Kathmandu Valley Multidisciplinary Project

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Purpose of this document:

This document will describe our multidisciplinary project with Smartphones4Water (S4W) Nepal. The result of this project was the research paper: ‘*Streams, Sewage, and Shallow Groundwater: Understanding Stream-Aquifer interactions in the Kathmandu Valley*’, which is supplied as a supplementary document in Appendix A. The purpose of this document is highlighting the ‘soft’ side of the project. We will give a brief overview of the project, evaluate and reflect on teamwork, and provide recommendations for future MDP groups working with S4W in Nepal.

Acknowledgements:

We like to especially thank Jeff Davids for his continuous feedback, help and support. Furthermore, we would like to thank Thom Bogaard for helping setting up the project. This work was supported by SmartPhones4Water, Nepal. We appreciate the dedicated efforts of the S4W-Nepal team, we would like to thank Eliyah Moktan, Amber Bahadur Thapa, and Rajaram Prajapatii for their extensive help in the field. We also thank Anusha Pandey, Pratik Shrestha, Anurag Gyawali, and Surabi Upadhyay for their provided assistance.

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1 Introduction

This project is part of the Civil Engineering masters programme at the TU Delft. The programme allows for a 2-3 month multidisciplinary project in which students are encouraged to explore other areas of study. We are 4 Hydraulic Engineering master students from the Technological University of Delft with a Civil Engineering bachelor's degree. For this project, we work together with Nepalese students Nischal Devkota and Amber Thapa, both studying Environmental Sciences at the Kathmandu University. Nischal is a team-member of S4W and Amber is an intern.

S4W focuses on leveraging citizen science and mobile technology to improve lives by strengthening our understanding and management of water. All of S4W's activities, including the research herein, have a focus on simple field data collection methods that can be standardized so that citizen scientists can repeat similar analyses in other data scarce areas. The organization is founded and lead by Jeff Davids, currently a PhD researcher at TU Delft. The local team consists of young scientists currently or previously studying at university with a focus on Environmental Sciences. For more information, please visit: www.smartphones4water.org.

We were supervised by Thom Bogaard (Associate Professor Hydrology at TU Delft, department Water Management) and Jeff Davids (PhD student at TU Delft, department Water Management).

2 Project Description

This specific project was about pre- and post-monsoon stream-aquifer interactions in the Kathmandu Valley. The proposal was based on previous fieldwork and wishes of S4W to investigate these interactions. For further details we refer to our research paper: '*Streams, Sewage, and Shallow Groundwater: Understanding Stream-Aquifer interactions in the Kathmandu Valley*' (see Appendix A).

The project was started in Delft with setting up the project proposal and preparing the project. In Kathmandu, we roughly spent 6 weeks collecting data in the field. For our project, we measured water level differences between the stream and a nearby groundwater well throughout the whole Kathmandu Valley. This was done using measuring tapes and an Autolevel survey. Water quality was tested in the field by measuring the concentration of various parameters in the stream and the well. After the fieldwork, we spent a week analyzing the results and preparing a presentation for the 2018 Mountains in a Changing World Conference (MoChWo) in Kathmandu. The last 3 weeks of the project, we continuously worked on the analysis of our data, writing the journal article, and helped S4W with some of their projects of their own. Once back in The Netherlands, we made some final edits to the article and the report and we gave a presentation at the faculty. After this project, we will continue to work on the journal article in order to publish it in a scientific journal. A more detailed timeline of the project can be found in Appendix B.

3 Evaluation and reflection on collaboration with local students

The full project team was made up of 6 members, four Dutch and 2 Nepalese. The two Nepalese students, Amber and Nischal are interns at S4W and also had other projects to work on simultaneously. Amber mostly contributed to carrying out the fieldwork, his experience in the field added a lot to our research. Nischal made large contributions in setting up the project proposal and preparing documents to carry out the fieldwork, carrying out the fieldwork, and writing and reviewing the research paper. His extensive knowledge about the water situation in the Kathmandu Valley has helped us a lot when reviewing the data.

Working together with local students has proven to be very beneficial. Not only for practical reasons such as translation during the fieldwork and showing the way, but also for data analysis. The local students were much more aware of the local conditions that were relevant to the research paper. Furthermore, they had more knowledge about water quality and environmental aspects. On the other hand our information about some measurement techniques was very helpful to them and will enable them to do these measurements themselves in the future. During the analysis of our results we involved the S4W staff, in that way their knowledge of the stream-aquifer interactions in the Kathmandu Valley improved.

Knowledge transfer was a key aspect of the project. We transferred knowledge about autolevel surveying, statistical data analysis and we gave planning and time management advice. On the other hand, we learned a lot about water quality aspects, fieldwork, measurement techniques and environmental implications.

Nischal's experience with MDP-2018:

One of the main goals of S4W-Nepal has been to assess different water-related interactions with a purpose to facilitate sustainable water management in Nepal. The first step towards it has been to generate necessary data through various research themes and inclusion of MDP has been a valuable addition to this endeavor. This time, our research focused on the groundwater and stream water interactions in Kathmandu which required certain hydrological and engineering skills to it which the present MDP was able to fulfill. I especially appreciated their working demeanor in a completely different environment than their own and openness with me and the team to work through the differences. Looking at the output of this work, believe both S4W-Nepal and the MDP students have undoubtedly benefited from each other and were able to foster the interdisciplinary approach of this program. This seems like a good partnership in this future too given the idea of the project and its possible outcomes are discussed well beforehand and the facilitators of the groups are communicating about it.

Amber's experience with MDP-2018:

A team of four Engineering students arrived S4W-Nepal from TU Delft, Netherlands in the end of August as multi-disciplinary project group 2018 (MDP), with the research theme of stream-aquifer interaction of Kathmandu valley. And I am one of the intern at S4W-Nepal and was lucky enough to be the part of MDP team. With my interest in the water researches, it was a great learning experience with them. The team is well-organized and cooperative. I find them comfortable with the situations and punctual. And of course, they are fast learner and friendly. It's hard for me find a negative point of the group. But just as a suggestion I would like you to be careful while handling the polluted water sample, because it can make you sick. I wish them success in the research and the career as a whole. Best of Luck!

