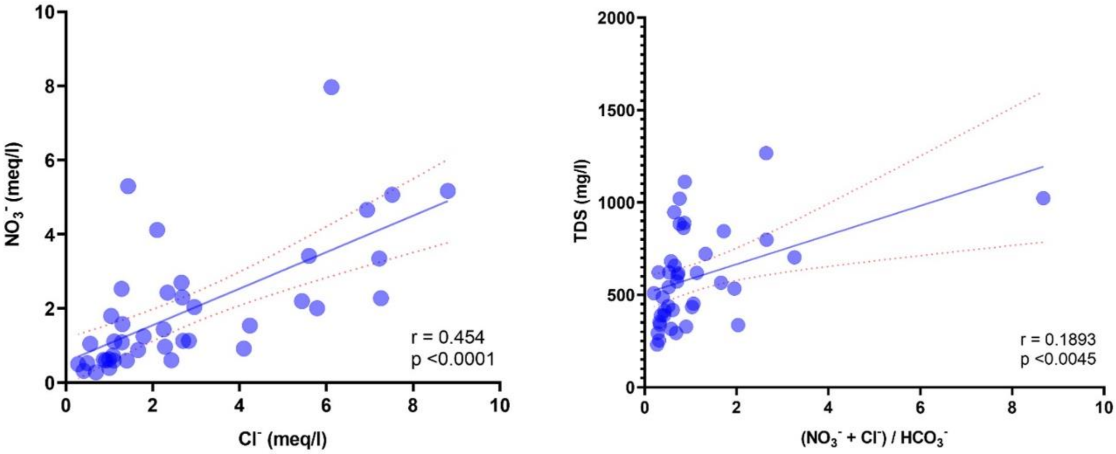

Figure 4.8 Signification correlation of NO_3^- with Cl^- suggesting a similar source, and relationship between TDS and $(NO_3^- + Cl^-)/HCO_3^-$.

4.3.6 Bacteriological contamination

Escherichia coli (*E. coli*) found in drinking water indicates water pollution with faeces which might contain different disease-causing microorganisms including certain types of bacteria, viruses and protozoa, WHO set a limit of zero colony-forming units per 100 millilitres (0 CFU/100 ml) (WHO 2017; Ibrahim 2019). The groundwater biological contamination in Kabul city was investigated by WHO and confirmed the presence of coliform bacteria as reported by Proctor and Redfern International Limited (1972). As reported by Banks and Soldal (2002), the bacteriological study of Kabul city groundwater in 1996 by Timmins, based on 1400 samples of drinking water sources, confirmed the presence of *E. coli* >100 CFU/100ml in wells with hand pumps (11.1%), open wells (31.9%) and distribution networks (15.7%).

The sampling campaign from 2004 to 2007 reported by Mack et al. (2010) found that *E. coli* was present in 97% of the groundwater samples (Figure S4.4); however, *E. coli* concentrations appeared to be spread randomly throughout the city. The range of *E. coli* presence in groundwater in the southwest of Kabul city was reported between 1 to 8 CFU/100 ml in 2007 (Figure S4.4) but the results of the current study found an unexpected increase to an average of 110 CFU/100ml in 2020 (Figure 4.9). The increase of *E. coli* prevalence in the southwest of Kabul is potentially related to an increase in inhabitants between 2007 to 2020 (Noori and Singh 2021; Zaryab et al. 2022b; Zaryab et al. 2022a), the common use of pit latrines in local houses, and the use of human excreta in nearby agricultural land as fertilizer. In light of these conditions, a determining factor for the widespread and increasing *E. coli* contamination in the area could be the shallow depth of groundwater (2 – 25 meters) beside the existence of three surface canals transporting water from the river to irrigate the land.

The increase of *E. coli* in groundwater between 2007 and 2020 is also consistent with an increase of NO_3^- in the southwest of Kabul city (which was also observed in the southeast of the city). The presence of *E. coli* in the northeast of Kabul city remains unchanged (0 – 6 CFU/100ml), while an evident increase of NO_3^- might have been an effect of the depth of the water table with an average depth of 80 meters.

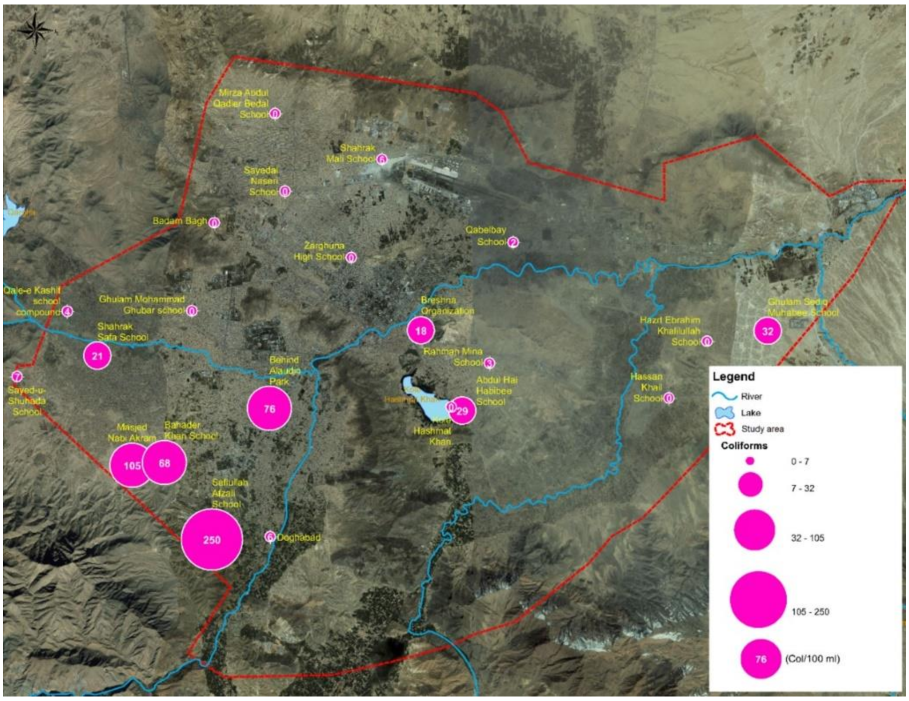

Figure 4.9 *E. coli* count in groundwater samples of Kabul city in 2020.

4.3.7 Health risks of shallow-groundwater consumption for drinking purposes

For every 1000 children born in Afghanistan, 97 children die before the age of five, and waterborne illnesses are a major contributor to this high level of child mortality (Rasooly et al. 2014). A survey of 71 health centres around Kabul city by (KMARP 2018a) found that reported waterborne diseases include amoebic dysentery, hepatitis A, typhoid and paratyphoid, shigellosis, salmonellosis (Figure 4.10).

The findings of this study suggest that the extensive and growing chemical and biological contamination of the groundwater in Kabul city risks aggravating this critical public health concern. Section 3.5 thereby demonstrated that the nitrate contamination (as NO_3^-) of groundwater in Kabul city is worryingly high, and Section 3.6 showed that the biological contamination is beyond the limit set by WHO. In the southwest of the city, groundwater biological contamination is high.

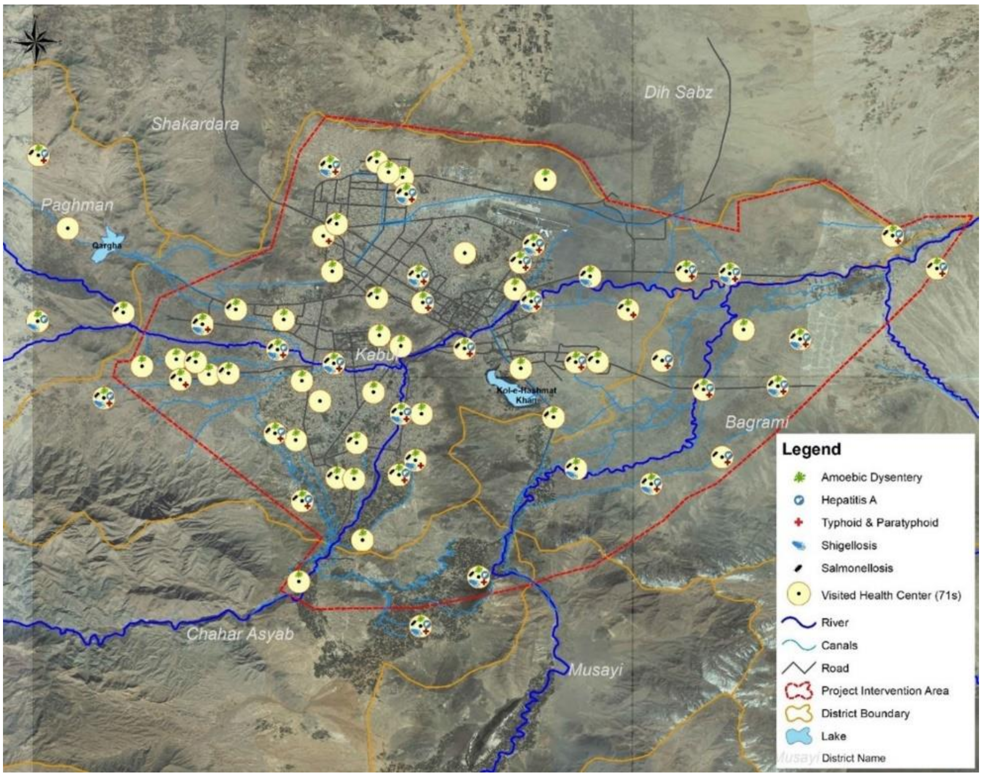

Figure 4.10 Waterborne disease prevalence in Kabul city (KMARP 2018a).

Taken together, the findings, therefore, establish that the prevalence of waterborne disease in Kabul city is spatially distributed, and the majority are linked to biological contamination with *E. coli*. Although the presence of *E. coli* is a proxy for broader bacterial, viral and protozoal contamination, the available data indicate the widespread and increasing faecal contamination of groundwater in Kabul city (see Section 3.6) that is particularly concerning in light of the high burden of waterborne disease, especially among children.

4.4 Conclusions

Kabul city is heavily reliant on groundwater for drinking and other purposes. This research used data from groundwater samples from 41 new piezometric wells compared to groundwater data from 2007 (75 sampling points). The findings of this research revealed a decline in water quality between 2007 to 2020. The results suggest that the prevalent groundwater hydrochemical type in Kabul City is the Ca-HCO_3 water type and the chemical composition of groundwater is primarily influenced by water-rock interaction. Further, the hydro-chemical analysis demonstrated an increase of Na^+, Cl^- and Mg^{2+} in the groundwater of Kabul city between 2007 to 2020. The results of this study suggest an increasing impact of anthropogenic activities on groundwater in Kabul city, which has led to an increase and the spread of chemical contamination, as illustrated using WQI. The increase of WQI in the southwest and southeast of Kabul city is potentially related to agricultural activities and growing population pressure between 2007 to 2020. Additionally, during the same period, an increase of NO_3^- and *E. coli* is observed in groundwater, indicating more intensive faecal contamination in areas that had already struggled with a high prevalence of waterborne diseases.

Sustainable access to clean water in the densely populated city of Kabul requires urgent attention as it threatens public health and the socio-economic recovery of a post-conflict environment. Although the construction of two dams are undergoing for providing piped drinking water to residents, water quality and the distribution network expansion remain major concerns due to the timescale and limited financial resources for major infrastructural developments. Considering the health risks of water contamination, sustainable groundwater management in Kabul requires establishing water distribution systems, wastewater treatment and long-term quality and water level monitoring. This requires long-term planning and extensive financial resources, which are further complicated by the events in August 2021 that left Afghanistan not only in a complex post-conflict context but indeed no longer recognized by the international community. Groundwater is frequently utilized without any form of treatment or even purification at the household level. As an interim, inexpensive, and sustainable solution for residents of Kabul city, interventions such as point-of-use (POU) water purification are proposed which may offer temporary respite for waterborne disease prevention.

Supplementary material

Supplementary material 4.1 The participation projection under different climate scenarios, adapted from World Bank (2021).

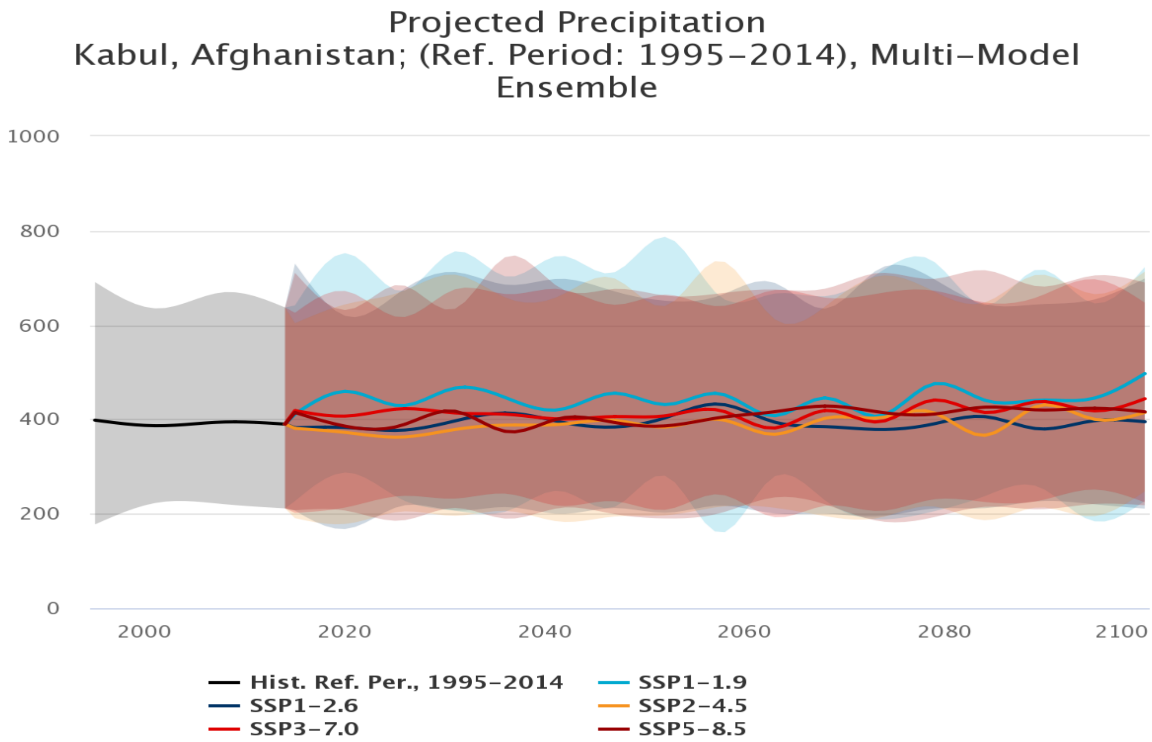

Figure S4.1 Precipitation projection, adapted from World Bank (2021).

Supplementary material 4.2 Measured Nitrate level in the groundwater of Kabul city in 2007 and 2020

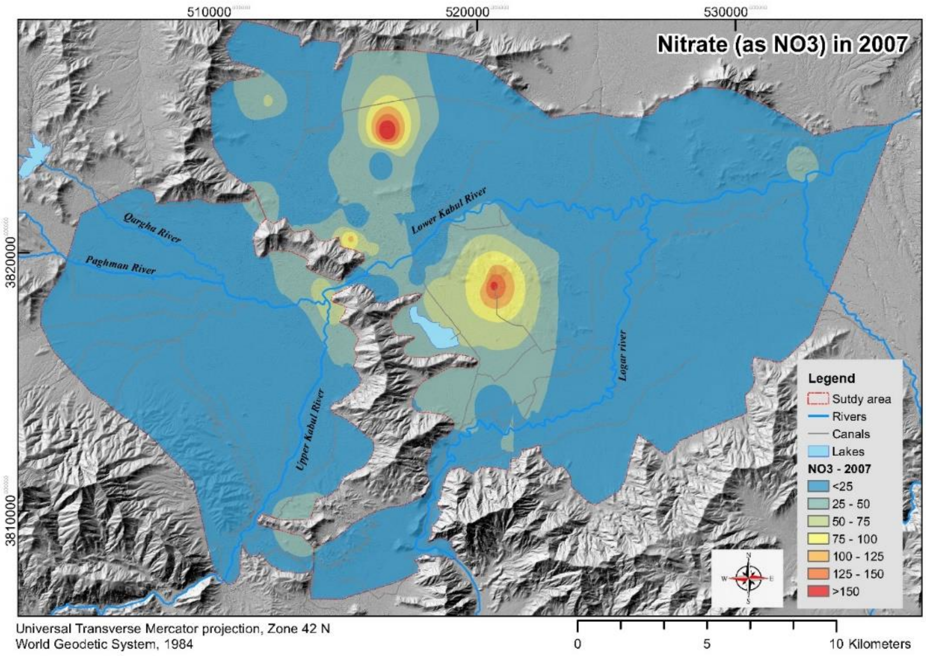

Figure S4.2 Measured Nitrate level in the groundwater of Kabul city in 2007.

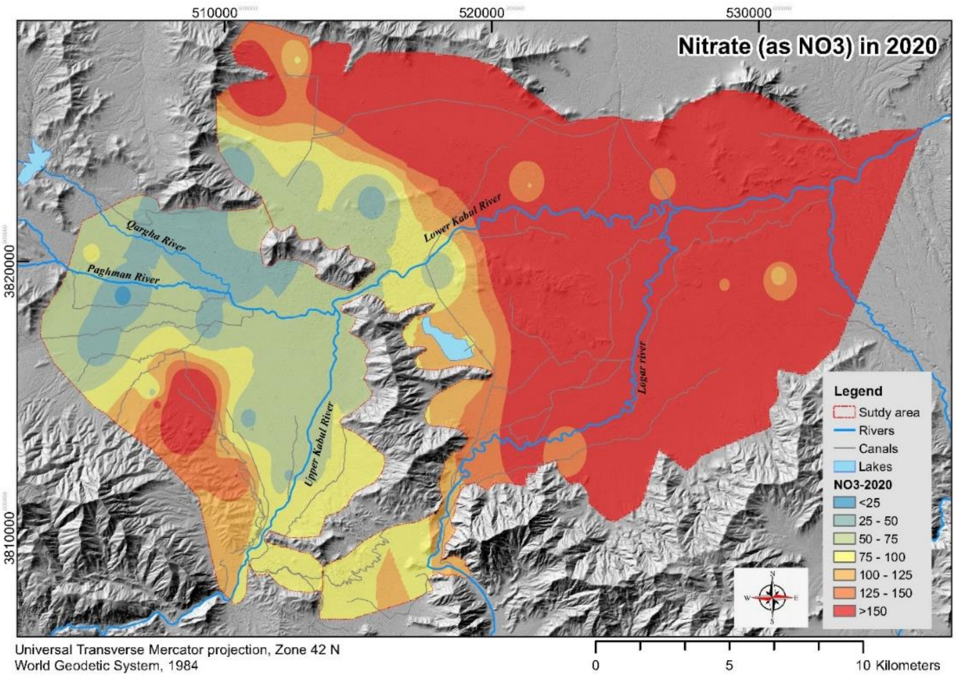

Figure S4.3 Measured Nitrate level in the groundwater of Kabul city in 2020.

Supplementary material 4.3 Measured *E. coli* in the groundwater of Kabul city in 2007, from Mack et al. (2010).

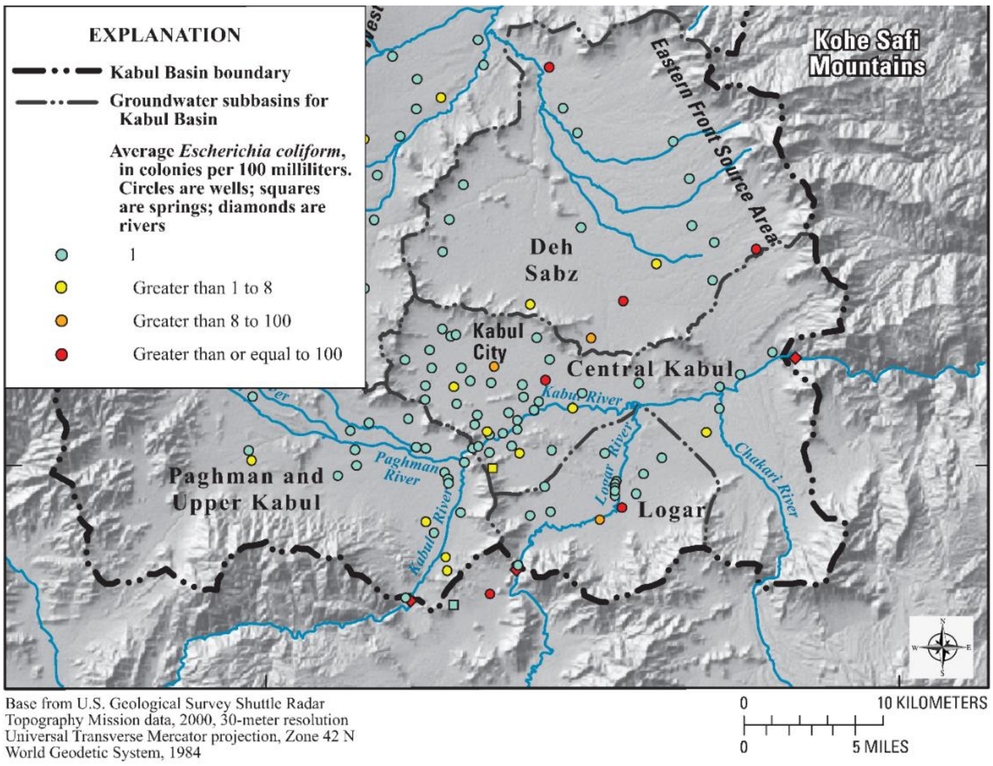

Figure S4.4 Average *E. coli* prevalence in groundwater in 2007, from Mack et al. (2010).

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Chapter 5

Mohammad Daud Hamidi, Marco J. Haenssgen, Edward (Jed) Stevenson, H. Chris Greenwell

Mohammad Daud Hamidi was responsible for conceptualization, data collection, data analysis, methodology, writing original draft, review and editing. MJH and EJS (my co-supervisor) contributed through discussions on setting up methodology and analysis, review and editing. HCG contributed through supervision (my primary supervisor), resources, review and editing. As the main author, I would like to thank MJH, EJS, and HCG for their helpful discussions and priceless suggestions.

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5 Access to Water in Kabul, Afghanistan: A Qualitative Study

5.1 Introduction

Access to clean drinking water is a critical global challenge. Access to safe drinking water and sanitation was recognized as a human right at the sixty-fourth general assembly of the UN (2010). Universal access to clean drinking water is a United Nations Sustainable Development Goal (UN SDG 6.1) to be achieved by 2030 (UN 2015). However, 2.3 billion people live in water-scarce regions, and of these 733 million people live in high and critically water-stressed countries (UN-Water 2021), particularly in low- and middle-income countries (Grafton 2017). Behind these headline international statistics, however, lies a great deal of complexity, and while the general claim that inequitable access to water is a priority for development is widely shared, the surveillance and research methods used to measure obstacles to accessing safe water are contested. According to the WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP), 96 % of the Kabul province population has basic access to drinking water (JMP 2020). In the JMP reports, basic access is defined as "Drinking water from an improved source, provided collection time is not more than 30 minutes for a roundtrip including queuing." [1] Thomas (2015) critically analysed the JMP baseline survey and its methodological discrepancies in Afghanistan, recommending that the statistics should be taken with great "caution and scepticism". The concerns included inflated data, methodological inconsistencies between various national surveys, biased trend assessments, and irrational presumptions about the long-term sustainability of existing water systems (Thomas 2015). Some research has gone so far as to describe similar statistics in other geographies even as "nonsense" and "dubious" (Onda et al. 2012; Nganyanyuka et al. 2014).

The development of water resources to meet human needs is the common thread among all definitions of water security (Aboelnga et al. 2019), despite the fact that water security

[1] Improved drinking water sources are those that, by virtue of their design and construction, have the ability to offer safe water, such as piped water, boreholes or tube wells, protected dug wells, protected springs, rainwater, and packaged or delivered water.

has been given many definitions[2] and is framed broadly, especially a widely-used definition of "holistic outlook" from UN-water which aimed at capturing all perspectives and dimensions (Aboelnga et al. 2019; Garrick and Hahn 2021). Octavianti and Staddon (2021) identified at least 80 measurement tools developed by scholars and practitioners to inform decisions about the allocation of resources to improve water security, clustering the water security scales into resource-based and experiential. In light of the difficulty in the deployment of a broad water security definition and the fact that billions of people lack access to safe drinking water, the focus has shifted from water security to water insecurity (Garrick and Hahn 2021). Water insecurity is defined as insufficient access to clean water that is necessary for a healthy and productive life (Wutich 2019). A recently established scale by Young et al. (2019), the Household Water Insecurity Experiences (HWISE) Scale, is intended to provide high-resolution data to determine precisely who is water insecure, to what extent, and where and when it occurs and is promoted as the first instrument making possible a comparative analysis of household water insecurity (Young et al. 2019). HWISE focuses on perceptions of the reliability, acceptability, and sufficiency of water supplies for different consumption purposes using a 12-item questionnaire (Young et al. 2019). It is offered as a complement to JMP data and according to its proponents is capable of responding to some of the most common criticisms pertaining to JMP methods (Wutich et al. 2021). The scale data has been used to study the relationship between water insecurity and diarrhoea (Jepson et al. 2021), and interpersonal conflict (Pearson et al. 2021). However, some of the HWISE scale limitations are highlighted in a review by Slaymaker and Johnston (2020). These limitations include not including information on water quality, not distinguishing between households that lack any kind of service and those that use services insufficient to meet their needs, and not offering much insight into the underlying causes of household water insecurity or whether the barriers to utilising services are primarily physical ability, economic or social.

In addition to the above-mentioned issues of JMP data and the limitations of the HWISE scale, the approaches are dominated by cross-sectional surveys that take little account of temporal changes, are sometimes not reflective of grounded realities of water access, and presume the same meanings and understandings of (challenges in) water access across countries and settings (Nganyanyuka et al. 2014; Das et al. 2016; Stevenson 2019;

[2] Four most used definition of water security are presented in Table S5.1 of appendix.

Dongzagla et al. 2021; Dongzagla 2021; Aondoakaa and Jewitt 2022). For instance, ethnographic and mixed methods researchers have brought to attention the effect of seasonality on access to water in Nigeria (Aondoakaa and Jewitt 2022), disruptions caused by infrastructure failure in Ethiopia (Stevenson 2019), and inequalities in aid distribution aimed to improve household access to clean drinking water in Bolivia (Wutich 2006).

In settings where access to water is multi-layered and complex and when there is disagreement about the measurement and expressing of the landscape shaping access to water, exploratory qualitative methods such as these, which allow a context-sensitive and bottom-up perspective, may be superior to quantitative methods (Creswell and David 2018; Haenssgen 2019). These concerns are relevant to Kabul given that it has experienced consecutive droughts in the past several years besides the rapid urban expansion leading to increased demand for water. Access to clean drinking water is deteriorating due to climate impact, population growth, change in water consumption behaviours, and groundwater over-abstraction.

In this chapter, the results of cross-sectional qualitative research are presented that forms the first stage of a sequential (exploratory) mixed-method research design and lays the groundwork for subsequent survey research that builds on qualitative insights (Creswell and David 2018). The qualitative work aimed to enrich the understanding of water access challenges in this setting by taking an open-ended exploratory approach to reach two objectives. The first objective is to uncover the grounded realities such as the status quo and contributing factors challenging access to clean drinking water in Kabul, and the second objective is to enrich the methodological approaches to measuring access to water.

5.2 Methods

The principal method employed was semi-structured interviews. The data collection instrument was a semi-structured interview guide that included two main parts. Part 1 included open-ended questions on 1) Main water source, storage and knowledge of water quality, 2) Knowledge of health risks from poor water quality, and 3) Water treatment and knowledge of techniques in the household; Part 2 captured demographic and household characteristics of the participants (for the interview guide, see Supplementary Material 5.1). The main topics of the interview guide were informed by the existing literature on access to water and household water purification practices including Mubarak et al. (2016), Sigel (2009), UNICEF/WHO (2006), and Wutich (2006). The flexible and open-ended format of the semi-structured interview approach enabled to let local residents share their water experiences from their perspective, and highlight realities on their terms without the research team pre-imposing or favouring specific types of factors.

The study sites for this research included the districts of Doghabad and Bagrami in the Kabul metropolitan area (Figure 5.1). The sites have a combined total population of approximately 150 000 (i.e., 3.7% of Kabul metro, which had a total population of 4.1 million as of 2020). The two peri-urban sites are located in two different watersheds, one having more constraints than the other in freshwater availability due to the impact of droughts and low river recharge rates. For instance, the shallow groundwater depth in Doghabad is 25 – 30 metres below ground level (mbgl) while it is 3 – 7 mbgl in Bagrami.

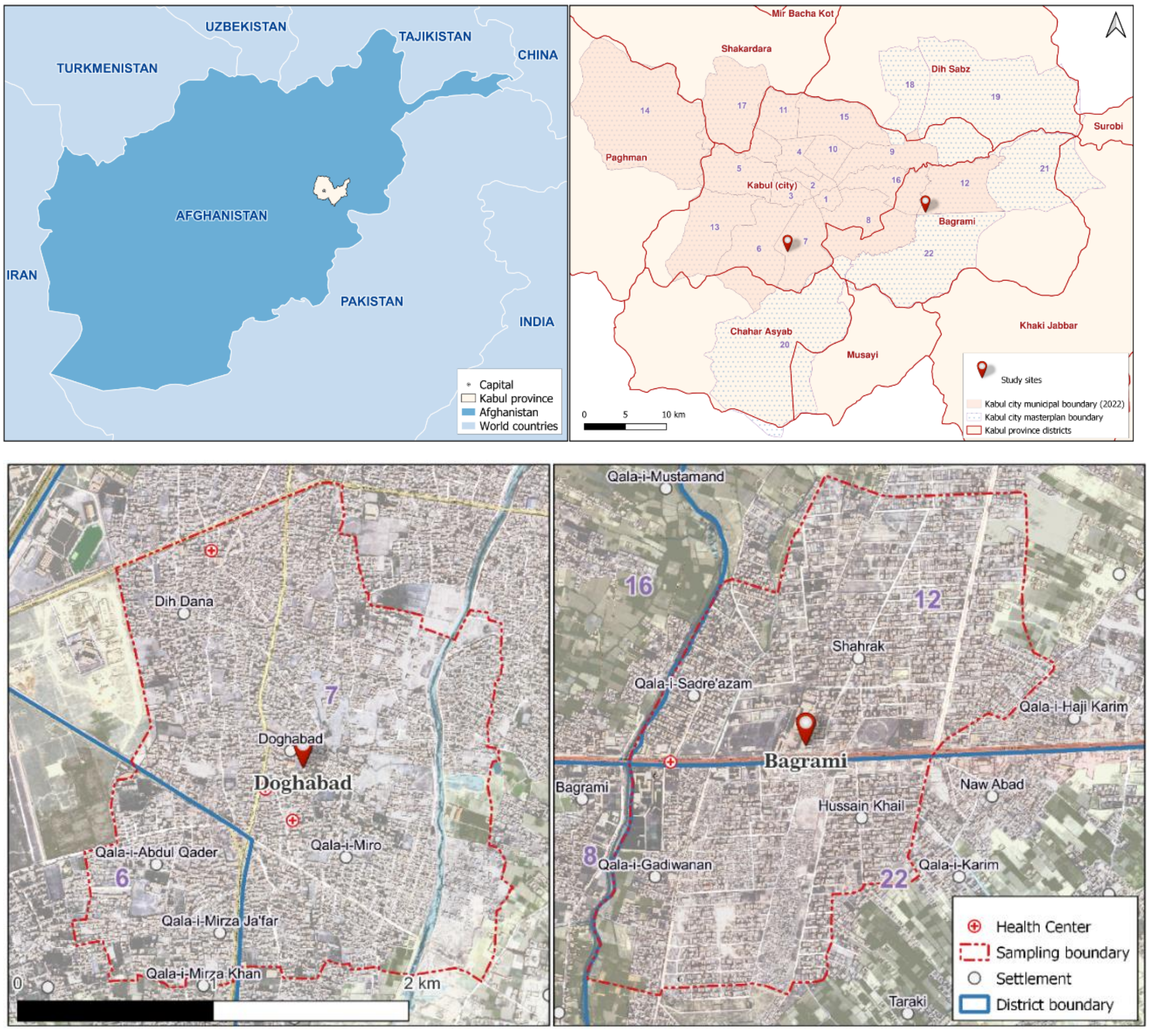


Figure 5.1 Study sites: Doghabad with Kabul River and Bagrami with Logar River.

The two sites represent a cross-section of greater Kabul in their ethnic diversity, the mixtures of socio-economic status included in them, and the relative turnover of residents (e.g., Bagrami including substantial numbers of displaced people). To explore the diversity of residents' living environments, participants were selected purposefully based on their residence location, age, gender, ethnicity, economic status, and variability in access to water resources. Concurrent analysis and local residents' guidance supported the sampling process, which continued until all selection criteria were successfully incorporated into this study. Following emerging practice in low- and middle-income country development research, further high-resolution satellite imagery[3] was employed to support the spatial distribution of the sampled households (Grais et al. 2007; Galway et al. 2012; Flynn et al. 2013; Escamilla et al. 2014; Haenssgen 2015; Cajka et al. 2018).

The resulting data consisted of 68 interviews of an average of 30 to 40 minutes each. Interviews were carried out either in Dari or Pashto, depending on the native language and/or the preference of the interviewee. Among the 68 participants who were recruited, 36 originated from Doghabad and 32 from the Bagrami study area. Refusals to the invitation to participate were limited and primarily due to feeling nervous or participants having concerns about audio-recording their responses (in 4 cases, persons with equivalent characteristics were recruited to substitute for candidates who refused). Male participants were mainly interviewed by myself, and female participants were interviewed by two female research assistants. All participants were provided with a Participant Information Sheet before obtaining a recorded verbal consent (see Supplementary Material 5.2), which was read out to the participants due to the low level of literacy in both study areas. Interviews were recorded using digital voice recorders.

The audio recordings of the interviews were transcribed verbatim and translated into English. Preliminary data analyses were done concurrently and during the transcription and translation, which informed the development of the theoretical framework as well as the sampling process. The formal qualitative analysis upon completion of the transcription involved thematic analysis in the original interview language so as to preserve the original context and maximise the informational content of the interviews for the analysis (Haenssgen 2019). The English translations were used to represent the main themes in the reporting of this research. The coding and thematic analysis were

[3] High-resolution satellite images (50cm) were provided by National Statistic and Information Authority (NSIA), Afghanistan from Planet, Skysat images - 2020

implemented using NVivo 12 (QSR International 2018). The thematic analysis in this study followed a systematic approach. Extensive engagement with the data enabled a comprehensive understanding, while coding of relevant segments facilitated the identification of initial themes. A thorough review and refinement ensured the coherence of the identified themes.

The interview guide, consent form (see Supplementary Material 5.3), and explanatory scripts were translated and back-translated in accordance with World Health Organization (WHO 2010) guidelines. The local division of the Kabul police, the district or village chief, the imam of the nearby mosque, and the Kabul Police headquarters were informed about the study (see Supplementary Material 5.4). The Department of Anthropology at Durham University approved the ethics application (Reference: ANTH-2020-11-28T00 10 33-lgww95).

5.3 Results

In the first section of the results, the constraints on access to clean drinking water in Kabul were discussed. In this process, especially the role of gender and the environment, which emerged as dominant themes, in shaping access to water will be explored. In the second section, the theme of interpersonal conflict and the temporal shocks that the community has been exposed to and experienced disruptions and lack of water access are presented. Finally, the community's resilience in navigating their response to shocks, including the spreading contamination of drinking water is explored.

5.3.1 Water access in peri-urban Kabul

Important qualitative themes in the interviews on water access in peri-urban Kabul were spatial disparities in access to clean drinking water and their implications for inequality in development aid allocation. Further, considered the participants’ reports of how gender and wealth shaped access to water.

5.3.1.1 Sources and experiences of accessing drinking water

Groundwater is the main source of drinking water for the majority of households in Kabul, and this also holds for the areas covered by this study. However, as noted above, a combination of climate-change-induced droughts and increased abstraction has led to a drawdown in the water table in parts of Kabul city, making groundwater increasingly difficult to obtain. The challenge of water quality is also pressing, forcing people to exert extra effort to access clean drinking water. In addition to wells and hand pumps, people in the study sites relied on bottled water, water trucks, and private networks. Table 5.1 illustrates the main sources of drinking water in the study sites, as reflected in qualitative interviews.

Table 5.1 Main drinking water sources for households located in two study areas in Kabul

Drinking water source	Doghabad	Bagrami
Privately owned sources in the household (well, hand pump)	✓	✓
Public water sources (well, hand pump)	✓	✓
Bottled water	✓	✓
Water trucks	×	✓
Private water supply network	✓	×

Source: Qualitative analysis

During the interviews, community members described daily challenges accessing clean drinking water where they had to transport water long distances, and traded off increased effort and expense against the risks of consuming contaminated water. For example, one household bought bottled water from the market, and at other times boiled it in hopes of preventing water-borne illness. The senior woman of the household would describe the process as follows:

> *One of my children is sick, his father is taking medicine even he brings bottles of Alkozia water from the market for himself. The other children use the water which we buy from suppliers in gallon containers, we pay 50 rupees. If it is not available for two or three days, then we boil the water and let it cool down before drinking. We don't have a purifier; we can't afford it; we are poor. The lack of jobs adds to many problems that we have.* (210616_017, Female, 53, Doghabad)

Another family brought water from the father's workplace, located in the centre of the city and far from the study area. As the man's 25-year-old daughter said, "*My father fills* *the gallon container of water at his workplace and brings it home. The water quality is good there* [at his workplace]*.*"[4]

These instances indicate the enormous disparities in the main sources of drinking water. More generally, it was also evident that there were serious inequalities in water pricing. Water trucks were more common in areas having serious water quality problems and were preferred by water vendors since the demand for safe drinking water was high in those areas. Table 5.2 indicates the comparative costs of one cubic meter of water from different suppliers in Kabul province, highlighting the considerable difference between the cost of clean drinking water supplied by water trucks and private water supply networks.

Table 5.2 Water price comparison in Kabul

Water source	**Price/m³ [AFN-USD†]**	**Total drinking water costs per household and month†† [AFN–USD] †††**
Government-supplied water (AUWSSC) - urban	25 ($0.31)	22 ($0.28)
Private supply network – peri-urban	30 ($0.38)	27 ($0.34)
Water trucks (20 AFN for 20 Litres)	1000 ($12.50)	900 ($11.25)
Bottled water (50 AFN for 19 Litres)	2631 ($32.88)	2368 ($29.59)

Source: Qualitative research fieldwork.
Notes: All sources in m³ for comparison, but note that dispensed amounts vary widely across sources and households. The average monthly household income in Kabul is between 100 – 150 USD.
† *1 USD = 80 AFN (as of August 2021)*
†† *Assuming one person consumes 3 litres of drinking water in a day and a household size of 10 people.*
††† *The price is only for drinking water consumption per month.*

The large price differences across the available sources of drinking water raise questions about why people should opt for the more expensive sources. This appears to be due first to issues of water quality and quantity, and second to issues of convenience, opportunity and trust. Bottled water was purchased mostly by affluent members of the community.

[4] 210621_001_R1, Female, 25, Bagrami

Water trucking was common in areas where there was no functioning water supply network and where the groundwater was not suitable for drinking purposes. Thus, in some areas (except for households that were filtering water) relying on water trucks was the only remaining option. Lastly, the establishment of private water supply companies was limited to certain areas and not growing steadily.

With respect to the access to the various water sources, one theme emerging from the interviews was that relations of trust between vendors and local users played a considerable role in the purchase of trucking water. As a 19-year-old female described, they trusted the water vendors and were not questioning or researching about water quality provided to them: *"I think they bring it from the company, they purify the water and sell it."*[5]. Others might ask about water quality, but took the vendor's explanation at face value. Vendors also encouraged custom (and consolidated relationships of trust) by providing customers with water 2-3 consecutive times if the household was not able to afford it at the time of buying water. The inability of many households to afford bottled water (the most expensive category) was also a factor disposing them to use trucking water (Figure 5.2).

Figure 5.2 The means of water trucking in the Bagrami area: child washing the gallon container before filling it (left); a locally assembled vehicle used for water trucking (right).

Privately owned groundwater sources at households (wells and handpumps) are neither registered nor monitored by the government and are free of charge. Households subscribed to private water supply companies because they perceived the water quality to be better, it required less effort and was secure to get water inside the household compared

[5] 210621_002_R1, Female, 19, Student, Bagrami

to the public wells. However, private companies' water supply was erratic, as the experience of one informant illustrated. As their household could not get water in the whole morning despite being subscribed to the private water network, their household had to *"leave the things that are not washed until the water is running in the pipes. It happened sometimes that the water will be running in the afternoon."*[6] The household would accordingly adapt their daily domestic work schedule to the availability of water. Similarly, a 36-year-old homemaker explained the privately supplied water at the point of use had low pressure which required the household extra time for collecting water and was also often turbid:

> *When filling the gallon containers today, it took a long time to fill them. It took an hour or two. It's slow and the water is turbid. The speed of water in our house depends on how much water they release. It has sand in it. During this week, the water was turbid for 2-3 days and when I leave the* water [for some time] *then the sand will set down in all the buckets.* (210616_005, Female, 36, Homemaker, Doghabad)

Furthermore, the problem of low pressure in the water pipes made the households put extra effort into collecting water; as a female informant said that they "*collect water during the day in the storage here* [The household had two water storages, one laid in the house and one on the roof.]"[7] because "*It* [the water in the pipes] *doesn't reach the water storage on the roof. It doesn't have enough pressure".* A 26-year-old female informant from Doghabad added that they had to "*use buckets and gallon containers*[8] *as well as the tap itself* [She is referring to the tap placed inside the house perimeter, it is common practice in Kabul that the tap is placed in the yard at a short distance from the connection to the main supply pipe]*"*. Such experiences with the malfunction of infrastructure appeared to be common and is part of the reality of daily challenges in access to water.

In areas that did not have access to water supply networks and were affected by droughts, international NGOs have made efforts to increase people's access to clean drinking water by drilling deep wells. Experiences such as those mentioned by a 30-year-old female

[6] 210616_011, Female, 21, Doghabad

[7] 210617_004_R2, Female, 26, Doghabad

[8] In this study, I used the term "gallon containers" for describing the plastic containers commonly used in Afghanistan for storing and fetching water and is mainly referred as "بشکه" or "گالن". Some other studies have used the term "jerry can" which is primally made of steel and used to carry fuel.

informant, from Doghabad, included that the number of wells was insufficient and people would consequently wait long for their turn:

"*This water is very good; it didn't happen yet* [water quality deterioration was not observed]. *The only issue is that we hardly get water; we have the well and can use the pump, and the water is clean. The problem is that in the whole region there is only one well."*[9]

While in Doghabad the residents needed more handpumps, my observations in the Bagrami area identified a handpump (Figure 5.3) that was built by NGOs but the public was not using it due to the high water salinity in the surrounding area. Disparities in access to clean drinking water sources point to inequalities in allocation and naïve prioritisation of the development efforts toward providing and increasing access to clean drinking water.