4 Recommendations for future MDP groups

All below recommendations are based on our experiences. Certain recommendations might not be applicable due to different circumstances. First some general, practical recommendations are given to help prepare and organize the project. Second, we give project specific recommendations to try to improve project as a whole. Last, we will give recommendations for the fieldwork to prevent future groups make the same errors again.

4.1 General recommendations

- **Transport**:
    - We advise the use of scooters. All sites were accessible by scooters and we had enough space to carry the equipment. We had 3 scooters for 5 persons. Scooters also gave us freedom in our free time to go anywhere we wanted at anytime. Rush hours are less problematic with scooters than a taxi or bus.
    - Fuel shortages sometimes occur in Kathmandu. We encountered one which lasted for several days. It can be advised to have a small stockpile of fuel (15-20 liters) for this kind of situations.

- **Safety**:
    - We had no issues regarding safety. Take into consideration that after 8 o'clock in the evening the streets are empty, not dangerous, but it might feel strange.

- **Housing**:
    - Our apartment was located close to the office in Sanepa (Patan). We advise staying close (<2km) to the office, rush hours are terrible in Kathmandu. We preferred living in Sanepa over living in Thamel, since it has less traffic jams and air pollution.

- **Working space:**
    - We worked at the S4W office at the conference table.
    - Power outages are frequent in Kathmandu. During our stay, they would last for around one hour.

- **Festivals:**
    - Nepal has over 100 festival days per year, during Dashain and Tihar shops and offices are closed. Take this into account in your planning.

- **Free-time**:
    - Mountain Bike, gym, hike, walk in the city

- **Connectivity**
    - Internet (4G) and WiFi works quite well in Kathmandu
    - We advise to buy a local NCELL sim card upon arrival

4.2 Project Specific recommendations

- Work together closely with the S4W staff. It will be very helpful and it is a good learning process for both sides.
- Embrace the local culture and have patience. Some things take unnecessarily long to arrange and there is no use in trying to speed it up.

4.3 Fieldwork recommendations

- Make a fieldwork planning and keep it up-to-date. Make sure it is open to the rest of the staff so that they can provide feedback since they have a better knowledge of local circumstances.
- Take the AutoLevel with you. Benchmarks & reference points change or disappear.

- Measure only the water quality parameters that you know are useful and make sure the range and precision of the measurement equipment is sufficient. Think about this before starting the fieldwork
- Take back-up batteries and back-up equipment with you where possible (i.e. EC meters)
- Aim to have everything prepared the night before. Even a small thing such as buying droppers or printing could take more than an hour in the morning.
- Take into account rush hours in the city when you have to travel long distances.

5 Conclusion

We look back at a very successful project. Goal of the project was to explore another field of study and work together with students with a different background, study and culture wise. Both of these objectives have been fulfilled. We experienced a steep learning curve during the whole project since we had limited experience with water quality projects, fieldwork in general, presenting at a conference, writing a research paper and working abroad. Especially working on the article in a multidisciplinary project added a lot for us, since it is also a good preparation for our master thesis. Working in the field is something that we have not done at this scale before, it was very helpful that the S4W staff could help us to get a kickstart. Overall we are very happy with our experiences in working together with the S4W staff and we would definitely recommend other groups to work with S4W in Nepal!

Appendices

Appendix A: Journal Article

See next page

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Streams, Sewage, and Shallow Groundwater: Stream-Aquifer Interactions in the Kathmandu Valley, Nepal

Abstract

Globally, growing demand for fresh water and declining water availability puts significant pressure on water resources. Due to rapid urbanization and insufficient water resource planning and waste water management, the Kathmandu Valley (Valley) is facing both a water quantity and quality crisis. Annually, groundwater extractions in the Valley significantly exceed recharge rates, resulting in a serious groundwater table declines. While streams often constitute an important linkage between surface water and groundwater systems, from both a quantity and quality perspective, understanding stream-aquifer interactions in the Valley are limited. To improve this understanding, we performed topographic surveys of water levels, and measured water quality, in streams and adjacent hand dug wells (shallow aquifer) in three watersheds (total of 16 stream-well pairs) during 2018 pre-monsoon (April and May) and eight watersheds (including the same three from pre-monsoon; total of 35 stream-well pairs) during 2018 post-monsoon (September and October). In pre-monsoon, we found 88 % of water levels in wells lower than adjacent streams with an average of -0.82 m, indicating a loss of stream water to the aquifer. However, in post-monsoon 69 % of wells had water levels higher than adjacent streams with an average water level difference of 0.44 m, indicating that monsoon rainfall recharged the shallow aquifer, causing streams to transition from losing to gaining. No recurring trend in water level difference was seen longitudinally from upstream to downstream. Our results indicate statistically significant correlations between electrical conductivity, ammonia, chloride, hardness, and alkalinity measured in streams and adjacent wells. Both stream and groundwater quality of adjacent wells depletes longitudinally from upstream to downstream. In order to prevent further deterioration of groundwater resources, stream-aquifer interactions should be taken into account for sustainable water resource management. Further research is essential to quantify the groundwater flow, and to investigate the long-term trends and reversibility of the problem. Our findings highlight the importance of managing streams and aquifers as a single integrated resource, from both a water quantity and quality perspective. For example, improper waste management in the Valley's streams is having a clear and negative impact on the shallow aquifer. The population of Kathmandu will become increasingly dependent on the government for water supply, potentially increasing the cost of living.

Keywords:
Groundwater, Stream, Aquifer, Interactions, Kathmandu Valley

1. Introduction

Water is an essential resource for human life; both groundwater and surface water, sustains environments and our agricultural, industrial, and domestic activities. The demand for fresh water is increasing globally due to growing world population and changing lifestyles, while on the other hand the water availability is decreasing due to pollution (UNESCO, 2012). In the past, surface water and groundwater have often been treated as two different resources. However, almost all surface waters interact with groundwater (Winter et al., 1998). An understanding of these interactions is crucial when managing water resources. Exchange between streams and aquifers may happen in three different ways: the stream is either gaining (see Figure 1.A) which means that groundwater flows into the stream, losing (see Figure 1.B) which means that stream water infiltrates into the groundwater,or it is disconnected (see Figure 1.C). A disconnected stream is a losing stream which is disconnected from the groundwater by an unsaturated zone. When a losing stream is polluted, the quality of the stream affects the quality of the surrounding groundwater. Therefore, the poor water quality in the Kathmandu Valley′s streams (Regmi and Mishra, 2016; Muzzini and Aparicio, 2013; Dhital, 2017) illustrates the relevance of this study. Knowledge about these interactions is crucial when developing sustainable and efficient ways of using water resources in a basin since they give information about the water quantity and quality (Brenot et al., 2015).

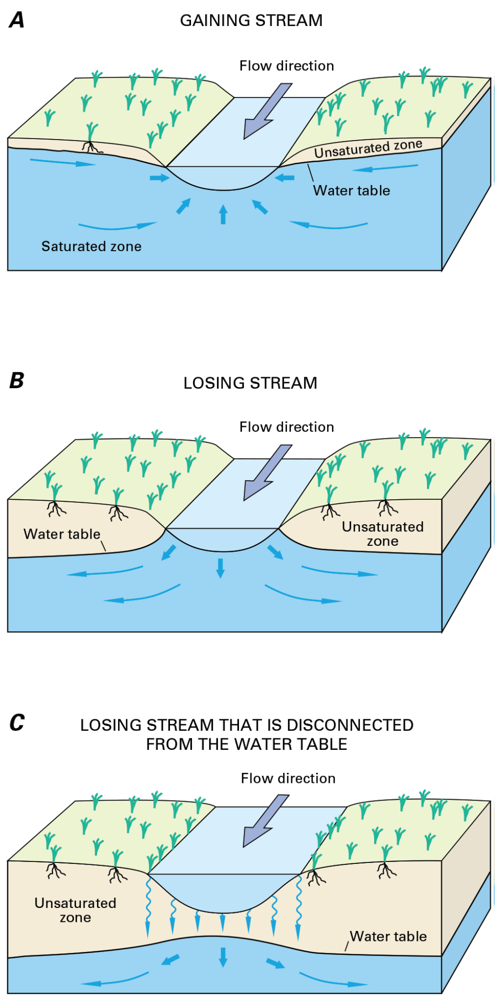

Figure 1: Gaining streams receive water from the groundwater system (A), losing streams lose water to the groundwater system (B), disconnected streams means that surface water and groundwater are separated by an unsaturated zone (C). Reprinted from Ground Water and Surface Water A Single Resource by (Winter et al., 1998), retrieved from https://pubs.usgs.gov/circ/1998/1139/report.pdf on October 19 2018. Copyright by USGS. Reprinted with permission.

1.1. The Kathmandu Valley

The Kathmandu Valley (Valley) is an intermontane basin with an area of 587 km2 which is located in the Central Region of Nepal at an average altitude of 1350 m (Shrestha et al., 2012). Altitudes range from 2780 m at Phulchowki peak to around 1260 m at Chobar. An overview map of the Valley with the relevant tributaries can be found in Figure 2. The Valley was home to about 2.5 million people in 2011 and the population is growing at a rate of 4 percent per year, making it one of the fastest growing metropolitan regions in South Asia (CBS, 2012; Muzzini and Aparicio, 2013). Due to the rapid urbanization combined with modernization, the city is facing numerous challenges, of which fresh water availability is one (Muzzini and Aparicio, 2013).

The groundwater system of the Kathmandu Valley is considered a closed and isolated groundwater basin, with more or less interconnected aquifers. The slope of the Valley floor coincides with that of the significant streams, with elevations decreasing slightly from north to south (Shrestha, 2000; Shrestha et al., 2012). With respect to land use and land cover, 41 % of the Valley floor can be classified as agricultural land use, while 33 % can be classified as natural and 28 % can be classified as built (urban) (Davids et al., 2018).

The Valley is drained by the Bagmati River and nine of its tributaries which join the Bagmati before exiting the Valley at the southwestern edge at Chobar. The Bagmati and its tributaries originate from the hills around the Valley. The discharge of the rivers shows a strong correlation with precipitation. Precipitation in the Valley is largely dictated by the South Asian monsoon, whereby about 80 percent of the 1755 mm annual rainfall occurs between June and September (Shrestha, 2000). The distribution of the rainfall is influenced by monsoonal air movement in combination with orographic effects. The overall amount of precipitation in the Valley is high, creating an opportunity to recharge the aquifer (Pandey et al., 2010).

Within the Valley currently, groundwater is extracted from both the shallow and the deep aquifer which is separated by a layer of clay (Eddy and Metcalf, 2000) Before the 1970s the shallow aquifer was the only source of produced groundwater. Subsequently, mechanized extraction from the deep aquifer was started by industry and the private sector. Water in the deeper aquifer is less affected by human activity, because it less actively recharged and therefore there is a long timescale of interactions with surficial processes (Shrestha et al., 2012). Even so, the rate of extraction has continued to increase until now (Shrestha et al., 2016). Since the rate of withdrawal of groundwater is significantly higher than the rate of recharge, the groundwater table has been declining since the 1980s (Shrestha et al., 2012; Eddy and Metcalf, 2000; Pandey et al., 2010). Although there is no regular monitoring mechanism, the fact that more and more stone spouts and dug wells are going dry supports this conclusion (Pratik et al., 2018). The lack of institutional responsibility in groundwater management intensifies the problem (Pandey et al., 2010), and if business continues like this the Valley's aquifer reserves are expected to be depleted in 100 years (Cresswell et al., 2001). In addition to the increased extraction, degradation in the water quality is also occurring due to anthropogenic activity (Pandey et al., 2010). Various studies have shown a decline in groundwater quality over time (Khadka, 1993; Jha M.G. et al., 1997; Kharel B.D. et al., 1998; Eddy and Metcalf, 2000; Chapagain et al., 2009). The shallow aquifer is contaminated by nitrates and E.coli and the deeper aquifer by ammonia, arsenic, iron and heavy metals (Shrestha et al., 2015; Shrestha et al., 2016).