Figure 5.3 A handpump in the Bagrami area, built by NGOs, was not used due to the high salinity of the water.

In summary, the qualitative analysis results revealed disparities in primary drinking water sources in peri-urban Kabul, substantial differences and inequalities in water prices, daily

[9] 210616_014, Female, 30, Doghabad

challenges due to malfunction of water supply infrastructure, and naïve prioritization and inequalities in development efforts aimed at increasing access to clean drinking water.

5.3.1.2 Gender

Related to water access, through the qualitative analysis, gender appeared an important factor to affect access to drinking water. For instance, it appeared that during the peak hours (noon and evening), adult men and male children would fetch[10] water from public water sources including handpumps and water wells (210619_015_R1, Female, 21, Student, Bagrami). In the households that did not have male children and in which the adult male was working, the young girls or the women of the household were fetching water from public water sources or neighbouring households during the day, especially out of peak hours when men were at work. This pattern was described by a participant as follows:

Q: You use it [the advanced water filter] *when there is electricity. What do you do if there is no electricity?*
R: If there is no electricity and we run out of water, we will bring water from the hand pump or somewhere else.
Q: Where is the hand pump that you fetch water from?
R: It's not far.
Q: How many minutes away from your home?
R: It is 10 or 5 minutes away from our house.
Q: Who brings water from the hand pump?
R: My daughters bring water. Just now, we didn't have water for ablution – they went and filled the gallon container. We didn't have water.
(210617_012_R2, Female, 30, Homemaker, Doghabad)

At the times when girls and women were fetching water from public sources, particularly the peak hours (when most men were collecting water), priority in the queue would be given to women. When not fetching water from public sources, women or girls may "*get from the neighbours' houses,*" as a 28-year-old mother from Bagrami said, noting it is only her "*two daughters* [who] *bring water*"[11]. Women and girls would navigate and negotiate fetching water from their neighbours' houses and having a conversation with the women who live there while getting water from the well or handpumps. Women's

[10] Plastic gallon containers are used to fetch water and are carried either by hand or wheelbarrow.

[11] 210619_006_R1, Female, 38, Bagrami

role in access to water is crucial due to the gendered division of labour that primarily assigns them the responsibility of managing water at the household level, including collecting and fetching. In short, women dominated water fetching activities whereas men would argue that they only do it *"sometimes I do it when I'm at home."*[12]

Reports in Kabul published through media and NGOs indicate that the children of households who were relying on getting water from sources outside their house, specifically girls, regularly miss school mainly for this reason (Nazar and Recknagel 2011).However, while they acknowledged the involvement of children in water collection, research participants from the two study areas in Kabul did not report any incident of children missing school due to fetching water. However, in several cases, households explained that due to economic problems, children have dropped school (girls went to school but boys worked, or in some cases, only boys of the household went to school).

These qualitative results brought to attention that in peri-urban Kabul, gender plays an important role in navigating the water landscape and negotiating access to water.

5.3.1.3 Home-ownership

A major theme that emerged regarding inequalities in water access was that house owners had an advantage over tenants. At the time of research (as of August 2021), there were no regulations or by-laws that might encourage landlords to provide tenants with a water supply or electricity. In the majority of cases, houses are rented with zero commitments from the landlord on providing access to water by any means (piped water, or digging wells). In some cases, "rented" houses did not have a water source (e.g., "*R: We have no water here at all. Q: You don't have water in this house? R: No. Q: What do you use? R: We use water from the outside.*"[13]). As reported by a 30-year-old woman who was living in a rented house:

Q: Why didn't you subscribe for piped water?
R: It depends on the landlord. We rented this house for 5000 [Afghanis] *per month. In the beginning, the water pump was also not working and he* [landlord] *was providing water from his house but later he* [landlord] *repaired the water pump. It doesn't provide us with enough water. Once we fill five gallon containers then the well dries up. It will have water if there is rain and snow; if there isn't then the well dries up quickly.*
(210617_012_R2, Female, 30, Homemaker, Doghabad)

[12] 210520_004, Male, 63, Doghabad

[13] 210619_015_R1, Female, 21, Student, Bagrami

Tenants often therefore either fetch water from neighbours, from public sources, or if they could afford it, they might buy water (bottled water or water trucks). Additionally, the tenancy status appeared to have an adverse impact on the household's tendency of spending money to improve the situation with access to clean drinking water. A family who owned their home would for example spend money to improve the situation by digging the well deeper if necessary (*"There was an old well in this house. When we bought the house, the well got dry and we dug it but it got dry again. Only one year it didn't have water and then we started to dig more again"*[14]). In contrast, those renting property, and who lack security of tenure, were reluctant to spend money on the household to improve access to water – as highlighted by one participant: "*It's not our own house. If it was our own house then we might do something. We escaped from the wars and this place is temporary. The house owner is in Turkey"*[15].

These qualitative findings highlighted that in peri-urban Kabul, household ownership status was determining both the access to water and the tendency on spending money to improve access to water.

5.3.2 Dynamics and stressors of access to water

In this section, the dynamics and stressors of access to clean drinking water are presented, including the impact of droughts, interpersonal conflict, groundwater contamination, and electricity disruption.

5.3.2.1 Droughts

People in Kabul used groundwater for domestic use in most cases but the effect of droughts is also contributing to the challenge of access to drinking water, especially in Doghabad. In interviews in Doghabad, community members more often referred to "dry wells" "droughts," and "dry years" than did those in Bagrami. They highlighted troubles accessing water during those years when their households were supposed to rely on other sources, like fetching water from neighbours, fetching water from public wells and handpumps and fetching water from other areas. One middle-aged mother described how

[14] 210617_006_R2, Female, 54, Doghabad

[15] 210621_009_R1, Female, 33, Homemaker, Bagrami

her children were fetching water from other places when the well "*dried, it was dry last year*". She added that *"grandchildren and children"* fetched *"water from the other place in gallon containers."*[16]

The challenges with access to water are increasing year on year as water users experience more incidents of dry water sources (wells and handpumps) in their households and abandon them. A tailor whose household abandoned the water well (22 meters deep) four years ago and since then they relied on a private water supplier – highlighted in this context that they would use the well if it has water which is indicating on how the existing realities are shaping challenges of access to clean drinking water.

Q: How long have you not used the well?
R: It has been almost four years.
Q: Since the water supply system has been established?
R: [Yes] *since the water supply system is established, the wells also dried up.*
Q: Is there any time that you use the water from the well?
R: [Yes] *in case there is water in the well. In the past, we used it for watering the flowers, and grass and washing clothes but there isn't much water available like in the past. Four or five years ago when water was available in the well, we used it every morning but it's not available now.*
(210517_001, Male, 40, Tailor, Doghabad)

A similar experience was highlighted by a 48-year woman from the area who said, "*the well has dried up"*[17]. She added that they "*have dug a well but there is no water. We have subscribed to the water supply network. The privately-owned network supplies water to all houses, we get water from them."*[18]. For other households in the area, the challenges of groundwater access for drinking purposes were more dynamic. One family[19] initially relied on their non-kin neighbour for groundwater for domestic use, and later turned to a relative before eventually digging a well inside their own house.. When the well later dried up, they started to fetch the water back from neighbours until a private company was established for providing drinking water.

Besides the efforts established by individual households to improve access to water, the desire for collective action is very strongly present in the communities where the

[16] 210616_017, Female, 53, Doghabad

[17] 210617_007_R2, Female, 48, Doghabad

[18] Ibid.

[19] 210616_005, Female, 36, Homemaker, Doghabad

community members collect money to fund efforts that lead to public benefit (*e.g.*, constructing a water well or hand pump). At the same time, due to the limited water sources in the area, the community elders had concluded that the water from the public handpumps should only be used for daily necessary consumption. As highlighted by a 30-year-old female informant who relied on public water pump as the main drinking water source, the community members used to water flowers and vegetables from these sources before the rule was established:

> *Q: Did it happen that at some time of the year the water in the hand pump decreases?*
> *R: It happens. Sometimes, the water gets almost dry. They collect money from this area and dig it more. Last year, the water got dry. And, my children went upside* [streets located upper side of the place of interview] *to fetch water. This year, by the grace of God, there is water, but they do not allow us to water a tree or do anything else. They just say to use it for solving our drinking needs.*
> (210616_014, Female, 30, Doghabad)

Together the qualitative analysis results presented in this section provide important insight into the dynamics of access to water due to the impact of droughts. More importantly, the qualitative analysis revealed a strong desire among the community members to fund public water sources (wells and handpumps). Additionally, the interviews revealed collective actions such as local decisions to safeguard access to drinking water for all households by prohibiting the use of public source water for watering trees.

5.3.2.2 Conflict and violence

Limited access to safe drinking water inside the household obliges people to search for water from other sources. One of the most remarkable results to emerge from the qualitative data was that interpersonal violence takes place among people, mainly children, who usually rely on fetching water from a public source. In circumstances such as droughts, people in the area were collectively adjusting their behaviour to the existing situation (establishing limitations over water use) while electricity disruption happens suddenly. Electricity disruption, specifically when accompanied by droughts, was exacerbating the situation which was more pronounced in Doghabad and was leading community members to rush for public water sources. When the electricity supply is lost, the situation gets worse as all users *who relied on other sources before the electricity disruption* rush to fetch water from public sources. Due to the high demand for domestic water use, the many water users relying on a single source was leading to crowds and potentially leading to more events of interpersonal violence, compared to drought-only situations, among individuals rushing to get water. The nature of interpersonal violence could include physical violence, psychological violence or verbal abuse – forms of violence that are mostly not reported or "told" to the parents by the children (As one parent put it, "*it might have happened but my children didn't tell us.*"[20]) but which direct observation suggests are commonplace. One of the main reasons that children do not report such incidents to their parents is the fear of escalating the conflict. It is important to note that sometimes the incidents of interpersonal conflicts among children could spark larger conflicts among households, and shall shape long-term conflicts (especially in rural communities).

Figure 5.4 Water collection at a handpump in Kabul (left), Children fetching water from a public tap (right). Conflicts over water access occasionally occur in these contexts.

The involvement of children in such conflicts stems partly from the common practice of sending children to fetch water (as noted above) and partly from the involvement of some children in selling water. Children from lower-income households sometimes take the opportunity to fetch water from the public handpumps and sell it to shops and community members to generate some income (Figure 5.4). These public handpumps are usually crowded and are monitored by a community member. On one occasion during fieldwork,

[20] 210617_015_R2, Female, 30, Homemaker, Doghabad

I was observing a handpump in an area where people were queuing to fetch water including the children who sold the water to the shops. The man who was responsible for the handpump was looking at the crowd of people fetching water from the handpump and carefully monitoring the frequency with which they were fetching water. As soon as he realized that it was the second or third time that the same group of children was fetching water for selling it to shops, he prohibited them from taking any more water from the hand pump. When one of the children did not comply with his order (to stop fetching water) it led to violence: starting with words, and escalating to slapping and punching until other people intervened to settle the conflict[21]. Such incidents are more likely to take place during the peak hours, at noon or dinnertime – the time most households fetch drinking water. The consequences of such violence are that it creates a setting that provokes trauma and that would have further implications for people on how they would treat water through cognitive processes.

5.3.2.3 Contamination

Concerns were expressed about water quality and research informants highlighted the communities' resilience in the utilization of groundwater and surface water for drinking purposes. The story of a 45-year-old woman in Bagrami[22] illustrated what such "resilience" concretely meant in the local context: their household relied on groundwater using a handpump. The shallow groundwater, however, was contaminated due to anthropogenic and geogenic activities, and the groundwater contamination extended to a larger area as the time passed "*two years*". To avoid the health risks of the water source, people in the area began to transport water from the Ghazi Dam, located 20 kilometres from Bagrami. Private companies emulated this behaviour and shortly thereafter started to transport water from the dam to sell to community members (using water trucks). Not all private companies took the same course, however, and others started importing high-tech water filters. Some families thus temporarily shifted to the logistically more challenging dam water before reverting to the contaminated groundwater which they could purify after purchasing a water filter.

[21] The mechanism of resolving agriculture water allocation disputes at the local level is illustrated by (Lee 2007) and is similarly applied to solve other disputes i.e., access to clean drinking water.

[22] 210619_007_R1, Female, 45, Homemaker, Bagrami

The results suggest that dynamics of access to water are not only limited to the impact of droughts but also indicate that is an interacting multi-layer complex system. For instance, stressors of access to water such as contamination have the potential to be addressed (e.g., using high-tech water filters) but only for affluent members of the community. On the other hand, the use of the filters is aggravating the impacts of droughts (and limits access to water for some members, the water has the potential to be used for other purposes) since the high-tech filters reject a sizeable amount of water in order to provide purified water. In the meantime, climate change impacts might reduce the levels of water in reservoirs, leading to higher prices of trucking water, and further limiting access to water for low-income households.

5.3.2.4 Electricity disruption

A number of issues are noteworthy that relate to the particular historical moment during which this study was carried out. As noted below, access to water and electricity are closely connected in Kabul. Besides the usual electricity disruption due to higher demand in summer; during the fieldwork, there was also disruption due to an increase in conflict around the country. Pylons were bombed (Omid 2021), cutting off electricity for millions living in Kabul and the provinces around. Such electricity supply disruption happened frequently during the fieldwork (May – July 2021) and very much impacted the situation of accessing clean drinking water in Kabul. Electricity cut-off impacted the water supply in at least two ways – because it was used to pump water from deep wells, and because it was used to power purifiers. During blackouts, some people in Kabul were able to use alternative drinking water resources such as bottled water. Others fell back on alternative energy sources such as solar energy or using power generators to fetch water from the wells, as experienced by a family represented by a 23-year-old female in the Bagrami area "*Those days for drinking. We will also fill the water tanker using the generator"*[23].

Furthermore, in some cases, the energy disruption also impacted the water supplied by water trucks that rely on electricity for water purification. As a 25-year-old female informant noted, they were boiling the well water for consumption since they were not able to buy water at the time that electricity is disrupted:

[23] 210621_007_R2, Female, 23, Bagrami

It is a long time [since started to boil water at home]*, at the times that we don't have electricity and had consumed all the mineral water at home* [trucking water]. *The companies have the machine to filter water and at the time that there isn't electricity they won't sell water on the street thus we boil water.* (210621_001_R1, Female, 25, Bagrami)

In short, the electricity disruption in Kabul added to daily challenges in accessing clean drinking water. Households were thus occasionally prevented from accessing clean drinking water by making it impossible to operate electric water pumps and water purifiers. The community members who relied on water filters and electric water pumps were supposed to boil water or rely on fetching water from a single source such as public taps, hand pumps and wells (available in some areas for common uses mainly located either in the mosque or on the street). These disruptions extend beyond the household since the water trucking and bottled water companies (whose services many households rely on) also relied on the electricity grid for water treatment prior to distribution.

5.4 Discussion

The qualitative analysis of water access in peri-urban Kabul highlights persistent inequalities and often-overlooked dimensions of water reality that call for an integrated approach to measuring access to water.

5.4.1 Inequalities in water access

Observations and qualitative analysis in this study revealed important dimensions and inequalities of access to water in peri-urban Kabul. Two study sites covered under this study were located in two different sub-basins with distinct water quality and groundwater levels. The geographical factors shaped the availability of different drinking water sources, for instance, water trucking was common in areas where water quality was not suitable for drinking. In another study area, besides microbially contaminated water, people relied in contrast only on groundwater sources (except for a portion of the population who had access to a recently established private water supply network).

Another important factor that was repeatedly appearing was the economic status of the households. A disparity in water prices was evident, and perversely people who had lower income were obliged to pay more for water (trucking water) compared to urban or private water supply networks – similar patterns were noted in other geographies (e.g., observation by Wutich (2006) in Bolivia). Related to economic status was household ownership: community members who owned their house had a greater tendency to spend money and increase their access to clean drinking water. Only higher-income families were able to afford bottled water. Water trucking was also prevalent, but many households could not afford it and instead consumed contaminated groundwater.

Gender stood out as another important socio-economic factor in the water access landscape. The analysis highlighted the division of labour within households and it appeared that responsibility for securing access to water during a normal working day rests mostly on women and girls of the household, also observed in other geographies (O'Reilly 2006; Freeman et al. 2012).

In a post-conflict and developing environment such as the two peri-urban areas covered under this study where (almost) all the projects dedicated to improving access to clean drinking water are funded by external donors, it is unsurprising that factors such as security, political environment and power relations shape development aid prioritization and inequality in allocation. The decision-making process and discussion of the broad landscape of aid development are beyond the scope of this chapter, but the few examples presented in this study are bringing to attention the naïve prioritization of development aid aimed at improving access to clean drinking water in Kabul. Frances (2012) delivered a detailed discussion on the factors influencing development resource allocation in different geographies including incompetence, conflict, corruption and the political nature of policy choices.

5.4.2 Measuring access to water

As presented throughout this study covering two peri-urban sites located in Kabul, disparities in the main source of drinking water among the population mainly dependent on groundwater include the privately owned wells in the households, public sources (wells, and handpumps), private water supply companies (water trucks from dam or purifying companies and bottled water suppliers), and private water supply networks. Access to drinking water was spatially diverse besides the fact that each of these sources had distinct characteristics (e.g., contamination levels), and it frequently happened that the water supplied by private companies was turbid. In Doghabad, a number of people had access to a private water supply network while experiencing frequent water cut-offs. Water trucking was also common in Kabul but many families could not afford it and were consuming contaminated groundwater. Given the links between electricity supply and water access, electricity disruption has increased water stress, sometimes leading to violence, especially during drought events. The findings also illustrated that in peri-urban parts of Kabul, the droughts impacted access to water and the community members took collective decisions and were resilient in experiencing the dynamics of access to clean drinking water. Such disparities and dynamics in access to water are not evident in JMP data, at least in Kabul, nor would the HWISE scale be capable of highlighting it due to its quantitative nature and a tendency to use cross-sectional designs.

Octavianti and Staddon (2021) clustered the water security scales as “resource-based” or “experience-based” with the former tending to resemble the sorts of discrete modelling exercises that overlook social, cultural, and other sorts of variability; such a classification, in fact, draws a line between the engineering and natural sciences, and social sciences. The boundary of analysis for the majority of the resource-based models are based on either basin or sub-basin drainage areas which are naturally delineated areas of land where precipitation collects and drains off into a common outlet. However, the boundary of analysis for the experience-based models are political boundaries.

The two study areas in this research are located in Kabul city but are part of two different drainage sub-basin areas. As described in section 5.3.2, the freshwater availability, the contamination level of water and the impact of drought, besides the dynamics, are different in each study area. It was evident that the dynamic impact of droughts which directly affect access to clean drinking water were more pronounced in Doghabad while the population residing in Bagrami did not observe changes in water level; nonetheless, the water in Bagrami is not suitable for drinking purposes (Hamidi et al. 2023).

The resource-based models are capable of demonstrating such dynamics very well, specifically in sub-basin drainage areas relying on the concepts of hydrology while social science research on water access that employs quantitative methodologies might neglect to investigate such changes in access to water over time, at least if they rely on cross-sectional designs. Additionally, the “resource-based” scales capabilities include investigating the impact of droughts, floods, and the spatial distribution of water networks

– not only based on the past but the present, and have the potential to project future scenarios.

The complex interplay of geographical, natural, and social factors even within the same metropolitan area underlines the importance of an integrated approach. Although extensive research has been carried out on measuring water security/insecurity, no single study exists, to my knowledge, focusing on an approach/model that integrates the “resource-based” and “experience-based” scales for spatially assessing water security/insecurity. Hoping this chapter sparks efforts in developing tools which will potentially be useful and easily translatable/understandable for a wide range of stakeholders including development organizations, NGOs and governments by providing a high-resolution analysis of water security/insecurity – specifically the access to clean drinking water.

5.5 Conclusions

Limited access to water constitutes a daily challenge in the everyday affairs of millions in low-and-middle-income countries. Grounded in 68 semi-structured interviews, this qualitative study explored the factors limiting access to clean drinking water in two-peri urban areas in Kabul. Geographically variable water source availability highlighted challenges such as dysfunctional water supply networks, inequalities in water prices, uneven development, and aid prioritization. Furthermore, gender and home ownership were documented, playing an important role in shaping the environment of access to water. Stressors and dynamic access to water in peri-urban Kabul are presented, with droughts, contamination, and electricity disruption limiting access to water from time to time. Besides, the role of interpersonal conflict in creating traumatic experiences accessing water was explored. In recognition of these multisectoral as well as dynamic drivers of water access, this study suggested an integrated approach for measuring access to water that can help prioritise interventions and make development aid allocation more effective.

Supplementary material

Supplementary material 5.1 The interview guide used for delivering semi-structure interviews:

Interview guide

Part 1

1.1: Water source, storage and knowledge of water quality

1. Tell me about the main source of drinking water in your household.
    a. Do you need to wait/walk for accessing drinking water? (*If possible, accompany the interviewee to the source, and record the source type, and the time it takes.)*
    b. Who fetches water for your household? (Is it always the same person? Does more than one person do this?)
    c. How often do they fetch water?
    d. Does everyone in the household use the same sources? (Is it the same source for children under five?)
2. How do you store drinking water in the household? Can you show me…?
    a. Types of containers?
    b. How long do you keep water in the container?
    c. Does the container need to be cleaned, or is it OK to leave it?
3. What is the situation of drinking water quality in your household? Is it good or bad, in your opinion?
    a. Does the quality vary over time, e.g. is it better at some times of year than others?
    b. What do people from the government or NGOs say about the water quality in this area?
4. How would you know if water was good or bad?
    a. Can you tell by the look of the water?
    b. By its smell?
    c. By its taste?
    d. Some other way?
    e. What do you do if you find the water quality is bad?

1.2: Knowledge of health risks from poor water quality

1. How does it affect people, if they drink bad quality water?
    a. Is it the same for adults and children?

   b. Can you remember a time that someone got ill due to water quality? What happened?

2. What kinds of illnesses arise from bad water?
   a. Can you name some of them?

1.3: Water treatment and knowledge of techniques at household

3. This leaflet talks about some ways of filtering water. Are you familiar with any of the techniques described here (*referring to leaflet*)?
   a. Which techniques are you familiar with?
4. Do you use any of these techniques of filtering? (If they say no, go to question 9)
   a. When did you start?
   b. Who is responsible for the filter (filling and clean up)?
   c. Do you buy them from a shop/market? (Or, supplied by NGO or Gov.)
   d. How much does it cost?
   e. Do you find it easy?
   f. How long does it take?
   g. Do you filter water for all household members or only for children?
   h. Where/who did you hear about filters from?
5. If you don't use a filter for drinking water, why is that?
   a. Do you know where they are available?
   b. Who did you hear of them from?
   c. Do you know how much they cost?
   d. Do they require a lot of work to use?
   e. How long it will take to filter water?
   f. Do you trust imported drinking water filters in the market?
6. Do you use clay made pot for storing water?
   a. If not, why?
   b. Would you use a cheap filter (*clay filter leaflet*) in case knowing it will perform well?
   c. Would you prefer a filter made of clay, made in AFG vs. other filters imported?

Part 2

2.1 Household general information

"Now, I would like to ask some general questions about you and the household."

1. How long have you lived in this house?
2. How old are you?

3. How many people live in this household?
    a. Total?
    b. Adults, 18 and older?
    c. Children (between 5 and 17)?
    d. Children below 5?
4. Are you the head of the household? If no: What is your role in this household?
    a. Yes
    b. No, I am …
5. What is the highest education level of the head of the household? (What is the highest year of schooling that he/she completed?)

Supplementary material 5.2 Participant's information sheet:

Participant Information Sheet

Purpose of the study
Water is important for health and development. The purpose of this study is to assess people's perceptions of water quality.

Why have I been chosen?
As part of this study, we are inviting people from different neighbourhoods in Kabul. Your house is located in one of the places we are interest to understand people's perception of water quality in the city of Kabul.

Do I have to take part?
Taking part is entirely voluntary. If you do not wish to take part, or wish to withdraw from the study at any point, there will be no penalty or loss, now or in the future.

What will happen if I take part?
If you choose to participate in this study, we will have a conversation with you regarding the water quality and water filtering. If you permit, our conversation will be audio-recorded.

What are the possible benefits of taking part?
You will contribute to a better understanding of how the population in Kabul perceives water quality.

Will my taking part in this study be kept confidential?
Yes. The anonymised Participation Form Code will only be used in the case that you request your data be removed; in which case your form code will be used to remove your data. However, the researchers will not ask you for your name or any other information which could be used to identify your responses. Any information you provide will be kept in a fully anonymised format.

What will happen to the results of this research project?
Results will be used for a student dissertation project. Results will be presented in terms of groups of individuals. *Individual data of specific people taking part in the study will not be presented.* All collected data will remain anonymous, so there is no means of identifying the individuals who took part. Results will be presented at international conferences and published in scientific outlets. Data will remain anonymous.

Who is organising and funding the research?
The research is organised, funded by Durham University and coordinated by Kabul University, Engineering Faculty.

Ethical review of the study
This project has received ethical approval from the Department of Anthropology Ethics Committee.

Contact for further information
Please contact for further information:
Mohammad Daud Hamidi; **0781 77 90 90**, PhD researcher, Durham University.
Dr. Abdul Qayeum Karim; **0700 591 991**, Head of Civil Engineering Department, Faculty of Engineering at Kabul University.

Can I withdraw from the study later?
Yes. If you wish to withdraw from the study, you can send SMS or call to Mohammad Daud Hamidi (**0781 77 90 90)**. Or, Dr. Abdul Qayeum Karim (**0700591991**).
Please make sure to take note of your form code, as this will be required if you wish to withdraw your data at a later date.

Supplementary material 5.3 Consent form

Consent Form

Form Code: …………….

Date: ………………

Consent of participation in the study on **understanding people's perceptions of water quality**. Please tick each statement to indicate your agreement. If you need any further information or clarification, please ask the interviewer:

- I confirm that I have understood the Participant Information Sheet and agree to take part in this survey ☐
- I have had the opportunity to ask questions and had them answered ☐
- I understand that my participation is voluntary and that I am free to withdraw at any time without giving a reason ☐

Filled by surveyor:

Participant's verbal consent to taking the survey is recorded? ☐

Supplementary material 5.4 Letter from Kabul Police headquarters

وزارت امور داخله جمهوری اسلامی افغانستان
دافغانستان داسلامی جمهوریت دکورنیو چارووزارت
Ministry of interior of Islamic Republic of Afghanistan
معینیت ارشد امور امنیتی
قوماندانی امنیه ولایت کابل
معاونیت امور امنیتی
مدیریت دفتر

درجه استعجالیت: عادی ☐ عاجل ☐ — درجه محرمیت: محرم ☐ اشد محرم ☐

نمبر مکتوب: ۱۵۵۰
تاریخ: ۱۶/ ۲ /1400
نمبر سجلات:
موضوع: درمورد همکاری باتیم سروی .

به آمریت محترم حوزه(۷)امنیتی پولیس!

مکتوب نمبر(1400) 1400/2/13 پوهنحی انجنیری پوهنتون کابل موسسه تحقیق وخدمات توامیت انجنیری واصل وذیلامینگارد.

موسسه تحقیق و خدمات توامیت انجنیری پوهنحی انجنیری پوهنتون کابل در نظر دارد تا یک تیم سروی را غرض جمع آوری معلومات در مورد آبهای آشامیدنی و کیفیت آن تحت نظر محترم داکتر محمد داوود حمیدی محقق این برنامه برای مدت 20 روز به ساحات بگرامی و دوغ آباد که مربوط حوزه های محترم دوازدهم و هفتم شهر کابل میشود ارسال نماید.

از اینرو، امید است به سلسله همکاری های قبلی خویش این بار نیز در رابطه اجرای سروی به حوزه های متذکره اطلاع داده ممنون سازید.

که در حشوه آن جناب قوماندان صاحب امنیه ولایت کابل چنین هدایت فرموده .

معاونیت محترم امور امنیتی !

1400/2/15

در زمینه اجراات قانونی صورت گیرد .

مراتب تحریری واصله فوق نقلا بشما نگاشته شد.بادرنظرداشت محتوای آن طبق هدایت مقام محترم بسهم خویش اجراات قانونی بدارید.

بااحترام

سموئوال محمد نبی"بیان"

معاون امورامنیتی ق امنیه کابل

کاپی به حوزات(7-12)امنیتی پولیس !

Unofficial translation

Ministry of Interior of the Islamic Republic of Afghanistan

"in Dari, Pashto and English"

Deputy Minister for Security Affairs
Kabul Province Police Headquarters
Deputy for Security Affairs
Administrative office

No: 1550

Date: 16/2/1400

Topic: Cooperation with the survey team

To the director of (7th) police district!

Letter No. (1400) dated (1400/2/13) from the Faculty of Engineering of Kabul University, Engineering Partnership Research and Services Organization is received and indicates below:

Engineering Partnership Research and Services Organization at Engineering Faculty of Kabul University is planning to dispatch a team of surveyors to collect information about drinking water and its quality under the supervision of Mohammad Daud Hamidi, the researcher of this program, for 20 days in Bagrami and Doghabad areas, which are related to 12th and 7th constituencies of Kabul city.

Therefore, based on your previous collaborations, we hope and will be grateful that you inform the police districts regarding the delivery of this survey.

On the sidelines, Kabul police chief gave such guidance:

Deputy of Kabul police chief for Security Affairs

15/2/1400

Take legal steps for enforcement in regard to the request.

The above-mentioned written instructions were forwarded to you. Considering its content and according to the guidance of the esteemed officials, take legal steps for enforcement in your share.

Best Regards,

General Mohammad Nabi "Bayan"

Deputy of Kabul police chief for Security Affairs

Copy to police districts (12th -7th).

Chapter 6

Mohammad Daud Hamidi, Edward (Jed) Stevenson, Marco J. Haenssgen, H. Chris Greenwell

Mohammad Daud Hamidi was responsible for conceptualization, data collection, data analysis, methodology, writing original draft, review and editing. EJS (my co-supervisor) and MJH contributed through discussions on setting up methodology and analysis, review and editing. HCG contributed through supervision (my primary supervisor), resources, review and editing. As the main author, I would like to thank EJS, MJH, and HCG for their helpful discussions and priceless suggestions.

6 Water-Sharing Practices in Kabul, Afghanistan: A Qualitative Study

6.1 Introduction

Social capital can be vital in alleviating urban poverty, according to the World Bank and other development organizations (Narayan and Pritchet 1997). One type of social capital operates through personal networks, wherein community members lend money or other resources and reciprocally offer each other various kinds of support (Grootaert et al. 2004). Economists and other social scientists such as Wiessner and Schiefenhövel (1996) have long considered how food, for example, is shared through social networks. Only recently, however, they have turned their attention to sharing of water, perhaps as a result of the problematics of water as a "fugitive resource" that is difficult to own and control (Ostrom 1990). The projected number of people living in areas that suffer from water scarcity would increase to half of the world's population by 2050 (UN-Water 2018; Boretti and Rosa 2019). The necessarily increasing demand for clean drinking water, however, is a development challenge as climate change alters and complicates precipitation regimes (Grafton 2017), which accentuates the need to consider social capital as a pathway to maintaining and restoring water security.

In the past two decades, a growing number of researchers have published on the moral economy and anthropology of water with a focus on inter-household water exchanges. Specifically, since the early 2000s a number of scholars highlighted the importance of non-paid water transfers. Allen et al. (2006) characterised water gifts as 'needs-driven' and an arrangement by which the poor gain access to water, frequently with little or no support from the state, its policies, and resources. Qualitative research by Zug and Graefe (2014) found, due malfunction of the water supply system in Khartoum, Sudan, that many households relied on water gifts that enabled them to drastically save expenditures on water. Wutich (2011) examined how closely water exchanges among water-scarce households in Bolivia complied with the social insurance paradigm of reciprocity. Furthermore, water exchanges among households are counted as "coping strategies" in water-scarce regions (Wutich 2011; Stoler et al. 2019; Wutich and Beresford 2019).

Inter-household water exchanges commonly occur in water-scarce regions, mainly low- and middle-income countries (Allen et al. 2006; Bond and Dugard 2008; Wutich 2011;

Zug and Graefe 2014; Pearson et al. 2015; Maes et al. 2018; Velzeboer et al. 2018; Wutich et al. 2018; Brewis et al. 2019; Stoler et al. 2019; Wutich and Beresford 2019; Rosinger et al. 2020; Ford et al. 2022; Wutich et al. 2022b). Several different terms are used to describe the behaviour, for example: “water gifts,” “non-paid water transfer” (Allen et al. 2006; Bond and Dugard 2008; Zug and Graefe 2014), and “water exchange” (Wutich (2009). More recently, the terms “sharing” and “borrowing” have been frequently used (Wutich et al. 2018; Wutich 2019; Ford et al. 2022; Wutich et al. 2022a; Wutich et al. 2022b). The profusion of terms carries risks of incoherence and imprecise use of terminology.

Major contributions to the literature on water sharing have come from the Household Water InSecurity Experiences (HWISE) research programme. HWISE draws on a set of standardised questionnaires that have been deployed to samples of approximately 250 people each in a variety of settings across 28 countries. In two recent publications, Brewis et al. (2019) and Rosinger et al. (2020) analysed the HWISE dataset with a focus on responses to the question: “In the last 4 weeks/30 days, how frequently have you or anyone in your household asked to borrow water from other people?” The answers provide an unparalleled opportunity to compare water transfers across a range of world areas. While the question posed in the HWISE questionnaire concerns water *borrowing* frequency, it is notable that the authors use the term water *sharing* in the analyses and presentation of results (Brewis et al. 2019).

Furthermore, the HWISE approach seems to presume that ‘borrowing’ is the key concept underlying informal water transfers. However, borrowing is a concept that presumes direct reciprocity, as opposed, for example, to the ‘sharing’ of water as a commonly owned resource. This narrow conceptualisation can therefore be problematic if it is not first established whether ‘borrowing’ patterns indeed govern inter-household water transfers. While much of the survey response will also rely on the translation of the term ‘borrow’ from English into local languages, the distinction between the meaning of the words ‘borrowing’ and ‘sharing’ is evident and likely to be carried over in translations. As a result, the analysis of the HWISE data may lead to a systematic underestimation or indeed misrepresentation of the prevalence of water sharing (in a broad sense) and its correlates. Sharing in this literature is treated as a residual category that is not explored directly, but is considered an odd variant of borrowing.

Aside from the conceptualisation of inter-household water transfers, the literature has also concerned itself with the drivers of these practices. A comprehensive literature review by Wutich et al. (2018) would accordingly categorise the determinants of inter-household water sharing into the *material, need-based, and self-interested motivations* (costs and benefits of sharing, and water availability, storage, infrastructure and technologies), *socioeconomic processes* (social and political power, water entitlements, ethnicity and gender, and sovereignty over territories, reserves, and reservations), and *cultural norms* (moral economies of water, water ontologies, and religion and religious beliefs). However, this typology of the factors influencing water sharing represents rather an eclectic assembly of disconnected pieces of underlying research rather than a framework or theory surrounding human behaviour.

One such framework is the COM-B behaviour change model, which was developed by Michie, Van Stralen, and West (2011) to harmonise diverse theories in the behaviour change literature. The simplest and most inclusive definition of behaviour suggested by Michie et al. (2011) requires three conditions for behaviour to take place, namely Capability (physical and psychological), Opportunity (physical and social), and Motivation (reflective and automatic). Although the typology of factors by Wutich et al. (2018) on determinants of water sharing corresponds broadly to the 'social' and 'physical' opportunities of COM-B behaviour definition, how concretely these factors interact to shape water-sharing practices remains elusive.

To help overcome this gap in understanding a critical global development issue, the current chapter draws on 68 semi-structured interviews from two-peri urban areas in Kabul. This qualitative work aimed to enrich understanding of water-sharing practices and factors that influence inter-household water-sharing by taking an open-ended exploratory approach.

6.2 Methods

The principal method employed was semi-structured interviews in a cross-sectional design. The data collection instrument was a semi-structured interview guide that included two main parts. Part 1 included open-ended questions on 1) Main water source, storage and knowledge of water quality, 2) Knowledge of health risks from poor water quality, and 3) Water treatment and knowledge of techniques in the household; Part 2 captured demographic and household characteristics of the participants (see Supplementary Material 5.1). The main topics of the interview guide were informed by the existing literature on access to water and household water purification practices including Mubarak et al. (2016), Sigel (2009), UNICEF/WHO (2006), and Wutich (2006). The approach to eliciting information on water sharing primarily relied on questions about the primary source of drinking water (e.g., “Tell me about the main source of drinking water for your household?”). This led people to describe in their own terms a variety of ways they obtained water, which included transfers or gifts of water of various kinds. When people volunteered such information, it was further probed to understand such issues as the frequency and duration of transfers, and relationships between donor and recipient. The portrait of water-sharing arrangements, therefore, emerged through inductive enquiry rather than following a hypothetico-deductive approach (Rodwell 1998; Ferguson et al. 2011).

The resulting data consisted of 68 interviews with an average duration of 30 to 40 minutes each. Interviews were carried out either in Dari or Pashto, depending on the native language and the preference of the interviewee. Among the 68 participants who were recruited, 36 originated from Doghabad and 32 from the Bagrami study area. Refusals to the invitation to participate were limited and primarily due to feeling nervous or participants having concerns about audio-recording their responses (in 4 cases, persons with equivalent characteristics were recruited to substitute for candidates who refused). Male participants were mainly interviewed by myself, and female participants were interviewed by two female research assistants. All participants were provided with a Participant Information Sheet before obtaining recorded verbal consent (see Supplementary Material 5.2), which was read out to the participants due to the low level of literacy in both study areas. Interviews were recorded using digital voice recorders.

The audio recordings of the interviews were transcribed verbatim and translated into English. Preliminary data analyses were done concurrently and during the transcription and translation, which informed the development of the theoretical framework as well as the sampling process. The coding and thematic analysis were implemented using NVivo 12 (QSR International 2018). The thematic analysis in this study followed a systematic approach. Extensive engagement with the data enabled a comprehensive understanding, while coding of relevant segments facilitated the identification of initial themes. A thorough review and refinement ensured the coherence of the identified themes. The

Department of Anthropology at Durham University approved the ethics application (Reference: ANTH-2020-11-28T00 10 33-lgww95).

6.3 Results

In this section, inter-household water-sharing practices were explored by relying on semi-structured interviews from two peri-urban study areas in Kabul. The terms used to describe the water-sharing behaviour in Kabul were: گرفتن (to get), دادن (to give), بردن (to take) and آوردن (to fetch). During the normal water years (average precipitation amount compared to droughts), water-sharing practices generally take place in large amounts from wells and handpumps in plastic gallon containers or by providing pipes (plastic pipes for temporarily transferring water). These terms imply prima facie an arrangement of donation of water, as opposed to lending or borrowing, which imply an expectation of compensation or return. The qualitative analysis suggests that water sharing of this sort was commonly practised among the study households. The following sections describe how people talked about water-sharing arrangements of varying frequency and under conditions of varying availability and water quality; present the distinctive moral economy that appeared to inform water sharing in this context; and, finally, reflect on the implications of periodic drought in disposing people to rely on water transfers from kin and neighbours.

1. *Physical factors informing water sharing*

During the normal water years (average precipitation amount compared to droughts), water-sharing practices generally take place in large amounts from wells and handpumps in plastic gallon containers or by providing pipes (plastic pipes for temporarily transferring water). Water availability in households influenced the practice of water sharing and it was most likely to take place where water was relatively plentiful. A woman from Bagrami, for example, expressed that they fetched water for domestic use from their neighbours' well, where water was accessible in lower depths. As she was pointing to the "*buckets*" that they *"fill them from the neighbour's house",* she added *"We don't use the well water* [fetched from the neighbour's house] *for drinking at all, we use it for washing clothes and dishes. We use mineral water for drinking. If we drink this* *water* [from the well], *it causes stomach ache"*[24]. It was common in Bagrami to share water which was not suitable for drinking purposes since the groundwater was abundant and the groundwater level was close to the surface making it easier for the recipient to fetch it from the wells or get water from handpumps.

In the households where water was abundant, community members shared water even for the longer term as far as the household which was sharing water did not face an economic burden in terms of the means used to abstract water (*i.e.*, sources like wells and hand pumps). However, in cases where the household was bearing economic costs for long-term water sharing then they tended to ask the recipient for compensation or they requested the recipient to provide the means for transporting water as highlighted by a 41-year-old female informant from Doghabad:

Q: Did it happen that neighbours fight over the water?
R: No, it didn't. God bless the owner he did not say anything and asked us to get water but we provided the electricity[25].
(210617_009_R2, Female, 41, Doghabad)

Where access to clean drinking water was limited, other factors such as the relationship between the donor and recipient, and the period (and frequency) over which water was shared, were important factors.

2. *Social factors, cultural norms and the moral economy of water*

As described in the chapter on Access to Water, the brokers of water-sharing arrangements were most commonly women who negotiated with women in neighbouring households to secure access to water, and who also made decisions related to the use of water for cooking and other purposes during the day. A non-kin neighbour, and even a stranger, might receive water even if there is an economic burden to the donor but only in case the request to access water is under a specific circumstance/occasional. For example, a young woman told me: "The *first day that we moved to this house, our water pump was broken and the neighbours provided us with some water."* These relationships

[24] 210619_005_R1, Female, 30, Bagrami

[25] It was a common practice that the donors were using a long wire for water pumps and the recipients could use it to provide electricity by plugging it inside their household. Such exchanges happened mostly between surrounding households.

of receiving water from the neighbours continued – as the same woman also pointed out a recent occasion when their household received water from the neighbours at the time their water pump was broken *("During Eid, the water pump broke again and we fetched water from the neighbours, filled all the gallon containers"*[26]*)*. In other cases, in which there were kin relationships, family people relied on relatives for water for extended periods, at a significant economic cost to their kin. An example representing this dominant theme was a family who received water for over two years from a neighbour who was a relative despite the fact that the donor was bearing economic costs (in this case, electricity costs for pumping groundwater):

Q: You have piped water to your house?
R: Yes, it is from my uncle's house. They have a water pump, [and we use] *if there is electricity.*
Q: How many times a day do you take water?
R: We take water daily [once a day]. *Sometimes when the electricity is disrupted or is at low voltage, we take water twice a day* [increased frequency of getting water].
(210617_006_R1, Female, 45, Doghabad)

The religious injunction to share water constitutes a moral economy (Wutich 2011; ElDidi and Corbera 2017; Wutich et al. 2018). The term that indexes this idea in the Kabul context is *thawab* [ثواب]. For example, a woman from Doghabad who fetched water from their neighbour's house explained the behaviour of her neighbours from whom she received water as follows: *"They call themselves to get water from their house, giving water is a reward* ["thawab"], *they give us water. Then, my son goes and brings water home"*[27].