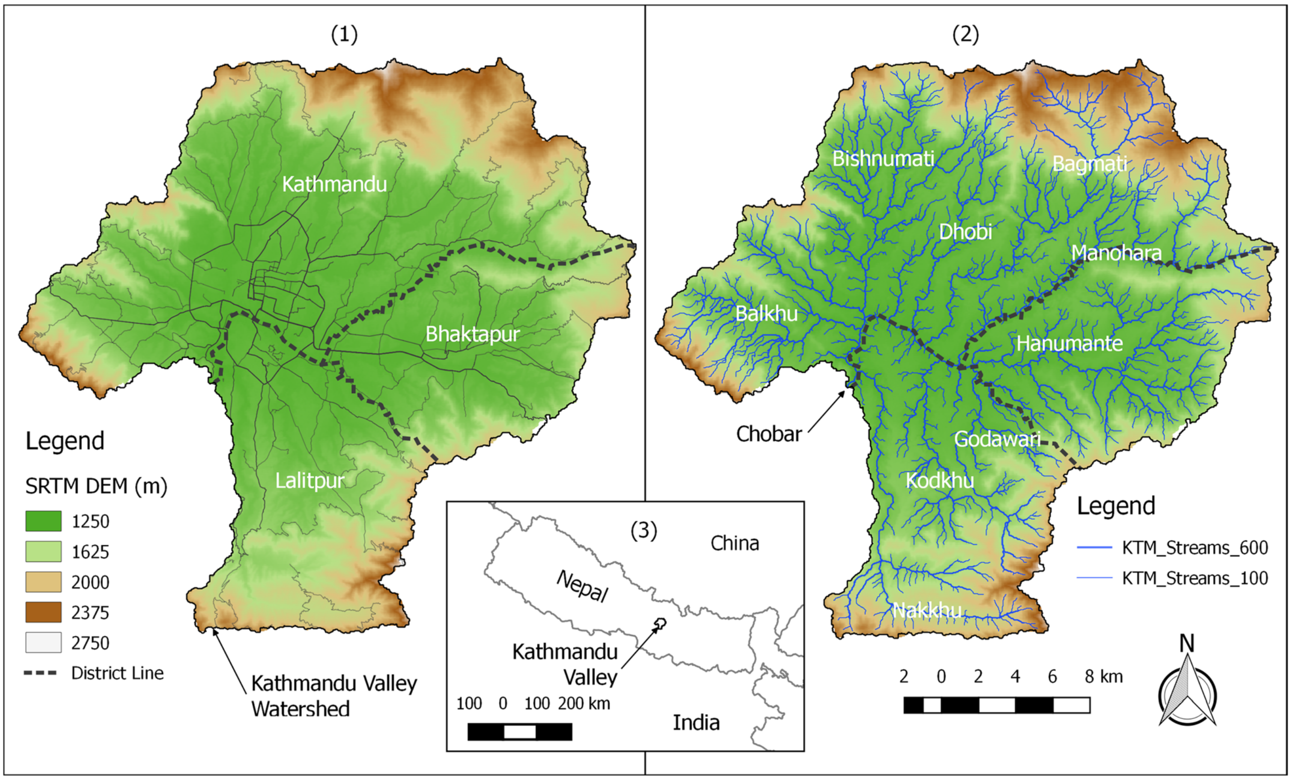

Figure 2: Kathmandu Valley watershed with roads, district boundaries, and Shuttle Radar Telemetry Mission digital elevation model at 30-m resolution (1), stream network with nine perennial streams labeled (2), and location map of Nepal and the Kathmandu Valley (3). The Kathmandu Valley Watershed shown uses Chobar as the pour point (Davids et al., 2018)

While many studies have highlighted deterioration of water quality of groundwater and surface water in the Valley independently, only one study has quantified interactions between streams and the underlying aquifer(s) and its implications. This study by Bajracharya et al. (2018) researched stream-aquifer interactions using chemical parameters and stable water isotopes and found that interaction exists near the river channel, but that whether the stream recharges or discharges to the aquifer differs per location. Furthermore the study concluded that the interconnectivity influences both the quantity and quality of both systems. They also found that the rivers in the Valley are deteriorating downstream and the concentration of the chemical ions decreased to nearly half from the pre-monsoon to the monsoon. The study concludes by stating that there are interactions, but more samples from wells and streams should be collected together with data on the water table depth of the wells, elevation of the water level of the river. Also more research has to be done on the subsurface lithography.

1.2. Geology and hydrogeology of The Valley

The Valley and its surrounding hills consist of 400 million years old basement rock (Precambrian to Devonian age). That layer is covered with unconsolidated to partly consolidated sediments of Pliocene or younger (Stocklin and Bhattarai, 1977). The thickness of that layer ranges from 10 m at the edges of the Valley to 500 m near the center, and it consists of fine texture sediment in the center and coarser sediment around it (Shrestha et al., 2012).

The valley deposits contain multiple sand and gravel beds which form the principal aquifers in the northern and northeastern part of the Valley. In the central part of the Valley these layers are overlain by a thick lacustrine clay layer that acts as aquitard. The south and southeastern part of the Valley consist of carbonate rocks which have been classified as aquifers. A cross-sectional view of the subsurface geology and hydrogeological system is shown in Figure 3 (Shrestha et al., 2012).