3. *Drought as a modifier of behaviour*

Another factor that influenced the water-sharing practices was droughts. A homemaker in Doghabad recalled the hard time her family had accessing water during the dry years when the private water network supply was disrupted and neighbours were reluctant to share drinking water. The 36-year-old pointed out that they "*just had access to the tap water* [water supply network] *if it was supplied* [pointing to regular disruptions]", and during the dry years they "*used to consume the water that* [they] *had, in small quantities".*

[26] 210621_001_R1, Female, 25, Bagrami

[27] 210616_016, Female, 45, Doghabad

She elaborated that during the dry years their household "*also spent days when* [they] *went for water at the neighbour's house; the neighbour said that "they also buy water" and* [claimed] *that they do not have water*[28]*"*. The aforementioned story was a common experience among the residents of Doghabad and highlighted the important role of droughts as a barrier to water-sharing practices.

Overall, the results presented above indicated that multiple factors played an important role in inter-household water-sharing practices. The factors included belief, context and environment (i.e., water availability and quality), economic costs for the donor, period and frequency, and relationships between recipients and donors.

6.4 Discussion

The findings of this study from two peri-urban areas in Kabul suggest that multiple factors driving water-sharing practices are overlooked or underplayed in existing research, in particular the cost, frequency, period and relationship between recipient and donor. This section will reflect further on the implications of the ways people speak about water sharing in this setting, and explore the determinants of inter-household water sharing from a COM-B perspective – especially physical and social factors, and the moral economy of water – as it appears in Kabul and its relationship to ideas of reciprocity in economics and anthropology.

From the perspective of the COM-B behaviour model, physical opportunity factors relate to inanimate parts of the environmental system and time (e.g., financial and material sources), whereas social opportunity factors include involving other individuals and organisations (e.g., social norms and culture). The physical and social opportunity factors influencing inter-household water-sharing practices are strongly interacting, as presented in the following paragraphs.

Physical opportunity factors influencing inter-household water-sharing practices documented in other geographies (e.g., Wutich et al. (2018)) included water availability, storage, and infrastructure and technologies. In this study of Kabul, it was noted that the most salient factors were the relative accessibility of water. Also relevant was the quality of water: it was more common for people in Bagrami (the site with plentiful but low-

[28] 210616_005, Female, 36, Homemaker, Doghabad

quality water) for people to share water than for people in Doghabad (the site with relatively good quality but less easily accessible water). In Bagrami people shared water with all their neighbours, albeit the water was only suitable for purposes such as bathing, washing clothes, carpets, etc. Water sharing was generally less common if the donor was bearing an economic cost for accessing the water (also related to the physical factors noted above such as water availability or primary source e.g., deep well vs shallow well or trucking water vs well water). On the other hand, the community members in Bagrami relied on water trucks as the primary source of drinking water, the drinking water-sharing in the circumstance that the donor paid for water was determined by the frequency (how many times the neighbour asked for water) and the relationship to the donor. In Doghabad, where the groundwater was suitable for drinking purposes but needed to be pumped from deep wells, donors typically asked their neighbours to provide electricity in order to pump water from their wells (donors not bearing the electricity costs for pumping water from the well). Overall, social relationships determined whether people were apt to share water and over what period.

The findings of this study imply that interconnecting factors such as water availability, costs to the donor, frequency of requests for water, and the period over which they operate significantly and dynamically impact water-sharing practices. Droughts played for example a significant role in modifying water availability and costs to the donor, which would in turn affect inter-household water-sharing practices. Water-sharing practices also appeared to vary over time, and for example during the droughts in Doghabad, people did not tend to share drinking water except in very few instances – irrespective of the relationship between donor and recipient.

In the Kabul context, related to social opportunity, religious belief played an important role in inter-household water sharing. Islam emerged and thrived in a desert region where water resources were critical, and Muslim sources (the Quran and Hadith) and Muslim scholars regularly discuss the ownership and transfer of water. Islam's status as a monotheistic religion that aimed at uniform control over people’s behaviour in accordance with Allah's directives is also noteworthy (Faruqui et al. 2001; Wescoat 2021). In Arabia before the Prophet Muhammad, there was no consistency in water laws; rather, wells belonged to a single tribe or to a person whose ancestors dug the well. All other tribes that came to the well to get water for themselves or their animals had to pay a price (Caponera 1973; Faruqui et al. 2001). It may not, therefore, be a surprise that water sharing or “donating water” is encouraged in Islam. One *Hadith* states the following:

"Sa'd asked: Messenger of Allah, Umm Sa'd [Saad's mother] has died; what form of donation "Sadaqah" is best? He replied: Water (is best). He dug a well and said: It is for Umm Sa'd"[29].

Other examples of encouraging water sharing in Islam include devoting water wells for public use, a practice that is highly rewarded[30]. Supplying water from wells in the form of donation "S*adaqah"* is encouraged in another *Hadith*[31]. Providing water to any thirsty living creature is recognized as the highest reward[32]. On another occasion, the *Hadith* [33,34] expresses the idea that withholding water from travellers is sinful. These traditions informed the water-sharing practices witnessed in Kabul, not least in the use of the term *thawab* as a rubric for thinking about water sharing.

The theoretical implications of this study are important as it suggests that due to the dynamics of water sharing and the interdependencies between many factors influencing the behaviour, it seems unnecessary to categorize water sharing as *either* a moral economy [influenced by religious belief] *or* a form of generalized reciprocity. To distinguish these categories as opposed is to ignore the close connections between religious convictions and everyday practices, which in this setting (and likely many others) cannot be isolated from one another. For example, if asked what they expect in return for sharing water, many people might say, "Nothing". Yet many respondents believe in receiving a reward ["thawab"] for such behaviour – a reward from God. This corresponds closely to generalized reciprocity (an economic concept) as defined by Sahlins (1972). On the other hand, the moral source of this behaviour is religion.

None of the participants in this study used the terms "borrow" or "lend" in relation to water sharing; instead, they used terms such as "give", "take", and "get" which do not

[29] Sunan Abi Dawud, Hadith 1681

[30] Sahih al-Bukhari, Distribution of Water (42), Chapter 1

[31] Sunan Abi Dawud, Hadith 1669

[32] Sahih al-Bukhari, Hadith 2363

[33] Sahih al-Bukhari, Hadith 2358

[34] There is a clear distinction between *Quran* and *Hadith* as described by (Maureen 2011). Some scholars have confused this distinction; e.g., Wutich et al. (2018) related ideas from this *Hadith* while falsely referring to Quran. It would be more accurate to say that "Islam" is encouraging "sharing" and "supplying" water.

necessarily imply any expectation of material reciprocity. This point of semantics is potentially important and holds practical implications in light of the use of the term “borrow” in large-scale international survey research which has dominated the literature on water sharing in the past several years, i.e., Brewis et al. (2019). The question “How frequently have you or anyone in your household asked to borrow (قرض گرفتن) water from other people” in this context would likely have confused participants and might have led to systematic underreporting of water transfers.

6.5 Conclusions

Inter-household water sharing is often framed as a coping strategy in water-scarce regions, where households may rely on their neighbours or social network to access water. However, the generalisability of this behaviour is problematic. Based on 68 semi-structured interviews from two-peri urban areas in Kabul, the qualitative study documented factors influencing household water sharing dynamically, especially water availability, costs to the donor, frequency of requests for water, and the period over which they operate. The analysis established that drought played a significant role in modifying the water availability and costs to the donor, which in turn affected the inter-household water-sharing practices but also vary in their impact over time. Given the dynamics of water sharing and the interdependencies between many factors influencing the behaviour, it appears unnecessary to categorize water sharing as *either* a moral economy [influenced by religious belief] *or* a form of generalized reciprocity. Taken together and considered from the behavioural science perspective of the COM-B framework, social and physical opportunity emerged as strongly interacting drivers of water-sharing practices.

Chapter 7

Mohammad Daud Hamidi, Marco J. Haenssgen, H. Chris Greenwell

Mohammad Daud Hamidi was responsible for conceptualization, data collection, data analysis, methodology, writing original draft, review and editing. MJH contributed through discussions on setting up methodology and analysis, review and editing. HCG contributed through supervision (my primary supervisor), resources, review and editing. As the main author, I would like to thank MJH and HCG for their helpful discussions and priceless suggestions.

7 Factors Determining Household Water Treatment in Kabul, Afghanistan: A Qualitative Study

7.1 Introduction

At least 2 billion people worldwide consume microbially contaminated drinking water. Especially faecal contamination poses a considerable risk of transmitting diarrhoeal diseases and is the greatest cause of mortality in children under the age of 5 years old, accounting for more than 500 000 deaths in 2019 globally (GBD 2019; WHO 2022).

Populations residing in low-income countries are frequently at risk of contracting diarrhoeal diseases due to the widespread lack of access to clean water and sanitation (Blakely et al. 2005; Clasen et al. 2006). Household water treatment serves as an intermediate remedy in the absence of suitable treatment infrastructure (Clasen et al. 2007; Sobsey et al. 2008). Common household water treatment techniques around the globe include straining water through a piece of cloth, boiling, solar disinfection (SODIS), ceramic filtration, bio-sand filtration, using high-tech (advanced) water purifiers, and chlorination in liquid form, tablets or coagulation-flocculation-disinfection available in sachets (Clasen 2005; Lantagne and Clasen 2012). However, international research has highlighted that simply providing household water treatment interventions is frequently insufficient and the “hardware” must be accompanied by a comprehensive behavioural change model to foster acceptance and consistent and long-term usage (Sonego et al. 2013; Lilje and Mosler 2017). Yet, the specification of these behavioural models is neither obvious nor universal and understanding the factors that determine current or desired alternative behaviour is thus a key requirement for behaviour change.

Several theoretical frameworks with different degrees of specificity have been established to help identify the factors determining water and sanitation (WASH) related behaviour and attain better uptake of WASH interventions. Recent systematic reviews would formulate for instance the broad and open-ended Integrated Behavioural Model for Water, Sanitation, and Hygiene (IBM-WASH) by considering psychosocial, contextual, and technological dimensions of WASH-related behaviour at different levels spanning the societal/structural, community, household, individual, and habitual (Dreibelbis et al.

2013; Martin et al. 2018). While this range of factors appears plausible, their concrete expression remains relatively vague and their actual extent is disputed. Some authors would for example maintain that socio-psychological factors are the main determinants of safe water drinking behaviour, whereas contextual factors had little contribution (Lilje and Mosler 2017; Lilje and Mosler 2018). This argument underlies one of the currently leading approaches to WASH-related behaviour change, namely the RANAS model. This model describes Risk, Attitude, Norm, Ability, and Self-regulation as the main behavioural drivers of WASH and environmental health practices in low- and middle-income countries (Mosler 2012).

From a more general behavioural science perspective, the emphasis on psychological factors with relatively little appreciation of context-specific socio-economic and cultural drivers of behaviour in the dominant RANAS model may surprise. A landmark systematic review by Michie et al. (2011) considered contextual and social elements as integral to any behaviour. Based on 19 behaviour change frameworks, the authors thus proposed the “behaviour change wheel” (BCW) for designing behaviour change interventions (Michie et al. 2011), whereby interventions respond to enablers and barriers to a behaviour such as water treatment across three main dimensions: Capability (physical and psychological), Opportunity (physical and social), and Motivation (reflective and automatic) – which together form the COM-B system. Compared to approaches dominated by notions of reflective decision-making, the domains of the COM-B framework also appreciate for instance that people make impulsive or habitual decisions without necessarily being aware of the decision-making process, or that not only social norms but indeed the configuration of physical and social spaces can shape whether decisions can be taken in the first place (Webb and Sheeran 2006). Although the BCW does not prescribe specific factors that influence behaviour, it offers an exhaustive range of conceptual domains for analysis, and its widespread application across the globe has helped it build a knowledge basis of contextually sensitive behavioural drivers (and the ensuing interventions to change behaviour) in domains as diverse as public health, personal finance, or energy consumption (French et al. 2012; Michie et al. 2014; Steinmo et al. 2015).

However, although the broader field of WASH has received ample attention through studies on sanitation and hygiene practices (e.g., hand washing or latrine use), relatively little knowledge exists on the COM-B enablers and barriers of household water treatment in low- and middle-income countries. Among the very few instances is Okello et al. (2019), who applied the COM-B model to assess a school-based WASH programme conducted in Tanzanian primary schools. Children's motivation to wash their hands improved as they were more aware of the consequences of not doing so. McGuinness et al. (2020a) utilized COM-B to determine enabling factors and barriers that influence WASH behaviours. Arriola et al. (2020) in Kenya, deployed the COM-B model to develop a behaviour change intervention for pregnant women and parents of children below two years old that aimed to reduce stunting and promote the adoption of nutrition- and WASH-related behaviours. Charnley (2021) used COM-B to explore the potential for school-based WASH programmes to spur progress toward SDG 6 in India, the study suggested opportunity and motivation domains were determinants of the behaviour. Two studies in western Kenya Ellis et al. (2020) and Ewart McClintic et al. (2022), also aimed to identify factors affecting the adoption of nutrition and WASH behaviours by deploying the COM-B model, suggested the most significant barriers to practice were a severe lack of social and physical opportunities. Studies such as these illustrate that the COM-B model can usefully be applied to water-related behaviours, and that it has the potential to inform the relative balance of contextual and individual factors of behavioural change.

This study aims to analyse the factors that influence the adoption of household water treatment in Kabul, Afghanistan, whereby the primary objective is to contribute to the ongoing controversy in the literature on whether, and how especially, contextual factors influence water treatment behaviour. While previous studies delivered quantitative and qualitative analyses of the factors determining household water treatment through the lens of RANAS and existing WASH models (Mosler et al. 2010; Mosler et al. 2011; Daniel et al. 2019; Bitew et al. 2020; Daniel et al. 2020; Daniel et al. 2021; Tamene 2021), this chapter will be built on the most inclusive definition of behaviour using the COM-B model. The study has been designed to capture the local realities of a low-income setting through qualitative research involving 68 semi-structured interviews in two neighbourhoods of Kabul. A secondary objective of this grounded approach is to revisit the primarily psychological factors perspectives in water behaviour that continue to dominate the research literature.

7.2 Methods

In settings where there is a dispute about the nature and expression of the various factors influencing water treatment behaviour, explanatory quantitative methods are inferior to the context-sensitive and bottom-up perspective that exploratory qualitative methods afford (Creswell and David 2018; Haenssgen 2019). Therefore, in this chapter, the results of cross-sectional qualitative research are presented which form the first stage of a sequential (exploratory) mixed-method research design, and lays the groundwork for subsequent survey research that builds on the qualitative insights (Creswell and David 2018).

The data collection instrument was a semi-structured interview guide that included two main parts. Part 1 included open-ended questions on 1) Main water source, storage and knowledge of water quality, 2) Knowledge of health risks from poor water quality, and 3) Water treatment and knowledge of techniques in the household; and Part 2 captured demographic and household characteristics of the participants (for the interview guide, see Supplementary Material 5.1). The main topics of the interview guide were informed by the existing literature on access to water, household water purification practices, and existing behaviour change frameworks, including Addo, Thoms, and Parsons (2018); Lilje and Mosler (2018); Michie, Atkins, and West (2014); Mubarak et al. (2016); Ochoo, Valcour, and Sarkar (2017); Sigel (2009); Slekiene and Mosler (2019); UNICEF/WHO (2006); and Wutich (2006). The flexible and open-ended format of the semi-structured interview approach enabled to let local residents share their water realities from their perspective, and highlight the drivers of purification practices on their terms without the research team pre-imposing or favouring specific types of factors.

This study is situated in Kabul given that waterborne diseases have a significant role in the high rate of child mortality in Afghanistan – where 97 out of every 1000 children born die before the age of five (Rasooly et al. 2014). The study sites for this research mainly included Doghabad (located in District 7 of Kabul city) and Bagrami (divided between the existing 12th district, and the planned 22nd district of Kabul city) – Figure 7.1. The sites have a combined total population of approximately 150 000 (i.e., 3.7% of Kabul metro, which had a total population of 4.1 million as of 2020). Both study areas were selected due to the high rate of water-borne disease. The prevalence of water-borne diseases reported by the Kabul Managed Aquifer Recharge Project (KMARP 2018a) in Doghabad are amoebic dysentery and salmonellosis. In Bagrami the range of disease prevalence is broader, including amoebic dysentery, hepatitis A, typhoid & paratyphoid, shigellosis, and salmonellosis. The Doghabad region, with a population of 50 000 people is an unplanned peri-urban area characterized to have highly microbially contaminated water. Bagrami has a population of 100 000 people, a planned peri-urban area and the water in the area is saline (CIESIN 2018; NISA 2020). The two sites are located in two different watersheds, one having more constraints than the other in freshwater availability due to the impact of droughts and low river recharge rates. For instance, the shallow groundwater depth in Doghabad is 25 – 30 metres below ground level (mbgl) while it is 3 – 7 mbgl in Bagrami.

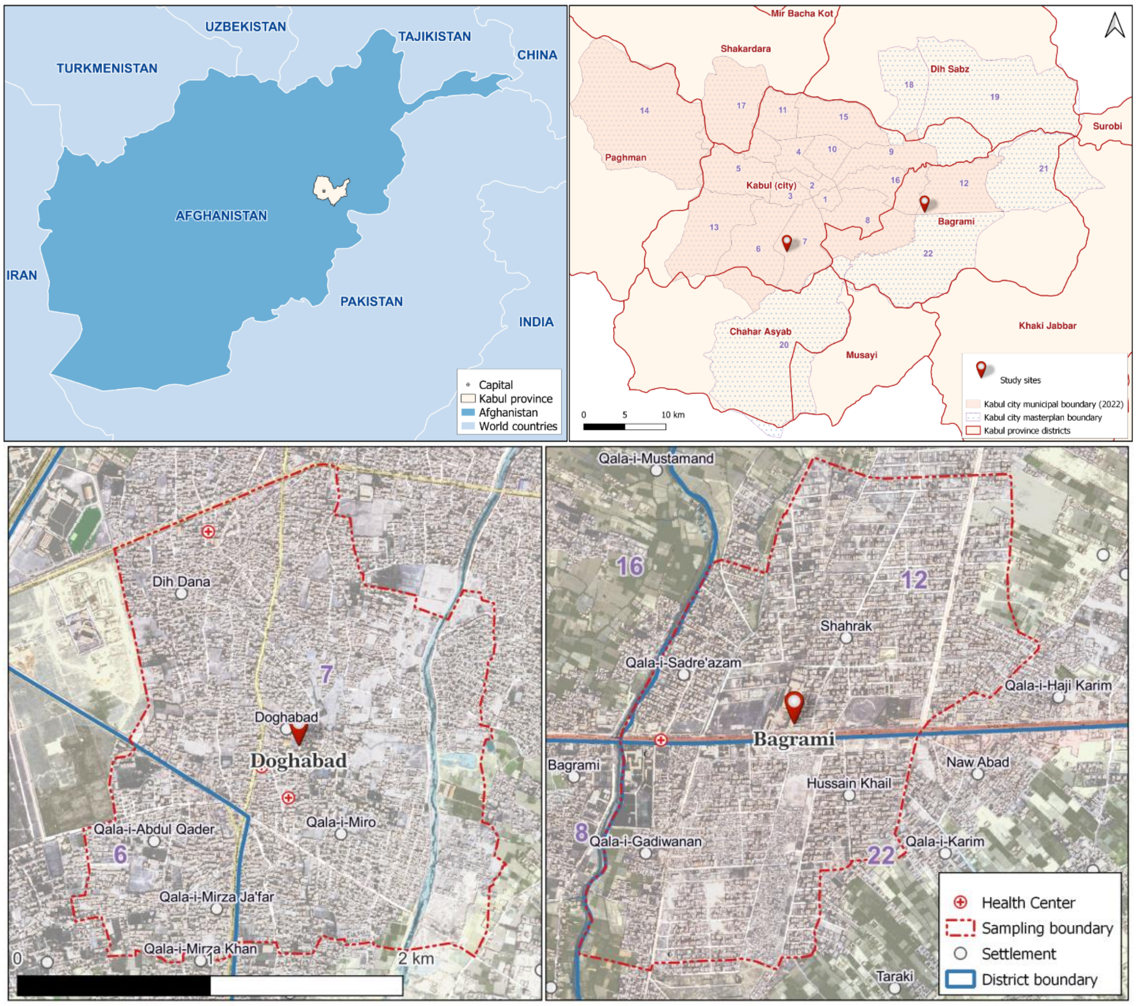


Figure 7.1. Study area maps. Kabul city boundary maps were developed as per the city master plan draft and provincial profile reports of NISA in 2020. Satellite images provided by NISA, and OpenStreetMap is superimposed.

To explore the diversity of residents' living environments and water treatment behaviours, participants were selected purposefully based on their residence location, age, gender, ethnicity, economic status, and variability in access to water resources. Concurrent analysis and local residents' guidance supported the sampling process, which continued until all selection criteria were successfully incorporated into this study. Following emerging practice in low- and middle-income country development research, high-resolution satellite imagery[35] were further employed to support the spatial distribution of the sampled households (Grais et al. 2007; Galway et al. 2012; Flynn et al. 2013; Escamilla et al. 2014; Haenssgen 2015; Cajka et al. 2018).

The resulting data involved interview records spanning an average of 30 to 40 minutes each. The questions were posed either in Dari or Pashto, depending on the native language and/or the preference of the interviewee. Among the 68 participants who were recruited, 36 originated from Doghabad and 32 from the Bagrami study area. Refusals to the invitation to partake in the study were limited and primarily due to feeling nervous or participants having concerns about audio-recording their responses (in these cases, the candidates were replaced with persons with equivalent characteristics). Male participants were mainly interviewed by a male researcher, whereas female participants were interviewed by two female research assistants. All participants were provided with a Participant Information Sheet before obtaining a recorded verbal consent (see Supplementary Material 5.2), which was read out to the participants due to the low level of literacy in both study areas. Interviews were recorded using digital voice recorders.

The audio-recorded semi-structured interviews were transcribed verbatim and translated into English. Preliminary data analyses were done concurrently and during the transcription and translation, which informed the development of the theoretical framework as well as the sampling process. The formal qualitative analysis upon completion of the transcription involved thematic analysis, which was conducted by the lead researcher (MDH) in the original interview language so as to preserve the original context and maximise the informational content of the interviews for the analysis (Haenssgen 2019). The English translations were used to represent the main themes in the reporting of this research. The coding and thematic analysis were implemented using NVivo 12 (QSR International 2018). In the case of NVivo 12, it was not capable of handling Persian (Dari) and Pashto languages. To overcome this limitation, the participant responses in Persian and Pashto were translated into English. The translated (English) versions of the responses were then used for coding and analysis within NVivo. For ethical approvals, all the material for the interview including the guiding questions

[35] High-resolution satellite images (50cm) were provided by National Statistic and Information Authority (NSIA), Afghanistan from Planet, Skysat images – 2020.

were translated and back-translated following WHO (2010). The ethics application was approved by the Department of Anthropology at Durham University (Reference: ANTH-2020-11-28T00_10_33-lgww95). Kabul Police headquarters, the head of the city district/village, the Imam of the mosque in the area, and the local division of Kabul police were informed about the research (see Supplementary Material 5.4).

7.3 Results

Delivering successful intervention on household water treatment requires identifying factors that impede and promote the desired behaviour. The perspectives of peri-urban community members are qualitatively examined through the analytical lens of the COM-B model in the context of Kabul. The presentation of the findings is structured according to key themes of water treatment behaviour as they emerged from the interviews, starting with local perceptions of "water quality" and "water-borne health risks," via common forms of water treatment encountered in the study sites, to the ongoing process of navigating and negotiating these treatment practices to the point that they may be discontinued. Contrary to the prevailing wisdom in the water treatment behaviour literature, the influence of contextual drivers such as wealth, social stratification, and competing livelihood challenges was prevalent throughout this study. This does not discount the absolute importance of psychological factors relating to reflective and automatic motivation. However, not only are those factors partly conditioned by the local physical and social environment that shape decision-making routines as well as impulses and habits (e.g., traumatic experiences), but the dimension of social opportunity was similarly pronounced while other dimensions such as psychological capability and physical opportunity also continued to influence household water treatment.

7.3.1 Making sense of water quality

It is easy to impose an outsider's conception of water quality, but this may not reflect how locals themselves conceptualise it – and these local conceptualisations can in turn impact water treatment practices. The qualitative analysis suggests that all components of COM-B influenced the informants to make sense of water quality, whereby the social opportunity, reflective and automatic motivation were especially pronounced. Water quality considerations are an essential basis for decisions to treat water. However, the scattered and unsystematic information landscape is presented that necessitates residents in peri-urban Kabul to rely heuristically on sensory and contextual quality markers alongside personal experiences of water-borne illnesses. These factors matter for treatment behaviour insofar as they are contextually and socially conditioned.

7.3.1.1 The water information landscape

In this section, the information environment that shapes notions of household water quality and water treatment in Kabul was explored. Information about water quality and household water treatment techniques has the potential to influence how households navigate and perform water treatment. Key elements of the local information landscape were community members, “doctors” (broadly defined as medically informed people), mass media, religious and community leaders, non-/governmental organizations, and commercial operators (for detailed description, see Supplementary Material 7.1). A salient theme of how COM-B dimensions played out in this landscape was the domain of social opportunity: Making sense of water through the information exchange among community members or through media would enable household water treatment and indirectly also influence reflective motivation, psychological capability and reflective motivation in this process.

According to a majority of the research participants, “doctors” were the main source of information on water quality and water purification in the study communities. The local concept of “doctor” was, however, not limited to medically trained personnel operating in health centres, private health clinics, and hospitals, but it could also refer to pharmacy staff and NGOs staff visiting the area. These local doctors were very likely to encourage people to consider and change their drinking water sources, and to consume treated water (boiling, buying bottled water, or buying the water from water trucks). For example, a 41-year-old female homemaker was observed from Bagrami who boiled drinking water for her sick children. When asked where she had received that recommendation from, she explained that, “*The doctor said it. I took* [the children] *to the doctor and he said, ‘Give them boiled water.’ Then, I boiled the water and let it cool down before drinking*”[36].

Nevertheless, such interactions with doctors were limited to a specific group of people since the cost of medical treatment was not affordable for lower-income families, and community members with mild diseases would not visit the doctor at all for this reason. Thus, the people receiving information from doctors tended to be more affluent residents who had experienced at least one severe case of water-borne disease in their families.

[36] 210619_014_R1, Female, 41, Homemaker, Bagrami

Alongside professional advice, social interaction among people was another important element of the local information landscape. Its impact on behaviour was noticeable as community members in Kabul described how they followed others in performing a behaviour that they talked about or demonstrated. Demonstration effects were for instance described in the experience of a household represented by a 45-year-old female from the Bagrami area, who observed that, "*Some people bought* [a water purifier]" who "*said the water* [from the filter] *is good,*" which prompted her household to buy a water purifier as well to "*get rid of the problem*" of fetching fresh water from further-away sources and instead draw from local wells[37].

As the trend of water quality in Kabul had been worsening, community members frequently had conversations about water quality and water purification techniques. Such conversations took place at home with a member of the same household, among relatives who are visiting each other, or at the community level, and shaped practice even without demonstration effects. However, the conversations at the community level only very rarely touched on water quality and water purification since the dominant topic of conversation was the political and security situation. Conversations between household members and relatives were relatively more influential. Responding to the question of what prompted him to adopt a water filter in his household, a 60-year-old male informant from Bagrami explained for instance that he, "*heard from people around me, they said it's good, purifies water and then we bought it. It has been 2-3 years that we are using it*"[38].

At the same time, social interaction could also discourage or confuse water purification at the household level. For instance, a 19-year-old female student from the Bagrami area described how her brother had just "*installed a water purifier* [at his home], *and so he said that we should install it.*" However, after the family bought a water filter, it was left idle as the "*brother said it doesn't work properly. Thus, we didn't install it* [and …] *it has been a long time that we haven't used it*"[39]. In other situations, word-of-mouth and vernacular interpretations of water treatment could also create confusion or fluid concepts surrounding water quality and treatment, as some respondents conflated for instance the

[37] 210619_007_R1, Female, 45, Homemaker, Bagrami

[38] 210621_004_R2, Male, 60, Bagrami

[39] 210621_002_R1, Female, 19, Student, Bagrami

notions of boiled and mineral water ("*Our husbands say that for it to become mineral water, we should boil water*"[40]).

This scattered information landscape created patterns of including and exclusion, which could unintentionally deprive some Kabul residents of potentially life-saving information and interventions. For example, emergency responses would often cover a narrowly defined geographic area, and information campaigns via TV or other media sources would exclude those groups for whom home entertainment and electricity were unaffordable. Also, social and gender norms would render women responsible for household water affairs and leave them busy with cooking and child care, especially during peak hours when advertisements are delivered (while men usually decide what to watch). It was therefore not usual to encounter female respondents such as a 45-year-old homemaker in Bagrami who had never come in contact with any of the wide range of water purification methods from boiling, straining via cloth filtration, chlorine, solar disinfection, to advanced water filters.[41]

Despite their nodal positions in the local communities, the analysis suggests a lack of involvement by Imam and Wakil in sharing water information. These actors are locally respected, recognized by the government, and responsible to define, discuss, and try to address community challenges at the local level. Moreover, it is a religious responsibility for the Imam to be aware of local community challenges and deliver speeches to people on both challenges and solutions, However, the research informants did not report a single event at which the Imam would address either water quality issues or the water purification techniques, and the role of the Wakil was similarly muted.

The fragmented and uneven information landscape influenced the performance of household water treatment, producing an environment where information exchange within the community or through health centres played a dominant role while the government- and NGO-orchestrated mass- and print media campaigns created systematic exclusion from vital water-related information.

7.3.1.2 Sensory markers of water risks

Community members in Bagrami and Doghabad commonly experienced water quality in terms of taste, colour, turbidity and scum on tea, which did not only shape their reality

[40] 210617_012_R2, Female, 30, Homemaker, Doghabad

[41] 210621_003_R2, Female, 45, Homemaker, Bagrami

but also implied that their environment was characterised by extensive sources of water contamination.

Taste is a common way of associating with water and judging its quality, and representations of "good" and "bad" water quality through taste were vividly present in the responses and narratives of the residents of Bagrami and Doghabad. People indeed had strong opinions about taste, which were expressed typically in relative terms but with very different reference points. Respondents made comparisons of the taste of water from the same well over time ("*in the past, it had a special taste. Now, that we use it, it does not taste like in the past.*"[42]), of characteristic water tastes across different areas that they visit or where they originate from ("*When visiting Qala-e-Shada* [an area near city], *the water in that area is soft and does not taste good. Then, we understand that this water is not good.*"[43]*),* or of different water sources (i.e., well water vs. the bottled water or the water from trucks) ("*The truck water is not bad, it tastes good. The water we get from the well does not taste good. It tastes very bad and can't be used for drinking.*"[44]*).* The importance of taste references as quality indicators was clear to the participants as well, as an exchange with a 36-year-old female homemaker that was typical for both sites illustrates:

> *R: This water makes the children fall sick, we had to buy a filter to use* [for drinking purposes]. *We only use well water for washing clothes and carpets.*
> *Q: The water inside your house is not good, is it bad?*
> *R: Yes.*
> *Q: How is it? What is wrong with its quality?*
> *R: When we drink it, it tastes rusty. That's why we had to buy a filter. We clean the filter every month. When there is no electricity, if we drink this water, it makes us sick. We have to avoid it and that's why we don't use it.*
> (210619_007_R2, Female, 36, Homemaker, Bagrami)

Colour was a similarly common notion when the research participants described water of varying quality. According to residents in both communities, a particularly instructive attribute of colour assessments was that change would indicate that the water had not been used for a long time, or otherwise hinting at neighbourhood activities like wastewater disposal that might be contaminating wells. For example, a 38-year-old

[42] 210517_003, Male, 36, Shopkeeper, Doghabad

[43] 210508_001, Male, 50, Real estate agent, Doghabad

[44] 210619_002_R2, Female, 40, Homemaker, Bagrami

homemaker from the Doghabad community explained upon the question of why her water quality was poor that, "*When people unload the pit latrines, the colour of the water turns yellow. Or, when the water is left for a long time in water storage, then it turns yellow*"[45].

The third key marker that respondents described in the interviews was turbidity – again a sensory assessment enabled through visual inspection. Based on the users' source of water, experiences of turbidity varied widely. People using the water supplied by the private network noticed few and low levels of turbidity. A 36-year-old female homemaker from Doghabad explained:

> *The speed of water in our house depends on how much water they release. It has sand in it, during this week, the water was turbid for 2-3 days and when I leave the water* [for some time] *then the sand will be set down in all the buckets.*[46]

Experiences of turbidity were also shared by research informants having a well in the household (particularly during the dry years: "*I started to boil water years ago when it was a dry year and the water level drawdown very much. The water from the pump was turbid. At that time, we boiled water for 6 months*."[47]) and those using public hand pumps ("*Sometimes they bring turbid water, they use pump badly and the water gets turbid; and, sometimes they bring clear water.*"[48]).

The fourth marker of water quality that was widely referred to in the interviews was the "*oily layer*" problem, a situation almost universal around Kabul city. From the perspective of community members, when boiling water, "*a layer will be formed at the top*"[49] that is then still visible in the glass of tea – therefore also shaping the experience of its consumption (and potentially creating powerful and negative affective associations that relate to reflective motivation in the COM-B framework).

The four key themes of sensory assessment of water quality from a user point of view (taste, colour, turbidity and scum on tea) were clearly linked to community members'

[45] 210619_012_R2, Female, 38, Homemaker, Bagrami

[46] 210616_005, Female, 36, Homemaker, Doghabad

[47] 210508_001, Male, 50, Real estate agent, Doghabad

[48] 210617_012_R2, Female, 30, Homemaker, Doghabad

[49] 210616_008, Female, 30, Doghabad

assessments and subsequent choices of using water for drinking purposes. People subscribed to a private water supply company (i.e., in areas not covered by the government water supply network) or purchased water from water trucks because the water from these sources tasted good or its colour was better.

This is not a trivial matter. Community members depended on these personal, sensory assessments of water quality since water quality information was not provided by water distributors – be it the government, private water supply companies, or other water vendors (bottled water and water trucks). As far as I could establish during the field research, the government had no formal policies for the regular monitoring and reporting of water quality provided by local water vendors including private water supply companies, bottled water companies, or water trucks. Monitoring was not entirely absent, however, and irregular visits might take place by ministry officials, but even in that case it often remains without consequence since the security environment (which limits physical access) and widespread corruption made it difficult to rectify any problems that the irregular monitoring could uncover.

The upshot of this situation was a persistent dearth of information for water users. A 25-year-old female informant described that even in the case of mineral water, lack of dependable information meant that community members needed to continually rely on assumptions and heuristic markers of water quality ("*We don't know, we just buy it and we are not sure. Other families buy it and we do too."*[50]*)*. Another interviewee, when asked *"Are you sure this mineral water is healthy or not?",* said*: "Not so much but the colour is better than this* [well] *water"*[51].

In lieu of independent and dependable information, communities also need to uncritically trust in the local water suppliers. In the Bagrami area, due to the contaminated water quality, the majority of informants rely on water trucks for drinking water. Community members and the vendors (water trucks) established a relationship based on trust where the water consumers are relying on their information about water quality, even if it is as reduced as, "*The person who sells the water said that it is clean*"[52].

Technical solutions offered little scope to overcome the information deficit. In general, it was rare to encounter community members who were familiar with (let alone be in the

[50] 210619_010_R1, Female, 22, Housewife, Bagrami

[51] 210621_001_R1, Female, 25, Bagrami

[52] 210619_012_R1, Female, 26, Student, Bagrami

possession of) devices for quantifying the chemical contamination level of water quality in the household, and even in those cases, the devices were only associated with chemical pollutants rather than broader notions of water quality. Only particularly affluent households had the means of accessing statistical indicators, namely through advanced water purifiers where the purifier has a digital indicator display of water quality. And yet, the interpretation of such indicators was not straightforward for users and information remained elusive still. For example, one such water purifier user observed daily changes of the digital indicator, but he was only able to interpret the results relative to a threshold of "good water quality" based on the sales brochure: "*Above 100 is not drinkable and below 100 is allowed* [to drink]."[53] The mere provision of technical information may therefore not automatically resolve uncertainties surrounding the quality of water from various sources.

7.3.1.3 Contextual markers of water risks

Related to the physical environment is also the depth at which well water would be abstracted, which would again enter the households' reflective assessment of health risks and treatment choices for drinking water. The water from deep wells (deeper than 60 mbgl) was generally deemed to be fit for consumption compared to water that was abstracted from shallow wells (less than 40 mbgl). Explicit descriptions of the link between the well depth and health risks were in fact rather common and reflected the water realities experienced by the communities. For example, a 50-year-old female participant described that, "*We drilled a 25 meter deep well but, in this area, if a well is drilled 50 meters, then the water quality is good*"[54], while a 36-year-old female informant relied on groundwater for domestic use in the Bagrami area reasoned that, "*The water is generally bad. If the well is drilled deep, then the water might taste a bit sweet. We drilled 30 meters but it might get better if drilled 50 – 60 meters*."[55]

Compared to instances where households abstracted water directly from a well at the time of the fieldwork, residents who subsequently switched to a privately supplied water network (water abstracted from 150 mbgl) did not consider further treatment necessary for daily drinking water consumption. A 51-year-old female informant from Doghabad explained that the difference between a 150m-deep well and a shallow 30m well is that,

[53] 210520_003, Male, 52, Doghabad

[54] 210621_006_R1, Female, 50, Homemaker, Bagrami

[55] 210619_007_R2, Female, 36, Homemaker, Bagrami

"*When we used the* [shallow] *well water, we boiled it, we couldn't drink it unless it was boiled but we use the water from the deep well without boiling and there is no problem*."[56] The physical environment determining the water source and abstraction depth therefore clearly shaped health risk perception and water treatment practice in turn.

7.3.1.4 Exposure to water-borne diseases

Among the study participants, experiences with water-borne diseases were common and thus constituted an important facet of local water realities with an important bearing on household water treatment practices. For example, the diarrheal infection with *Helicobacter Pylori* was almost universally known and referred to in the vernacular as "H. Pillory." In the case of *H. Pylori*, the persistent and chronic diarrhoea would require community members to seek medical treatment and thus expose them to medical advice on water quality, but it would also be an event to initiate new perspectives and practices around clean water. In the case of a Bagrami household, a 57-year-old female household member would explain how they "*didn't have the filter and used the raw water for five or six months. After falling sick, diagnosed with H. Pylori - then we bought a water filter*" but also describe water quality not merely through sensory attributes but even with reference to microbial contamination: "*When the water is filtered* [boiled] *then it will not have microbes. The raw water has microbes.*"[57] In contrast, milder episodes of diarrhoeal cases were not normally reported to medical authorities, neither for adults or children. While they would use herbs and "*anise seeds*" as home remedies,[58] they would not gain exposure to medical information but nonetheless boil water in response to the illness of their household members.

The research informants reported several other health conditions as well – including stomach ache, vomiting, nausea, and typhoid – which they experienced personally or in their household, and which they actively linked to water-borne diseases. An experience shared by many was that of a 50-year-old female homemaker, whose household member experienced typhoid:

[56] 210617_013_R2, Female, 51, Doghabad

[57] 210621_007_R1, Female, 57, Bagrami

[58] 210619_015_R1, Female, 21, Student, Bagrami

Q: Do you remember someone getting sick at home because of the poor water quality?
R: Of course, it happens to get sick. My brother, older than me, was sick. I spent 100,000 [Afghanis = 1250 USD] *on him to recover. Now, we only use this water for washing clothes.*
T: What was his illness?
R: He was diagnosed with typhoid. When they drink this water, it increases microbes [in the body]. *We also took these girls* [to the doctor]. *We paid a lot. Now, we ban the use of it* [for drinking purposes], *we just use it for washing clothes.*
Q: Did the doctor tell you that he got ill because of water?
R: Yes, he got sick from the water. There was nothing else at home [that could cause disease].
(210621_006_R1, Female, 50, Homemaker, Bagrami)

The story illustrates several elements that appeared consistently in the qualitative research: community members have generally a working concept of water-borne illness, they clearly link water purification to water contamination, they are conscious of the health and financial costs of contracting infections from contaminated water, and they personally identify and negotiated solutions for water treatment. Also, albeit this is a shared experience, it is concentrated among poorer households and those who recently moved to the area and thus lacked the local understanding of water quality (e.g., "*We used it* [well water] *at the beginning* [when we just moved here], *then we realized that the children fall ill and my father said that it may be caused by water. Then, we started to buy mineral water*"[59]). Affluent households did not only command more access to secondary information (as opposed to experiencing water-borne illness first-hand) but also the means to avoid water-related health risks. A 33-year-old female homemaker from a wealthy household in Bagrami simply stated that, "*We didn't drink this* [well] *water; they said the water is bad and don't use it. Thus, we buy water. We only use the well water for washing clothes and bathing*."[60], indicating that access to financial resources is encouraging investing in measures to prevent water-borne diseases in the household.

The awareness and the experiences of water-borne diseases constitutes an important element of local water realities that consequently shape household water treatment practices.

[59] 210621_001_R1, Female, 25, Bagrami

[60] 210621_009_R1, Female, 33, Homemaker, Bagrami

7.3.2 Water storage forms and common dimensions of performing household water treatment

Performing household water treatment provides a healthier environment by protecting the household members from water-borne disease, the common forms are presented in Table 7.1. The qualitative analysis uncovered a complex landscape of water sources in which practices of water treatment and non-treatment signify how residents navigate and negotiate the often-elusive health risks of water contamination. The ensuing behaviours include for instance water boiling and chlorine treatment but also active considerations of when and when not to apply them. The decision-making patterns on the individual level are shaped distinctly by a combination of cognitive, and environmental factors.

Common household water treatment techniques around the globe include straining water through a piece of cloth, boiling, solar disinfection (SODIS), ceramic filtration, bio-sand filtration, using high-tech (advanced) water purifiers, and chlorination in liquid form, tablets or coagulation-flocculation-disinfection available in sachets

The following sub-sections present social and physical opportunity factors such as the household economic status, residence, high cost of water purifies, and gender in performing household water treatment. Besides, the residence area also indirectly influenced reflective and automatic motivation surrounding household water treatment. Also, the new behaviours are presented which is shaped by the use of high-tech water filters in combination with environmental factors.

Table 7.1. Common forms of household water treatment techniques in the study sites.

Household water treatment technique	Applicability	Energy source requirements	Cost
Straining through cloth †	Turbidity and sand particles, and micro-organisms	None	No cost
Boiling	Bacteria, viruses, and protozoa in water	Electricity, Gas, Wood	Depending on the source of energy and frequency of performing.
Liquid Chlorine (250 ml) ††	Bacteria and viruses in water, low protection against protozoa	None	60 Afghani/bottle (0.75 USD)
Solar disinfection	Viruses, bacteria, and protozoa in water	None	No cost if using recycled plastic bottles
Sachets or Tablets ††	Bacteria, viruses, and protozoa in water	None	30 Afghani/sachet/packet (0.38 USD)
Sand filtration †††	Protozoa and most bacteria, not as effective against viruses	None	High initial cost
Advanced water purifiers	Bacteria, viruses, and protozoa in water	Electricity	Above 8000 Afghani (100 USD)

Source: Research fieldwork; "applicability" based on (CDC 2022).
† *Depends on the type of cloth and directly depends on micro-organisms size.*
†† *Distributed by NGOs, and available in pharmacies.*
††† *Promoted by NGOs only through certain projects.*

7.3.2.1 Water treatment as a response to illness

Water boiling was among the most commonly mentioned water treatment techniques in this qualitative study, but it was not practised universally or even continuously. Rather, the interview respondents related the practice to acute and past experiences of water health risks as well as in response to acute illnesses of household members, especially to those experienced by children. Boiling water in circumstances where a family member has fallen ill was not specific to the water source, as the informants stated that they boiled water from all sources, including water bought from water trucks. For instance, when asked "*Do you always perform boiling water?*", a 41-year-old homemaker who heard from other people said: "*they say if we pour this* [chlorine], *it is good. Boiling water* *before drinking is good"* while she was providing boiled water to her child only "*when they fall ill."*[61] Other responses to this question included a mother who boiled the water that they bought from water trucks for her child who was experiencing water-borne disease ("*We also boiled the water that we bought* [from the water trucks] *and then poured it into a bottle for giving to the child."),* but she stopped providing boiled water to her child as soon as the child recovered.[62] These narratives indicate the influence of cognitive factors (awareness of the risk of untreated water) on performing household water treatment.

Furthermore, the responses illustrated a broader pattern according to which community members were paying specific attention to children's health in terms of the drinking water source. A majority thereby indicated that they were indeed aware of the health risks of widespread groundwater contamination in Kabul, either mentioned directly during the interview or indicated indirectly by the actions they performed to prevent water-borne disease among their children (typically under the age of five) in their family – such as buying mineral water only for the children in the household "*because they fall ill quickly*"[63].

In practical terms, interviews and observations suggested that mothers were the household members spending the majority of their time with children and were responsible for water treatment inside the household (mostly boiling water). Almost all of the mothers who participated in this research expressed that they were aware of the health risk of consuming groundwater, and consistently so across the two study sites. Water was commonly boiled to prevent diseases among children under the age of five since "*Everyone knows that it* [groundwater] *makes the child get sick.*"[64] The same respondent (a 30-year-old mother from Bagrami) would further explain how boiled water forms a basic element in the child's diet: "*My child is using milk powder, we cannot give him raw water. First, we boil it and once it gets cool, we will add to milk or we just give him the water to drink.*"[65].

Although, community members perceived that well water was of such bad quality (environmental factor) that it could potentially cause them to fall ill and complained that

[61] 210619_014_R1, Female, 41, Homemaker, Bagrami

[62] 210621_005_R2, Female, 33, Homemaker, Bagrami

[63] 210617_007_R1, Male, 32, Doghabad

[64] 210619_005_R1, Female, 30, Bagrami

[65] 210619_005_R1, Female, 30, Bagrami

"*It does not taste good*", they would still continue using well water for drinking purposes given that, "*we can't buy water all the time*"[66]. Considerations of affordability and practicability, therefore, limited the extent to which community members could respond to their active recognition of poor water quality and the risk of water-borne illness.

7.3.2.2 Water storage practices

Not only different forms of water treatment featured in the Kabul residents' narratives, but also water storage was a central theme in the conversations – whose relevance should not be under-estimated in shaping the physical environment in the households to access clean drinking water.

The interviews and fieldwork observations suggested that variations in water storage practices across Kabul households had a substantial bearing on the experience of water quality and the logistical context of water use. Such practices are related to adopting storage containers, setting them up, and extracting water from them. Key COM-B elements influencing these practices related to physical as well as social opportunity factors that often followed wealth gradients. Plastic gallon containers and tankers (i.e., larger storage barrels) and steel-made water tankers were the most common means for storing drinking water within households.

Disparities in storing water were pronounced between the middle-income and lower-income households participating in this study. Middle-income families were able to place the water tankers inside a small room on the roof or to cover the surface of the tanker from direct sunshine by other means, thus keeping the tank clean and water fresh for over a year. In contrast, households with lower income without the means to afford sheltered storage space would place the water tankers on the roof, exposed to direct sunlight. The consequences of storing the water tankers under the direct sunshine included algae growth, deterioration of water quality, and higher maintenance efforts, thus effectively adding to the operational costs and diminishing the quality of water for households who were already struggling financially. A 48-year-old female informant in such a household shared that they experienced algae growth in their water tankers and noticed that those algae affected the taste of water (using the local notion of "*Jamanak* [جمنک]" and describing it as a "*green thing in water*"). The algae contamination triggered the household to wash the water tankers once or twice a year ("*we cleaned the water storage*

[66] 210621_008_R1, Female, 32, Bagrami

[the one on the roof], *they* [her children] *brushed and cleaned it, they also took fibreglass around it*"), specifically after the summer and before the onset of winter[67]. The physical constraints surrounding water storage for poor households thus came with additional maintenance costs in terms of physical labour and potentially costly insulation and cleaning material.

The typical water storage among lower-income families was plastic gallons. Especially those families renting rather than owning their houses would be reluctant to buy the more dependable yet expensive water tankers, given that they were likely to move homes regularly and landlords would seldomly place a water tanker in the building. These constraints were summarised succinctly by a 63-year-old male informant in Doghabad, who argued that, "*We take cold water from a hand pump. We don't have water storage. This is not my house that I should buy water storage. We are changing places year by year"*[68]. His case also reflected the realities of other poor households who used the smaller and more mobile plastic gallons to fetch water from public sources – instead of the permanently installed home-based water tankers. These small plastic gallons had the advantage that they were easy to carry by children and women, relatively affordable, and widely available, but community members also explained that they needed to wash these plastic gallons (though easily) every two days on average and were thus more maintenance intensive.

The use of plastic water tankers and gallons already hinted at the physical opportunity constraints that poorer households experienced, but the broader wealth gradient across the Kabul households was even more striking. In contrast to the laborious and precarious water storage practice among poor families, the few affluent households in the Kabul study sites appeared entirely resilient to changes in water availability. Sheltered and controlled storage conditions, as well as ownership of fridges, enabled them access to quality drinking water during uncertain circumstances. A 48-year-old female informant described for example that they would store bottles of purified water in the fridge for instant access to quality drinking water for children, especially during the summer: "*We give boiled water to our children, I asked my daughters-in-law to boil water for the children. We fill bottles* [with boiled water] *and store them in the fridge"*[69]. The

[67] 210617_004_R1, Female, 48, Doghabad

[68] 210520_004, Male, 63, Doghabad

[69] 210619_009_R2, Female, 48, Homemaker, Bagrami

aforementioned brings to attention the critical role of water storage practices, especially among affluent households, in providing an environment preventing water-borne disease by keeping water safe from contamination (and treated water safe from re-contamination).

7.3.2.3 Spatial, social, and economic dimensions of practice

This qualitative research brought to the fore a range of further cross-cutting elements that created systematic variation in how households performed their water-related practices – all of which strongly relate to the physical and social opportunity elements of COM-B, with indirect influences also on other dimensions such as reflective motivation.

One key characteristic of households that generated such systematically different experiences of water quality and treatment within and across the two study communities was residency. On the one hand, research informants from households in Doghabad who had lived in the area for over 15 to 20 years highlighted their observations of changes in water quality. Compared to migratory households who settled more recently (and who were particularly common in Bagrami), their long experience enabled them to compare the water quality status quo to the past and to pinpoint the changes that had impacted their daily life. The aforementioned situation of pit latrines contaminating the groundwater is a case in point. Respondents such as a 50-year-old male real estate agent in Doghabad would put these observations into long-term perspective and argue that:

> *The quality of water in this area is not the same as 20 years ago because there has been an increase in the number of pit latrines and cesspits. Our water quality has also deteriorated for this reason.* (210508_001, Male, 50, Real estate agent, Doghabad)

In this case, the ability to put current developments into a longer-term perspective – enabled by the physical opportunity factor of residency – also enables the respondent to judge water quality with more information than residents who had only recently moved to Kabul (i.e., indirectly affecting reflective motivation as a dimension of water-related behaviour).

On the other hand, and perhaps not surprisingly, residency also entailed systematic site-specific experiences and realities of water access. In Doghabad, private water supply companies relied for instance on deep groundwater to provide access to clean drinking water. However, the majority of the households relied on shallow groundwater using wells and handpumps. Although the water quality was bad, it did not trigger the households to subscribe to a privately supplied water network – at least not until the shallow wells started drying up[70]. In contrast, community members in Bagrami were struggling especially with the chemical contamination of groundwater. Shared experiences of salty taste and water-borne diseases reduced shallow wells to such purposes as "*dishwashing, bathing and toilet storage*"[71]. Households in Bagrami thus had to rely on water trucks and bottled water for drinking water since well water "*makes us sick and we shouldn't use it*"[72].

Another social factor influencing water treatment was the household size. The analysis suggested that the research participants perceived that purchasing a water filter was viable for large families provided that they could afford the expense, for instance a 25-year-old male said they are "*At home, my uncles are with us, there are 45 or 46 of us*" and acknowledged "*It's a lot* [the number of people using one purifier]*"*[73]. Small families, so the informants argued, would prefer to buy bottled water "*The bottled water that we buy is 18 litres. It is enough for a week because we are a small family, we do not consume that much.*"[74]. This view was echoed by another informant who said "*The water purifier is expensive; it is good for large families. We buy the mineral water for 40-50 Afghanis which is purified."* [75] Overall, this narrative was common in both study sites among community members that big families would rely on one filter for drinking water, while most smaller families would rely on either bottled water or water trucks.

The qualitative analysis draws attention to two further complicating factors of household water treatment in Kabul: cost and rejected water from high-tech purifiers. The research participants alluded consistently to the economic situation of the household as the main reason for continuing the consumption of evidently bad-tasting and poor-quality water. A 38-year-old female informant made this point very clearly as she highlighted that her

[70] Doghabad is located in the Upper Kabul sub-basin. Excessive groundwater abstraction, consequent droughts and low river recharge rates had led to a significant drawdown of the water table.

[71] 210619_011_R1, Male, 23, Student, Bagrami

[72] 210619_007_R2, Female, 36, Homemaker, Bagrami

[73] 210520_002, Male, 25, Doghabad

[74] 210526_001, Female, 22, Student, Doghabad

[75] 210617_007_R1, Male, 32, Doghabad

poor household was forced to consume unclean water despite knowing the risks and for want of other financially viable alternatives:

> *Their water is not drinkable* [pointing to a neighbouring house], *also the same is this house in front of us. We bring water from this house* [pointing to another house] *and their water is a little better – it is not drinkable either, but we have to* [drink it]. (210619_006_R1, Female, 38, Bagrami)

Groundwater over-abstraction is a major challenge in Kabul city, beside the city has experienced several consecutive droughts which caused a significant drawdown of groundwater levels in the Doghabad region and central parts of Kabul city. Water scarcity constitutes an environmental factor (i.e., physical opportunity) that prompts new water behaviours, particularly in affluent households located in the Doghabad region and central parts of Kabul city. The research participants were referring to the amount of water that was rejected[76] by using high-tech filters as a concerning issue. Being acutely aware of wastage in a water-scarce environment, a 22-year-old student would explain for example how their household would start recycling the rejected water from their filter: "*The problem is that it has water waste. And we try to use the wastewater from the filter for washing dishes.*"[77]

Overall, this suggests that the use of high-tech water purifiers would require abstracting a larger amount of water for treatment which further limits access to water for poorer households who are solely dependent on groundwater.

Aside from spatial and economic gradients, also social factors and especially gender influenced the patterns of water treatment in the study sites (in COM-B terms, this would correspond to "social opportunity"). The analysis suggests that common household water treatment practices including boiling water, straining through a piece of cloth, and adding chlorine were performed by women since they are mostly responsible for household affairs, especially in peri-urban areas[78]. It would indeed be common to encounter

[76] An average reverse osmosis (RO) water purifier rejects approximately 3 litres of water for every 1 litre of purified water (Bestrowaterpurifier.in 2017).

[77] 210526_004, Female, 22, Student, Doghabad

[78] Brochures used during the qualitative interviews (see Supplementary Material 7.2) illustrated common forms of household water treatment including: straining through a piece of cloth, boiling, chlorination, solar

statements such as that, "*Our husbands say that* […] *we should boil water. We use gas, they say it's okay if we spend money on gas, but we should boil water before drinking, it will be purified*." – as expressed in this case by a 30-year-old female informant[79]. Other water-related tasks were reserved for men, such as washing the water tanker[80].

While common tasks related to clean water were therefore clearly gender driven, gender also influenced how individuals related to and thought about water – thus indirectly affecting reflective motivation underlying water treatment practices. The difference in male and female perspectives was visible across the interviews as men emphasized the expenses surrounding water treatment whereas women more heavily reflected on (e.g., health-related) experiences with and the long-term benefits of water purification. Respondents across both communities were similarly aware of these differences, for example, a conversation with a female resident of Bagrami indicated:

> *Sometimes my husband complains that we spend a lot of money on buying water since everyone is at home and all are jobless – thus I bought more water. I replied to him what should I do, it is better to buy water than going to the hospital.* (210619_009_R2, Female, 48, Homemaker, Bagrami)

Together this section provided important insights into factors that influence performing water treatment including residency, household size, economic status, high cost of water filters and gender – which are social and physical opportunity in terms of the COM-B model. Site-specific factors are also presented to be indirectly influencing automatic and reflective motivation. The new behaviour which is shaped by the use of high-tech water filters in combination with environmental factors is also presented which may unintentionally limit physical opportunity (access to water) for poor households.

7.3.3 Navigating and negotiating water treatment

It is established thus far, in this chapter, that locally specific forms of sensemaking and a wide range of associated practices and socio-environmental factors created a fragmented, individual-specific, fluid, and partly obscure landscape of water treatment options. This section explored a group of themes emerging from the qualitative analysis that help

disinfection, using sachets and tablets, sand filtration and using high-tech water purifiers. Participants were invited to comment on this range of options.

[79] 210617_012_R2, Female, 30, Homemaker, Doghabad

[80] 210617_004_R1, Female, 48, Doghabad

understand how individuals and households navigate and weigh these options. Reflective motivation has a dominant influence in this decision-making process on households' willingness to pay, navigate treatment options, and weigh water risks and household water treatment benefits. Also, the influence of psychological capability and physical opportunity was pronounced, especially in negotiating competing priorities and weighing the risk of contaminated water versus the benefit of household water treatment.

7.3.3.1 Weighing water risks and treatment benefits

A common view amongst interviewees was that they were generally inclined toward water treatment and deemed it a useful solution, meaning that the benefits of water treatment were widely understood. Local notions of water safety and treatment effectiveness were nuanced and grounded. For example, informants highlighted that boiling water was not wholly effective in killing bacteria and in purifying water in general, but for practical reasons they would still boil groundwater to attain at least *some* level of protection rather than none. Observing the digital water quality indicator of his advanced water purifier for boiled and raw water, a 28-year-old affluent resident of Doghabad concluded concisely that, "*Boiling water is not as effective as it is said to be, but it is better than raw water*"[81].

An indicator of health risks, which would also shape the concrete choice of water treatment, was the influence of pit latrines that households observed (or at least assumed) on groundwater contamination. Chlorine was distributed among the communities at the very early stages of water contamination in Kabul, but it was not used continuously by families who rather poured it in the well once every one or two months and at irregular intervals. As a consequence, many families did not observe the promised health benefits of chlorine purification and gradually stopped paying attention to chlorine as a means of water treatment. A 26-year-old shopkeeper from Doghabad described for example that, "*We didn't buy* [chlorine], *people were reckless in using chlorine in the wells* [years ago]. *Now, we observed and got familiar that* [water-borne] *diseases occur* [as a result of the inconsistent chlorine use]. *Thus, we bought a water purifier*."[82] Chlorine was also not suitable to address residents' heuristic markers of water quality – colour, and scum on tea. Community members perceived it to be ineffective since they did not observe

[81] 210508_006, Male, 28, Doghabad

[82] 210517_002, Male, 26, Shopkeeper, Doghabad

changes in water quality mainly through these sensory judgments, which would lead them to abandon the well water for drinking purposes. Among the portfolio of water treatment solutions, this household (in line with others interviewed) would therefore opt for a water filter rather than chlorine sterilisation based on bio-chemical contamination that produced – in their view – the concrete water health risk.

Aside from individual assessments of health risks, practical constraints also shaped households' water treatment practices (e.g., water boiling). Summertime in Kabul is when the incidence of water-borne diseases peaks, which would in principle (and even just by residents' observation of community public health) warrant widespread water boiling. However, community members expressed that water boiling was generally more common in winter. Especially low-income families without access to a fridge would not boil water during summer since it would take a long time to cool the water down and "*our children* [between 3 and 7 years] *do not drink boiled water*" [83]. The physical environment shaped these constraints and prevented in particular poor households from boiling water, thus contributing to water-borne disease occurrence despite households' explicit understanding of the water health risks.

Seasonality and environmental effects further influenced water quantity and quality, and these varying conditions in people's "physical opportunity" required them to routinely re-evaluate their water treatment options. Community members recalled how, during the occasional droughts in Kabul, they fetched only turbid groundwater from handpumps for domestic use, which in many instances provided the first impetus for them to start boiling their drinking water. This practice did not necessarily persist, however, as a 50-year-old man from Doghabad argued that, "*At that time* [of the drought], *we boiled water for six months*"[84] but the household would subsequently revert to their accustomed, untreated water use once the drought had passed after those six months.

Where circumstances invited the treatment of water, residents' reflective assessments of treatment options involving cost and efficacy considerations influenced the ensuing uptake patterns. These considerations were partly informed by past experiences and experimentation with different options. For example, community members who boiled their drinking water – a practice that was often sparked by drought-induced changes in water quality – were also more vocal in articulating the (at least theoretical) benefits.

[83] 210616_005, Female, 36, Homemaker, Doghabad

[84] 210508_001, Male, 50, Real estate agent, Doghabad

Similarly, a 45-year-old female homemaker from Bagrami explained how she experimented with chlorination to find that it did not meet her household needs. She described how "*We threw chlorine in the well several times but it did not change* [the water quality]*"*[85], and thus she discontinued its use for lack of effect. Such instances of experimentation and observation were common and informed community members' understanding and reflective decision-making process about water purification methods.

The research participants were thus aware of a range of solutions, and this also included high-tech water filters. However, observations across the study sites indicated a general lack of affordable and cost-effective products around Kabul and available filters with a price tag of USD 150 were deemed "*expensive*"[86] and widely unaffordable. Only a few privileged households that could afford such devices would be able to articulate (generally positive) opinions about their efficacy – describing the technology as "*easy, it has a machine, it does the filtering automatically and fills the container*"[87] and confirming that the filtered water is fit for drinking[88]. However, their costs made digital water filters essentially inaccessible and they therefore only played a marginal role in the broader landscape of water treatment solutions. Further complications around high-tech filters included the maintenance costs, and a 36-year-old female informant highlighted in this context that their household used the well water for cooking. She mentioned her perception was that the family did not feel the bad taste of water in food once it is used for cooking. This further helps them reduce water rejected from the filter and lower the filter's maintenance costs ("*We only use the well water for cooking because the taste would be unknown. The filter element needs to be changed every month.*"[89]).

The section, from a COM-B model perspective, indicated that reflective motivation and physical opportunity are interacting components. As illustrated, reflective motivation was a determining factor in the households on boiling water to attain at least some level of protection due to bio-chemically contaminated water (physical opportunity). In addition, the bio-chemical contamination of groundwater shaped the reflective and automatic motivation in assessing the efficacy of chlorination. And, lastly presented the residents'

[85] 210619_007_R1, Female, 45, Homemaker, Bagrami

[86] 210621_008_R1, Female, 32, Bagrami

[87] 210619_007_R2, Female, 36, Homemaker, Bagrami

[88] 210520_003, Male, 52, Doghabad

[89] 210619_007_R2, Female, 36, Homemaker, Bagrami

reflective assessment in navigating treatment options which involved the high cost of water purifiers.

7.3.3.2 Competing priorities and competing behaviour

The viewpoints shared by the informants demonstrated that the uptake of water treatment practices is not only subject to an absolute trade-off between the costs and benefits of using clean water, but it also stands in competition with other behaviours and priorities that the households face. To an extent, these issues were shaped by such factors as the household's economic status, its size, and their willingness to pay; but competing behaviours to water purification also included such practices as buying water from water trucks and establishment/expansion of private water supply networks.

The respondents routinely highlighted how household economic status would influence the performance of household water treatment, given that households have to make spending decisions under tight budget constraints – should their scarce money and time be devoted to producing clean water, to buying food, fuel, or medicine, or to rearing their several children including the associated household responsibilities of washing clothes, cooking, and maintaining the household?[90] A 35-year-old woman in Bagrami would for example explain that their household was experiencing water-borne diseases and that they received advice from the local doctor to boil their water, but they would just not be able to afford the time and fuel costs for doing so: "*We have stomach aches each day. If we visit the doctor, he says to boil water before drinking but we can't afford it.*"[91]. Adding to this point, another example was a 41-year-old community member who argued that "*We can't continue with boiling water*" to produce drinking water given that now people are being asked to "*buy gas for making food, tea and now boiling water*"[92].

Chlorine was distributed to the internally displaced people, the majority of whom were displaced to Kabul from the conflict-affected areas, and some lived in tents which were provided by international NGOs as part of temporary shelter efforts. In either case, these community members did not like the taste of chlorine, or did not perceive the health benefits of chlorine, or both. There were clear indications that, due to their low income following displacement, they sold the chlorine in the market or to other villagers to

[90] The trade-offs are not trivial: mothers would occasionally even have to miss prayers so as to be able to take care of their children and household responsibilities.

[91] 210619_008_R1, Female, 35, Homemaker, Bagrami

[92] 210617_009_R2, Female, 41, Doghabad

generate cash income. The payoffs might arguably be very low, but they could still afford them other priority needs. A side-effect of this process was that chlorine donated to specific communities tended to circulate into much wider channels:

> *My mother-in-law and another woman are providing us* [with chlorine]. *It is distributed to that area. The whole the area was tents and now they built small accommodations. It* [the chlorine] *is not for multi-story houses. Those people participated in the training and received chlorine. My mother-in-law gave us too, we didn't buy ourselves. I am not lying; it was only for people living in tents.* (210619_009_R2, Female, 48, Homemaker, Bagrami)

The quote above illustrates the acknowledgement of a 48-year-old female that the chlorine used at their household was not initially targeted for the area and she has received it from her mother-in-law who took it from the area near their residency. Furthermore, it is uncovering an environment where the targeted population for intervention may take part in the intervention only for the purpose of receiving incentives (free chlorine).

Where choices were possible, there was a sense of willingness to pay amongst the interviewees. Many community members were facing economic issues, but the majority expressed that their desire for accessing quality drinking water was high. A 63-year-old male research participant explained in this context that the households were willing to pay for a cost-effective purification technique in case the costs are affordable, considering their minimal income rate for a longer period and comparing it to the other existing methods which require daily expenditure:

> *Q: If this type of filter is made locally, for example, and suppose it costs 300 Afghanis, and it works for a year.*
>
> *R: For one year, we have to find 300 Afghanis and we can buy it. But we can't afford it if it's a tablet thrown in the well every day, boiling water, or, buying a filter for 13,000 Afghanis* [163 USD].
> (210520_004, Male, 63, Doghabad)

These findings have important implications for designing an intervention: When trying to promote specific practices under behaviour change interventions, it is essential to be mindful of the challenging trade-offs that households face, and the alternative routes that can lead them to the same outcome. The economic status of households led to difficult choices between water purification or other basic needs, but it also more generally influenced the decision-making process in making trade-offs between costs and benefits or purification – from a COM-B model point of view, the physical opportunity in combination with automatic and reflective motivation played a central role. For instance, as presented in previous sections, the high cost of water purifiers is determining its uptake as the households navigate in-between expensive versus inexpensive alternatives, whereby water trucks were less expensive compared to high-tech water purifiers and buying bottled water would compete with boiling scarce and difficult to abstract groundwater.

7.3.4 Discontinuities of water treatment behaviour

As the previous theme indicated already, the reflective uptake of water treatment does not ensure its continuation. Research participants from both study areas rather revealed how they became increasingly tolerant of water-related health risks, or how changing circumstances led them to re-assess benefits and risks, and gradually discontinued water treatment. The impact of electricity disruptions, physical opportunity (from a COM-B lens), on household water treatment practices are presented. In the last section, the impact of NGO's emergency interventions on performing household water treatment was highlighted.

7.3.4.1 Fluid landscapes of options, benefits, and risks

Among the aforementioned instances were the temporary uptake of water boiling for acutely ill children (i.e., offering temporary respite from health risks for specific household members), in the winter season (i.e., changing opportunities for water storage), and during drought periods (i.e., responding to temporarily visible markers of turbidity).

A yet more concerning facet, however, was a gradual adjustment of perceived health risks over time, which frequently sparked the cessation of treatment efforts. A 40-year-old tailor from the Doghabad area exemplified this situation with chlorine. The conversation about water treatment only after some time sparked his memory that, "*We used chlorine in the past. But now it has been forgotten and erased from our memories and I just remembered it.*" Asked why they discontinued it, he argued that, "*We are* [in general] *a little reckless people. We did not take it seriously and did not use it*"[93]. The fact that he deemed only the women in the household responsible for water treatment did remove him

[93] 210517_001, Male, 40, Tailor, Doghabad

somewhat from active considerations, but the note about their recklessness and seriousness suggested that, despite their awareness, they had become accepting of the risk involved in stopping chlorine treatment of their water. The exact notion of being "reckless" was in fact very common in narratives of discontinued water treatment, sometimes in relation to specific options within the treatment portfolio (e.g., boiling water because they were "*reckless*" about chlorine treatment[94]) and sometimes in active recognition of persistent health risks (e.g., "*I haven't boiled water since she* [the respondent's daughter] *got better* [recovered from the disease]. *I boil water only when she is ill. I got a bit reckless.*"[95]).

These discontinuities reminded the dynamic nature of human behaviour, the practical (and policy) consequence of which is that any behaviour change is unlikely to last for extended periods of time. Even where contextual changes continue to accommodate the behaviour (e.g., if people acquired fridges to store boiled water in summer), the gradually growing tolerance towards health risks is prone to subverting treatment practices over time, all else being equal.

7.3.4.2 Disruptions from energy sources

Another important household-level theme related to water treatment behaviour – correlated partly though imperfectly with wealth – was the available energy source for boiling drinking water and high-tech water purifiers. The research informants mentioned the most used energy sources for boiling drinking water were electricity, gas, wood, and in a few cases also plastic waste. While the latter clearly come with other health implications while helping to purify water, electricity as the most common fuel source for boiling exposed households to another set of problems: In the months during which the research fieldwork was implemented, frequent electricity disruptions were observed that interrupted not only families' access to water (through groundwater pumps) but also their water treatment practices[96].

Three main outcomes ensued: Firstly, most households also had to rely on gas for boiling their water. However, a 24-year-old female informant explained that it would not be

[94] 210621_007_R2, Female, 23, Bagrami

[95] 210621_005_R2, Female, 33, Homemaker, Bagrami

[96] Besides the usual electricity disruption due to an increase in demand specifically in summer; during the fieldwork there was an increase of armed conflict around the country. Pylons were bombed, cutting off electricity for millions living in Kabul and the surrounding provinces.

economically viable to boil water using gas for all household members, and indeed many community members would therefore only boil the drinking water for family members who were sick at that specific time. Secondly, poor families relied on fires made with plastic garbage for boiling drinking water, or otherwise on buying water from water trucks if available and affordable. This posed a problem of correlated constraints, however: power outages affecting the household also affected the companies supplying bottled water and water trucks. A resident in Bagrami recalled in this context that: "*The companies have the machine to filter water and at the time that there isn't electricity they won't sell water on the street thus we boil water* [groundwater]"[97]. The water supply more generally was therefore limited during those periods, and shifted towards the available stock of bottled mineral water. Lastly, where no other options would be available, especially poorer households would be pressed into fetching water from a public source located a far distance from their houses or would consume low-quality well water until the electricity situation stabilised. In such situations, a 24-year-old interviewee explained that they were simply "*supposed to consume it* [well water]."[98]

This section highlighted that the energy source, related costs and disruption in the energy supply source (physical opportunity, from a COM-B model lens) were determining performing household water treatment in Kabul and should be flagged as important in designing behaviour change interventions.

7.3.4.3 Efforts of the government to provide access to clean drinking water and raise awareness about water quality

In the interviews, community members typically valued the efforts of NGOs to improve the water landscape, but they also criticized the NGO approach of delivering interventions in the form of emergency response. NGOs' efforts were perceived as not effective in terms of preventing a problem rather than responding to a specific situation; that is, the water contamination in Kabul had been a major problem since 2004. Many programs were frequently delivered in responding to Acute Watery Diarrhoea (AWD) outbreaks, but until 2021 (the time of implementing my research fieldwork), this approach had not evolved towards the longer-term root causes of local water contamination and efforts were continually delivered under emergency response initiatives.

[97] 210621_001_R1, Female, 25, Bagrami

[98] 210621_003_R1, Female, 24, Homemaker, Bagrami

Reflecting the short-term emergency mindset indicated above, international donors and NGOs typically built on chlorination as the dominant intervention in humanitarian and emergencies. Chlorination in Kabul was promoted both in peri-urban and rural areas by different donor agencies, while there were no follow-up studies on the uptake.[99] An example representing this dominant theme was the experience of a 63-year-old informant from Doghabad who received chlorination tablets from NGOs for free but did not observe an improvement in water quality as a result:

> *Q: Did they bring to you these tablets?*
>
> *R: Yes, they brought it five or six years ago. They said to throw one in the well for a week.*
>
> *Q: Was it expensive?*
>
> *R: They gave it themselves* [for free]*; we did not buy it. It was in a bottle. Every week we threw one tablet in the well.*
>
> *Q: Did it improve the quality?*
>
> *R: I did not feel the quality was good or bad* [change in quality] *but we always threw* [the chlorine tablet].
> (210520_004, Male, 63, Doghabad)

The quote above also underlies a situation that the household that took part in the intervention not because they observed the benefit but were persuaded and somewhat coerced into nominal compliance. This coercion might not necessarily be the result of malevolent intent but could have resulted from well-meaning persuasive efforts that left communities unconvinced, financial incentives to participate where households struggle to meet ends otherwise, and/or as a form of social obligation towards the Wakil and Imam in the area as people would treat them with respect (and would wish to maintain their goodwill) and thus accept their invitations to take part in such programs.

Interventions in peri-urban and rural areas of Kabul mostly focused on low-income households or people who were displaced to Kabul, where the recipients were then provided with free chlorine to treat their water. The emergency response of local donors and NGOs in Afghanistan was thereby common knowledge: at the beginning of the year, the budget required for emergency response would be prepared by the water, sanitation

[99] This is unlike follow-up studies that NGOs delivered as "lessons learned" for improving their performance in delivering future interventions.

and hygiene (WASH) cluster of NGOs and donors led by UNICEF, together with the required materials to be used during the emergency events. The outcome would be a universal emergency solution for all existing and emerging problems during the budget period. The practical manifestation of this situation was experienced by the community members in Doghabad and expressed by a 48-year-female informant as follows:

> *Some young people from NGOs visited our streets and my father-in-law told them the problem* [taste and colour of water]*. Then they said that they will add chlorine into the well – the chlorine tablets. They did it, and it smelled* [of chlorine] *for one week. But it didn't help change the water's taste. It's been around a year since we stopped making the effort and thought it will not get better. Now, we buy water for drinking.* (210617_007_R2, Female, 48, Doghabad)

The short-term and emergency-based mindset of water purification programs delivered by NGOs and the government had thereby failed to respond to the concrete local causes of water contamination. The continuation of the problem thus created the unintended consequences of provoking the discontinuation (and likely impeding the trust in the viability) of household water treatment, specifically chlorination and aqua tabs.

Furthermore, the data analysis revealed that the governmental and non-governmental organizations (NGOs) have delivered programs for providing clean drinking water by digging deep wells. Yet, these organisations did not provide any information to the community members on the status of the water quality in the area – a problem that was so common that were repeatedly encounter resentful expressions like, "*No, no one came. Nobody told us about water problems*."[100]

From a process perspective, these problems indicate that community members were not usually included/consulted in the design stage of programs (particularly the emergency response). Only village leaders and imams were at times involved in delivering programs including household water purification campaigns., but their participation would also create trust issues in program uptake since the Wakil and Imam would usually be paid to promote the programs and to provide an environment for the successful delivery of

[100] 210617_006_R2, Female, 54, Doghabad

interventions[101]. Although the Imam and Wakil were respected authorities among the community members, they would neither be able to represent the diverse voices of local communities, nor would they be universally trusted – reports abound of patronage and favours, particularly at the time of distributing donations from NGOs to the community members.

Issues related to lack of access and disparities in understanding household water treatment were prominent in the interview data. Concerns exist that people moving to Kabul who are usually affected by war or flee from their provinces due to natural hazards are having the least understanding of household water purification techniques. The disparities and lack of awareness could be due to exclusions happening at the initial stage of the design of interventions for remote areas and considering the security threat as a barrier to smoothly delivering a full-scale program. The majority of the programs in remote areas aimed to raise awareness were usually designed to be delivered quickly and mostly without overnight staying, a day visit. The initiatives that would require long-term effort like building infrastructures (water reservoirs, handpumps, wells) for increasing access to clean drinking water were instead outsourced to local companies.

7.4 Discussion

As a basic need for daily life, access to clean drinking water is a human right (UN 2010). Systematic reviews of WASH interventions have shown the impact on reducing diarrhoeal diseases and microbial contamination (Wright et al. 2004; Fewtrell et al. 2005; Clasen et al. 2015; Martin et al. 2018). In response to the surprising weight put on psychological factors in the behavioural water literature, the objective of this study was to explore the factors determining household water treatment from a COM-B model perspective in Kabul, Afghanistan.

This qualitative study to this end built on 68 semi-structured interviews from two study sites in Kabul. In a semi-arid peri-urban context characterized by high levels of water contamination and frequent spells of water scarcity, water was primarily sourced from privately owned sources in the household (well/hand pump), public water sources (well/hand pump), bottled water, water trucks and private supply networks. The range of options for water treatment in this context comprised boiling water, high-tech water

[101] The duties of Wakil and their relationships with administrative corruption is studied by (Razaq 2013).

filters, sand-filtration, chlorination and solar disinfection. However, the adoption of these sources was not straightforward. The thematic analysis uncovered the nature of local water realities being shaped by a scattered information landscape that was dominated by interpersonal communication and inequitable formal sources of water-related information, which necessitated residents to rely on sensory and heuristic markers as well as observation of health outcomes to judge water quality. Hu et al. (2011) found that U.S. consumers are more likely to report bottled water as their primary drinking water source when they perceive that drinking water is not safe. Associated practices of water storage, gender norms, and environmental, epidemiological, and economic variability introduced further complexity into households' portfolios of plausible water treatment options. The uptake of these options followed not a mere one-off decision but rather resembled the navigation of a complex, idiosyncratic, and obscure landscape of benefits and costs that were not only constantly changing but also stood in competition with other livelihood priorities. Complicating things further were the presence of behaviours that made water treatment obsolete (e.g., buying clean water) and external interventions that imposed specific water treatment solutions onto local communities without regard to their underlying behaviours (and their enablers and barriers) and the long-term development of water sources.

From a COM-B perspective, these findings highlighted that psychological factors such as reflective motivation do play an evident role in performing household water treatment. For example, residents demonstrated a clear reflective weighing of benefits and costs when choosing to boil water, indicating awareness of water-borne diseases and even in some cases microbial contamination, articulating expectations of the relative efficacy of boiling to purify water, and making reasoned decisions thus to attain at least *some* level of protection. Families' experience of water-borne diseases in many cases triggered boiling water before drinking, and especially mothers appeared to be vigilant about water-borne diseases and provided boiled water to children below the age of five in most circumstances despite the fact that it was often challenging for low-income families. Psychological capability more fundamentally (e.g., ability to read and write, or the ability to make specific decisions or perform behaviours), however, did not appear to shape water treatment practices considerably – at least not as far as this qualitative data enabled me to discern.

A range of other factors also influenced water treatment behaviours – both psychological and contextual, and both directly and indirectly. Among other psychological factors were elements related to automatic motivation; that is, those relating to the habit and impulse systems of the brain. These powerful yet often muted elements directly related to the water realities experienced by Kabul residents, where sensory markers and experiences with water-borne illnesses (both of which have strong emotional dimensions) dominated the everyday experience with water and subsequently also featured in assessments of the efficacy of such water treatment options as chlorination.

Contextual factors stood out as well. Among them, social opportunity factors had an indirect influence on behaviour *via* reflective motivation as it shaped how households could navigate the landscape of the types and nature of water-related information surrounding them. Gender norms also influenced reflective motivation insofar as the social realities of water use shaped the frames of reference with which to evaluate water treatment practices – with cost considerations dominating in the case of men, and personal experiences and longer-term considerations of benefits and costs being more pronounced among women. As a directly influencing factor, gender norms as a social opportunity factor also determined who would perform specific water-related behaviours (e.g., men scrubbing water storage tanks while women boiled water).

Physical opportunity as another dimension of context was similarly pronounced. People's residence clearly shaped the local quality and the need for water treatment, as well as available drinking water options (e.g., if private water networks were at all available). Yet more pressing for people's water treatment behaviour were factors related to the epidemiological, infrastructural, and environmental context, with water-borne disease outbreaks, power outages, and droughts contributing especially to the dynamics that prompted uptake and discontinuation of water treatment options in the two study areas. If nothing else, the passing of time alone led residents to re-evaluate water treatment as they gradually became more tolerant of water-borne disease risks. In contrast, physical capability factors such as age and bodily functioning did not feature as notable themes in the analysis.

In combination, contextual factors in the physical and social environment also determined the environment in which families may not only weigh the direct benefits and costs of water treatment but have to consider altogether competing priorities as well. The uses of scarce fuel, limited household budgets for food, and the time requirements to raise a family and maintain the household all added to the challenges in navigating and negotiating water treatment options. But not only priorities competed with water treatment. Another useful consideration implicit in the COM-B model, namely that the B (behaviour), also drew attention to practices that would make household water treatment redundant, which again were shaped by different contextual and psychological elements. A site-specific competing behaviour in Bagrami was for instance buying already clean water from water trucks, which emerged as the main source of drinking water because community members could not consume saline groundwater (sensory quality markers triggering automatic motivation) and purchasing advanced water filters was not affordable for many (physical opportunity).

However, the COM-B model also has limitations as less readily discernible – yet qualitatively pronounced – factors in the study sites related to the political influence on the water treatment portfolio. The delivery of water purifying interventions by NGOs and the government which were designed for the short term and with an emergency mindset had unintended repercussions including the discontinuation of using chlorine for household water treatment. Further, the role of incentives and social obligation (i.e., respecting the request of Wakil or Iman) in making the households take part in interventions were important factors shaping the temporary but favourable environment for delivering interventions.

In relation to past research, the findings of this study resonate with Daniel et al. (2020; 2021) and Dreibelbis et al. (2013), who stressed the influence of socio-economic, contextual, and technological factors besides the psychological drivers on performing household water treatment. However, those approaches are limited by looking through the lens of other limited existing models, whereby for example the RANAS model is only focused on psychological factors. IBM-WASH is a relatively broad and encompassing model that does not specify factors and lacks a specific definition and clear analytical framing of water-related behaviour.

Yet more importantly – and in light of the research objective – the critical role of contextual factors, competing priories, and alternative behaviours in this qualitative study are contrary to those studies that foregrounded and privileged the influence of psychological factors (Mosler 2012; Inauen et al. 2013; Mosler and Contzen 2016; Lilje and Mosler 2017; Lilje and Mosler 2018). While it is plausible that contextual factors may have remained invisible as they could exert an indirect influence on psychological drivers of behaviour, their salience in this study calls for a research agenda into the missed contextual dimensions of water-related behaviour in other geographies (and ideally through interdisciplinary research teams), even where psychological drivers had previously been detected. The severity of accidentally omitting contextual drivers of water-related behaviour should not be underestimated. For example, only relying on psychosocial factors in promoting chlorine as presented in Lilje and Mosler (2018) would not lead to successful intervention in Kabul as it would remain unresponsive to site-specific challenges, inefficacy in addressing chemical characteristics of water quality (e.g., salinity and yellow colour), competing behaviours and priorities, historical experiences of ineffective chlorine interventions, and the necessary involvement of community members in the design and implementation phase of intervention.

A behavioural analysis through the COM-B lens therefore helps to formulate practical routes to improving clean water use in Kabul that are more faithful to local realities. Specifically, effective potential interventions for improving household water treatment in Kabul should consider involving community members, village/city district heads and religious scholars (social opportunity, automatic motivation [legitimate "messengers"]) from the design process to the implementation phase. Another important dimension to target is motivation (both automatic and reflective) and physical opportunity by providing an effective technology that shall bypass the stressors like electricity disruption and should not only be affordable but also has efficacy in removing contaminants, and addressing sensory and contextual makers of risk from drinking water.

The limitations of this research pertain to the delivery of semi-structured interviews during the intense conflict period around Afghanistan (May to June 2021), which had a small effect on the depth of the research as some participants declined participation due to security concerns. Further limitations included the COVID-19 restrictions in force during the fieldwork, which also slightly impeded otherwise unfettered interactions. Nevertheless, every effort was made to include diverse voices in the sampling strategy (e.g., by following local customs and interviewing participants in light of prevailing gender norms) and were able to replace residents who declined the invitations through individuals with similar characteristics. Further, this research was interview-based as opposed to long-term observational research, which is liable to post-hoc reasoning as respondents may make sense of decisions only after they actually made them (Smith 2008). While this is an issue in any interview-based qualitative and quantitative research (e.g. surveys based on recalled responses), its potential impact was mitigated as the research implementation was led by myself, a local Afghan scholar, who was familiar with the local water environment, who engaged in broader questions that would shed light on the context and decision-making processes without requiring people to directly state what drove them in a particular situation, and who complemented the interviews with non-participant observations of the local setting during the fieldwork. Lastly, the sampling strategy involving two distinct peri-urban areas in Kabul metro also means that the results cannot speak easily to rural areas outside Kabul and those peri-urban with different contextual and environmental characteristics. While this limits the specific empirical findings, the methodological approach of COM-B-based behavioural analysis to uncover psychological as well as other individual and contextual drivers of household water treatment practices is applicable more broadly.