Based on geological conditions and the groundwater characteristics, the Japan International Cooperation Agency (JICA, 1990) divided the Kathmandu Valley into three groundwater districts, as can be seen in Figure 4. The Northern Groundwater District has high recharge potential and consists of unconsolidated and highly permeable sand and gravel, this forms the main aquifer in the Valley. The upper layer of the Central Groundwater District consists of very thick stiff black clay (Kalimati clay), unconsolidated low permeable coarse sediment is found under this layer. This confined aquifer is stagnant and is not directly rechargeable vertically from above. The Southern Groundwater District consists of thick impermeable clay and only along the Bagmati River between Chobhar and Pharping is there an aquifer. An important implication of this division is that the artificial recharge of the deep aquifer is not possible due to the Kalimati clay layer. However, the shallow aquifer does have the potential to be recharged, which is confirmed by the yearly fluctuating levels during the monsoon. It is believed that natural recharge of the aquifer is declining due to the in-

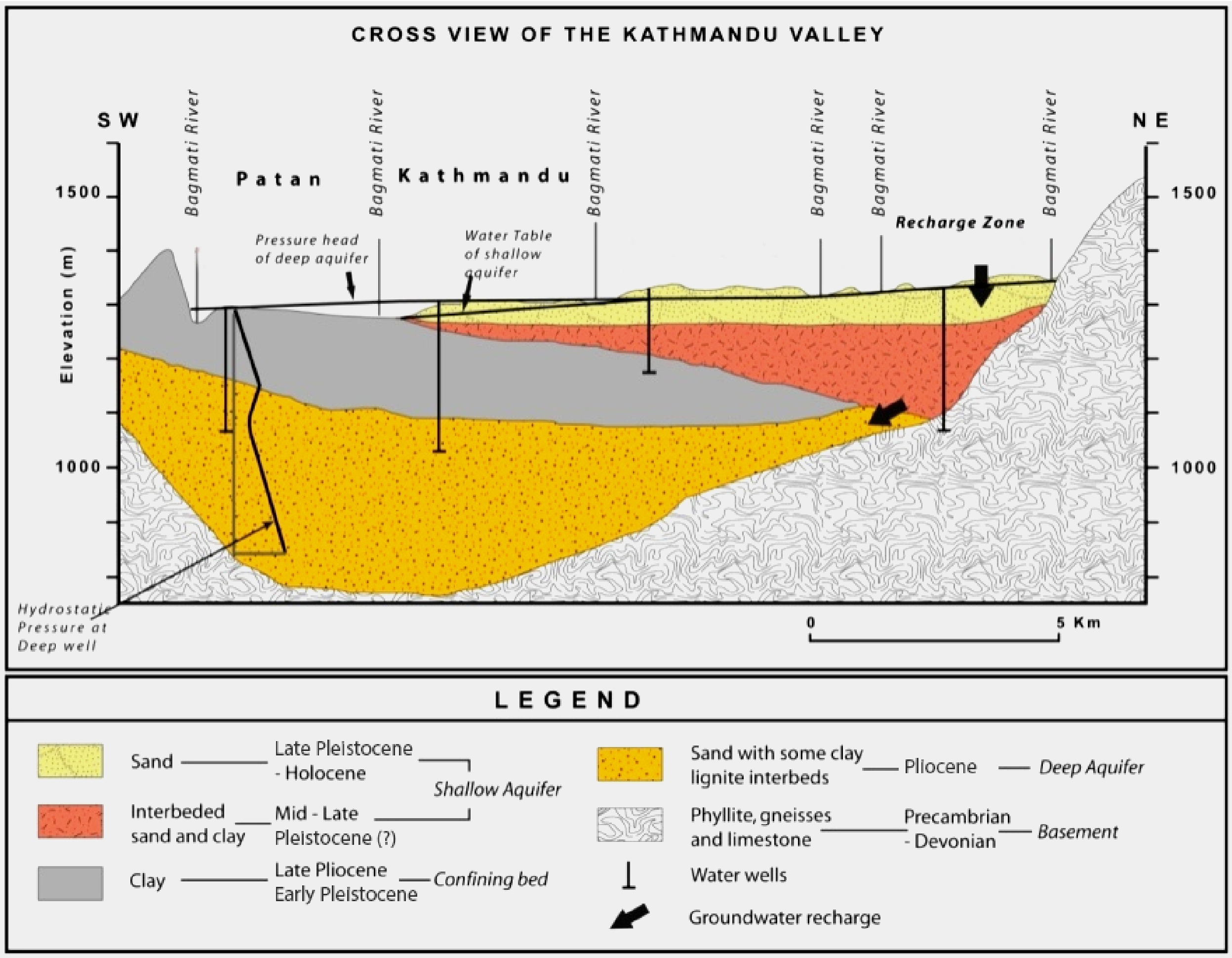

Figure 3: Conceptual cross section through the Kathmandu Valley Basin groundwater system. Edited from "A first Estimate of groundwater ages for the deep aquifer of the Kathmandu Basin, Nepal, Using the Radioisotope Chlorine-36" by (Cresswell et al., 2001) retrieved from https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1745-6584.2001.tb02329.x Copyright by (Cresswell et al., 2001) Reprinted with permission. Line of section is shown in Figure 4.

creased sealing of the surface by urbanization, since rainwater cannot reach the aquifer (Shrestha et al., 2012). Following this idea, research has shown that it might be possible to recharge the deep aquifer (Joshi and Shrestha, 2008).

1.3. Water quantity and quality crisis

Due to a lack of water resources planning and wastewater management, the Kathmandu Valley finds itself in a water quantity and quality crisis. Fifty percent of the population of the Kathmandu Valley is dependent on groundwater due to the fact that surface water resources are scarce and polluted (Gautam and Prajapati, 2014). Rapid urbanization and changing lifestyles have increased the demand for water, increased the discharge of untreated wastewater into the rivers, and has reduced the groundwater recharge (Shrestha et al., 2012). Depending on the time of year, the groundwater system provides between 50 and 75 % of the residential, industrial, and agricultural water demand in the Valley. Understanding stream-aquifer interactions therefore is critical for sustainable management of both water quantity and quality.