7.5 Conclusions

Microbially contaminated drinking water is a global challenge. To promote acceptance and regular long-term usage of household water treatment solutions, the “hardware” must be accompanied by a comprehensive behavioural change model. This chapter is based on 68 semi-structured interviews in two peri-urban study sites in Kabul to explore the factors determining household water treatment practices from the perspective of the most comprehensive behaviour change model (COM-B). It is established in this research that psychological factors such as reflective motivation play an important role in performing household water treatment. An aspect of context that was prominent was the physical opportunity, the location of people’s residences unequivocally shaped the local quality and the need for water treatment, and alternative drinking water sources (e.g., if private water networks were at all available). Factors related to the epidemiological, infrastructural, and environmental context were even more crucial for influencing people’s household water treatment practices. For example, water-borne disease outbreaks, power outages, and droughts particularly contributed to the dynamics that prompted the adoption and abandonment of household water treatment options. Contextual factors were documented, for example the social opportunity factors had an indirect influence on behaviour via reflective motivation as it shaped the types and nature of water-related information that was available to households. Physical and social environmental factors were presented that influenced the environment in which families may not only weigh the direct benefits and costs of water treatment but had to consider altogether competing priorities as well. The uses of scarce fuel, limited household budgets for food, and the time requirements to raise a family and maintain the household all exacerbated challenges in navigating and negotiating water treatment options. The findings of this qualitative chapter through the COM-B lens revealed that its six dimensions help to formulate practical routes to delivering household water treatment intervention which is faithful to local realities.

Supplementary material

Supplementary material 7.1 Water information landscape in Kabul communities.

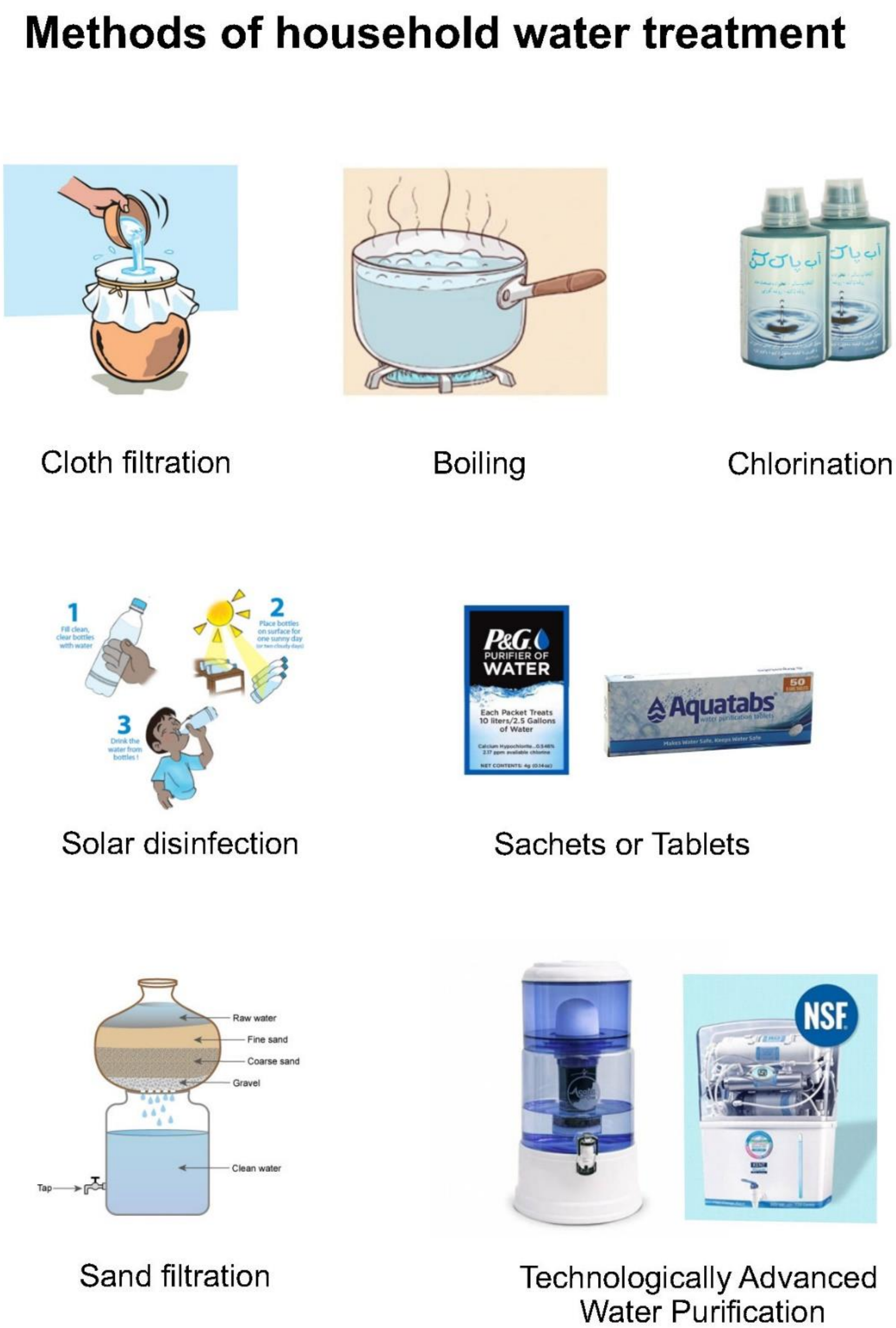
Table S7.1 Water information landscape in Kabul communities.

Source	Explanation *Situation, context, mode*	Type of informatio n on water purification	Patterns of inclusion and exclusion
Doctors	Spoken information Doctors (from the health centre, pharmacists, and hospitals) and NGOs hired staff to visit specific areas No preventive campaigns – information is only provided if the patient visits the doctor.	Using mineral water Purify water Boiling water Chlorination Water quality status in the area	Included: Severely ill people, at least once experienced Excluded: less server experience of waterborne disease, healthy people, people with other of type disease, disabled people, very old people who cannot visit the doctor
TV	Advertisements – usually broadcasted in the evenings when most of the household members are at home The advertisements were delivered in form of animation or 10-minute tutorial videos The content included information on the waterborne disease, prevention techniques and a demonstration of the methods and frequency	Boiling water Water filters Chlorination	Inclusion: People having access to TV, access to cable networks, people who have a house Execution: People who do not access TV, people who do not use TV, IDPs who used to watch local TVs or did not have access to TV
Relatives	Spoken information The exchange of information takes place between household members, and relatives visiting each other. The information could include both demonstrations or only word of mouth	Chlorination Water filters (encourage using and information on prices) Water quality	Inclusion: a member of the household and close relatives
Broader community	Spoken information These meetings or conversation takes place at the shops, bakeries, and people setting on	Water quality Water filters	Inclusion: People working, or having a small business (shops) in the

	the street during their free time, on the handpump (men-to-men, women to women) or at the mosque (usually men). Other community places, clinics, sports halls, schools or funeral ceremonies.	Chlorination Using salt in the well	community, part-time employees. Exclusion: People working in the city, full-time employees.
NGOs and Government	Humanitarian project-based targeted campaigns for vulnerable areas (water quality contaminated). The activities take place by visiting schools, people's houses, a group of people or community leaders. The information is delivered through demonstrations and also other means such as distributing brochures or installing banners *Usually, the programs implemented by NGOs are coordinated or aligned with government activities*	Chlorination Purification using Tablets Purification using sachets	Inclusion: a specific area, availability of household members, school students of specific age or grade Exclusion: Households who are temporally away, women of certain households who will not open the door for strangers, households that do not have school students
Commercial sources	Shops, distributors in local areas, and maintenance staff The above-mentioned spread information about the filters for increasing sales and are mostly speaking of the filters' benefits	Water filters	Targeted campaigns take place by companies.
Imam (religious leader)	Spoken information at the time of prayers – *obligated by religion to speak about community problems, especially on Fridays - is the peak of the participation rate.*		Inclusion: Male Exclusion: Female
Wakil (village leader)	Spoken information *Wakil is in close coordination with the imam for spreading information regarding the issues in the community.*	Water quality	Inclusion: Visitors of the wakil's office, mostly men. The fact that almost all wakils are men. Exclusion: Women

Source: Author, based on research fieldwork.

Supplementary material 7.2 The brochure of the methods for household water treatment, it was used during the interviews.



Chapter 8

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Mohammad Daud Hamidi was responsible for conceptualization, data collection, data analysis, methodology, visualization, writing original draft, review and editing. MJH and MV (my co-supervisor) contributed through discussions on setting up methodology and analysis, review and editing. HCG contributed through supervision (my primary supervisor), resources, review and editing. As the main author, I would like to thank MJH, MV, and HCG for their helpful discussions and priceless suggestions.

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8 Determinants of Household Safe Drinking Water Practices in Kabul, Afghanistan: A Quantitative Survey Study

8.1 Introduction

At least 2 billion people worldwide consume water that has been contaminated with faeces, and microbiological contamination due to faecal contamination is the biggest threat to the safety of drinking water (WHO 2022). Data from the World Health Organization (WHO) indicates that in 2019, diarrhoea was the eighth highest cause of mortality, accounting for more than 1.5 million deaths worldwide (WHO 2020). Waterborne disease is one of the largest contributing factors of mortality among children under the age of five in Afghanistan where one out of every four children is estimated to die before reaching five years of age (UNICEF 2021).

An assessment of point-of-use water treatment technologies by Sobsey et al. (2008) suggested that ceramic and biosand household water filters are the most effective and practical tools for providing sustainable drinking water in low-and-middle income counties. The study suggested that the aforementioned household water filtering methods have the most potential to be adopted broadly and provide sustainable access to clean drinking water to prevent the spread of disease and reduce mortality from waterborne diseases (Sobsey et al. 2008). However, research has repeatedly emphasised that simply offering household water treatment solutions is usually insufficient and the “hardware” must be accompanied by a comprehensive behavioural change model to foster adoption and regular and long-term usage (Sonego et al. 2013; Lilje and Mosler 2017). A “comprehensive behaviour change model” differs from “capacity-building” by encompassing more than just enhancing knowledge and skills. From a COM-B perspective, a comprehensive behaviour change model extends beyond “capacity-building” by considering the broader aspects of capability, opportunity, and motivation. It integrates efforts to enhance knowledge and skills (capability), create supportive environments (opportunity), and influence attitudes and motivation (motivation) to drive meaningful and sustainable behaviour change in the adoption and utilization of technology.

To better understand the factors influencing water, sanitation and hygiene (WASH) behaviour and to increase the uptake of WASH interventions, several theoretical frameworks with varying degrees of specificity have been developed. Recent systematic reviews, for instance, proposed the comprehensive and open-ended Integrated Behavioural Model for Water, Sanitation, and Hygiene (IBM-WASH) by taking into account psychosocial, contextual, and technological dimensions of WASH-related behaviour at different levels spanning the societal/structural, community, household, individual, and habitual levels (Dreibelbis et al. 2013; Martin et al. 2018). Although this assortment of components seems realistic, their exact manifestation is still unclear and their true scope is disputed. According to several scholars, socio-psychological variables, rather than contextual factors, are the primary predictors of household water treatment behaviour (Lilje and Mosler 2017; Lilje and Mosler 2018). This argument underlies one of the currently leading approaches to WASH-related behaviour change, namely the RANAS (Risks, Attitudes, Norms, Abilities and Self-regulation) model. The primary behavioural factors influencing WASH and environmental health practices in low- and middle-income countries, according to this model, are risk, attitude, norm, ability, and self-regulation (Mosler 2012). From a more broad-based viewpoint, it may come as a surprise that the prevailing RANAS model places greater emphasis on psychological elements with less regard for context-specific socio-economic and cultural determinants of behaviour.

Michie et al. (2011) conducted a ground-breaking systematic review of behaviour change techniques that recognised the importance of social and contextual factors in behaviour. The authors, therefore, proposed the "behaviour change wheel" (BCW) (Michie et al. 2011), which responds to enablers and barriers to a behaviour (such as water treatment) across three main dimensions: Capability (physical and psychological), Opportunity (physical and social), and Motivation (reflective and automatic), which together form the COM-B system. In contrast to approaches dominated by concepts of reflective decision-making, the domains of the COM-B framework also recognise, for example, that people make impulsive or habitual decisions without necessarily being aware of the decision-making process, or that social norms and even the design of physical and social spaces can influence whether decisions can be made at all (Webb and Sheeran 2006).

Although the BCW does not specify particular factors that affect behaviour, it does provide an exhaustive range of conceptual domains for analysis, and its widespread application around the world has assisted in the development of a body of knowledge about contextually sensitive behavioural drivers (and the ensuing interventions to change behaviour) in a variety of areas, such as public health, personal finance, or energy consumption (French et al. 2012; Michie et al. 2014; Steinmo et al. 2015). Two studies in western Kenya, Ellis et al. (2020) and Ewart McClintic et al. (2022), which used the COM-B model to identify variables influencing the adoption of nutrition and WASH behaviours, revealed that a severe lack of social and physical opportunities were the biggest hindrances to performing the behaviour. Studies like this show how the COM-B model may be applied to behaviours related to water consumption and how the model could be used to provide insights into the relative importance of contextual and individual elements involved in behaviour change with a particular look at water treatment for encouraging safe drinking practices.

Previous quantitative studies on the factors determining household water treatment emphasized the psychological determinants through the RANAS behaviour change model including Sonego, Huber, and Mosler (2013); Mosler, Blöchliger, and Inauen (2010); and, Mosler, Huber, and Bhend (2011). While developers of the RANAS behaviour model have undermined the importance of including socio-economic and contextual factors in water-related behaviour models (Lilje and Mosler 2017; Lilje and Mosler 2018), a recent study has highlighted the significant association of socio-economic factors with performing household water treatment through a lens of RANAS relying on Bayesian Belief Network (BBN) modelling (Daniel et al. 2019; Daniel et al. 2020; Daniel et al. 2021). Recent qualitative research on determinants of household water treatment suggests the importance of interpersonal contact and social support (Tamene 2021). A qualitative study in Northwest Ethiopia by Bitew et al. (2020) documented the barriers to implementing household water treatment (solar disinfection) including socio-cultural (i.e., inadequate information, parents paying less care), environmental (i.e., turbidity, geographical setting) and behavioural (i.e., mishandling treated water).

While the aforementioned studies on the factors determining household water treatment are dominated by RANAS and existing WASH models, for the first time, this chapter will build on the most inclusive definition of behaviour using the COM-B model. Before applying the quantitative approach to the study sites, this qualitative analysis and observation from a COM-B model perspective have revealed that contextual factors (physical and social opportunity) as well as motivation (automatic and reflective) appear to play an important role in performing household water treatment (see Chapter 7).

The main objective of this study was to gain a comprehensive picture of the range of socio-economic, psychosocial and contextual factors influencing household water treatment behaviour in Afghanistan. Although the direct comparison of the two sampling sites themselves is not the main focus of this survey study, their specific characteristic will likely play an important role in understanding contextual variability underlying household water treatment.

8.2 Materials and methods

8.2.1 Research design and study setting

This study aimed to investigate the factors influencing the performance of household water treatment in two peri-urban communities in Kabul, Afghanistan. The relevance of choosing Afghanistan as a priority setting for water treatment behaviour becomes clear in its worrying child mortality statistics, the rate of mortality among children under the age of five was reported at 58 per 1000 live births in the year 2020 and the proportion of the population living below the National Poverty Line (less than $2 income per day) was 49.4% in the same year (ADB 2022).

Within Kabul city, the study sites were selected due to their high rate of water-borne disease and their ethnically diverse populations (note that the study was not designed to compare two study sites specifically but to draw on their contextual variability in informing water treatment behaviours). The peri-urban districts of Doghabad and Bagrami located in the Kabul metropolitan area have an approximate total population of 150 000 (3.7% of Kabul metro with a total population of 4.1 million as of 2020). Doghabad with 50 000 people population was characterized to have high microbially contaminated water. Bagrami has a population of 100 000 people and the water in the area is saline (CIESIN 2018; NISA 2020). The prevalence of water-borne diseases reported by KMARP (2018a) in Doghabad was Amoebic dysentery and Salmonellosis. In Bagrami, the range of disease prevalence was broader, including Amoebic dysentery, hepatitis A, typhoid & Paratyphoid, Shigellosis, and Salmonellosis. Continuing conflict across Afghanistan also had a significant influence on household welfare at the time of the fieldwork (1-10 July 2021).

To study water treatment behaviour and its drivers, a cross-sectional cluster random survey was implemented in the two neighbourhoods located in Kabul, Afghanistan. A two-stage sampling design was used which involved first the purposive selection of the two study sites, followed by a probabilistic and satellite-aided selection of households (one respondent per household). A sample of 497 households in Doghabad and 416 households in Bagrami were thus included in the study to represent the general adult population of Doghabad (50 000) and Bagrami (100 000). In the broader mixed-method research design of this project, preliminary qualitative research preceded the survey in order to identify relevant water treatment behaviours and to establish the relevance of COM-B as a suitable framework in peri-urban Kabul (for more details see Chapter 7).

8.2.2 Sampling

Afghanistan has been unable to perform a nationwide population and housing census since 1979 due to decades of insecurity, which required the collection of original survey data while facing the common challenge in low- and middle-income country research that sampling frames are often missing. A two-stage survey design was utilised with a first purposive selection of the two study communities. Official government population numbers are mostly based on forecasts from the 1979 baseline (UNFPA 2020). Therefore, the site selection was built on a secondary set of data from the Kabul Managed Aquifer Recharge project (KMARP 2018a) that reported the types of water-borne diseases and the number of people served by health centres. Two peri-urban sites that had a relatively high rate of water-borne diseases were selected. Other factors that influenced the site selection were the distance of the peri-urban area from the city centre and the distance from a local police station so as to ensure the safety of team members in receiving a quick response and rapid evacuation in uncertain situations.

The second stage of probabilistic household representative selection in the two study sites had to respond to the problem of missing sampling frames. However, the recent advances in global position systems (GPS), geographic information systems (GIS), and remote sensing (RS) technologies provided a unique opportunity for constructing an effective spatial sampling design that was capable of overcoming this constraint (Galway et al. 2012; Haenssgen 2015; Johnson 2019; Hoogeveen et al. 2020). Following Grais et al.

(2007), Kumar (2007), Shannon et al. (2012), Flynn et al. (2013), and Cajka et al. (2018), ArcGIS 10.8 was used (ESRI 2021), whereby the second-stage sampling process involved GIS software using high-resolution satellite imagery provided by the Afghanistan National Statistics and Information Authority (NISA) and an Open Street Maps layer. The two peri-urban sites were divided into grids of 600 × 600 m, the centre of which was set as starting point for a sampling cluster. All the surveyors were deployed to the starting point. From the starting point, the closest house was interviewed first, and each house on alternating sides of the following streets was invited to participate in the survey until the survey team would arrive back at the starting point in the grid.[102] The sampling grids are shown in Figure 8.1. A double monitoring procedure was established to ensure that households are surveyed by the enumerators. Surveyors monitored each other's work and a supervisor was also monitoring survey teams to ensure smooth delivery of the survey and their safety. Additionally, the survey team regularly reported to the survey team leader to monitor the progress and quality of the survey.

One household member (over the age of 18) from the eligible households in the two sampling areas was invited to take part in the survey study. Data collection was carried out through a face-to-face 63-item questionnaire, administered using the offline survey software *Qualtrics* (Qualtrics 2020). The data were collected in June 2020. A group of 17 surveyors (12 female and 5 male) were locally recruited by Kabul University and received 3 days prior training on the procedures of delivering the survey on site. The 63-item questionnaire was translated from English to local languages (Dari and Pashto) and back-translated following best-practice recommendations for this type of research (WHO 2010).

[102] The driving rationale behind this close clustering of houses was the unstable security situation of Kabul at the time of the survey. As the survey did not capture geolocations and starting grid points, this sample is treated as a random walk in the remainder of this chapter but are conscious that a small degree of spatial correlation may influence the clustering of standard errors.

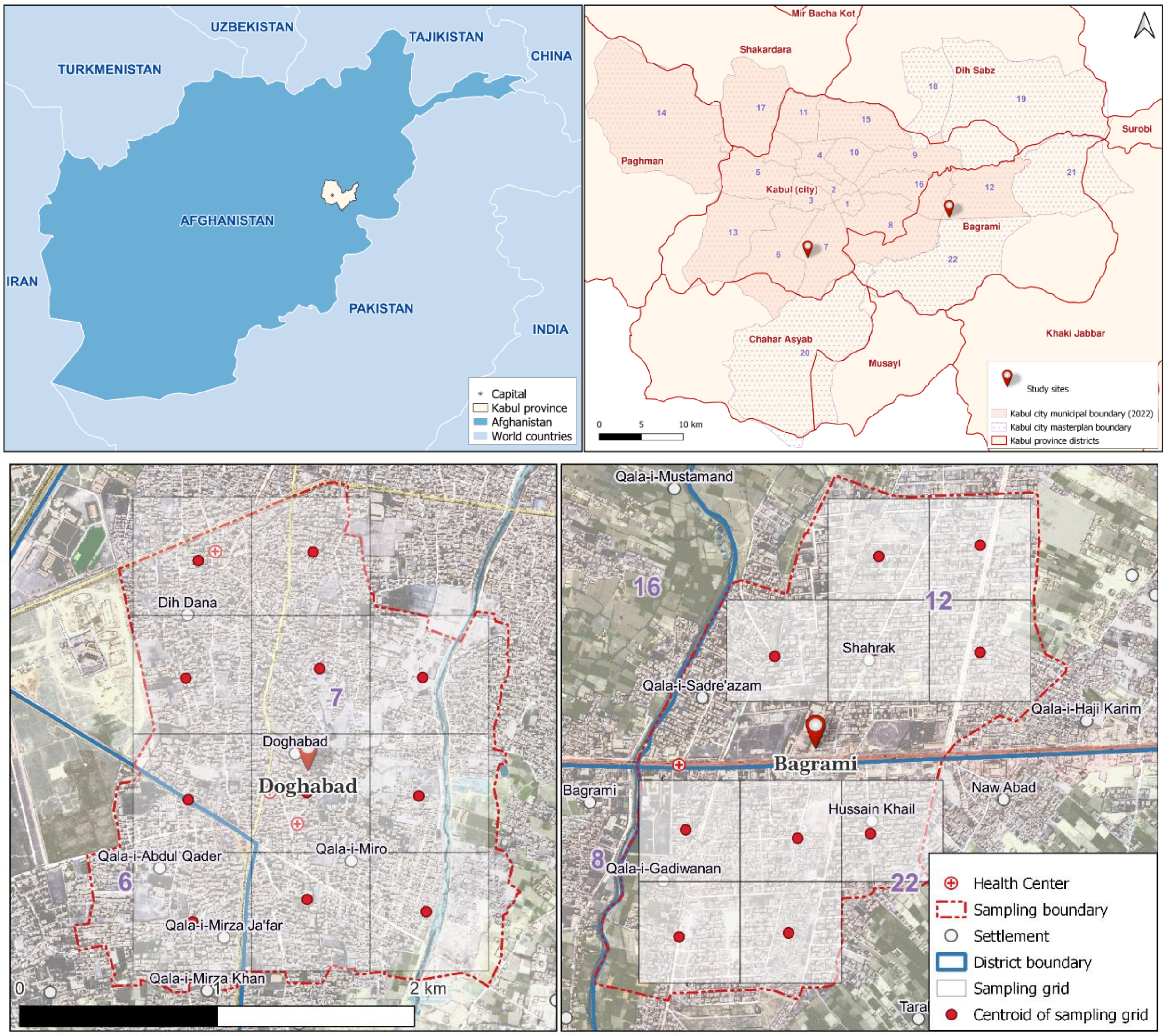

Figure 8.1. Study area map and sampling grids.

Both languages were available in the survey software as well. The questionnaire was piloted before the survey to ensure that the questions were sufficiently simple and understandable for residents in both study areas (the process resulted in minor changes of question-wording, but not question focus or questionnaire structure). Oral consent was recorded from all participants of the survey. The questionnaire was filled out either in Dari or Pashto, depending on the preference of the interviewee – where a participant had a low or no-literacy, they were assisted by the surveyor in reading/filling the questionnaire.

8.2.3 Data collection

The questionnaire (see Supplementary Material 8.1) was informed by the existing literature on access to water and household water purification practices from Mubarak et al. (2016), Sigel (2009), UNICEF/WHO (2006), and Wutich (2006). Existing behaviour change frameworks that were adapted for this survey included research by Michie, Atkins, and West (2014), Ochoo, Valcour, and Sarkar (2017), Addo, Thoms, and Parsons (2018), Lilje and Mosler (2018), and Slekiene and Mosler (2019). The questionnaire had 7 sections: 1) Water use and storage, 2) Knowledge of water quality, 3) Knowledge of health risks from poor water quality, 4) Water treatment in the household, 5) Knowledge of water treatment techniques, 6) COVID-19 related questions, and 7) demographic information. The questions started with the main source of water, water consumption and storage practices at the household level. A household was defined as a shared kitchen and a residence of at least six months prior. The questionnaire followed the household's understanding of water quality and the knowledge of health risks due to poor water quality. Further, the research participants were asked about their understanding of water treatment practices and knowledge of water purification techniques. Before the last question, participants were asked about the impact of COVID-19 on their performance in household water treatment since the study was conducted during a period of the COVID-19 pandemic. Lastly, details on participants' demographic backgrounds were collated. The questionnaire items included in 7 sections, aforementioned, were mapped into the six COM categories of physical and psychological Capability, physical and social Opportunity, and reflective and automatic Motivation (for details see Supplementary Material 8.1). Additionally, among the items of the questionnaire 6 household water treatment behaviours were identified. Qualitative research prior to this survey helped me establish the relevance of these dimensions.

For ethical approvals, all materials for the quantitative survey were translated and back-translated following WHO (2010). The ethics application was approved by the Psychology Department Ethics Sub-committee at Durham University (Reference: ES-2020-01-10T14:40:38-lgww95). As part of project governance Kabul Police headquarters, the head of the city district/village, the Imam of the mosque in the area, and the local division of Kabul police were informed about the conduct of the survey (see Supplementary Material 5.4).

8.2.4 Analysis

This study used descriptive statistical analysis and regression analysis to identify the role of "COM" factors (Capability (physical and psychological), Opportunity (physical and social), and Motivation (reflective and automatic) associated with six identified household water treatment behaviours "B" among the population sample so as to complement existing household water treatment intervention behaviour change models. The interpretation of the findings was grounded in the extensive qualitative research that preceded the quantitative survey. The analysis was divided into four stages:

Stage 1. **Study site context:** In the absence of detailed and current contextualising sources such as administrative statistics and secondary household survey data, an overview of the demographic and socio-economic situation was developed in the study sites based on the primary survey data. The site contextualisation process used descriptive statistical analysis on the household and site levels.

Stage 2. **Overview of the existing situation on household's access to water, water storage and water treatment practices:** This stage highlighted the current state of access to water, and the dominant water storage and water treatment practices in the households. This section will help situate the subsequent analysis of factors influencing the performance of household water treatment behaviour. This stage involved descriptive statistical analysis of the household and site levels.

Stage 3. **Overview of COM factors determining household water treatment:** This step was analysed through bivariate analysis of the COM (Capability, Opportunity, and Motivation) factors associated with the performance of household water treatment. Each individual COM element in the COM-B framework was normalized and coded such that a value of [0] considered the element "disabled" and a value of [1] considered as "enabled" for the water treatment behaviour in question (for non-binary variables, this would correspond to a scale from [0] to [1] – from full disablement to full enablement). The item responses were normalized in accordance with Eq. 8.1:

$$X'_i = \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (8.1)$$

Where X'_i is the normalized value of X_i (Witten et al. 2016). The elements were then aggregated into the six COM dimensions by averaging the normalized individual indicators into COM-indices that again range from [0] (*i.e.,* dimension fully disabled) to [1] (dimension fully enabled).

The mean values and 95% confidence intervals of item responses categorized in COM-B dimensions for each study site were specifically presented and overall to characterise the configuration of common behavioural drivers in the study area. Furthermore, the significance of the difference in responses for each item between the two study sites were compared, and for this purpose, the Pearson χ^2 test for categorical variables and the Student's *t*-test for continuous variables were used.

Stage 4. Relationship of "COM"-B model dimensions to performing household water treatment behaviours ("B"): The final stage of the analysis examined and compared the relationship of the "COM"-B model dimensions (Capability, Opportunity, and Motivation) to the six identified household water treatment behaviours (B) as dependent variables. As a first step, the bivariate analysis of the COM drivers of water treatment behaviour is presented. Following bivariate analysis, regression analysis is utilized to study the relative contribution of each COM dimension to each of the six identified behaviours. To reduce complexity, the regression analyses only considered the six aggregate dimension indices (as opposed to the 37 disaggregated elements) as independent variables. Logistic regression was employed for behaviours having binary responses and linear regression for behaviours having continuous (5-item Likert scale) responses.

The analysis included robustness checks involved including and excluding location to check the sensitivity of study site water quality and considering the effect of the gender of the survey team on responses, given that the majority of research assistants were female. In light of the lack of sampling frames and detailed and current population statistics, it was not possible to assign sampling weights to the survey responses. Stata 17 was used for analysis (StataCorp 2021). The assumption was that socioeconomic, psychosocial and contextual factors influence household water treatment behaviour.

8.3 Results

8.3.1 Study site context

The first step in the analysis involved the statistical description of the study areas to contextualise the subsequent analysis of performing household water treatment. The site socio-economic and demographic variables were considered as key contextual indicators across the two study sites. These are summarised in Table 8.1 below.

Table 8.1 Demographic and socio-economic indicators across study sites

Variables	**Overall** N=913 *n* (%)	**Doghabad** N=497 *n* (%)	**Bagrami** N=416 *n* (%)
Gender			
Male	497 (54.44)	245 (49.30)	252 (60.58)
Female	416 (45.56)	252 (50.70)	164 (39.42)
Age (SD)	33 (13.92)	34 (13.70)	33 (14.19)
Highest education level of the family head			
No education	226 (24.75)	122 (24.55)	104 (25.00)
Primary	71 (7.78)	38 (7.65)	33 (7.93)
Middle	97 (10.62)	53 (10.66)	44 (10.58)
High school	248 (27.16)	135 (27.16)	113 (27.16)
Bachelor’s Degree or Equivalent	230 (25.19)	127 (25.55)	103 (24.76)
Post-graduate Degree	41 (4.49)	22 (4.43)	19 (4.57)
Household income per month (in Afghanis)			
2500 or less	77 (8.43)	48 (9.66)	29 (6.97)
Between 2500 and 10 000	344 (37.68)	180 (36.22)	164 (39.42)
More than 10 000	492 (53.89)	269 (54.12)	223 (53.61)
Duration of living in the house			
1 year or less	130 (14.24)	62 (12.47)	68 (16.35)
Between 1 and 5 years	268 (29.35)	126 (25.35)	142 (34.13)
Between 5 and 10 years	181 (19.82)	69 (13.88)	112 (26.92)
More than 10 years	334 (36.58)	240 (48.29)	94 (22.60)
Household size (SD)	11 (5.97)	9 (5.18)	12 (6.55)

Source: authors, based on research fieldwork.
Notes: Number of observations = 913. USD/AFG = 80 (in August 2021). Mean is presented for Age and Household size with Standard Deviation (SD) in the bracket.

In the ethnically diverse sites, the survey data indicated a relatively low average level of educational attainment, with approximately a quarter of household heads being illiterate both in Bagrami and in Doghabad. Across the sites, an average household had eleven members and 46% of the surveyed households had a monthly income of less than 10 000 Afghanis (circa 125 USD). Another important parameter among the socio-economic indicators was the duration of residency which varied widely across the two study sites. In Doghabad, 48% of the households resided in the area for more than 10 years while in

Bagrami approximately 23% resided for more than 10 years, with 50% of the surveyed households residing less than five years in the area (compared to Doghabad with 38% households having less than five years residency).

This preliminary exploration helped demonstrate that the population in both study sites faced challenges not only with respect to the education level of the head of the household but most importantly the household's level of income per month. It is plausible to expect that such constrained living conditions may influence the performance of household water treatment.

8.3.2 Overview of the existing situation on access to water, water storage and water treatment practices

The second analytical stage documented the status quo of access to clean drinking water, water storage and water treatment practices in the two peri-urban populations. Before presenting results, it is worth highlighting two site-specific characteristics which had the potential of directly impacting not only access to water but also its consumption for drinking purposes. The water quality in the Bagrami area was classified as unsuitable for drinking purposes due to high salinity, while in Doghabad the water was biologically contaminated (see Chapter 4). On the other hand, the average depth of shallow groundwater in Bagrami was 3 – 7 meters while the range for Doghabad was 25 – 35 meters (see Chapter 3).

Table 8.2 shows that the primary source of drinking water differed widely among the population and between the two study sites. Of the population residing in Doghabad, only 56% had access to piped water supplied by a privately established water supply network. Shallow groundwater was the primary drinking water source for 14% of households, while 15% relied on deep groundwater wells. However, in Bagrami, the primary drinking water source for 35% of households was trucking water and 32% of households extracted water from deep groundwater wells for drinking purposes. This was despite the fact that many families in both study areas did not own a dug well (51% in Doghabad and 66% in Bagrami). Sensory markers played a major role in consumers' judgment of water quality. The taste of water was the most common self-reported marker used to reflect poor water quality across both study sites (75% of households in Doghabad and 86% of households in Bagrami). Other markers included colour, odour, clarity, and presence of particles as can be seen in Table 8.2.

Table 8.2 Drinking water source landscape across the study site

Variables	**Overall** N=913 *n* (%)	**Doghabad** N=497 *n* (%)	**Bagrami** N=416 *n* (%)
The primary source of drinking water †			
Dug well	119 (13.03)	72 (14.49)	47 (11.30)
Drilled well (Private)	211 (23.11)	77 (15.49)	134 (32.21)
Hand pump	87 (9.53)	44 (8.85)	43 (10.34)
Piped water	312 (34.17)	280 (56.34)	32 (7.69)
Buying bottled water/water trucks	159 (17.42)	13 (2.62)	146 (35.10)
Other	25 (2.74)	11 (2.21)	14 (3.37)
Own a dug well	383 (41.95)	242 (48.69)	141 (33.89)
How do you know water has poor quality? †			
Colour	397 (43.48)	220 (44.27)	177 (42.55)
Taste	731 (80.07)	374 (75.25)	357 (85.82)
Odour	266 (29.13)	149 (29.98)	117 (28.13)
Clarity	168 (18.40)	100 (20.12)	68 (16.35)
Having particles	191 (20.92)	110 (22.13)	81 (19.47)
When did you start treating water in your household?			
We don’t treat water	391 (42.83)	251 (50.50)	140 (33.65)
1 year ago, or less	156 (17.09)	84 (16.90)	72 (17.31)
Between 1 and up to 5 years ago	278 (30.45)	107 (21.53)	171 (41.11)
More than 5 and up to 10 years ago	52 (5.70)	30 (6.04)	22 (5.29)
More than 10 years ago	36 (3.94)	25 (5.03)	11 (2.64)
What was the reason you started to treat water in the household?			
Health issues	585 (64.07)	297 (59.76)	288 (69.23)
Neighbours/family suggested	35 (3.83)	18 (3.62)	17 (4.09)
Advice from the government	3 (0.33)	2 (0.40)	1 (0.24)
None	259 (28.37)	170 (34.21)	89 (21.39)
Can you name what illnesses arise from untreated water? †			
Cholera	93 (10.19)	60 (12.07)	33 (7.93)
Typhoid	142 (15.55)	85 (17.10)	57 (13.70)
Diarrhoea	659 (72.18)	363 (73.04)	296 (71.15)
H-Pillory	329 (36.04)	161 (32.39)	168 (40.38)
Hepatitis	30 (3.29)	18 (3.62)	12 (2.88)
Polio	6 (0.66)	4 (0.80)	2 (0.48)
Kidney problems	457 (50.05)	236 (47.48)	221 (53.13)
I don't know	42 (4.60)	35 (7.04)	7 (1.68)
Type of drinking water container †			
Metal	176 (19.28)	117 (23.54)	59 (14.18)

Plastic	578 (63.31)	290 (58.35)	288 (69.23)
Clay pot	6 (0.66)	1 (0.20)	5 (1.20)
Glassware	131 (14.35)	78 (15.69)	53 (12.74)
Other	22 (2.41)	11 (2.21)	11 (2.64)

Source: authors, based on research fieldwork.

Notes: Number of observations = 913.

† *Multiple choice questions*

Engagement in household water treatment appeared to be on the rise among the residents of both study areas in the five years preceding the survey, albeit in Bagrami at a higher proportion (41%) compared to Doghabad (21%). However, the share of households who did not perform household water treatment was statistically significantly higher ($p<0.001$) in Doghabad (50%) compared to Bagrami (34%). Meanwhile, it was important to explore the main motive behind starting household water treatment from an interviewee's perspective. A majority of households reported that the reason they started to perform household water treatment was due to health issues (60% in Doghabad and 69% in Bagrami). The main challenge here would be to quantify health issues, though, participants showed a high rate of familiarity with Diarrhoea, H-Pillory, and Kidney problems as exemplars of water-borne diseases.

Table 8.3 Common forms of household water treatment across study areas

Household water treatment method †	**Doghabad** N=497 *n* (%)		**Bagrami** N=416 *n* (%)	
	Using	**Aware but not using**	**Using**	**Aware but not using**
Boil water	323 (64.99)	142 (28.57)	192 (46.15)	180 (43.27)
Chlorination	94 (18.91)	188 (37.83)	41 (9.86)	118 (28.37)
Strain water through a piece of cloth	6 (1.21)	17 (3.42)	1 (0.24)	14 (3.37)
Use a water filter	76 (15.29)	186 (37.42)	123 (29.57)	131 (31.49)
Solar disinfection	61 (12.27)	60 (12.07)	18 (4.33)	53 (12.74)
Let sand settle down	15 (3.02)	20 (4.02)	1 (0.24)	5 (1.20)
Other	4 (0.80)	17 (3.42)	29 (6.97)	12 (2.88)

Source: authors, based on research fieldwork.

Notes: Number of observations = 913.

† *Multiple choice question.*

Another important dimension that was explored through the questionnaire were the methods of storing water in households. Plastic and metal containers were common for water storage among the communities in both study areas. Subsequently, the participants' awareness of and the type of methods of household water treatment (HWT) performed in the two study areas were investigated (see Table 8.3). A closer look at the table shows that, in Doghabad, the majority of households (65%) were boiling water, 19% were using chlorination, and 15% were using an advanced water purifier. However, in Bagrami, the most common forms of HWT were using advanced water purifiers (30%) followed by boiling water (46%). Furthermore, it is apparent from Table 8.3 that a high number of households were aware of different forms of HWT that they chose not to perform (*e.g.,* boiling water, chlorination and advanced water purifiers).

The background information on the status quo included water levels, water quality, the main source of drinking water, the evolution of performing household water treatment, the familiarity of residents with water-borne diseases, water storage practices, and awareness of different methods of HWT demonstrate the importance of contextual factors and the role of information shaping the environment for performing household water treatment in the two study sites. The next analytical step involved documenting and describing the factors influencing household water treatment from a COM-B model perspective.

8.3.3 Overview of COM factors determining household water treatment

Zooming in on factors influencing household water treatment, Table 8.4 provides a breakdown of questionnaire items into Capability, Motivation and Opportunity (COM) dimensions of the COM-B model (see Supplementary Material 8.2 for details on aggregated questionnaire items into COM dimensions). The normalized mean value of response items is presented in Table 8.4, having a range of 0 to 1 (with 0 indicating disabling and 1 indicating enabling to perform the behaviour). Overall, the sub-domain indices in Table 8.4 show that the highest index value related to reflective (0.798; 95% CI: 0.307 – 1.290), followed by physical capability and automatic motivation (0.736 (95% CI: 0.486 – 0.986) and 0.684 (95% CI: 0.278 – 1.091), respectively). Social opportunity received the lowest index value of 0.453 (95% CI: 0.349 – 0.558), meaning that it is more likely than other dimensions to act as a disabler of water treatment behaviour.

Among the individual elements across these dimensions, particularly factors related to reflective motivation stood out. The majority of the participants strongly agreed that regularly treating water reduces the risk of falling ill (0.966; 95% CI: 0.893 – 1.039) and that it should be everyone's responsibility to provide safe drinking water for children (0.977; 95% CI: 0.965 – 0.989). Other factors related to reflective motivation included thoughts on the necessity to boil water before drinking, the importance for the household to learn about affordable household water treatment techniques, experiences and awareness of severe diseases due to drinking untreated water, differentiating between water used for drinking and other purposes, and the household's willingness to pay for clean drinking water. Similarly remarkable were factors related to automatic motivation, which also received higher mean values than other domains of the COM-B model. For example, the majority of the respondents strongly agreed that they felt a personal obligation to treat drinking water for children under the age of five years (0.823; 95% CI: 0.810 – 0.835) and that they more often performed water treatment (e.g., boiling water, using advance purifiers, and etc) before drinking water and cooking in their household due to COVID-19 (0.721; 95% CI: 0.201 – 1.241). Other automatic motivation factors included worry about the health impact of drinking water, the frequency of suffering from water-borne illnesses, and the taste of drinking water.

The opportunity domain factors were slightly less pronounced than motivation, in particular the physical opportunity factors. One of the very important factors, with which the majority strongly agreed, was having a separate container for storing drinking water (0.791; 95% CI: 0.428 – 1.153). Other physical-opportunity-related factors included water quality, the community's curiosity to test water quality, and household income. Additionally, related to physical opportunity were factors such as cost, time requirement, and amount of effort required to treat drinking water. Social Opportunity factors included gender, frequency of people talking to each other about water treatment, community members looking for affordable methods of household water treatment, and a very important factor in this context was the role of community leaders in encouraging drinking treated water.

The capability domain of the COM-B model, which includes the psychological capability and physical capability, is also presented in Table 8.4. The factors under the psychological capability included respondents' ability to read and write, to test household water quality, awareness about the health impact of poor water quality, knowledge of performing household water treatment, and the highest education level of the head of household. One of the most important factors for physical capability included in was survey was age, whereby a threshold of over the age of 55 was deemed as disabling for HWT (based on qualitative research fieldwork, presuming this as the average age at which someone tended not to be physically able to perform household water treatment). Another factor under the physical capability domain was investigating the participant's ability to always treat water before drinking.

Table 8.4 Responses to COM-B categories influencing performing household water treatment and the difference between the two study areas

COM-B dimensions		Questionnaire item	Overall (*n=913*) Mean [95% CI]	Doghabad (*n=497*) Mean [95% CI]	Bagrami (*n=416*) Mean [95% CI]	Difference in mean	test-statistics	*P* value	Index (*n=913*) Mean [95% CI]
Capability	Physical	Participant's age	0.897 [0.864,0.930]	0.899 [0.873,0.926]	0.894 [0.865,0.924]	0.005	0.065	.799	0.547 [0.450,0.640]
		How certain are you that you will always be able to treat your household drinking water before drinking?	0.575 [0.042,1.108]	0.536 [0.508,0.565]	0.621 [0.592,0.650]	-0.085	16.766	.000***	
	Psychological	Are you able to read? †	0.346 [0.123,0.569]	0.330 [0.289,0.372]	0.365 [0.319,0.412]	-0.035	1.254	.263	0.736 [0.486,0.986]
		Are you able to write? †	0.406 [0.046,0.767]	0.380 [0.338,0.423]	0.438 [0.390,0.485]	-0.057	3.073	.080	
		Has your household water quality ever been tested? †	0.105 [-0.153,0.363]	0.087 [0.062,0.111]	0.127 [0.095,0.160]	-0.041	4.023	.045*	
		Are you aware that poor water quality will affect your health?	0.985 [0.962,1.009]	0.987 [0.978,0.996]	0.983 [0.973,0.993]	0.004	0.317	.573	
		There is a lack of public awareness of poor water quality risks to health.	0.758 [0.535,0.982]	0.775 [0.742,0.808]	0.739 [0.699,0.779]	0.035	1.810	.179	
		My household knows how to perform household water treatment.	0.761 [0.676,0.846]	0.755 [0.720,0.789]	0.768 [0.731,0.805]	-0.014	0.281	.596	
		What is the highest education level of the head of the household?	0.467 [0.438,0.497]	0.470 [0.441,0.498]	0.465 [0.434,0.496]	0.005	0.048	.827	
Opportunity	Physical	Do you have a separate container for storing drinking water? †	0.791 [0.428,1.153]	0.765 [0.727,0.802]	0.822 [0.785,0.859]	-0.058	4.530	.033*	0.647 [-0.175,1.468]
		Site water quality[103] †	0.456 [-5.847,6.759]	0.000	1.000	-1.000	913.000	.000***	
		It is important to provide opportunities for our community to test the quality of water.	0.919 [0.877,0.962]	0.923 [0.902,0.944]	0.916 [0.893,0.939]	0.007	0.175	.676	

[103] The water quality of Bagrami is not suitable for drinking purpose due to high salinity and the population in Bagrami have to rely on trucking water or household water treatment. Thus, I assigned value of 1 for Bagrami.

		How effortful do you think is treating drinking water in the household?	0.396 [0.074,0.718]	0.420 [0.397,0.442]	0.368 [0.343,0.394]	0.051	8.754	.003**	
		It is time-consuming to treat household drinking water.	0.711 [0.278,1.145]	0.680 [0.644,0.717]	0.749 [0.712,0.786]	-0.069	6.731	.010**	
		How expensive is it for you to treat your drinking water?	0.289 [-0.095,0.673]	0.317 [0.291,0.343]	0.256 [0.230,0.282]	0.061	10.743	.001**	
		Monthly income	0.727 [0.659,0.796]	0.722 [0.693,0.752]	0.733 [0.703,0.763]	-0.011	0.258	.612	
		People look for affordable techniques to treat drinking water in the household.	0.883 [0.730,1.037]	0.872 [0.846,0.898]	0.897 [0.871,0.923]	-0.024	1.696	.193	
	Social	Participant's gender †	0.456 [-0.255,1.167]	0.507 [0.463,0.551]	0.394 [0.347,0.441]	0.113	11.619	.001***	0.453 [0.349,0.558]
		How often do you talk about water treatment with other people?	0.301 [-0.257,0.859]	0.261 [0.234,0.287]	0.349 [0.318,0.381]	-0.089	17.980	.000***	
		People in my community treat drinking water in the household because of their cultural beliefs.	0.616 [0.594,0.638]	0.618 [0.581,0.655]	0.614 [0.572,0.656]	0.004	0.015	.902	
		People encourage neighbours to treat the drinking water in their household.	0.531 [0.065,0.997]	0.497 [0.456,0.538]	0.571 [0.526,0.616]	-0.074	5.687	.017*	
		Thinking about the people who are important to you like your family members, friends, the chief of the village, or the Mosque, rate how much they encourage that you always use clean water or treat drinking water in the household?	0.364 [0.131,0.597]	0.347 [0.317,0.377]	0.384 [0.352,0.416]	-0.037	2.748	.098	
Motivation	Automatic	How worried are you about the health effects of the drinking water you use?	0.670 [-0.002,1.342]	0.622 [0.594,0.649]	0.728 [0.704,0.753]	-0.107	32.213	.000***	0.684 [0.278,1.091]
		How frequently does your household suffer from illness due to poor water quality?	0.395 [-0.047,0.836]	0.363 [0.334,0.391]	0.433 [0.406,0.459]	-0.070	12.418	.000***	
		Do you feel a personal obligation to treat your household drinking water?	0.697 [0.409,0.985]	0.676 [0.649,0.703]	0.722 [0.696,0.748]	-0.046	5.773	0.016*	
		Do you feel a personal obligation to treat your household drinking water for children under the age of 5 years?	0.823 [0.810,0.835]	0.823 [0.802,0.845]	0.822 [0.801,0.842]	0.002	0.016	.898	

		How much do you like the taste of treated drinking water?	0.801 [0.274,1.329]	0.763 [0.738,0.788]	0.847 [0.826,0.868]	-0.084	25.598	.000***	
		Due to COVID-19, we perform water treatment such as water boiling or filtering before drinking and cooking more often in my household.	0.721 [0.201,1.241]	0.683 [0.644,0.722]	0.766 [0.726,0.806]	-0.082	8.412	.004**	
	Reflective	Do you differentiate between the quality of water you use for drinking, washing vegetables, cooking meals, religious ablution, washing clothes, and bathing?	0.536 [-1.498,2.571]	0.389 [0.354,0.424]	0.712 [0.675,0.749]	-0.323	156.728	.000***	0.798 [0.307,1.290]
		We have information on our household water quality.	0.785 [0.339,1.231]	0.753 [0.717,0.788]	0.823 [0.791,0.856]	-0.071	8.323	.004**	
		Access to good quality drinking water is a priority for my household.	0.966 [0.907,1.025]	0.962 [0.947,0.977]	0.971 [0.957,0.985]	-0.009	0.815	.367	
		It is everyone's responsibility to provide safe drinking water for children.	0.977 [0.965,0.989]	0.978 [0.967,0.989]	0.976 [0.964,0.988]	0.002	0.051	.821	
		If getting ill from drinking untreated water, how severe do you think the illness might be?	0.587 [0.298,0.877]	0.566 [0.540,0.593]	0.612 [0.584,0.641]	-0.046	5.483	.019*	
		I believe that treating water regularly reduces the risk of falling ill.	0.966 [0.893,1.039]	0.961 [0.947,0.975]	0.972 [0.959,0.986]	-0.012	1.362	.243	
		It is necessary to boil water before drinking.	0.903 [0.546,1.260]	0.877 [0.850,0.904]	0.934 [0.912,0.956]	-0.057	10.158	.001**	
		It is important for my household to learn about cheap and accessible household water treatment techniques.	0.933 [0.869,0.997]	0.929 [0.909,0.949]	0.939 [0.920,0.958]	-0.010	0.518	.472	
		How much would your household spend in maximum to enhance the quality of water in a month?	0.532 [-0.583,1.646	0.451 [0.421,0.482]	0.628 [0.594,0.662]	-0.177	58.683	.000***	

Notes: 95% confidence intervals in brackets, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, † Categorical variables

Although the main objective of this study was not to compare the two sampling sites, statistically significant differences in the means of the response of several factors demonstrated the variability of COM dimensions not only across households but also systematically across locations. For instance, Bagrami recorded higher mean responses to factors such as water quality information, differentiating water for drinking purposes, water storage practices, the time required for performing HWT, talking to people about water quality, encouraging others to perform HWT, feeling worried about health impacts of poor water quality, experienced water-borne disease and severity, and willingness to pay. A higher mean value in response to the aforementioned factors in Bagrami conformed with previously presented variance in demographic, socio-economic, water source landscape, and performed methods of household water treatment. However, only two factors had a higher mean value in response from Doghabad compared to Bagrami; the factors included the amount of effort needed and the cost of treating water. Corroborating with the main source of drinking water and performed methods of HWT in Doghabad, presented in Section 6.3.2, it is plausible to observe a higher mean value in response to these two factors.

This section brought to attention the factors and important aspects related to COM indices in the household water treatment landscape. The next section will investigate the relation of Capability, Opportunity and Motivation (COM) factors, presented above, to identified household water treatment behaviours (B).

8.3.4 Relationship of COM dimensions to household water treatment behaviours (B)

Examining the hypothesis that broader socioeconomic, psychosocial, and contextual factors shape household water treatment behaviour, this final step of the analysis will examine the relationship of Capability, Opportunity and Motivation (COM) sub-dimensions to household water treatment behaviours (B). To evaluate the significance of COM on household water treatment behaviours, linear and logistic regression models were used to identify the most influential determinants.

In the first step, bivariate relationships were calculated between all 37 items included in COM-B and the six main behaviours. Bivariate analysis of the COM items and six water treatment behaviour are presented in Appendix 1 (end of thesis). The results of bivariate analysis highlighted that all the 37 items included in the COM-B model had a significate association with the six identified household water treatment behaviours. Thus, it was concluded that all items should remain in the model.

Following bivariate analysis, multivariate multiple regression was utilized to investigate associations between each domain and the three main behaviours, which are presented in Table 8.5. The results make apparent that automatic and reflective motivation, and physical opportunity had a statistically significant association with the identified household water treatment behaviours (Models 1 and 3). However, in the aforementioned models, social opportunity and psychological capability did not appear to have a significant link to household water treatment practices.

Three of the main behaviours presented in Table 8.5 point toward a similar direction where a statistically significant and positive relationship is observed between the behaviour on the one hand, and the enablement of automatic and reflective motivation, and physical opportunity on the other hand. However, purchasing bottled water (Model 2) appeared an odd variation which needs further clarification: as presented in Section 6.3.2, trucking water is dominant and only available in one study site. This trucking water is less expensive and constitutes a competing behaviour with other forms of household water treatment. As a competing behaviour, disablers for water *treatment* could therefore plausibly emerge as enablers for water *purchases*, which is consistent with the model results.

Among the sub-behaviours (Models 5 and 6) presented in the Supplementary Material (Table S8.3), the social opportunity had a significant association with the identified household water treatment behaviours besides the automatic and reflective motivation, and physical opportunity. The present study was designed to determine the relative contribution of socioeconomic, psychosocial and contextual factors in explaining households' water treatment behaviour. Insights from a preceding qualitative analysis help interpret and contextualise these results (Chapter 7). For example, it was observed that boiling water happened in both study sites (albeit more so in Doghabad), which was performed mostly to provide clean drinking water for children and people who were falling ill. The relation between, Model 4, boiling and automatic motivation is significant and very precisely describes items such as worry, illness, obligation, and risk perception. However, due to its high costs in terms of fuel and time, people could not continuously boil water at their homes, which helps explain the positive association with physical opportunity alongside the statistically insignificant relationship to reflective motivation.

Table 8.5 Regression results of the relationship between COM indices and water treatment behaviours

COM-B components	**b_Q5_2** (Model 1) Do you treat water before drinking in your household? †	**b_botwa** (Model 2) Bottled water, the main source of drinking water †	**Q5_4** (Model 3) When did you start treating water in your household? Doers †
Capability- Psychological	-0.010 (.985) [-1.00,0.98]	-0.101 (.878) [-1.39,1.19]	0.005 (.992) [-1.03,1.04]
Capability - Physical	2.487 (.000)*** [1.63,3.35]	0.205 (.661) [-0.71,1.12]	1.298 (.001)*** [0.56,2.04]
Opportunity - Physical	3.536 (.000)*** [2.34,4.73]	-1.783 (.007)** [-3.08,-0.48]	4.049 (.000)*** [2.86,5.24]
Opportunity - Social	0.534 (.147) [-0.19,1.25]	-1.093 (.029)* [-2.08,-0.11]	0.436 (.239) [-0.29,1.16]
Motivation - Reflective	2.725 (.001)** [1.08,4.37]	2.938 (.008)** [0.77,5.10]	3.777 (.000)*** [2.14,5.41]
Motivation - Automatic	2.921 (.000)*** [1.72,4.12]	2.331 (.004)** [0.75,3.91]	3.581 (.000)*** [2.44,4.73]
Constant	-8.971 (.000)*** [-10.61,-7.34]	-4.112 (.000)*** [-6.04,-2.18]	-9.026 (.000)*** [-10.67,-7.38]
χ^2	151	36	161
p-value	(.000)***	(.000)***	(.000)***
Log Likelihood	-522	-383	-510
Observations	913	913	913

Notes: Logistic regressions. Coefficients reported. 95% confidence intervals in brackets, p-values in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
† Binary variables

It was mentioned in the methodology section that the sample was drawn by randomly selecting two study sites and then sampling individuals from within each. In order to reduce the sampling error and for generalizing the findings to the larger population, also the models with standard errors adjusted for community-level clustering is reported

(Table 8.6). Again, even with adjusted standard errors for the community level, automatic and reflective motivation, and physical opportunity had a statistically significant association with the identified household water treatment behaviours (Models 1 and 3) presented in Table 8.6. It is important to note that as a result of adjusted standard errors at the community level, the social opportunity illustrated a statistically significant association with performing household water treatment in Model 3 (Table 8.6).

Table 8.6 Regression results of the relationship between COM indices and water treatment behaviours (adjusted for study site clusters)

COM-B domains	**b_Q5_2** (Model 1) Do you treat water before drinking in your household? †	**b_botwa** (Model 2) bottled water, the main source of drinking water †	**Q5_4** (Model 3) When did you start treating water in your household? Doers †
Capability - Psychological	-0.010 (.978) [-0.69,0.67]	-0.101 (.925) [-2.20,2.00]	0.005 (.966) [-0.22,0.23]
Capability - Physical	2.487 (.000) *** [2.41,2.57]	0.205 (.795) [-1.34,1.75]	1.298 (.000)*** [0.69,1.90]
Opportunity - Physical	3.536 (.000)*** [2.35,4.72]	-1.783 (.180) [-4.39,0.82]	4.049 (.006)** [1.13,6.96]
Opportunity - Social	0.534 (.591) [-1.41,2.48]	-1.093 (.002)** [-1.78,-0.40]	0.436 (.001)** [0.17,0.70]
Motivation - Reflective	2.725 (.000)*** [2.41,3.04]	2.938 (.033)* [0.24,5.63]	3.777 (.000)*** [2.38,5.17]
Motivation - Automatic	2.921 (.000)*** [1.71,4.14]	2.331 (.000)*** [2.30,2.36]	3.581 (.000)*** [2.77,4.39]
Constant	-8.971 (.000)*** [-10.17,-7.77]	-4.112 (.024)* [-7.67,-0.55]	-9.026 (.000)*** [-10.47,-7.58]
Log Likelihood	-522	-383	-510
Observations	913	913	913

Notes: Logistic regressions. Coefficients reported. 95% confidence intervals in brackets, p-values in parentheses. Standard errors adjusted for site-level clustering.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
† Binary variables

However, with adjusted standard errors at the community level for three sub-behaviours (Models 4, 5, and 6) presented in the Supplementary Material (Table S8.4), automatic motivation was statistically significant in all models. In Models 5 and 6, the physical opportunity remained statistically significant while the significance levels of reflective motivation and social opportunity were more sensitive to site-level clustering.

The main results presented above are excluding a site-specific characteristic factor which would capture for instance systematic variations in water quality. At the same time, it is worth mentioning that the inclusion of site-specific characteristics (water quality) contributed to household water treatment behaviour in a way that is most consistent with "physical opportunity" and its separate inclusion as a dummy variable did not substantively alter the main results (see Table S8.5).

8.4 Discussion

8.4.1 Summary of Findings

Identification of the socio-economic, psychosocial, and contextual determinants with the greatest impact on household water treatment behaviour is critical for the development of effective interventions and policies. Relying on the most comprehensive framing of behaviour and utilising logistic and regression models, the COM-B approach, this study highlighted the statistically significant associations of socio-economic, psychosocial and contextual determinants with household water treatment behaviours. From a COM-B perspective, the regression analysis suggested that reflective and automatic motivation, and physical opportunity were determining household water treatment behaviour.

For instance, related to contextual and socio-economic factors, the physical opportunity showed significant association with almost all models of household water treatment behaviours, highlighting the importance of issues such as site water quality, storage options, access to affordable techniques, or household resources (time, material, financial) in performing household water treatment. Additionally, this survey revealed an average household size was eleven people across both sites, and 46% of the households had a monthly income of under 10,000 Afghanis (125 USD), which is five times below the National Poverty Line (less than $2 income per person day). Household and demographic surveys in Ethiopia illustrated a significant association between wealth status and household water treatment practices, higher income households were more likely to perform household water treatment compared to low-income households (Geremew et al. 2018). Accessibly, ease of use and cost of the product were determining factors in household water treatment practices in rural Kenya (Makutsa et al. 2001; Francis et al. 2015).

Additionally, the significant association of social opportunity with household water treatment practices in most of the models in this study highlighted the critical role of social influences (social norms, and talking to others about HWT), following other people performing HWT, and gender (also highlighted in the qualitative findings) in performing household water treatment. Recent qualitative research on determinants of household water treatment suggests the importance of interpersonal contact and social support (Tamene 2021). Indigenous belief was determining factor in the delivery of WASH interventions in Uganda (Okurut et al. 2015). Daniel et al. (2021) highlighted that indigenous beliefs played a significant role in performing household water treatment in Indonesia.

Meanwhile, related to psychosocial factors, automatic and reflective motivation components of COM-B models highlighted the association of factors such as worry, fear, traumatic experiences, perceived risk and perceived benefit with performing household water treatment. A majority of households reported that the reason they started to perform household water treatment was due to health issues (60% in Doghabad and 69% in Bagrami). Psychological factors such as vulnerability, health knowledge, and water-borne disease severity were found to have significant positive in-direct effects on household water treatment practices (Huber and Mosler 2013; Lilje and Mosler 2018). Additionally, related to psychological factors, this survey findings highlighted that the average level of education was quite low, with around one-fourth of household heads being illiterate in both Bagrami and Doghabad. Performing household water treatment appeared to be on the rise among the residents of both study areas in the five years preceding the survey, albeit more so in Bagrami (41%) than in Doghabad (21%). The association of education and awareness about the HWT methods with performing household water treatment were highlighted by Admasie, Abera, and Feleke (2022), DuBois et al. (2010), and Ibrahim et al. (2016). Household and demographic surveys in Egypt highlighted that households with heads who have completed at least primary school are more likely to perform HWT than those who have not (Wright and Gundry 2009). However, in Nigeria, there was minimal difference in the likelihood of performing HWT between families where the heads have only received primary school education and those who have not (Abubakar 2021).

Previous quantitative studies on the factors determining household water treatment emphasized the psychosocial determinants through the RANAS behaviour change model including Sonego, Huber, and Mosler (2013); Mosler, Blöchliger, and Inauen (2010); and, Mosler, Huber, and Bhend (2011). While developers of the RANAS behaviour model have undermined the importance of including socio-economic and contextual factors in water-related behaviour models (Lilje and Mosler 2017; Lilje and Mosler 2018).

The COM-B model acknowledges that for any behaviour to be carried out, people must have the capability, the opportunity, and must be more motivated to perform the behaviour than any other factor. All necessary enablers must be present, the required change will not happen if even just one of these is missing (West et al. 2019). The findings of this study and a contemporary finding of a qualitative study relying on the comprehensive COM-B approach revealed that its six dimensions offer a more faithful and context-specific mapping of local water realities. The regression analysis suggested that reflective and automatic motivation, and physical opportunity had a statistically significant association with performing household water treatment behaviours. Thus, based on the finding of this study, socioeconomic, psychosocial and contextual factors are integral to household water treatment behaviour and all should be included in the process of designing and delivering WASH-related interventions, specifically household water treatment interventions which was the focus of this study.

8.4.2 Limitations

The limitations of this research pertain to the delivery of this cross-sectional survey during the intense conflict period around Afghanistan (May to June 2021), which had a small effect on the depth of the research as some participants declined participation due to security concerns. It is important to consider that these conclusions were based on a survey of self-reported household water treatment behaviours which are more likely to be responded to in a way that is socially acceptable than data collection methods involving for instance participant observation (Curtis et al. 1993; Halder et al. 2010). Even though effort was made to reduce the self-report bias by posing several items with various scales, there is still a possibility of self-reported bias that future ethnographic research can help inform and overcome. The gender of the surveyor may have impacted the research participant’s response, biased toward socially desirable responses (Haber et al. 2018), but analysis of the survey data indicated that there was no significant difference between the mean values of responses for each COM-B domain based on the surveyor gender (Table S8.6). Lastly, the sampling strategy involving two distinct peri-urban areas in Kabul metro also means that the results cannot speak easily to rural areas outside Kabul and those peri-urban with different contextual and environmental characteristics. While this limits the specific findings, the methodological approach of COM-B-based behavioural analysis to uncover psychological as well as other individual and contextual drivers of household water treatment practices is applicable more broadly.

8.4.3 Implications

This cross-sectional survey research offers implications for designing and implementing interventions aimed at household water treatment in low- and middle-income countries. In the context of Kabul, 42% of the participants in this study reported not performing household water treatment. However, boiling water was common among the household performing household water treatment (64% in Doghabad, and 46% in Bagrami) – this qualitative research highlighted that boiling water was not performed regularly and it was only performed to provide clean drinking water to children or individual/s experiencing severe disease. Only a small proportion of the household had access to advance water purifiers (15% in Doghabad, and 29% in Bagrami). Health issues were reported as the main reason for performing HWT by 64% of the research participants. Lack of awareness about the benefits, and poverty are barriers to large-scale uptake of household water treatment techniques (WHO 2009; Akosile et al. 2020; Abubakar 2021). The current study indicated that the inclusion of socioeconomic, psychosocial and contextual factors are an integral part of household water treatment behaviour and thus should be investigated in interventions aimed at increasing the uptake of household water treatment practices for providing sustained access to clean drinking water. The six models included in this study illustrated a significant association between reflective and automatic motivation, and physical opportunity to household water treatment behaviours. The models describing a broader domain of household water treatment behaviours, for instance, Model 1 and Model 3, could be utilised for delivering household water treatment interventions - particularly in the context of Kabul. In order to target household water treatment behaviour in Kabul using the COM-B approach, a combination of BCW (Behaviour Change Wheel) intervention functions should be utilized, as described below:

Persuasion: Related to reflective and automatic motivation, using communication to spread information on the status quo of water quality and health risks of not performing

HWT (e.g., sever water borne disease), raising awareness on the benefits of performing household water treatment, raising awareness on affordable HWT techniques (i.e., Ceramic water filters).

Training: Related to physical opportunity, training local potters on methods of producing Ceramic filters (which are affordable, have proven efficacy in other geographies, and do not require energy), and establishing a mechanism for the distribution of filters among communities.

Enablement: Related to physical and social opportunity, information should be targeted to the women in households who are mainly responsible for household water management (face-to-face and/or groups). Involving community members during the process and delivering the intervention, especially the local leaders. Providing access to affordable HWT methods (i.e., Ceramic filters).

8.5 Conclusion

Revisiting the primarily psychological factors perspectives in water behaviour that continue to dominate the research literature, this study presented factors influencing household water treatment behaviour relying on the simplest definition of behaviour, the COM-B approach, and based on a cross-sectional quantitative survey in two peri-urban areas of Kabul, Afghanistan. From a COM-B approach perspective, the results highlighted that physical opportunity, reflective and automatic motivation had a statistically significant association with performing household water treatment behaviours. The findings of this study suggest that socioeconomic, psychosocial and contextual factors are integral to household water treatment behaviour and all should be included in the process of designing and delivering more effective WASH-related interventions.

Supplementary material

Supplementary material 8.1 A complete version of questionnaire items used for data collection during the fieldwork.

Questionnaire

Date:

Form Code: …………….

Name of enumerator:

Starting time:

Ending time:

Part 1: Interviewee and Household general information

"First I would like to ask some general questions about you and the household."

5. Are you able to read?
   1. Yes 2. No
6. Are you able to write?
   1. Yes 2. No
7. Who filled the survey?
   Interviewee ☐ Interviewer ☐
8. Gender: Male ☐ Female ☐
9. Age:
10. How many people live in this household?
    Total:
    Adults, 18 and older:
    Children (between 5 and 17):
    Children below 5:
11. Are you the head of the household? 1. Yes 2. No
12. What is the highest education level of the head of the household?
    a. Illiterate
    b. Primary
    c. Middle
    d. High school
    e. Bachelor's Degree or Equivalent
    f. Post-graduate Degree
13. How long have you lived in this house?
    1 year or less ☐ Between 1 and 5 years ☐
    Between 5 and 10 years ☐ More than 10 years ☐
14. What is the main source of drinking water for members of your household?
    Dug well Hand pump
    Drilled well (Private) Traditional Karez
    Piped water Buy bottled water Other: _________
15. Do you own a dug well (accessibility)?
    1. Yes 2. No

16. How much do you earn in a month (in Afghani)?

2500 or less	☐	Between 2500 and 5000	
Between 5000 and 10000	☐	More than 10000	☐

Part 2: Water use and storage

"In this part, I would like to ask some questions about the amount of water you use and drinking water storage in your household."

1. How many glasses of water do you drink during a 24-hr period?
   1 2 3 4 5 6 7 8
2. Approximately how many litres of water does your household consume every day (for drinking)?
   1. ______ litres per day 2. Don't know
3. Approximately how many litres of water does your household consume every day (including all sources and uses)?
   1. ______ litres per day 2. Don't know
4. How long does it take to take drinking water from the source?
   Minutes _ _
5. Do you have a separate container for storing drinking water?
   1. Yes 2. No 3. Not applicable
6. What type of water container do you use for keeping water?
   1. Metal 2. Plastic 3. Ceramic 4. Glass 5. Other (specify): _______________
7. For how long do you usually store drinking water at home?

Less than one day	1 day	2 days	3 days to a week	More than a week
1	2	3	4	5

Part 3: Knowledge of water quality

"In this part, I would like to ask you some questions about your understanding of the water quality that you use for drinking in your household."

1. Do you differentiate between the quality of water you use for drinking, washing vegetables, cooking meals, religious ablution, washing clothes, and bathing?

Never	Seldom	Sometimes	Often	Almost always
1	2	3	4	5

2. Has your household water quality ever been tested?
   1. Yes 2. No 3. Don't know/not sure
3. In your opinion, what do you think the quality of the drinking water is in your household?

Very poor	Poor	Fair	Good	Very good
1	2	3	4	5

4. If poor quality, how do you know (tick all that apply)?
   a. Colour
   b. Taste
   c. Odour
   d. Clarity
   e. Have particles
   f. Other, specify: ___________

5. We have information on our household water quality.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

6. It is important to provide opportunities for our community to test the quality of water.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

7. Access to good quality drinking water is a priority for my household.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

Part 4: Knowledge of health risks from poor water quality

"In this part, I would like to ask you some questions about your understanding of the health risks arising from drinking poor-quality water.

1. Are you aware that poor water quality will affect your health?

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

2. If getting ill from drinking untreated water, how severe do you think the illness might be?

Not at all severe	Slightly severe	Somewhat severe	Moderately severe	Extremely severe
1	2	3	4	5

3. How worried are you about the health effects of the drinking water you use?

Not at all	Somewhat	Rather	Quite a lot	Very much
1	2	3	4	5

4. How frequently does your household suffer from ill health due to poor water quality?

Never	Seldom	Sometimes	Often	Almost always
1	2	3	4	5

5. Can you name what illnesses arise from untreated water (tick all that apply)?
   - Cholera ☐
   - Typhoid ☐
   - Diarrhoea ☐
   - H Pillory ☐
   - Polio ☐
   - Kidney problems ☐
   - Other ☐
   - I don't know ☐

6. I believe that treating water regularly reduces the risk of falling ill?

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

7. It is necessary to boil water before drinking.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

8. There is a lack of public awareness of poor water quality risks to health.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

9. It is everyone's responsibility to provide safe drinking water for children.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

Part 5: Water treatment at the household

"In this part, I would like to ask you some questions about water treatment in your household."

1. Do you treat water before drinking in your household?
   1. Yes 2. No 3. Don't know/not sure
2. If you treat your water, what methods you are aware and what method do you use?

Methods aware (tick all that apply)		Method currently using (tick all that apply)	
Boil		Boil	
Chlorination		Chlorination	
Strain it through a cloth		Strain it through a cloth	
Use a water filter		Use a water filter	
Solar disinfection		Solar disinfection	
Let it stand and settle		Let it stand and settle	
Other (specify): ____________		Other (specify): ____________	
None		None	

3. When did you start treating water in your household?
   - We don't filter ☐
   - 1 year ago or less ☐
   - Between 1 and 5 years ☐
   - Between 5 and 10 years ☐
   - More than 10 years ☐
4. What was the reason you started to treat water in the household?
   1. Health issues 2. Neighbours/Family suggested 3. NGOs support
   4. Government advise 5. Other, please specify: _______ 6. None
5. How many people in your household always treat drinking water?

Nobody	Some of them	Half of them	Most of them	All of them
1	2	3	4	5

6. How often do you use treated water at home?

Never	Seldom	Sometimes	Often	Almost always
1	2	3	4	5

7. How much do you like the taste of treated drinking water?

Not at all	Somewhat	Rather	Quite a lot	Very much
1	2	3	4	5

8. Do you boil water before drinking?

Never	Seldom	Sometimes	Often	Almost always
1	2	3	4	5

9. It is important for my household to learn about cheap and accessible household water treatment techniques.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

10. How effortful do you think is treating drinking water in the household?

Not at all	Somewhat	Rather	Quite a lot	Very much
1	2	3	4	5

11. It is time-consuming to treat household drinking water.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

12. How expensive is it for you to treat your drinking water?

Not at all	Somewhat	Rather	Quite a lot	Very much	Don’t treat
1	2	3	4	5	6

13. Do you feel a personal obligation to treat your household drinking water?

Not at all	Somewhat	Rather	Quite a lot	Very much
1	2	3	4	5

14. Do you feel a personal obligation to treat your household drinking water for children under the age of 5 years?

Not at all	Somewhat	Rather	Quite a lot	Very much
1	2	3	4	5

15. How certain are you that you will always be able to treat your household drinking water before drinking?

Not at all	Somewhat	Rather	Quite a lot	Very much
1	2	3	4	5

16. When you think about the last 24 h: How often did it happen that you forgot to treat drinking water in your household?

Not at all	Somewhat	Rather	Quite a lot	Very much
1	2	3	4	5

17. How much would your household spend in maximum to enhance the quality of water in a month?
    1. Wouldn’t pay
    2. 100 – 300
    3. 300 – 500

4. 500 – 800
5. 800 - 1000

Part 6: Knowledge of water treatment techniques

"In this part, I would like to ask some questions about your understanding of water drinking treatment techniques in your household."

1. How often do you talk about water treatment with other people?

Never	Seldom	Sometimes	Often	Almost always
1	2	3	4	5

2. My household knows how to perform household water treatment.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

3. People in my community treat drinking water in the household because of their cultural beliefs.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

4. People encourage neighbours to treat drinking water in their households.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

5. People look for affordable techniques to treat drinking water in the household.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

6. Thinking about the people who are important to you like your family members, friends, the chief of the village, or the Mosque, rate how much they encourage that you always use clean water or treat drinking water in the household?

Not at all	Somewhat	Rather	Quite a lot	Very much
1	2	3	4	5

Part 7: COVID-19 related questions

"In this part, I would like to ask some questions if COVID had changed your practices of using and treating water at the household level."

1. Due to COVID-19, we perform water treatment such as water boiling or filtering before drinking and cooking more often in my household.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

2. Due to COVID-19, we wash our hands more often in my household.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

3. COVID-19 has highlighted the importance of having clean drinking water for use in my household.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

4. Due to COVID-19, we keep drinking water in separate containers.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

Post questionnaires:

This section is filled by the surveyor.

1. How cooperative was the respondent?

Very much	Cooperative	Not cooperative
1	2	3

2. How interested was the respondent in the survey?

Very interested	Interested	Not interested
1	2	3

Supplementary material 8.2 Aggregated questionnaire items into the COM-B model

In order to inform the process of aggregating the questionnaire items into the COM-B model of behaviour, I relied on the definition of each component presented by Michie et al. (2014). The detailed method and example questions in the guide developed by West et al. (2019) were instrumental during the process of aggregating items into COM domains (Capability, Opportunity, Motivation). Furthermore, in the process of aggregating the questionnaire items into the COM-B model, also benefited from the qualitative analysis of semi-structured interviews on determinants of household water treatment (HWT) which was delivered in the same study area prior to the quantitative survey. It was deemed necessary to present the definitions for Capability, Opportunity, and Motivation from a COM-B perspective:

Capability: Refers to people's psychological and physical abilities (e.g., knowledge, physical and mental skills, mobility, and strength)
Opportunity: Refers to the environment with which people interact, whether it be the physical environment of objects, events and time, or the social environment of culture, and norms.
Motivation: Relates to the following influences that energise and direct behaviour: intentions and evaluations (collectively known as 'reflective' motivation), and desires, emotions and habits (collectively known as 'automatic' motivation).

Table S8.1 Aggregated questionnaire items into Capability, Opportunity, and Motivation (COM) domains of the COM-B model

COM	Sub-dimensions	Item code	Response	Item	Description	Source
Capability	Physical	cph_age	Number	Participant's age	Age is a facet of Physical Capability; deemed the threshold over the age of 55 as disabling for HWT (presuming this as the average age at which someone tended not to be physically able to perform household water treatment).	(UNICEF/WHO 2006)

	Psychological	cph_Q5_16	5-Point Likert	How certain are you that you will always be able to treat your household drinking water before drinking?	Aimed at investigating ability in performing HWT, adapted from RANAS behaviour model.	(Lilje and Mosler 2018; Slekiene and Mosler 2019)
		cps_Q1_3†	Yes/No	Are you able to read?	Reading capability could be enabling behaviour by helping to understand how to perform HWT and its benefit.	(Daniel et al. 2020; Daniel et al. 2021)
		cps_Q1_4†	Yes/No	Are you able to write?	The writing capability could be enabling behaviour by helping to understand how to perform HWT and its benefit.	(Daniel et al. 2020; Daniel et al. 2021)
		cps_Q3_3†	Yes/No	Has your household water quality ever been tested?	This question aimed at investigating the likelihood of remembering behaviour.	(Ochoo et al. 2017; West et al. 2019)
		cps_Q4_2	5-Point Likert	Are you aware that poor water quality will affect your health?	Aimed to investigate participants' understanding of the importance of performing HWT (what happens if they don't).	(Lilje and Mosler 2018; Slekiene and Mosler 2019; West et al. 2019)
		cps_Q4_9	5-Point Likert	There is a lack of public awareness of poor water quality risks to health.	An additional question aimed to investigate understanding the importance of performing HWT.	Adapted from Ochoo et al. (2017).
		cps_Q6_3	5-Point Likert	My household knows how to perform household water treatment.	The question investigates if the participant knows how to do HTW.	(Ochoo et al., 2017; West et al., 2019)
		cps_Q8_5	6-Point item	What is the highest education level of the head of the household?	Daniel's research has illustrated a significant association of education with performing HWT through the lens of the RANAS behaviour model.	(Daniel et al. 2020; Daniel et al. 2021)
Opportunity	Physical	op_Q2_6†	Yes/No	Do you have a separate container for storing drinking water?	Investigating material support.	(West et al. 2019)
		op_loc †	Good/Bad	Site water quality	Data-driven water quality indicator in the study area.	

				The study of objective indicators and qualitative study highlighted that both study sites had poor water quality, Bagrami with saline water and Doghabad with microbially contaminated water.	
	op_Q3_7	5-Point Likert	It is important to provide opportunities for our community to test the quality of water.	Aimed at investigating access to resources.	Adapted from Ochoo et al. (2017).
	op_Q5_11	5-Point Likert	How effortful do you think is treating drinking water in the household?	Aimed at investigating easy access to necessary material/equipment for performing HWT.	(Lilje and Mosler 2018; Slekiene and Mosler 2019; West et al. 2019)
	op_Q5_12	5-Point Likert	It is time-consuming to treat household drinking water.	Aimed at investigating time constraints.	(Lilje and Mosler 2018; Slekiene and Mosler 2019)
	op_Q5_13	6-Point item	How expensive is it for you to treat your drinking water?	Aimed at investigating easy access to necessary resources for performing HWT.	(Ochoo et al. 2017; West et al. 2019)
	op_Q8_7	4-Point item	Earn in a month	Aimed at investigating access to financial resources to perform the HWT.	(Daniel et al. 2020; Daniel et al. 2021)
	op_Q6_6	5-Point Likert	People look for affordable techniques to treat drinking water in the household.	Aimed at investigating easy access to necessary material for performing HWT.	(Ochoo et al. 2017)
Social	os_Q1_6[†]	Male/Female	Participant's gender	Based on qualitative research fieldwork, gender played an important role in performing HWT.	
	os_Q6_2	5-Point Likert	How often do you talk about water treatment with other people?	Aimed at investigating social triggers on performing HWT.	Adapted from (Ochoo et al. 2017). Also listed in West et al. (2019).
	os_Q6_4	5-Point Likert	People in my community treat drinking water in the household because of their cultural beliefs.	Aimed at investigating social norm influences on performing HWT.	(Ochoo et al. 2017; West et al. 2019)

		os_Q6_5	5-Point Likert	People encourage neighbours to treat drinking water in their households.	Aimed at investigating social triggers on performing HWT.	(Ochoo et al. 2017; West et al. 2019)
		os_Q6_7	5-Point Likert	Thinking about the people who are important to you like your family members, friends, the chief of the village, or the Mosque, rate how much they encourage that you always use clean water or treat drinking water in the household?	Aimed at investigating social influence facilitating performing HWT.	(Lilje and Mosler 2018; Slekiene and Mosler 2019; West et al. 2019)
Motivation	Automatic	ma_Q4_4	5-Point Likert	How worried are you about the health effects of the drinking water you use?	Aimed at investigating to what extent emotion (worry) facilitates or hinders performing HWT.	(Ochoo et al. 2017; West et al. 2019; Daniel et al. 2021)
		ma_Q4_5	5-Point Likert	How frequently does your household suffer from illness due to poor water quality?	Aimed at investigating the urge to avoid performing HWT.	(Lilje and Mosler 2018; Slekiene and Mosler 2019; West et al. 2019)
		ma_Q5_14	5-Point Likert	Do you feel a personal obligation to treat your household drinking water?	Aimed at investigating self-conscious motivation in performing HWT.	(Tomasello 2020)
		ma_Q5_15	5-Point Likert	Do you feel a personal obligation to treat your household drinking water for children under the age of 5 years?	Aimed at investigating self-conscious motivation in performing HWT.	(Tomasello 2020)
		ma_Q5_8	5-Point Likert	How much do you like the taste of treated drinking water?	Aimed at investigating to what extent sensory feeling (taste) facilitates or hinders performing HWT.	(Lilje and Mosler 2018; Slekiene and Mosler 2019)
		ma_Q7_2	5-Point Likert	Due to COVID-19, we perform water treatment such as water boiling or filtering before drinking and cooking more often in my household.	Aimed at investigating the potential of developing a habit due to COVID-19 on performing HWT.	
	Reflective	mr_Q3_2	5-Point Likert	Do you differentiate between the quality of water you use for drinking, washing vegetables, cooking meals, religious ablution, washing clothes, and bathing?	Aimed at investigating the belief in performing HWT (i.e., do they believe that it is a necessary thing to do).	(West et al. 2019)
		mr_Q3_6	5-Point Likert	We have information on our household water quality.	Aimed at investigating the belief in performing HWT (i.e., do they believe that it is a necessary thing to do).	(Ochoo et al. 2017)

	mr_Q3_8	5-Point Likert	Access to good quality drinking water is a priority for my household.	Aimed at investigating the willingness to prioritise performing HWT.	(West et al. 2019)
	mr_Q4_10	5-Point Likert	It is everyone's responsibility to provide safe drinking water for children.	Aimed at investigating the belief in performing HWT.	(Ochoo et al. 2017; West et al. 2019)
	mr_Q4_3	5-Point Likert	If getting ill from drinking untreated water, how severe do you think the illness might be?	Aimed at investigating the care about the negative consequences of not performing HWT.	
	mr_Q4_7	5-Point Likert	I believe that treating water regularly reduces the risk of falling ill.	Aimed to investigate if participants consider the benefits of doing the behaviour.	(Lilje and Mosler 2018; Slekiene and Mosler 2019)
	mr_Q4_8	5-Point Likert	It is necessary to boil water before drinking.	Aimed at investigating if participants feel that they need to perform HWT enough.	(West et al. 2019)
	mr_Q5_10	5-Point Likert	It is important for my household to learn about cheap and accessible household water treatment techniques.	Aimed at investigating if participants feel that they need to perform HWT enough.	(West et al. 2019)
	mr_Q5_18	5-Point item	How much would your household spend in maximum to enhance the quality of water in a month?	Aimed at investigating if other things might interfere with the performing HWT.	(West et al. 2019)

† Categorical variables

Table S8.2 Identified behaviours from questionnaire items

	Code	Response	Item	Description
Behaviours	b_Q5_2†	Yes/No	Do you treat water before drinking in your household?	The question investigates performing household water treatment behaviour in general, without mentioning any specific water treatment method.
	b_botwa (Q1_7_8) †	Buying bottled water vs not buying bottled water	Buying bottled water	The dichotomous variable was generated from responses to Q1_7 (the primary source of drinking water). The question investigates the behaviour of acquiring bottled water for drinking purposes.
	Doer (Q5_4) †	Performing vs not-performing	When did you start treating water in your household?	The dichotomous variable (Doer/Non-doer) was generated from responses to Q5_4. The aim was to cross-check the responses to question b_Q5_2 and to reduce self-report bias in performing household water treatment.
	b_Q5_9	5-Point Likert	Do you boil water before drinking?	The question investigates only boiling the drinking water in households.
	b_Q5_7	5-Point Likert	How often do you use treated water at home?	Follow-up question, aimed at investigating the frequency of using treated water, the question was not limited to any specific method of water treatment.
	b_Q5_6	5-Point Likert	How many people in your household always treat drinking water?	Follow-up question, aimed at investigating the frequency of performing household water treatment the question was not limited to any specific method of water treatment.