1.4. Objectives

The aims of this paper were to (1) understand stream-aquifer interactions in the Valley, with a specific focus on the northern tributaries, (2) compare these interactions during the pre-and post-monsoon season and (3) investigate the impact of these interactions on water quality. The following research questions were answered:

1. For the primary tributaries to the Bagmati River within the Kathmandu Valley, what is the pre- and post-monsoon status of stream-aquifer interactions?
2. How does this change longitudinally from upstream to downstream?
3. How do the pre- and post-monsoon interactions relate to the stream and groundwater quality?

1.5. Smartphones4Water

This research was performed in the context of a larger citizen science project called SmartPhones4Water or S4W (Davids et al. (2017), www.SmartPhones4Water.org). S4W focuses on leveraging citizen science and mobile technology to improve

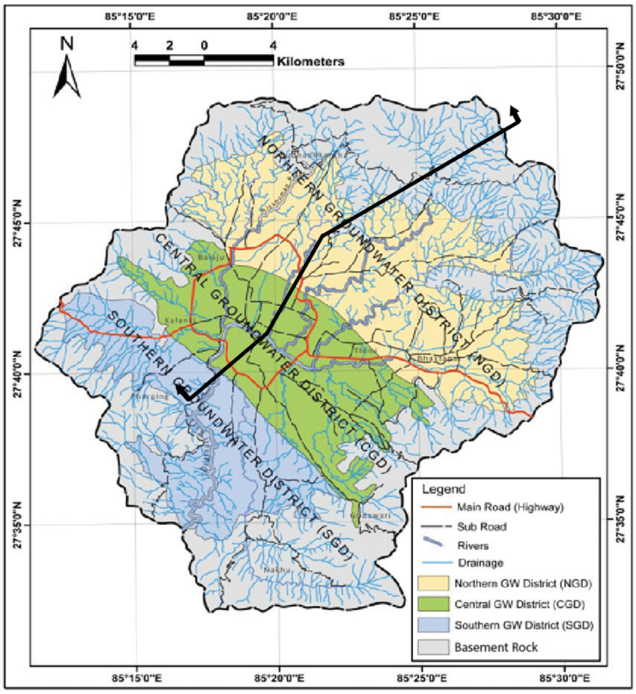

Figure 4: Groundwater basin of the Kathmandu Valley Edited from Groundwater management project in the Kathmandu Valley Final Report By Japan International Cooperation Agency (JICA), 1990. Retrieved from http://open_jicareport.jica.go.jp/618/618/618_116_10869980.html October 18 2018. Copyright by JICA (1990). Reprinted with permission. The indicated cross sectional line is based on the regional geology and is shown in Figure 3.

lives by strengthening our understanding and management of water. All of S4W's activities, including the research herein, have a focus on simple field data collection methods that can be standardized so that citizen scientists can repeat similar analyses in other data scarce areas.

2. Method and Materials

The methods and materials section is subdivided in three sections: (1) a description of the monitoring locations, and data handling and analysis, (2) the elaboration of the measurements of water-level interactions, water quality interactions, the correlation analysis, and short term water level variations, (3) the limitation of the methods are stated.

2.1. General

2.1.1. Monitoring Locations

To improve understanding of stream-aquifer interactions, we selected eight watersheds within the Kathmandu Valley (i.e. the Bagmati River and seven of its primary tributaries). Focus was placed on the Northern tributaries overlying the productive and actively recharging zones of the Valley aquifer.

We investigated both pre-monsoon and post-monsoon stream-aquifer interactions during the 2018 research campaign. Pre-monsoon data collection was performed from April 6 to April 10 2018. Post-monsoon data collection was performed between September 6 and September 29 2018. Measurement locations for both pre- and post-monsoon data collection can be found in Figure 5. The three Northern watersheds, Bishnumati, Dhobi and Bagmati, have been subject to both pre- and post-monsoon data collection, indicated with the red circles in the Figure. The five other watersheds, Manohara, Hanumante, Godawari, Nakkhu and Balkhu, were added for the post-monsoon data collection campaign to investigate the influence of different geological origin. Post-monsoon measurement locations are indicated with a blue circle in Figure 5.

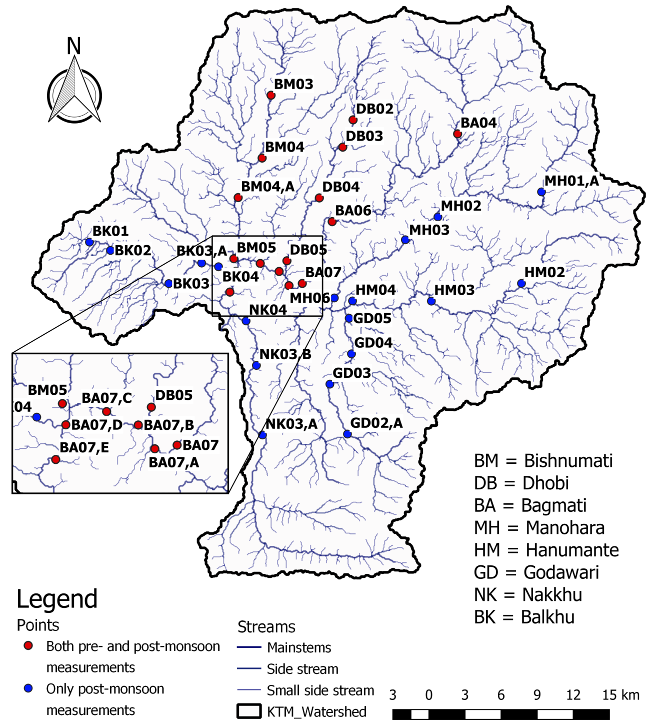

Figure 5: Map showing measurements locations in the Kathmandu Valley with the network of the nine perennial streams used as a base map (Davids et al., 2018). Monitoring sites (n = 35) that were measured in both the pre- and post-monsoon 2018 (n = 16) are shown as red circles; blue circles were only measured during the post-monsoon 2018 (n = 19). Measurements at each site included a water level and quality measurement in the stream in addition to a water level and quality measurement in an adjacent shallow (i.e. hand dug) monitoring well.