† Categorical variables

Supplementary material 8.3 Regression results

Table S8.3– *Regression results of the relationship between COM indices and three water treatment behaviours*

COM-B components	**b_Q5_9** (Model 4) Do you boil water before drinking?	**b_Q5_6** (Model 5) How many people in your household always treat drinking water?	**b_Q5_7** (Model 6) How often do you use treated water at home?
Capability- Psychological	0.199 (.009)** [0.05,0.35]	-0.026 (.757) [-0.19,0.14]	0.067 (.395) [-0.09,0.22]
Capability - Physical	0.188 (.001)*** [0.08,0.29]	0.256 (.000)*** [0.14,0.37]	0.278 (.000)*** [0.17,0.39]
Opportunity - Physical	-0.115 (.223) [-0.30,0.07]	0.435 (.000)*** [0.26,0.61]	0.618 (.000)*** [0.45,0.79]
Opportunity - Social	0.186 (.002)** [0.07,0.30]	0.128 (.035)* [0.01,0.25]	0.107 (.048)* [0.00,0.21]
Motivation - Reflective	-0.150 (.185) [-0.37,0.07]	0.967 (.000)*** [0.73,1.20]	0.841 (.000)*** [0.62,1.06]
Motivation - Automatic	0.705 (.000)*** [0.54,0.87]	0.362 (.000)*** [0.19,0.53]	0.523 (.000)*** [0.36,0.68]
Constant	-0.145 (.144) [-0.34,0.05]	-1.084 (.000)*** [-1.28,-0.89]	-1.181 (.000)*** [-1.36,-1.00]
R^2	0.156	0.228	0.305
p-value	(.000)***	(.000)***	(.000)***
Log Likelihood	-325	-374	-290
Observations	913	913	913

Notes: Coefficients reported. 95% confidence intervals in brackets, p-values in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table S8.4 – *Regression results of the relationship between COM indices and three water treatment behaviours (adjusted for study site clusters)*

COM-B components	**b_Q5_9** (Model 4) Do you boil water before drinking?	**b_Q5_6** (Model 5) How many people in your household always treat drinking water?	**b_Q5_7** (Model 6) How often do you use treated water at home?
Capability-Psychological	0.199 (.032)* [0.07,0.33]	-0.026 (.783) [-0.97,0.92]	0.067 (.419) [-0.59,0.73]
Capability - Physical	0.188 (.016)* [0.13,0.25]	0.256 (.170) [-0.64,1.15]	0.278 (.160) [-0.63,1.18]
Opportunity - Physical	-0.115 (.563) [-1.90,1.67]	0.435 (.041)* [0.07,0.79]	0.618 (.017)* [0.41,0.83]
Opportunity - Social	0.186 (.069) [-0.07,0.44]	0.128 (.333) [-0.81,1.06]	0.107 (.076) [-0.06,0.27]
Motivation - Reflective	-0.150 (.647) [-3.23,2.93]	0.967 (.173) [-2.46,4.40]	0.841 (.090) [-0.69,2.37]
Motivation - Automatic	0.705 (.026)* [0.34,1.07]	0.362 (.011)* [0.28,0.44]	0.523 (.063) [-0.14,1.19]
Constant	-0.145 (.668) [-3.35,3.06]	-1.084 (.065) [-2.50,0.34]	-1.181 (.008)** [-1.37,-0.99]
R^2	0.156	0.228	0.305
Log Likelihood	-325	-374	-290
Observations	913	913	913

Notes: Logistic regressions. Coefficients reported. 95% confidence intervals in brackets, p-values in parentheses. Standard errors adjusted for site-level clustering.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Supplementary material 8.4 Robustness checks

Table S8.5 – Robustness check for Location as dummy variable

```
-> Location = Doghabad

Iteration 0:   log pseudolikelihood =   -344.469
Iteration 1:   log pseudolikelihood = -273.06832
Iteration 2:   log pseudolikelihood = -272.88069
Iteration 3:   log pseudolikelihood = -272.88062
Iteration 4:   log pseudolikelihood = -272.88062

Logistic regression                                     Number of obs =    497
                                                        Wald chi2(6)  =  94.95
                                                        Prob > chi2   = 0.0000
Log pseudolikelihood = -272.88062                       Pseudo R2     = 0.2078
```

Doer	Coefficient	Robust std. err.	z	P>|z|	[95% conf. interval]	
cps_index	.1078546	.7128483	0.15	0.880	-1.289302	1.505012
cph_index	1.022999	.5219841	1.96	0.050	-.0000705	2.046069
alt_opindex	5.474603	.8756742	6.25	0.000	3.758313	7.190893
os_index	.6067735	.4968431	1.22	0.222	-.3670211	1.580568
mr_index	2.832774	1.213387	2.33	0.020	.4545798	5.210969
ma_index	3.912827	.7647806	5.12	0.000	2.413885	5.41177
_cons	-9.536992	1.153452	-8.27	0.000	-11.79772	-7.276267

```
-> Location = Bagrami

Iteration 0:   log pseudolikelihood = -265.70449
Iteration 1:   log pseudolikelihood = -232.11762
Iteration 2:   log pseudolikelihood = -231.71174
Iteration 3:   log pseudolikelihood = -231.71148
Iteration 4:   log pseudolikelihood = -231.71148

Logistic regression                                     Number of obs =    416
                                                        Wald chi2(6)  =  57.47
                                                        Prob > chi2   = 0.0000
Log pseudolikelihood = -231.71148                       Pseudo R2     = 0.1279
```

Doer	Coefficient	Robust std. err.	z	P>|z|	[95% conf. interval]	
cps_index	-.1795641	.8284534	-0.22	0.828	-1.803303	1.444175
cph_index	1.634634	.5437471	3.01	0.003	.5689093	2.700359
alt_opindex	2.415806	.9034858	2.67	0.007	.645006	4.186605
os_index	.3654446	.5851002	0.62	0.532	-.7813307	1.51222
mr_index	4.2926	1.260942	3.40	0.001	1.8212	6.764001
ma_index	3.004497	.9682932	3.10	0.002	1.106678	4.902317
_cons	-7.934139	1.301526	-6.10	0.000	-10.48508	-5.383194

Table S8.6– Robustness check for Surveyor Gender

Summary statistics: Mean
Group variable: surv_gender

surv_gender	cps_in~x	cph_in~x	op_index	os_index	mr_index	ma_index
Male	0.506412	0.700787	0.660679	0.366732	0.795494	0.626476
Female	0.542152	0.727881	0.673354	0.395885	0.812986	0.712106
Total	0.523886	0.714034	0.666876	0.380986	0.804047	0.668343

Chapter 9

Mohammad Daud Hamidi, Gary Sharples, H. Chris Greenwell

Contributions: Mohammad Daud Hamidi was responsible for conceptualization, data collection, data analysis, methodology, visualization, writing original draft, review and editing. GS (my co-supervisor) contributed through discussions and facilitating the lab for microbial removal efficacy tests, review and editing. HCG contributed through supervision (my primary supervisor), resources, review and editing. As the main author, I would like to thank GS and HCG for their helpful discussions and priceless suggestions.

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9 Low-cost Household Drinking Water Treatment using Clay Disc Filters

9.1 Introduction

Waterborne diseases are often associated with poor sanitation and hygiene, as well as inadequate water treatment and storage practices, and mainly occur in low-and middle-income countries (Cissé 2019). Waterborne diseases have a substantial role in the high rate of child mortality in Afghanistan, where 97 out of every 1000 children born die before the age of five (Rasooly et al. 2014). Due to the lack of water supply networks, lack of wastewater networks and contaminated drinking water sources in Afghanistan, the need for household water treatment is critical to reducing the risks of water-borne diseases. Examples of household water treatment methods include the use of ceramic or clay-disc filters, boiling, solar water disinfection (SODIS), chlorination, combined coagulant chlorine, and Biosand (Clasen 2005). The ceramic filters showed the greatest effectiveness compared to all other interventions such as Biosand, chlorine, combined coagulant-chlorine, and SODIS (Sobsey et al. 2008). Although household water treatment has the potential to be advantageous, there are obstacles to its adoption. Cost and accessibility of appropriate water treatment technology are major concerns, especially in low-and middle-income countries where resources may be limited.

Ceramic filters are relatively simple and affordable, making them a popular choice in developing countries where access to clean drinking water is limited (Oyanedel-Craver and Smith 2008; Rayner et al. 2013; Ren et al. 2013; PFP 2019; Yang et al. 2020b). Several studies indicated that ceramic filters are effective at reducing the levels of bacteria and other contaminants in water. For example, efficient removal of E.coli (96.51 %) was observed in clay filters made of 80 % clay, 15 % sawdust, and 5 % grog which was fired at 800 °C, meanwhile, it has been noted that ceramic filters with lower porosity had the best removal efficiency (Bulta and Micheal 2019). The performance projection indicated that ceramic filters can operate for up to 225 days with regular maintenance, and can provide enough drinking water for a family of four for at least 146 days, the analysis has shown that continuous filtration led to a longer filter lifetime than non-continuous filtration (Ahmed 2017). Furthermore, researchers suggest that the use of silver as an antibacterial agent does not play a dominant role, and no significant difference was found between the filters with or without silver (Oyanedel-Craver and Smith, 2008; Brown and Sobsey, 2010).

In many parts of the world, ceramic filters were found effective at reducing the levels of bacteria in water (Brown and Sobsey 2006). Taking into consideration that groundwater contamination with bacteria is a serious problem in Afghanistan, particularly in Kabul, the use of ceramic water filters as an interim, inexpensive, and sustainable solution is a viable option. Pottery has a long history in Afghanistan (Allchin et al. 1978). Pottery in Afghanistan is typically made using a combination of local clays and glazes, and is often decorated with intricate patterns (Istalifi 2020). The pottery products have been used for a variety of purposes, including cooking, storing, and decoration. Many people in the country have found career opportunities and financial stability in the pottery industry. The culture in Afghanistan still heavily incorporates pottery today, and many potters are attempting to maintain and revive age-old techniques and designs. However, besides the long history of pottery in Afghanistan, ceramic filters are not produced in the country. Lack of awareness about the production of ceramic filters may be the main reason.

This chapter aims to characterise clay sourced from two deposits in Kabul and explore the development affordable of clay disc filters with maximum bacterial removal efficacy. Using clay disc filters for household water treatment in Kabul does not require electricity or other resources to operate and can replace importing water treatment technology and increase the income of local potters. In any case, affordable solutions to the problem of contaminated groundwater in Kabul will ensure that the broader population has access to clean, safe drinking water.

9.2 Methods

9.2.1 Clay material characterization

9.2.1.1 X-ray fluorescence

The major oxide composition of bulk rock samples was determined by X-ray fluorescence (XRF) using a Rigaku Supermini200 WD-XRF Spectrometer, by X-ray Mineral Services Ltd. The clay samples were dried in an oven at 80 ºC and then crushed using a mortar and pestle. Milled samples (1 g) were transferred to a ceramic crucible and placed in a furnace preheated to 1050 ºC for 1 h before XRF analysis. The minor element composition of bulk rock samples was analysed using a Rigaku NEX-DE ED-XRF Spectrometer by X-ray Mineral Services Ltd. Samples were dried in an oven at 80 ºC, crushed using a pestle and mortar and milled in an agate ball mill at 500 rpm for 5 min. Milled samples (10 ± 0.2 g) were mixed with a polyvinyl alcohol binder (1% Moviol) and the resulting mixture was pressed at 15 tonnes for 2 min using polished stainless-steel platens to produce a 32 mm diameter pellet. Pelleted samples were dried in the oven at 80 ºC for a minimum of 2 h before analysis by XRF to identify minor elements.

9.2.1.2 X-ray diffraction

The mineralogy of clay samples was determined in a PANalytical X'Pert3 Diffractometer, by X-ray Minerals Services Ltd. A sample weight of 2 g was ground in a McCrone Micronizing Mill. Randomly oriented samples were prepared using the front-loading technique and analysed from 4º to 75º 2Θ at a step size of 0.013º with a nominal time per step of 0.2 s using X-ray radiation from a copper anode (Cu kα, $\lambda = 0.1$ nm) at 40 kV and 40 mA. Mineral quantification was carried out by Rietveld analysis of the XRD patterns using Autoquant software (Kleeberg and Bergmann 1998). Separated clay fraction samples were analysed on a Philips PW1730 diffractometer. Less than 2 µm fraction was achieved by separation using centrifugation, by varying centrifuge speed and separation period. The mounted clay XRD sample was obtained by filtering the clay suspension through a Millipore glass microfibre and drying the filtrate onto filter paper. Samples were analysed as untreated clay, after saturation with ethylene glycol vapour for 24 h and heating at 380 ºC for 2 h, with further heating to 550 ºC for 1 h. Scans for treated samples were from 3º to 35º 2Θ at a step size of 0.05 º/sec. Untreated samples were also analysed between 24º and 27º 2Θ at a step size of 0.02 º/2 sec.

9.2.2 Clay disc filters

9.2.2.1 Producing clay disc filters

Clay disc filters were manufactured in the lab environment using Terracotta clay and sawdust. The clay was crushed with mortar and pestle, before being sieved. Both the crushed clay and sawdust were separately sorted using the 35-mesh sieve (500 µm) and 60-mesh sieve (250 µm), only the materials passed through the 35-mesh sieve and remained on the 60-mesh sieve were used for the production of clay discs (Figure 9.1 a and b). The required proportions of sieved clay and sawdust were measured by volume (1:2, the ratio of clay to sawdust, for simplicity), were mixed dry, and then wetted by adding water. Once the clay reached saturation, it was mixed kneaded and rolled into a smooth homogeneous mixture. The clay mixture was moulded into a disc-like shape using a mould (Figure 9.1 c).

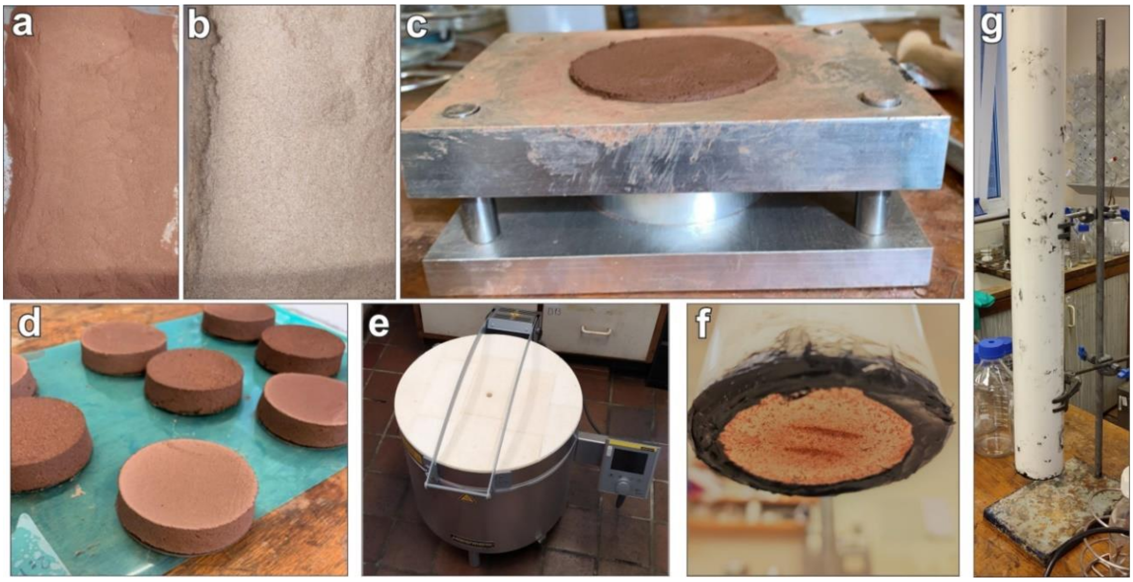

Figure 9.1 Process of producing the clay disc filters and delivering tests: sieved clay (a), sieved sawdust (b), mould for shaping circular disc from a saturated mixture of clay and sawdust (c) disc left at room temperature to dry (d), kiln for burning the disc in high temperature of over 700 °C (e), sintered clay disc attached to a pipe with silicon sealant (f), set-up for testing filtration rate and microbial efficacy of sintered clay disc (g).

The moulded wet clay discs were dried in air at room temperature for 4 days, it could be extended if needed (Figure 9.1 d). The dried discs were labelled before sintering at 850 °C. A programmable pottery kiln (Nabertherm Top 16/R) was used for sintering the dried clay discs. Since clay loses a lot of water and shrinks, the quick rise in kiln temperature can cause cracks. Therefore, the kiln was heated slowly from 0 °C to 650 °C at 150 °C per hour. Then, the kiln reached 850° C for 20 mins, and finally, the kiln sintered the disc for 5 hours (Figure 9.1 e). The total time required for sintering the discs at 850 °C was 9 hours and 40 minutes.

9.2.2.2 Filtration rate measurements

It is important to measure the amount of filtered water that could be provided in a matter of time to a household using clay disc filters. Therefore, the filtration rate of sintered clay discs was measured. The disc was attached to one end of a PVC pipe (height: 650 mm, and internal diameter: 67.8 mm) with silicone sealant. After 24 hours that the sealant dried, water (1.5 l) was poured into the pipe (Figure 9.1 g). In two rounds, for 70 minutes, the amount of water flowing through the disc was measured every 10 minutes.

9.2.2.3 Testing for Microbial efficacy

One of the main criteria for evaluating household water treatment technologies is testing for microbiological performance (WHO 2011). *E. coli* (BW25113 strain, see the details of strain in Supplementary Material 9.1) was grown at 37 °C for 24 h. The suspension was prepared by adding 50 ml of BW25113 to inoculate 1 litre of sterile distilled water (SDW). The suspension was applied to the column with the sintered clay disc sealed in one end, and fractions flowing through the disc were collected in 200 ml volumes (Figure 9.1 f and g). A control was obtained from the suspension before application to the column, and was maintained at room temperature for the duration of the experiment. The control and collected fractions were serially diluted in SDW down to 10^{-6}, and 10 µl volumes at each dilution were applied to 3 separate Luria-Bertani (LB) agar plates. Plates were incubated at 30 °C overnight, and imaged using the Gel Dock. During the experiment, optical density (OD), the concentration of bacteria in control and fractions was measured using a spectrophotometer (OD600, Thermo Fisher Scientific).

The efficiency of the clay disc filters at removing *E. coli* from the suspension was estimated using the following equation:

$$LRV = \log_{10}\left(\frac{Initial\ CFU}{Final\ CFU}\right) \qquad (1)$$

Where LRV is the log reduction value, the Initial CFU is the number of colonies forming units (CFU) in the control (before filtration), and the Final CFU is the number of colonies forming units in the collected fractions (after filtration).

9.3 Results & Discussion

9.3.1 Geochemical and mineralogical characteristics of clays in Kabul

Clay samples sourced from two deposits located in Kabul province in Afghanistan were characterized. The clay sourced from Istalif (N 34° 49’ 25.80’’; E 69° 07’ 08.30’’) and

Paghman (N 34° 36’ 24.10’’; E 69° 57’ 53.91’) deposits are used by local potters and brick factories.

Major and minor element compositions of clays from Kabul were analysed in parallel by XRF (Table 9.1). The clay content included SiO_2, Al_2O_3, Na_2O, K_2O, and CaO which represents the variations in the amounts of quartz, feldspars, calcite, illite and kaolinite. The presence of MgO, Fe_2O_3 and TiO_2 content is attributed to the abundance of smectite and chlorite in the samples (Figure 9.2).

Table 9.1. Major and minor element composition of clay samples from Kabul

Composition	Istalif (%)	Paghman (%)
Na_2O	1.37	1.35
MgO	2.57	3.64
Al_2O_3	15.62	11.98
SiO_2	52.42	50.72
P_2O_5	0.09	0.18
SO_3	<0.01	0.08
K_2O	2.32	2.37
CaO	6.8	10.39
TiO_2	0.76	0.65
Mn_2O_3	0.12	0.12
Fe_2O_3	6.43	5.16
BaO	0.07	0.08
LOI	11.1	12.5

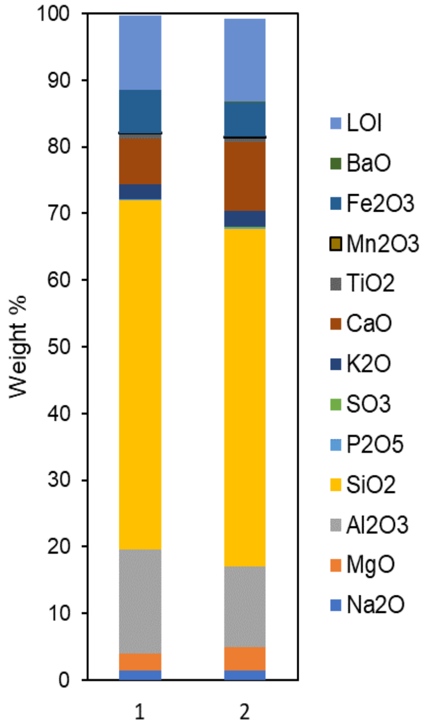

Figure 9.2 Major and minor element composition of clay samples from Kabul: Istalif (1), and Paghman (2).

The morphological analysis of clay minerals using XRD revealed the presence of illite-smectite and chlorite-smectite mixed layers, indicating the smectite transformation being at an early stage. The presence of low amounts of illite (10-30%) and chlorite in the illite-mixed layer and chlorite mixed layers also indicated early-stage transformation of smectite into illite and chlorite, respectively.

The bulk clay samples had a mixed mineral composition, typical of most natural clay deposits. The two clays from the Kabul Basin in Afghanistan had similar mineralogical compositions (Table 9.2 and Figure 9.3). The percentage of quartz in the sample was 34.2% while the percentage of illite+mica was 14.6%. The presence of these minerals in the sample suggests that the rock has undergone weathering and clay formation processes.

Table 9.2. XRD results of whole rock clay samples from Kabul

Mineral	Istalif (%wt)	Paghman (%wt)
Illite/Smectite	1.6	0
Illite+Mica	14.6	17.2
Kaolinite	0.5	2
Chlorite	2	3.1
Quartz	34.2	36.1
K Feldspar	5.5	4.3
Plagioclase	22.4	14
Amphibole	2	1.3
Calcite	17.2	19.1
Dolomite	0	2.9
Total	100	100

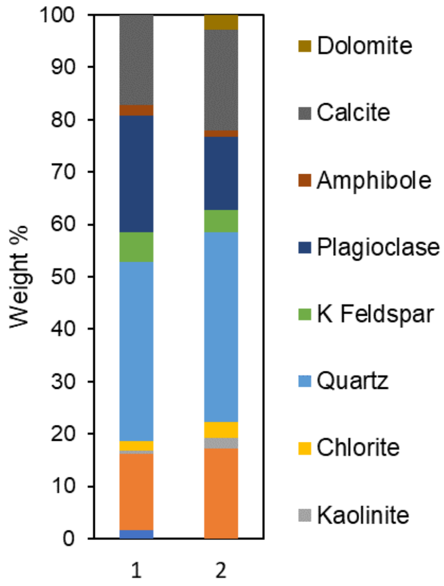

Figure 9.3. XRD results of whole rock clay samples from Kabul: Istalif (1), and Paghman (2).

The quantitative mineralogy (weight %) of the < 2 µm clay fractions are presented in Table 9.3 and Figure 9.4, illite makes up over 50% of the clay samples from both deposits. Illite is a type of clay mineral that is commonly found in sedimentary rocks.

Table 9.3. XRD results of < 2-micron clay samples from Kabul

Mineral	Istalif (%wt)	Paghman (%wt)
Smectite	0	0
Illite/Smectite (RI=20%-30%)	27.3	-
Illite	50.7	68.2
Kaolinite	9.1	11.6
Chl/Smectite	0	0
Chlorite	9.8	14.6
Quartz	1.7	1.7
Calcite	1.5	3.9
Total	100	100

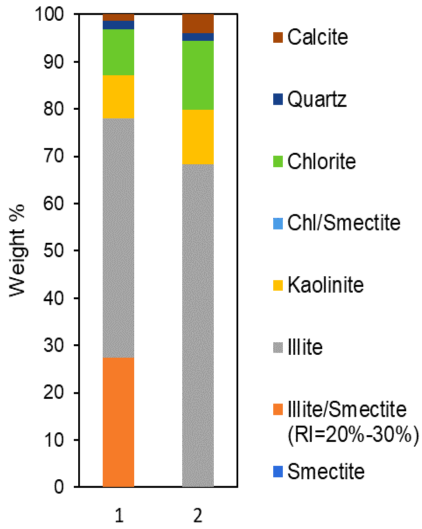

Figure 9.4 XRD results of < 2-micron clay samples from Kabul: Istalif (1), and Paghman (2).

Clay mineralogy can impact the performance of clay disc filters by affecting the ability of bacteria to attach to the walls of pores in the clay disc. This is because the composition and structure of clay minerals can influence the surface properties of the pore walls, making them more or less conducive to bacterial attachment (Asadishad et al. 2013; Unuabonah et al. 2018; Venis and Basu 2020). Furthermore, the clay mineralogy affects clay disc performance by controlling the amount of shrinkage observed during the firing process, the amount of shrinkage that occurs during sintering depends on the composition and structure of the clay minerals, as well as the temperature and duration of the firing process (Oyanedel-Craver and Smith 2008). The major elements of clay samples sourced from Kabul are identical to the clay used for the production of clay discs in the lab environment by Yang et al., (2020a).

9.3.2 Clay disc filters

The production of clay disc filters is deliberately simple, such that it could be done easily at home, by local users, as long as access to a kiln for reaching high temperatures is possible, or they could be made in batches at local potteries. These filters are made from locally-sourced clay and are relatively inexpensive to produce. I had the opportunity to interview several local potters about their skills and the pottery industry in Kabul and was impressed by their creativity in the design of their products. Furthermore, during my interviews with local potters, it became clear they are very flexible in terms of designing and customizing products to meet the needs of different communities. Following my explanation of the clay disc filters, the potters shared that they are able to adjust the size and shape of the filters to suit the specific needs of the community. The following sections, however, are the result of experiments on clay disc filters produced in a lab environment at Durham University.

9.3.2.1 Filtration rate of the sintered clay discs

The filtration rate of the sintered clay disc (mixture of 1:2, the ratio of clay to sawdust by volume, sintered at 850 °C) is presented in Figure 9.5. The peak amount of water passed through the disc (390±5 ml) was observed during the first 10 minutes of the experiment and decreased to a minimum amount at the end of the experiment (70±3 ml).

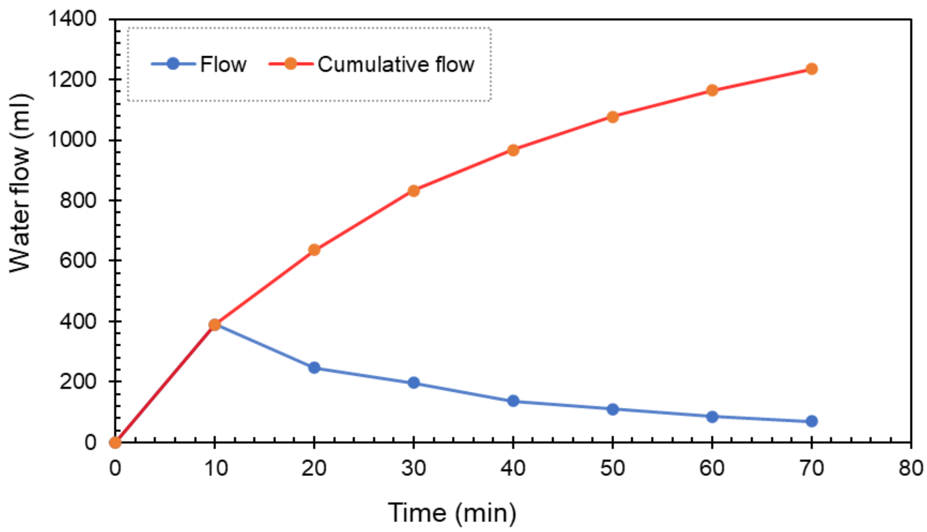

Figure 9.5. Sintered clay disc filtration rate: the blue line is the water flow at each 10-minute interval, and the red line is the cumulative amount of water passed from the sintered clay disc.

The cumulative amount of water passed in one hour from the sinter clay disc was promising (1164± 10 ml/h). One filter with a filtration rate of above 1 l/h, will satisfy filtering the daily drinking water needs of a family with 12 members (assuming each person consumes 2 litres of drinking water in 24 h).

Critical parameters determining the filtration rate in clay disc filters are the porosity of the clay disc, the size of the pores in the clay disc, and the water pressure applied to the clay disc (van Halem 2006; van Halem et al. 2007; Klarman 2009; Zereffa and Bekalo 2017; Shepard et al. 2020; Venis and Basu 2020; Yang et al. 2020b). The ratio of clay to combustible material (sawdust and rice husk) is a determinant of the porosity, which is the amount of open space or “pores” in the clay disc (Servi et al. 2013; Lemons et al. 2016; Nnaji et al. 2016; Bulta and Micheal 2019). The size of combustible material (sawdust) is determining the size of pores in the clay disc (Hagan et al. 2008; Ren et al. 2013; Rayner et al. 2017). However, properly size sorting the combustible material is overlooked both in the laboratory environment and industry practices, which is very likely the reason behind reporting inconsistent filtration rates. For example, Bulta and Micheal (2019), Abiriga and Kinyera (2014), Soppe et al. (2015) and many other researchers, particularly in industry, had only reported one sieve size for sorting the clay and combustible material (sawdust and rice husk). Using two sieves can improve the sorting of materials by allowing smaller particles to pass through the first sieve and larger particles to be caught by the second sieve, which can help to more effectively separate the combustible material and improve the filtration rate in the clay disc filters. After several trials in this work, the 35-mesh sieve (500 µm) and 60-mesh sieve (250 µm) were used for sorting combustible material (sawdust) which was potentially the cause for consistent filtration rate among the clay disc filters with a similar mixture (ratio of clay to sawdust).

9.3.2.2 Microbial removal efficacy of sintered clay disc

The results of the microbial removal efficacy analysis are presented in Figure S9.1, which shows the images of LB agar plates containing colonies for both the control group and the suspension at different fractions. The number of colonies for each plate is presented in Table S9.1 - 3, and the average colony-forming unit per 100 ml (CFU/100 ml) is presented in Table 9.4. The average number of CFU in the control was 370000 CFU/100 ml. The average number of CFU in Fraction 1 was 15666 CFU/100 ml which indicated a 95.8 % reduction compared to the control.

Table 9.4 Average colony-forming unit in 100 ml, Log Reduction Values (LRV), and optical density of control and collected suspension at fractions

Description	Cumulative water flow (ml)	Average CFU/100ml	LRV	Optical density
Control		370000		0.094
Fraction 1	200±15	15666.67	1.4	0.036
Fraction 2	400±15	25000.00	1.2	0.049
Fraction 3	600±15	35000.00	1.0	0.057
Fraction 4	800±15	27000.00	1.1	0.065

The microbial removal efficacy of the clay disc filter is presented as LRV (Table 9.4, Figure 9.6), indicating the peak removal efficacy in the first fraction of suspension passed through the clay disc filter. A decrease was observed in microbial removal efficacy, and the lowest LRV was observed in the last fraction of suspension passed through the filter. The optical density of control and collected fractions of suspension, filtered through the clay disc, is present in Table 9.4 and Figure 9.6, indicating a declining trend of optical density towards the end of the experiment.

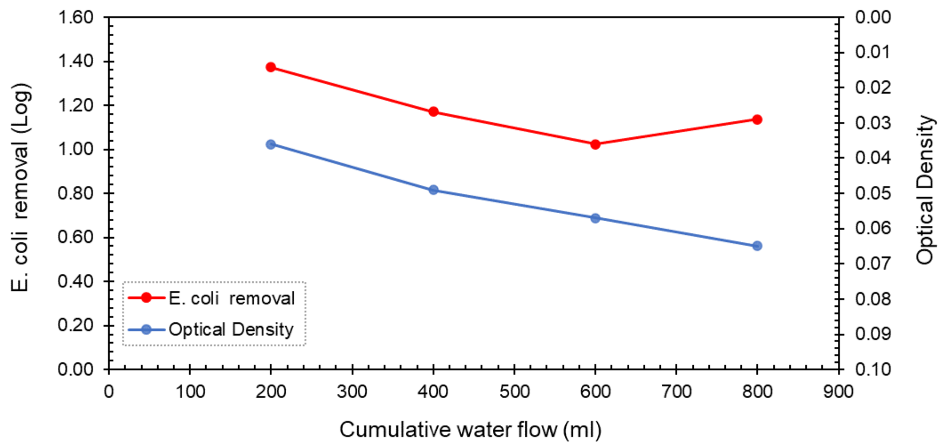

Figure 9.6 *E. coli* removal efficiency of sintered clay discs and optical density values of suspension at fractions.

The microbial removal process in clay disc filters is primarily described as a mechanical straining process where larger particles are physically unable to pass through the pores of the filter and an adsorption process where the microorganisms become trapped and are unable to pass through the filter (Rayner et al. 2013). Therefore, parameters such as the porosity of the clay disc, and the size of the pores in the clay disc are critical for microbial removal efficacy (van Halem et al. 2007; Lantagne et al. 2010; Mwabi et al. 2012; Zereffa and Bekalo 2017; PFP 2019; Shepard et al. 2020; Yang et al. 2020b). Large pores lead to higher porosity and increased flow rate. However, small pores are better at trapping and removing microbes. Finding a middle ground between optimum flow rate and maximum efficacy practically requires simultaneous control of several parameters. The findings of this study illustrated that a higher filtration rate is achievable by properly size-sorting combustible material. Though the microbial removal efficacy of 1.4 LRV is promising, it doesn't meet the requirements set by World Health Organization (WHO). Thus, future work should focus on the ratio of clay to sawdust (e.g., 1:1.5, the ratio of clay to sawdust) to achieve higher microbial removal efficacy (at least 2 LRV, as set by WHO). Furthermore, this work must be transferred to local potters in Kabul (and, around Afghanistan) so that they also have the opportunity to integrate their creativity into developing the clay disc filters.

9.4 Conclusions

Affordable solutions to the problem of contaminated water will ensure that the broader population has access to clean, safe drinking water. The clay samples sourced from Kabul, Afghanistan were found suitable for the production of clay discs. The clay samples from both deposits were found to have similar mineralogical compositions and included quartz, illite, and mica. Properly sorting combustible material was found to be an important factor, which has, hitherto, been overlooked in research and industry. Combustible material passed through a 35-mesh sieve and remained on a 60-mesh sieve and was used for producing clay discs. Clay discs were produced by mixing the clay and the sorted sawdust in a ratio of 1:2 (clay to sawdust, by volume). Experiments on sintered clay discs in the lab environment showed that they are effective at removing bacteria from water (1.4 LRV), with a filtration rate of 1 l/h, making them a potential solution for improving water quality in Afghanistan. The flexibility of local potters in terms of designing and customizing products to meet the needs of different communities could also help in the production of clay disc filters. The results of this study demonstrate the potential of clay disc filters as a low-cost and locally-sourced solution for improving water quality in Afghanistan. Further research and development are needed to optimize the production and performance of these filters in different environments, especially relying on local potter skills.

Supplementary material

Supplementary material 9.1 Detail of the Strain used for testing microbial efficacy

Strain details: BW25113, CGSC7636 (*lacI*$^+$ *rrnBT14 ΔlacZWJ16 hsdR514 ΔaraBADAH33 ΔrhaBADLD78 rph-1 Δ(araB–D)567 Δ(rhaD–B)568 ΔlacZ4787(::rrnB-3) hsdR514 rph-1*).

Luria Bertani (LB Lennox) medium was used for bacterial cultivation on agar plates (Sigma Aldrich, L7533) and broth (Sigma Aldrich, L3022). All media and agar were sterilised at 121˚C for 15 min at 15 psi in a Dixons Vario 1528 autoclave. Media and other water-soluble reagents were made up of distilled water obtained from a Milli-Q® Integral 15, Merck Millipore water filtration system, and sterilised by autoclaving. Overnight cultures were prepared by picking a single colony from a Luria Bertani (LB) agar plate using a sterile plastic loop (Sarstedt, 86.1562.010) and inoculating 5 ml of LB broth in a sterile 15 ml screw-capped Falcon tube (Sarstedt, 62.554.502). Cultures were incubated at 37°C in a shaking incubator at 150 rpm (Stuart Orbital Incubator SI500) for 16-20 h. 2 x 25ml overnight cultures were made by inoculating LB in 50 ml Falcon tubes.

Supplementary material 9.2 Images of three LB agar plates for colonies count

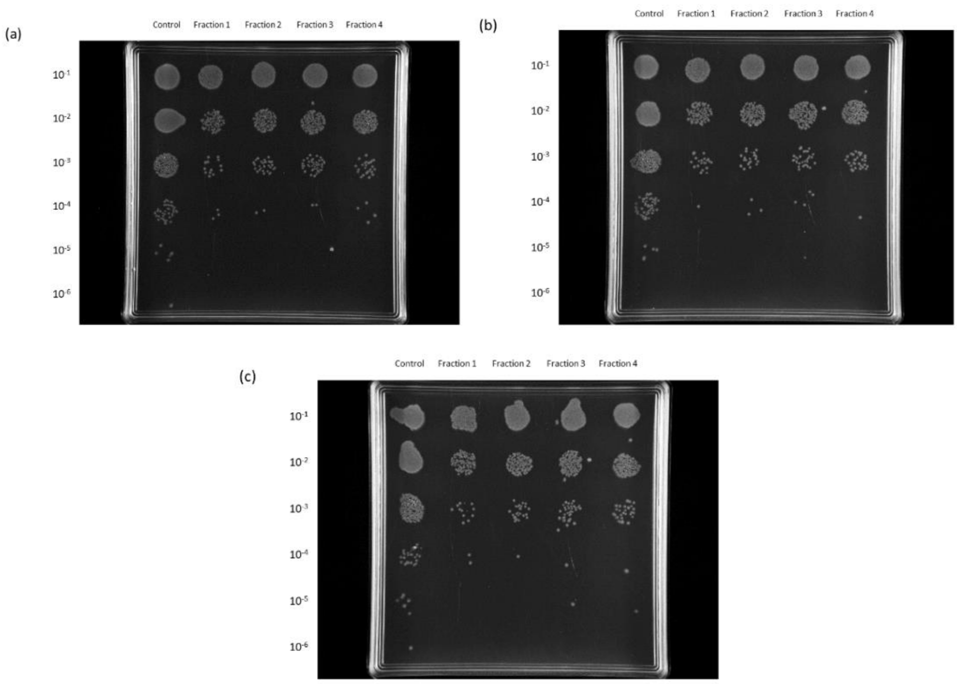

Figure S9.1 Images of three LB agar plates for colonies count in control and collected suspension at fractions

Supplementary material 9.3 Colonies counts for plates a, b, and c (Figure S9.1)

Table S9.1 Colonies counts for plates a (Figure S9.1).

Plate 1 (a)

Sample	Colonies count	Dilution	Amount in 1 ml	Amount in 1 ml neat
Control	36	10^-4	3600	36000000
Fraction 1	13	10^-3	1300	1300000
Fraction 2	29	10^-3	2900	2900000
Fraction 3	39	10^-3	3900	3900000
Fraction 4	26	10^-3	2600	2600000

Table S9.2 Colonies counts for plate b (Figure S9.1).

Plate 2 (b)

Sample	Colonies count	Dilution	Amount in 1 ml	Amount in 1 ml neat
Control	52	10^-4	5200	52000000
Fraction 1	22	10^-3	2200	2200000
Fraction 2	21	10^-3	2100	2100000
Fraction 3	32	10^-3	3200	3200000
Fraction 4	28	10^-3	2800	2800000

Table S9.3 Colonies counts for plate c (Figure S9.1).

Plate 3 (c)

Sample	Colonies count	Dilution	Amount in 1 ml	Amount in 1 ml neat
Control	23	10^-4	2300	23000000
Fraction 1	12	10^-3	1200	1200000
Fraction 2	25	10^-3	2500	2500000
Fraction 3	34	10^-3	3400	3400000
Fraction 4	27	10^-3	2700	2700000

Chapter 10

10 Conclusions

10.1 Summary

This thesis successfully achieved important objectives including: quantified the interaction between surface and groundwater sources in the Kabul aquifer system, and assessed water quality in Kabul City to identify vulnerable neighbourhoods. The thesis also investigated the development of a low-cost, locally sourced water treatment method that can be used by local communities. These achievements provide valuable insights into the dynamics of the Kabul aquifer system and the quality of water in Kabul City, and offer a practical solution for improving access to clean drinking water in the region. Furthermore, the thesis qualitatively examined access to water and inter-household water-sharing practices in peri-urban Kabul.

Additionally, this thesis conducted a thorough qualitative and quantitative investigation of the factors influencing household water treatment practices. This work serves as a valuable foundation for delivering future interventions on the sustainable use of the developed water treatment technology, as it helps to identify the key factors influencing the adoption of household water treatment methods with implications in low-and-middle-income settings. Overall, this thesis provided valuable contributions by synthesizing perspectives from the natural and social sciences, to understanding and addressing the challenges related to access to safe drinking water in Kabul City. Below are the summary of achievements:

10.1.1 Groundwater sources in Kabul city

- Groundwater levels in Kabul city have spatially changed, with substantial depletion occurring in the Central Kabul sub-basin and western parts of the city between 2007 and 2020.
- River water contributed to an average of over 60% of groundwater recharge in 2007, but this has decreased to an average of less than 50% in 2020, with considerable variability in relation to the depth, and spatially.
- The predominant groundwater type in Kabul city is Ca-HCO_3, the chemical composition of the groundwater is governed by water-rock interaction.

- There has been an increase in Na^{+}, Cl^{-}, and Mg^{2+} in the groundwater of Kabul between 2007 and 2020, also highlighted by the increasing Water Quality Index (WQI).
- An increase in NO_3^{-} and *E. coli* is observed between 2007 and 2020, indicating an increase in faecal contamination, and associated with anthropogenic activities.
- Point-of-use water purification interventions may offer a temporary solution for microbial removal and help prevent waterborne diseases.

10.1.2 Challenges with access to water and measuring access to water

- Factors limiting access to clean drinking water in two peri-urban areas in Kabul included: dysfunctional water supply networks, inequalities in water prices, uneven development, and development aid prioritization. Furthermore, droughts, groundwater contamination, and electricity disruption also limited access to water.
- Gender and home ownership also played a role in limiting access to water, this brings two important factors to attention for future interventions. For instance, both gender and home ownership could be targeted through government policy and awareness-raising campaigns.
- Interpersonal conflict cases were presented that have the potential of creating traumatic experiences in accessing water.
- A case was established on the limitation of existing approaches in measuring access to water, an integrated approach for measuring access to water that can help prioritise interventions and make development aid allocation more effective.

10.1.3 Water sharing practices

- The qualitative study found that various factors influence inter-household water-sharing practices, including water availability, costs to the donor, costs to the donor, frequency of requests for water, and the period over which they operate.

- Drought can significantly affect water availability and costs, which in turn impacted inter-household water-sharing practices.
- It is unnecessary to categorize water sharing as a moral economy or generalized reciprocity; rather, from a behaviour science perspective, social and physical opportunity factors appear to be drivers of water-sharing practices.

10.1.4 Household water treatment and the factors influencing the practices

- *Qualitatively:* A comprehensive behaviour change model (COM-B) was used to explore factors influencing household water treatment practices in two peri-urban areas in Kabul, which highlighted:
- Physical and social context also determined household water treatment practices, including location, availability of alternative drinking water sources, water-borne disease outbreaks, electricity outages, droughts, and competing priorities for time and resources.
- Psychological factors, such as reflective motivation, play a role in performing household water treatment.
- *Quantitively:* the study examined factors influencing household water treatment behaviour relying on the COM-B approach and suggested that reflective and automatic motivation, and physical opportunity were determining factors.
- The findings of this research suggested that socioeconomic, psychosocial, and contextual factors are important in understanding the determinants of household water treatment behaviour, contrary to dominant behaviour models asserting only on psychological factors.

10.1.5 Ceramic filters as a low-cost approach for household water treatment in Kabul

- Clay samples from Kabul, Afghanistan were characterized and were found identical to the clay used for the production of clay disc filters.

- XRD analysis of whole rock clay samples from two deposits in Kabul Basin showed that quartz accounted for 34.2% of the composition, while illite+mica made up 14.6%. The presence of these minerals suggests that the rock underwent weathering and clay formation processes in the rock.
- XRD analysis of < 2-micron clay samples indicated that over 50% of the clay samples from both deposits were composed of illite. Illite is a common clay mineral in sedimentary rocks.
- Proper sorting of combustible material was found to be important in the production of clay disc filters, to get an optimal filtration rate and microbial removal efficacy.
- Clay and combustible materials passed through the 35-mesh sieve and remained on the 60-mesh sieve were used to produce clay discs in a ratio of 1:2 (clay to sawdust, by volume), the discs were found to be effective at removing bacteria from water (1.4 LRV), and have a filtration rate of 1 l/h, making them a potential solution for improving water quality.

10.2 Policy recommendations

10.2.1 Groundwater sustainable management in Kabul city

- The recommendation of the World Bank (2010) for the construction of a conveyance link to bring water from the Panjshir sub-basin to Kabul as a solution to address water shortages is plausible for the short term. However, it should be noted that this solution may not be sustainable for the long term due to climate impact where projections by Ghulami et al. (2022) indicated a significant decrease in river flow in the near future (2030 - 2040). Moreover, the findings of the current thesis highlighted a decline in river water contribution to groundwater recharge (Chapter 3). Thus, considering other strategies is critical for sustainable access to water in Kabul for instance investment in expanding the water supply network, establishing wastewater treatment facilities, implementing Managed Aquifer Recharge (MAR), increasing awareness of water conservation practices, prioritizing drinking water and implementing interventions on responsible use of water resources.

- In the absence of a recognized government in Afghanistan, international development organizations, the UN, and other NGOs should take the initiative to secure funding and technical assistance for establishing measures that ensure sustainable water management and infrastructure development. Particularly, co-creation with local communities.
- Implement regular monitoring of groundwater quality and levels to ensure safe and reliable access to safe drinking water.
- Consider implementing point-of-use water treatment interventions as a temporary solution for households without access to clean water while engaging with local communities to ensure that technology is sensitive to their needs and priorities.

10.2.2 Household water treatment interventions in low-and-middle income counties

- Consider implementing comprehensive behaviour change in WASH interventions, particularly through the COM-B behaviour change model which is more honest to local realities by covering a broad range of factors including psychosocial, contextual and environmental factors in influencing household water treatment behaviours.
- Implement targeted interventions that are tailored to the specific needs and realities of communities. This could involve working with local partners to identify the most effective approaches for promoting household water treatment and addressing any barriers to adoption, both socially and technologically.

10.2.3 Intervention design on the use of Ceramic filters for household water treatment

- It is necessary to support local potters in Kabul for the design, optimization, and production of clay disc filters by providing skills training and necessary equipment. Developing models that enhance the local economy may offer a new way forward to build resilience and self-sufficiency within the community.

- Ceramic filters intervention would not only benefit the local potters economically but also would improve access to clean drinking water in vulnerable communities, the intervention from a COM-B behaviour change model perspective in Kabul would benefit the communities by:
  - *Psychological/physical capability:* ease of use, although it may not be a primary concern.
  - *Reflective motivation:* Cheap and relatively fast, low maintenance, doesn't require attention while purification is happening (unlike boiling).
  - *Automatic motivation:* Messaging can respond to a healthy family, filtered water is clear of all sensory markers of quality, it does not carry the stigma of past chlorine interventions; as a locally developed intervention it also responds to the "messenger" idea insofar as that it comes from a local and trustworthy source.
  - *Social opportunity:* Women are not excluded, and products can be marketed through local potters, which are not discriminating by wealth or status; buyers might be men who can be swayed by cost arguments.
  - *Physical opportunity:* It takes less space and is not dependent on homeownership, water can be stored directly within the filter so no separate storage is required; but: only useful where water is available and sourced water requires treatment.

10.3 Future research

10.3.1 Groundwater Exploration

- Eight deep wells were drilled by the Japan International Cooperation Agency (JICA) to study the deep aquifers (up to 800 meters deep) located in Kabul city (JICA 2011). JICA team concluded that the deep aquifer is a "fossil aquifer," meaning that it is not connected to a natural water cycle based on its distribution condition and water quality. However, the evidence is limited to support this conclusion, and further research, such as Carbon-14 dating, may be needed to confirm this hypothesis.

- The data from this thesis (stable isotopes and chemical composition of groundwater) and the data from previous studies could be combined with advanced modelling techniques to deliver a detailed understanding of the shallow aquifer systems in Kabul including their connectivity.

10.3.2 An integrated approach for measuring access to water

- Further research is required to integrate qualitative and quantitative data, particularly by creating an index which includes multiple variables for measuring access to water, alternatively a tool with multiple layers. The spatial variables could range from socioeconomic, health, flood and drought, water networks, water access points, population density, records of water-borne disease prevalence and so forth. This approach would provide a high-resolution understanding of the status quo about communities' access to clean drinking water and thus could support decision-making by governments and in development aid prioritization and allocation.

10.3.3 Household water treatment interventions, localized approaches to delivering safe drinking water

- Further exploring the role of psychosocial, contextual and environmental factors in influencing household water treatment behaviours in different environments, cultures and geographical contexts, particularly through the COM-B behaviour change model which is more honest to local realities by covering a broad range of factors.

10.3.4 Ceramic water filters

- Further research is required to optimize the production and design of clay disc filters such as identifying the optimal ratios of clay to sawdust to improve the performance of the clay disc filters as well as exploring opportunities for local potters in Kabul to become more involved in the creative design and production of the filters.

- Evaluating the social and economic impacts of clay disc filters, studying the extent to which the use of clay disc filters has improved access to clean drinking water as well as the economic benefits for the local potters.
- Investigating the long-term microbial removal effectiveness of clay disc filters, and potentially improving the removal of NO_3^-.

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Appendix

APPENDIX

Appendix 1 Bivariate relationships between all 37 items included in COM-B and the six main behaviours

Do you treat water before drinking in your household? - b_Q5_2

b_Q5_2 (Model 1)	mr_Q3_8	mr_Q4_7	mr_Q4_8	mr_Q4_10	mr_Q5_18	mr_Q3_2	mr_Q5_10	mr_Q3_6	mr_Q4_3	ma_Q4_4	ma_Q4_5	ma_Q5_8	ma_Q5_14	ma_Q5_15	ma_Q7_2	op_loc	op_Q2_6	op_Q3_7	op_Q5_12	op_Q6_6	op_Q8_7	op_Q5_13	op_Q5_11	os_Q6_2	os_Q6_4	os_Q6_5	os_Q6_7	os_Q1_6	cph_age	cph_Q5_16	cps_Q4_2	cps_Q4_9	cps_Q6_3	cps_Q1_3	cps_Q1_4	cps_Q8_5	cps_Q3_3
Access to good quality drinking water is a priority for my household.	0.793 (0.099)																																				
I believe that treating water regularly reduces the risk of falling ill.		0.539 (0.251)																																			
It is necessary to boil water every time before drinking.			1.118*** (0.000)																																		
It is everyone's responsibility to provide safe drinking water for children.				0.363 (0.523)																																	
How much would your household spend in maximum to enhance the quality of water in a month?					1.423*** (0.000)																																
Do you differentiate between the quality of water you use for drinking, washing vegetables, cooking meals, religious ablution, washing clothes, and bathing?						1.587*** (0.000)																															
It is important for my household to learn about cheap and accessible household water treatment techniques.							0.876* (0.015)																														
We have information of our household drinking water quality.								0.055 (0.759)																													
If getting ill from drinking untreated water, how severe do you think the illness might be?									-0.402 (0.078)																												
How worried are you about the health effects of the drinking water you use?										0.058 (0.8)																											
How frequently does your household suffer from illness due to poor water quality?											0.023 (0.916)																										
How much do you like the taste of treated drinking water?												1.609*** (0.000)																									
Do you feel a personal obligation to treat your household drinking water?													2.655*** (0.000)																								
Do you feel a personal obligation to treat your household drinking water for children under the age of 5 years?														2.145*** (0.000)																							
Due to COVID-19, we perform water treatment such as water boiling or filtering before drinking and cooking more often in my household.															1.078*** (0.000)																						
Study area																0.619*** (0.000)																					
Do you have a separate container for storing drinking water?																	0.928*** (0.000)																				
It is important to provide opportunities for our community to test the quality of water.																		0.559 (0.058)																			
It is time-consuming to treat the household drinking water.																			-0.17 (0.308)																		
People look for affordable techniques to treat drinking water in the household.																				0.916*** (0.000)																	
How much do you earn in a month (in Afghani)?																					0.760*** (0.000)																
How expensive is it for you to treat your drinking water?																						1.596*** (0.000)															
How effortful do you think is treating drinking water at the household?																							0.580* (0.024)														
How often do you talk about water treatment with other people?																								1.075*** (0.000)													
People in my community treat drinking water in the household because of their cultural beliefs.																									0.596*** (0.000)												
People encourage neighbours to treat drinking water in their household.																										0.371* (0.01)											
Thinking about the people who are important to you like your family members, friends, the chief of the village, or the Mosque, rate how much they encourage that you always use clean water or treat drinking water in the household?																											0.814*** (0.000)										
Participant Gender																												0.132 (0.324)									
Age																													0.17 (0.444)								
How worried are you about the health effects of the drinking water you use?																														3.093*** (0.000)							
Are you aware that poor water quality will affect your health?																															0.442 (0.53)						
There is a lack of public awareness on poor water quality risks for health.																																-0.362* (0.032)					
My household knows how to perform household water treatment.																																	1.399*** (0.000)				
Are you able to read?																																		-0.286* (0.043)			
Are you able to write?																																			-0.329* (0.016)		
What is the highest education level of the head of the household?																																				0.812*** (0.000)	
Has your household water quality ever been tested?																																					0.934*** (0.000)
Constant	-1.003* (0.033)	-0.757 (0.1)	-1.256*** (0.000)	-0.59 (0.292)	-1.008*** (0.000)	-1.117*** (0.000)	-1.057** (0.002)	-0.278 (0.073)	0 (1)	-0.274 (0.101)	-0.245* (0.025)	-1.541*** (0.000)	-2.143*** (0.000)	-2.025*** (0.000)	-1.032*** (0.000)	-0.523*** (0.000)	-0.983*** (0.000)	-0.751** (0.008)	-0.115 (0.394)	-1.052*** (0.000)	-0.793*** (0.000)	-0.704*** (0.000)	-0.466*** (0.000)	-0.564*** (0.000)	-0.607*** (0.000)	-0.434*** (0.000)	-0.536*** (0.000)	-0.296** (0.001)	-0.388 (0.065)	-2.091*** (0.000)	-0.671 (0.335)	0.039 (0.789)	-1.329*** (0.000)	-0.138 (0.094)	-0.103 (0.23)	-0.620*** (0.000)	-0.334*** (0.000)
χ^2	3	1	15	0	56	86	6	0	3	0	0	33	83	42	41	21	27	4	1	11	14	39	5	25	14	7	17	1	1	141	0	5	48	4	6	15	17
Log Likelihood	-625	-626	-617	-626	-599	-580	-623	-627	-625	-627	-627	-609	-575	-604	-604	-616	-612	-625	-626	-620	-620	-604	-624	-614	-619	-623	-618	-626	-626	-544	-626	-624	-599	-624	-624	-619	-617
Observations	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913

p-values in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Bottled water, the main source of drinking water - b_botwa

b_botwa (Model 2)	mr_Q3_8	mr_Q4_7	mr_Q4_8	mr_Q4_10	mr_Q5_18	mr_Q3_2	mr_Q5_10	mr_Q3_6	mr_Q4_3	ma_Q4_4	ma_Q4_5	ma_Q5_8	ma_Q5_14	ma_Q5_15	ma_Q7_2	op_loc	op_Q2_6	op_Q3_7	op_Q5_12	op_Q6_6	op_Q8_7	op_Q5_13	op_Q5_11	os_Q6_2	os_Q6_4	os_Q6_5	os_Q6_7	os_Q1_6	cph_age	cph_Q5_16	cps_Q4_2	cps_Q4_9	cps_Q6_3	cps_Q1_3	cps_Q1_4	cps_Q8_5	cps_Q3_3
Access to good quality drinking water is a priority for my household.	-1.234** (0.006)																																				
I believe that treating water regularly reduces the risk of falling ill.		-0.341 (0.569)																																			
It is necessary to boil water every time before drinking.			0.016 (0.96)																																		
It is everyone's responsibility to provide safe drinking water for children.				-1.385* (0.013)																																	
How much would your household spend in maximum to enhance the quality of water in a month?					1.099*** (0.000)																																
Do you differentiate between the quality of water you use for drinking, washing vegetables, cooking meals, religious ablution, washing clothes, and bathing?						1.300*** (0.000)																															
It is important for my household to learn about cheap and accessible household water treatment techniques.							-0.21 (0.626)																														
We have information of our household drinking water quality.								-0.584* (0.01)																													
If getting ill from drinking untreated water, how severe do you think the illness might be?									2.709*** (0.000)																												
How worried are you about the health effects of the drinking water you use?										1.461*** (0.000)																											
How frequently does your household suffer from illness due to poor water quality?											1.098*** (0.000)																										
How much do you like the taste of treated drinking water?												0.003 (0.994)																									
Do you feel a personal obligation to treat your household drinking water?													1.249*** (0.001)																								
Do you feel a personal obligation to treat your household drinking water for children under the age of 5 years?														1.113* (0.026)																							
Due to COVID-19, we perform water treatment such as water boiling or filtering before drinking and cooking more often in my household.															-0.159 (0.449)																						
Study area																0.987*** (0.000)																					
Do you have a separate container for storing drinking water?																	-0.345 (0.099)																				
It is important to provide opportunities for our community to test the quality of water.																		1.221 (0.051)																			
It is time-consuming to treat the household drinking water.																			-0.357 (0.107)																		
People look for affordable techniques to treat drinking water in the household.																				-0.236 (0.449)																	
How much do you earn in a month (in Afghani)?																					-0.053 (0.845)																
How expensive is it for you to treat your drinking water?																						-0.576 (0.078)															
How effortful do you think is treating drinking water at the household?																							-0.163 (0.629)														
How often do you talk about water treatment with other people?																								0.128 (0.676)													
People in my community treat drinking water in the household because of their cultural beliefs.																									-0.152 (0.495)												
People encourage neighbours to treat drinking water in their household.																										-0.542** (0.007)											
Thinking about the people who are important to you like your family members, friends, the chief of the village, or the Mosque, rate how much they encourage that you always use clean water or treat drinking water in the household?																											-0.155 (0.588)										
Participant Gender																												0.081 (0.654)									
Age																													-0.084 (0.774)								
How worried are you about the health effects of the drinking water you use?																														0.578* (0.047)							
Are you aware that poor water quality will affect your health?																															0.135 (0.89)						
There is a lack of public awareness on poor water quality risks for health.																																-0.116 (0.622)					
My household knows how to perform household water treatment.																																	-0.345 (0.136)				
Are you able to read?																																		-0.204 (0.295)			
Are you able to write?																																			0.123 (0.5)		
What is the highest education level of the head of the household?																																				0.453 (0.1)	
Has your household water quality ever been tested?																																					0.641* (0.012)
Constant	-0.48 (0.268)	-1.330* (0.022)	-1.674*** (0.000)	-0.317 (0.561)	-2.295*** (0.000)	-2.456*** (0.000)	-1.463*** (0.000)	-1.217*** (0.000)	-3.453*** (0.000)	-2.696*** (0.000)	-2.130*** (0.000)	-1.661*** (0.000)	-2.572*** (0.000)	-2.596*** (0.000)	-1.546*** (0.000)	-2.191*** (0.000)	-1.393*** (0.000)	-2.807*** (0.000)	-1.412*** (0.000)	-1.452*** (0.000)	-1.620*** (0.000)	-1.501*** (0.000)	-1.595*** (0.000)	-1.698*** (0.000)	-1.567*** (0.000)	-1.393*** (0.000)	-1.603*** (0.000)	-1.696*** (0.000)	-1.584*** (0.000)	-2.002*** (0.000)	-1.792 (0.065)	-1.572*** (0.000)	-1.402*** (0.000)	-1.591*** (0.000)	-1.710*** (0.000)	-1.878*** (0.000)	-1.740*** (0.000)
χ2	8	0	0	6	17	31	0	7	45	18	15	0	11	5	1	27	3	4	3	1	0	3	0	0	0	7	0	0	0	4	0	0	2	1	0	3	6
Log Likelihood	-398	-401	-401	-399	-392	-385	-401	-398	-371	-392	-394	-401	-395	-398	-401	-387	-400	-398	-400	-401	-401	-400	-401	-401	-401	-397	-401	-401	-401	-399	-401	-401	-400	-401	-401	-400	-398
Observations	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913

p-values in parentheses

* p < 0.05, ** p < 0.01, *** p < 0.001

Doers - Q5_4

Doer (Model 3)	mr_Q3_8	mr_Q4_7	mr_Q4_8	mr_Q4_10	mr_Q5_18	mr_Q3_2	mr_Q5_10	mr_Q3_6	mr_Q4_3	ma_Q4_4	ma_Q4_5	ma_Q5_8	ma_Q5_14	ma_Q5_15	ma_Q7_2	op_loc	op_Q2_6	op_Q3_7	op_Q5_12	op_Q6_6	op_Q8_7	op_Q5_13	op_Q5_11	os_Q6_2	os_Q6_4	os_Q6_5	os_Q6_7	os_Q1_6	cph_age	cph_Q5_16	cps_Q4_2	cps_Q4_9	cps_Q6_3	cps_Q1_3	cps_Q1_4	cps_Q8_5	cps_Q3_3
Access to good quality drinking water is a priority for my household.	0.566 (0.181)																																				
I believe that treating water regularly reduces the risk of falling ill.		0.332 (0.449)																																			
It is necessary to boil water every time before drinking.			0.827*** (0.001)																																		
It is everyone's responsibility to provide safe drinking water for children.				0.418 (0.43)																																	
How much would your household spend in maximum to enhance the quality of water in a month?					1.561*** (0.000)																																
Do you differentiate between the quality of water you use for drinking, washing vegetables, cooking meals, religious ablution, washing clothes, and bathing?						1.457*** (0.000)																															
It is important for my household to learn about cheap and accessible household water treatment techniques.							1.167*** (0.001)																														
We have information of our household drinking water quality.								0.639*** (0.000)																													
If getting ill from drinking untreated water, how severe do you think the illness might be?									0.097 (0.666)																												
How worried are you about the health effects of the drinking water you use?										0.710** (0.002)																											
How frequently does your household suffer from illness due to poor water quality?											0.279 (0.205)																										
How much do you like the taste of treated drinking water?												2.262*** (0.000)																									
Do you feel a personal obligation to treat your household drinking water?													2.012*** (0.000)																								
Do you feel a personal obligation to treat your household drinking water for children under the age of 5 years?														1.471*** (0.000)																							
Due to COVID-19, we perform water treatment such as water boiling or filtering before drinking and cooking more often in my household.															1.075*** (0.000)																						
Study area																0.699*** (0.000)																					
Do you have a separate container for storing drinking water?																	1.034*** (0.000)																				
It is important to provide opportunities for our community to test the quality of water.																		0.580* (0.042)																			
It is time-consuming to treat the household drinking water.																			0.211 (0.199)																		
People look for affordable techniques to treat drinking water in the household.																				1.256*** (0.000)																	
How much do you earn in a month (in Afghani)?																					0.702*** (0.001)																
How expensive is it for you to treat your drinking water?																						1.186*** (0.000)															
How effortful do you think is treating drinking water at the household?																							0.111 (0.668)														
How often do you talk about water treatment with other people?																								2.003*** (0.000)													
People in my community treat drinking water in the household because of their cultural beliefs.																									0.363* (0.02)												
People encourage neighbours to treat drinking water in their household.																										0.494*** (0.001)											
Thinking about the people who are important to you like your family members, friends, the chief of the village, or the Mosque, rate how much they encourage that you always use clean water or treat drinking water in the household?																											1.501*** (0.000)										
Participant Gender																												-0.322* (0.017)									
Age																													-0.061 (0.782)								
How worried are you about the health effects of the drinking water you use?																														2.403*** (0.000)							
Are you aware that poor water quality will affect your health?																															0.098 (0.882)						
There is a lack of public awareness on poor water quality risks for health.																																-0.247 (0.15)					
My household knows how to perform household water treatment.																																	1.720*** (0.000)				
Are you able to read?																																		-0.426** (0.002)			
Are you able to write?																																			-0.428** (0.002)		
What is the highest education level of the head of the household?																																				1.026*** (0.000)	
Has your household water quality ever been tested?																																					0.777** (0.001)
Constant	-0.258 (0.534)	-0.032 (0.941)	-0.457 (0.051)	-0.12 (0.819)	-0.520*** (0.000)	-0.468*** (0.000)	-0.799* (0.018)	-0.21 (0.177)	0.232 (0.116)	-0.184 (0.267)	0.179 (0.1)	-1.519*** (0.000)	-1.103*** (0.000)	-0.918*** (0.000)	-0.479*** (0.000)	-0.02 (0.823)	-0.525*** (0.000)	-0.243 (0.37)	0.14 (0.3)	-0.820*** (0.001)	-0.218 (0.181)	-0.044 (0.647)	0.245* (0.044)	-0.276** (0.003)	0.067 (0.566)	0.031 (0.76)	-0.236* (0.017)	0.437*** (0.000)	0.344 (0.101)	-1.067*** (0.000)	0.192 (0.769)	0.477** (0.001)	-1.015*** (0.000)	0.439*** (0.000)	0.466*** (0.000)	-0.183 (0.118)	0.214** (0.002)
χ2	2	1	11	1	62	75	11	13	0	10	2	66	69	24	46	26	38	4	2	23	11	20	0	66	5	12	47	6	0	101	0	2	76	9	10	24	10
Log Likelihood	-622	-623	-618	-623	-591	-584	-617	-617	-623	-619	-623	-589	-588	-611	-600	-610	-604	-621	-623	-610	-618	-611	-623	-585	-621	-618	-597	-621	-623	-566	-623	-622	-578	-619	-618	-611	-618
Observations	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913

p-values in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Do you boil water before drinking? - b_Q5_9

b_Q5_9 (Model 4)	mr_Q3_8	mr_Q4_7	mr_Q4_8	mr_Q4_10	mr_Q5_18	mr_Q3_2	mr_Q5_10	mr_Q3_6	mr_Q4_3
Access to good quality drinking water is a priority for my household.	0.07 (0.329)								
I believe that treating water regularly reduces the risk of falling ill.		-0.102 (0.235)							
It is necessary to boil water every time before drinking.			0.327*** (0.000)						
It is everyone's responsibility to provide safe drinking water for children.				-0.007 (0.95)					
How much would your household spend in maximum to enhance the quality of water in a month?					0.124*** (0.000)				
Do you differentiate between the quality of water you use for drinking, washing vegetables, cooking meals, religious ablution, washing clothes, and bathing?						0.054 (0.071)			
It is important for my household to learn about cheap and accessible household water treatment techniques.							0.185*** (0.001)		
We have information of our household drinking water quality.								-0.022 (0.533)	
If getting ill from drinking untreated water, how severe do you think the illness might be?									-0.043 (0.316)
Constant	0.403*** (0.000)	0.570*** (0.000)	0.176*** (0.000)	0.478*** (0.000)	0.405*** (0.000)	0.443*** (0.000)	0.299*** (0.000)	0.489*** (0.000)	0.497*** (0.000)
R-squared	0.001	0.002	0.057	0	0.014	0.004	0.011	0	0.001
Log Likelihood	-402	-401	-375	-402	-396	-401	-397	-402	-402
Observations	913	913	913	913	913	913	913	913	913

b_Q5_9 (Model 4)	ma_Q4_4	ma_Q4_5	ma_Q5_8	ma_Q5_14	ma_Q5_15	ma_Q7_2	op_loc	op_Q2_6	op_Q3_7
How worried are you about the health effects of the drinking water you use?	0.139** (0.001)								
How frequently does your household suffer from illness due to poor water quality?		0.136** (0.001)							
How much do you like the taste of treated drinking water?			0.147** (0.003)						
Do you feel a personal obligation to treat your household drinking water?				0.125** (0.006)					
Do you feel a personal obligation to treat your household drinking water for children under the age of 5 years?					0.286*** (0.000)				
Due to COVID-19, we perform water treatment such as water boiling or filtering before drinking and cooking more often in my household.						0.334*** (0.000)			
Study area							-0.066** (0.008)		
Do you have a separate container for storing drinking water?								-0.014 (0.653)	
It is important to provide opportunities for our community to test the quality of water.									-0.1 (0.069)
Constant	0.378*** (0.000)	0.418*** (0.000)	0.354*** (0.000)	0.385*** (0.000)	0.236*** (0.000)	0.230*** (0.000)	0.502*** (0.000)	0.483*** (0.000)	0.563*** (0.000)
R-squared	0.012	0.012	0.01	0.009	0.03	0.148	0.008	0	0.004
Log Likelihood	-397	-397	-398	-398	-388	-329	-399	-402	-400
Observations	913	913	913	913	913	913	913	913	913

b_Q5_9 (Model 4)	op_Q5_12	op_Q6_6	op_Q8_7	op_Q5_13	op_Q5_11	os_Q6_2	os_Q6_4	os_Q6_5	os_Q6_7	os_Q1_6
It is time-consuming to treat the household drinking water.	0.04 (0.201)									
People look for affordable techniques to treat drinking water in the household.		0.022 (0.629)								
How much do you earn in a month (in Afghani)?			0.049 (0.188)							
How expensive is it for you to treat your drinking water?				0.092* (0.039)						
How effortful do you think is treating drinking water at the household?					-0.108* (0.021)					
How often do you talk about water treatment with other people?						0.098* (0.016)				
People in my community treat drinking water in the household because of their cultural beliefs.							0.161*** (0.000)			
People encourage neighbours to treat drinking water in their household.								0.067* (0.012)		
Thinking about the people who are important to you like your family members, friends, the chief of the village, or the Mosque, rate how much they encourage that you always use clean water or treat drinking water in the household?									0.091* (0.018)	
Participant Gender										0.131*** (0.000)
Constant	0.443*** (0.000)	0.452*** (0.000)	0.436*** (0.000)	0.445*** (0.000)	0.514*** (0.000)	0.442*** (0.000)	0.372*** (0.000)	0.436*** (0.000)	0.439*** (0.000)	0.412*** (0.000)
R-squared	0.002	0	0.002	0.005	0.006	0.007	0.034	0.007	0.007	0.03
Log Likelihood	-401	-402	-401	-400	-400	-399	-387	-399	-399	-388
Observations	913	913	913	913	913	913	913	913	913	913

b_Q5_9 (Model 4)	cph_age	cph_Q5_16	cps_Q4_2	cps_Q4_9	cps_Q6_3	cps_Q1_3	cps_Q1_4	cps_Q8_5	cps_Q3_3
Age	-0.023 (0.568)								
How worried are you about the health effects of the drinking water you use?		0.357*** (0.000)							
Are you aware that poor water quality will affect your health?			-0.263 (0.072)						
There is a lack of public awareness on poor water quality risks for health.				0.087** (0.005)					
My household knows how to perform household water treatment.					0.110*** (0.001)				
Are you able to read?						0.071** (0.006)			
Are you able to write?							0.098*** (0.000)		
What is the highest education level of the head of the household?								-0.045 (0.245)	
Has your household water quality ever been tested?									0.026 (0.495)
Constant	0.492*** (0.000)	0.266*** (0.000)	0.731*** (0.000)	0.406*** (0.000)	0.388*** (0.000)	0.447*** (0.000)	0.432*** (0.000)	0.493*** (0.000)	0.469*** (0.000)
R-squared	0	0.09	0.005	0.008	0.013	0.008	0.016	0.002	0
Log Likelihood	-402	-359	-400	-398	-396	-398	-395	-401	-402
Observations	913	913	913	913	913	913	913	913	913

p-values in parentheses
* p < 0.05, ** p < 0.01, *** p < 0.001

How many people in your household always treat drinking water? - b_Q5_6

b_Q5_6 (Model 5)	mr_Q3_8	mr_Q4_7	mr_Q4_8	mr_Q4_10	mr_Q5_18	mr_Q3_2	mr_Q5_10	mr_Q3_6	mr_Q4_3	ma_Q4_4	ma_Q4_5	ma_Q5_8	ma_Q5_14	ma_Q5_15	ma_Q7_2	op_loc	op_Q2_6	op_Q3_7	op_Q5_12	op_Q6_6	op_Q8_7	op_Q5_13	op_Q5_11	os_Q6_2	os_Q6_4	os_Q6_5	os_Q6_7	os_Q1_6	cph_age	cph_Q5_16	cps_Q4_2	cps_Q4_9	cps_Q6_3	cps_Q1_3	cps_Q1_4	cps_Q8_5	cps_Q3_3
Access to good quality drinking water is a priority for my household.	0.242*** (0.001)																																				
I believe that treating water regularly reduces the risk of falling ill.		0.08 (0.346)																																			
It is necessary to boil water every time before drinking.			0.117* (0.023)																																		
It is everyone's responsibility to provide safe drinking water for children.				0.116 (0.262)																																	
How much would your household spend in maximum to enhance the quality of water in a month?					0.402*** (0.000)																																
Do you differentiate between the quality of water you use for drinking, washing vegetables, cooking meals, religious ablution, washing clothes, and bathing?						0.435*** (0.000)																															
It is important for my household to learn about cheap and accessible household water treatment techniques.							0.200** (0.003)																														
We have information of our household drinking water quality.								0.059 (0.115)																													
If getting ill from drinking untreated water, how severe do you think the illness might be?									0.017 (0.729)																												
How worried are you about the health effects of the drinking water you use?										0.163** (0.001)																											
How frequently does your household suffer from illness due to poor water quality?											0.032 (0.486)																										
How much do you like the taste of treated drinking water?												0.341*** (0.000)																									
Do you feel a personal obligation to treat your household drinking water?													0.426*** (0.000)																								
Do you feel a personal obligation to treat your household drinking water for children under the age of 5 years?														0.304*** (0.000)																							
Due to COVID-19, we perform water treatment such as water boiling or filtering before drinking and cooking more often in my household.															0.189*** (0.000)																						
Study area																0.230*** (0.000)																					
Do you have a separate container for storing drinking water?																	0.183*** (0.000)																				
It is important to provide opportunities for our community to test the quality of water.																		0.192*** (0.001)																			
It is time-consuming to treat the household drinking water.																			-0.011 (0.746)																		
People look for affordable techniques to treat drinking water in the household.																				0.244*** (0.000)																	
How much do you earn in a month (in Afghani)?																					0.168*** (0.000)																
How expensive is it for you to treat your drinking water?																						0.153** (0.002)															
How effortful do you think is treating drinking water at the household?																							-0.047 (0.374)														
How often do you talk about water treatment with other people?																								0.372*** (0.000)													
People in my community treat drinking water in the household because of their cultural beliefs.																									0.118*** (0.000)												
People encourage neighbours to treat drinking water in their household.																										0.140*** (0.000)											
Thinking about the people who are important to you like your family members, friends, the chief of the village, or the Mosque, rate how much they encourage that you always use clean water or treat drinking water in the household?																											0.217*** (0.000)										
Participant Gender																												-0.079** (0.004)									
Age																													0.001 (0.975)								
How worried are you about the health effects of the drinking water you use?																														0.479*** (0.000)							
Are you aware that poor water quality will affect your health?																															0.039 (0.786)						
There is a lack of public awareness on poor water quality risks for health.																																0.012 (0.716)					
My household knows how to perform household water treatment.																																	0.284*** (0.000)				
Are you able to read?																																		-0.091** (0.002)			
Are you able to write?																																			-0.093*** (0.001)		
What is the highest education level of the head of the household?																																				0.177*** (0.000)	
Has your household water quality ever been tested?																																					0.180*** (0.000)
Constant	0.228** (0.001)	0.384*** (0.000)	0.356*** (0.000)	0.348*** (0.001)	0.248*** (0.000)	0.228*** (0.000)	0.275*** (0.000)	0.415*** (0.000)	0.452*** (0.000)	0.352*** (0.000)	0.449*** (0.000)	0.189*** (0.000)	0.164*** (0.000)	0.211*** (0.000)	0.325*** (0.000)	0.357*** (0.000)	0.317*** (0.000)	0.285*** (0.000)	0.469*** (0.000)	0.246*** (0.000)	0.339*** (0.000)	0.417*** (0.000)	0.480*** (0.000)	0.349*** (0.000)	0.389*** (0.000)	0.387*** (0.000)	0.382*** (0.000)	0.497*** (0.000)	0.460*** (0.000)	0.186*** (0.000)	0.423** (0.003)	0.452*** (0.000)	0.245*** (0.000)	0.493*** (0.000)	0.499*** (0.000)	0.379*** (0.000)	0.442*** (0.000)
R-squared	0.009	0.001	0.006	0.001	0.12	0.195	0.011	0.003	0	0.013	0.001	0.045	0.089	0.028	0.039	0.076	0.032	0.012	0	0.028	0.017	0.011	0.001	0.08	0.015	0.025	0.031	0.009	0	0.133	0	0	0.069	0.011	0.012	0.019	0.018
Log Likelihood	-488	-492	-489	-491	-434	-393	-487	-491	-492	-486	-492	-471	-450	-479	-474	-456	-477	-486	-492	-479	-484	-487	-492	-454	-485	-480	-478	-488	-492	-427	-492	-492	-459	-487	-487	-483	-484
Observations	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913

p-values in parentheses
* p < 0.05, ** p < 0.01, *** p < 0.001

How often do you use treated water at home? - b_Q5_7

b_Q5_7 (Model 6)

	mr_Q3_8	mr_Q4_7	mr_Q4_8	mr_Q4_10	mr_Q5_18	mr_Q3_2	mr_Q5_10	mr_Q3_6	mr_Q4_3	ma_Q4_4	ma_Q4_5	ma_Q5_8	ma_Q5_14	ma_Q5_15	ma_Q7_2	op_loc	op_Q2_6	op_Q3_7	op_Q5_12	op_Q6_6	op_Q8_7	op_Q5_13	op_Q5_11	os_Q6_2	os_Q6_4	os_Q6_5	os_Q6_7	os_Q1_6	cph_age	cph_Q5_16	cps_Q4_2	cps_Q4_9	cps_Q6_3	cps_Q1_3	cps_Q1_4	cps_Q8_5	cps_Q3_3
Access to good quality drinking water is a priority for my household.	0.205** (0.008)																																				
I believe that treating water regularly reduces the risk of falling ill.		0.117 (0.173)																																		
It is necessary to boil water every time before drinking.			0.134** (0.01)																																	
It is everyone's responsibility to provide safe drinking water for children.				0.209 (0.055)																																
How much would your household spend in maximum to enhance the quality of water in a month?					0.393*** (0.000)																															
Do you differentiate between the quality of water you use for drinking, washing vegetables, cooking meals, religious ablution, washing clothes, and bathing?						0.435*** (0.000)																														
It is important for my household to learn about cheap and accessible household water treatment techniques.							0.184** (0.005)																													
We have information of our household drinking water quality.								0.104** (0.004)																												
If getting ill from drinking untreated water, how severe do you think the illness might be?									-0.027 (0.559)																											
How worried are you about the health effects of the drinking water you use?										0.205*** (0.000)																										
How frequently does your household suffer from illness due to poor water quality?											0.009 (0.832)																									
How much do you like the taste of treated drinking water?												0.453*** (0.000)																								
Do you feel a personal obligation to treat your household drinking water?													0.511*** (0.000)																							
Do you feel a personal obligation to treat your household drinking water for children under the age of 5 years?														0.369*** (0.000)																						
Due to COVID-19, we perform water treatment such as water boiling or filtering before drinking and cooking more often in my household.															0.200*** (0.000)																					
Study area																0.222*** (0.000)																				
Do you have a separate container for storing drinking water?																	0.195*** (0.000)																			
It is important to provide opportunities for our community to test the quality of water.																		0.213*** (0.000)																		
It is time-consuming to treat the household drinking water.																			0.04 (0.234)																	
People look for affordable techniques to treat drinking water in the household.																				0.293*** (0.000)																
How much do you earn in a month (in Afghani)?																					0.181*** (0.000)															
How expensive is it for you to treat your drinking water?																						0.224*** (0.000)														
How effortful do you think is treating drinking water at the household?																							-0.06 (0.232)													
How often do you talk about water treatment with other people?																								0.336*** (0.000)												
People in my community treat drinking water in the household because of their cultural beliefs.																									0.140*** (0.000)											
People encourage neighbours to treat drinking water in their household.																										0.122*** (0.000)										
Thinking about the people who are important to you like your family members, friends, the chief of the village, or the Mosque, rate how much they encourage that you always use clean water or treat drinking water in the household?																											0.273*** (0.000)									
Participant Gender																												-0.046 (0.083)								
Age																													-0.001 (0.983)							
How worried are you about the health effects of the drinking water you use?																														0.537*** (0.000)						
Are you aware that poor water quality will affect your health?																															0.013 (0.927)					
There is a lack of public awareness on poor water quality risks for health.																																0.002 (0.955)				
My household knows how to perform household water treatment.																																	0.353*** (0.000)			
Are you able to read?																																		-0.068* (0.015)		
Are you able to write?																																			-0.069* (0.011)	
What is the highest education level of the head of the household?																																				0.180*** (0.000)
Has your household water quality ever been tested?																																					0.154*** (0.000)
Constant	0.357*** (0.000)	0.442*** (0.000)	0.434*** (0.000)	0.351** (0.001)	0.346*** (0.000)	0.322*** (0.000)	0.383*** (0.000)	0.473*** (0.000)	0.571*** (0.000)	0.418*** (0.000)	0.551*** (0.000)	0.192*** (0.000)	0.199*** (0.000)	0.251*** (0.000)	0.411*** (0.000)	0.454*** (0.000)	0.401*** (0.000)	0.359*** (0.000)	0.527*** (0.000)	0.296*** (0.000)	0.423*** (0.000)	0.490*** (0.000)	0.579*** (0.000)	0.454*** (0.000)	0.469*** (0.000)	0.490*** (0.000)	0.456*** (0.000)	0.576*** (0.000)	0.556*** (0.000)	0.247*** (0.000)	0.542*** (0.000)	0.554*** (0.000)	0.287*** (0.000)	0.579*** (0.000)	0.583*** (0.000)	0.471*** (0.000)	0.539*** (0.000)
R-squared	0.007	0.002	0.009	0.004	0.125	0.211	0.01	0.01	0	0.023	0	0.086	0.138	0.045	0.047	0.077	0.04	0.016	0.002	0.044	0.021	0.025	0.002	0.07	0.023	0.021	0.053	0.003	0	0.181	0	0	0.115	0.007	0.007	0.021	0.014
Log Likelihood	-453	-455	-452	-454	-395	-347	-451	-451	-455	-445	-456	-415	-388	-435	-434	-419	-437	-448	-455	-435	-446	-444	-455	-422	-445	-446	-431	-454	-456	-365	-456	-456	-400	-453	-452	-446	-449
Observations	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913	913

p-values in parentheses
* p < 0.05, ** p < 0.01, *** p < 0.001

Appendix 2 Ethics Approvals

Anthropology Department

Ethical Approval: ANTH-2020-11-28T00_10_33-lgww95

Ethics <no-reply@sharepointonline.com>
Wed 2021-03-31 4:10 PM
To: HAMIDI, MOHAMMAD DAUD <mohammad.d.hamidi@durham.ac.uk>
Cc: ANTHROPOLOGY-ETHICS, A N. <anthropology.ethics@durham.ac.uk>; STEVENSON, EDWARD G.J. <jed.stevenson@durham.ac.uk>

Please do not reply to this email.

Dear Daud,

The following project has received ethical approval:

Project Title: *Understanding people's perceptions of water quality;*
Start Date: *10 February 2021*;
End Date: *06 May 2022;*
Reference: *ANTH-2020-11-28T00_10_33-lgww95*
Date of ethical approval: *31 March 2021*.

Dear Daud, Thank you for resubmitting your application and making all the changes. I am approving the application and just wanted to stress that you should come back to your supervisors and the Ethics Committee if there are any issues with involving the police and local leaders (gatekeepers) in the project. All best wishes for your project.

Nayanika Mookherjee

Chair, Ethics Committee

Please be aware that if you make any significant changes to the design, duration or delivery of your project, you should contact your department ethics representative for advice, as further consideration and approval may then be required.

If you have any queries regarding this approval or need anything further, please contact anthropology.ethics@durham.ac.uk

Psychology Department

JOWETT, RUTH C.R. <ruth.jowett@durham.ac.uk>
Fri 2021-05-07 1:50 PM
To: HAMIDI, MOHAMMAD DAUD <mohammad.d.hamidi@durham.ac.uk>
Cc: VASILJEVIC, MILICA <milica.vasiljevic@durham.ac.uk>

Durham University
Psychology Ethics

TO: Mohammad Daud Hamidi

FROM: Markus Hausmann, Chair, Psychology Department Ethics Sub-committee

DATE: 7 May 2021

CC: Milica Vasiljevic

REF: ES-2020-01-10T14:40:38-lgww95

Thank you for submitting the above application for amendment (as below) to a previously approved project to the Psychology Department Ethics Sub-committee and for responding to any queries raised. I am pleased to let you know that your application has been approved. Your ethical approval is valid for three years from the date of the original approval letter.

It is important that you conduct your study in accordance with your application for ethical approval and if you wish you make any changes to your project then you must request approval from the sub-committee in writing.

You must ensure that the actual conduct of your research conforms to the University's Data Protection Policy 2008 (www.dur.ac.uk/data.protection/policy/) and the ethical guidelines of the British Psychological Society which are available on DUO via Psychology Ethics > Ethics Guidelines.

A Project Progress Review Form should be submitted to the sub-committee each summer and when the project has been completed.

Amendment(s) approved:

- Data collection to change from paper-based questionnaires to Qualtrics accessed via tablet computers
- Security (of both tablets and data) to be handled as indicated in request dated 1 May 2021
- Other documentation to remain paper-based