For each watershed three to ten monitoring locations were chosen for field data collection (see Figure 5). The locations were chosen on an equidistant cover along the river, together with the availability of dug wells reaching into the shallow aquifer located as close to the stream as possible. Efforts were made to select evenly distributed monitoring locations from upstream to downstream along each of the perennial tributaries and the Bagmati river. Upstream measurement locations along the Bagmati are not equidistant because BA05 (not shown in Figure 5) was measured during the pre-monsoon season, but the well was closed off before the post-monsoon measurement campaign. It has therefore been removed from all the results.

In case of an unused (stagnant) well, it was only used for groundwater level measurements. An adjacent used well was found for water quality measurements. This is the case at monitoring locations BA06, GD04 and BK03.

Wells should be located in the fluvial plain since topographic conditions of a site will influence groundwater levels (Sophocleous, 2002). Sites with a steep and elevated hinterland will likely have a higher groundwater level. For that reason, efforts were made to select sites where the well and stream are roughly located at the same elevation.

2.1.2. Data handling and analysis

All field measurements were stored using an Android application called Open Data Kit (ODK) as described in Anokwa et al. (2009). This application supports recording GPS locations, taking photographs of measurements, storing the data and making it available for analysis in an online web application.

We developed Python scripts with Matplotlib extensions to create several graphs showing water level differences, water quality parameters, and correlations using both pre- and post-monsoon data. Trendlines have been made using the Numpy polyfit function (Least squares polynomial fit). Box plots have been made using the pyplot Box plots function. Pearson correlation values are calculated using the Numpy correlation coefficient function corrcoeff. All used scripts can be found here:
`https://github.com/jcdavids/KTMStreamAquiferInteractions`.

2.2. Data collection and analyses

The same equipment and measurement techniques were used pre- and post-monsoon, but a partly different group of researchers performed the data collection. Care was taken to avoid sampling during extreme rainfall events to capture base flow conditions. The measurement campaign was interrupted in case of heavy rain or recent water extraction from the well. Measurement locations were noted in a supplementary document with GPS coordinates and detailed pictures and drawings of the topographic survey of the measurement locations.

2.2.1. Water level measurements

2.2.1.1 Pre- and post-monsoon stream and aquifer water level measurements.

To calculate the stream-aquifer water level difference (Δh), a topographic survey of water levels in the stream and the adjacent well was done using a Topcon AT-B series Automatic Level. We created a benchmark (BM) and reference point (RP) at the monitoring locations using permanent markings to ensure that future measurements will be done at exactly the same locations. Some sites were equipped with pre-installed staff gauges. Measuring the groundwater level (RP_GSWE) was done using a dropdown measuring tape . Measuring the water level in wells installed in the fluvial plain is a standard method to determine hydraulic head (Freeze and Cherry, 1979). Stream measurements we done using a dropdown (BM_SWE), or staff gauge reading when available. When measuring the height difference between the well and the stream, the point on the river closest to the well was chosen. A schematic representation of the measurements can be found in Figure 6.

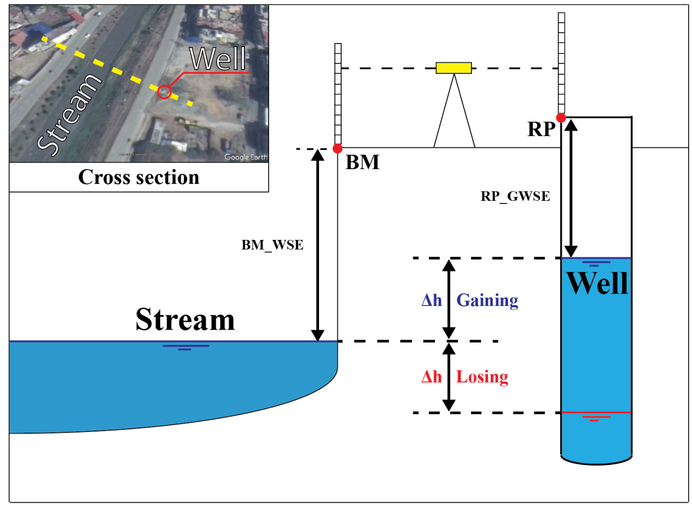

Figure 6: Schematic representation of the stream-aquifer water level difference determination (Δh). The reference point (RP) and benchmark (BM) are indicated with red dots. Stream dropdown measurement is indicated with BM_WSE and well dropdown measurement is indicated with RP_GWSE. Automatic level measurements are conducted to determine the height difference between RP and BM.

2.2.1.2 Short-term water level variations.

Our measurements of the water levels in the pre- and post-monsoon campaign are a "snapshot" in time. Measurements do not show the effect of rainfall events or extraction of groundwater, on the dynamics between the two points. Therefore, we performed regular water level difference measurements at monitoring locations BM05, BA07 and DB05 to investigate the effect of temporal variations between September 7th and October 26th 2018. These measurement locations cover a range of different types of wells: rare use (BM05), occasional (domestic) use (BA07), and frequent (industrial) use (DB05). These sites have been equipped with staff gauges to make ongoing water level measurements easy and accurate.

2.2.2. Water quality measurements

2.2.2.1 Pre- and post-monsoon, stream and aquifer water quality measurements.

We measured the water quality parameters of both well and stream to get a better insight in the spatial and temporal water quality changes and for supporting proof of stream aquifer interactions. The following parameters were measured: electrical conductivity (EC), ammonia, phosphorus, hardness, chloride, alkalinity, and E. coli. During the measurement campaign temperature, pH, dissolved oxygen, iron, nitrate, and nitrite were also measured, but results of the measurement were either not significant, not relevant or not correctly measured at all monitoring locations and therefore left out of the article. The concentration limit set by the Government of Nepal and the World Health Organization (WHO) of each parameter is stated in Table 1. No health based concentration limits for alkalinity and phosphorus are defined by both the Government of Nepal and the WHO and are therefore excluded from the table.

EC is an important water quality parameter because it shows a significant correlation with ten water quality parameters, in-

	Concentration limit	
	GNP	WHO
Electrical Conductivity [μS/cm]	1500	2500
Ammonia [ppm]	1.5	1.5
Hardness [ppm]	500	500
Chloride [ppm]	250	250

Table 1: Drinking water quality concentration limits for Electrical Conductivity, ammonia, hardness, and chloride as set by the Government of Nepal (GNP) (**?**) and the World Health Organization (WHO, 2017). The Electrical Conductivity is expressed in microSiemens per cm (μS/cm), Ammonia, Hardness, and Chloride are expressed in parts per million (ppm).

cluding alkalinity, hardness, and chloride (Kumar and Sinha, 2010). Previous research on pollution in the Kathmandu Valley also indicates that EC covaries with several water quality parameters (Doorn et al., 2017). The WHO guideline for human consumption has a threshold value of 2500 μS/cm (microSiemens per cm), provided there is no organic pollution and not too much suspended clay material (WHO, 2017). Natural ammonia levels in groundwater are usually below 0.2 ppm (parts per million) (WHO, 2017). Values above the geogenic levels are an important indicator for possible bacterial, sewage and animal waste pollution (WHO, 2017). Hardness is the result of dissolved compounds of calcium and magnesium in water and is expressed in terms of equivalent quantities of calcium carbonate. High concentration of chloride indicates sewage pollution and gives undesirable taste (Phillips, 1994). Phosphorus is found in natural rocks, domestic sewage and decaying vegetable matter. In excess amounts it stimulates nuisance algae and growth. Phosphorous is not harmful to the organisms but its analysis is useful for pollution study as stated by the Environment and Public Health Organization (ENPHO) water test kit manual. Alkalinity is the water's capacity to resist changes in pH that would make the water more acidic.

We used a portable water quality test kit from the Environment and Public Health Organization (ENPHO) to measure ammonia, phosphates, hardness, and chloride. Water quality test strips from Baldwin Meadows were used to measure total alkalinity. At most sites, water quality testing was done in-situ. For the sites where in-situ testing was not possible samples were taken to the office in polyethylene bottles to perform measurements later on the same day. The polyethylene bottles were cleaned thoroughly before use and purged by the same water to be collected from the sources.

A Greisinger GMH 3431 digital conductivity meter was used to measure conductivity and temperature on site. 3M Petrifilm E. coli/coliform count plates were used to enumerate the E. coli (Escherichia coli) and total coliform. Sterile droppers were used for every plate and sample water was withdrawn directly from the well where possible to avoid any contamination. The prepared petrifilms were stored for incubation at room temperature for 48-72 hours to allow for the sample to fully develop.

2.2.2.2 Water quality correlation analysis.

The Pearson's correlation coefficient r value is used to describe the relationship between the water quality parameters in the stream and the well in the pre- and post-monsoon season (Rodgers and Nicewander, 1988). Significance for correlations was tested with a two-tailed p value hypothesis test for p = 0.01.

2.3. *Limitations of the data collection*

Despite our efforts to capture base flow conditions and avoid measurements during rainfall, an important limitation of our research methods was that the measurements represent a specific point or "snapshot" in time. When looking at the water level difference measurements, the vertical components of the groundwater flow are not considered since this would require that a piezometer nest would have to be installed which was not possible when using existing dug wells (Kalbus et al., 2006). This research is limited by the availability of dug wells penetrating into the shallow aquifer. For some watersheds (i.e. Manohara), it was difficult to find usable, equidistant monitoring locations along the stream.

The ENPHO Water Test Kit measures ammonia on a scale from 0 to 3 ppm. It was found that downstream of most watersheds, the values of ammonia often exceeded 3 ppm. This made it impossible to see any variation in concentration once the ammonia levels in the stream exceeds 3 ppm. Upstream measurements are useful and give a solid representation, but downstream values are limited, possibly influencing the further analysis of values for ammonia. Alkalinity measurements are limited with the Baldwin Meadow strips, where values are measured with steps of 40 ppm. Large steps allow for less variations in measurement results and can result in more similar values for stream-aquifer correlations.

Water level difference merely indicates potential groundwater flow, it is not a measure of actual groundwater flow. To calculate flow, water level measurements would have to be combined with hydraulic conductivity, which we did not measure. We have selected a method that would still give insight into interactions, and that is also quick and easy to perform.

3. Results

The results section is subdivided into (1) water-level interactions, and (2) water quality interactions.

3.1. *Water level results*

3.1.1. *Pre- and post-monsoon, stream and aquifer water level results*

Stream-aquifer water level differences (Δh) range between -4.29 m and 1.10 m in the pre-monsoon season and between -1.34 m and 2.24 m in the post monsoon season. During pre-monsoon season, 14 out of 16 streams are losing water to the aquifer (negative Δh). Although most monitoring locations in the post-monsoon are gaining, 11 out of 35 are still losing water to their surroundings. All groundwater levels increased from pre- to post-monsoon, with an average of 1.99 m.

The pre- (a) and post- (b) monsoon interactions between stream and aquifer are shown in Figure 7. Longitudinal graphs of the interactions are shown in Figure 8. During pre-monsoon, one upstream site (BM03) and one site in the Valley floor

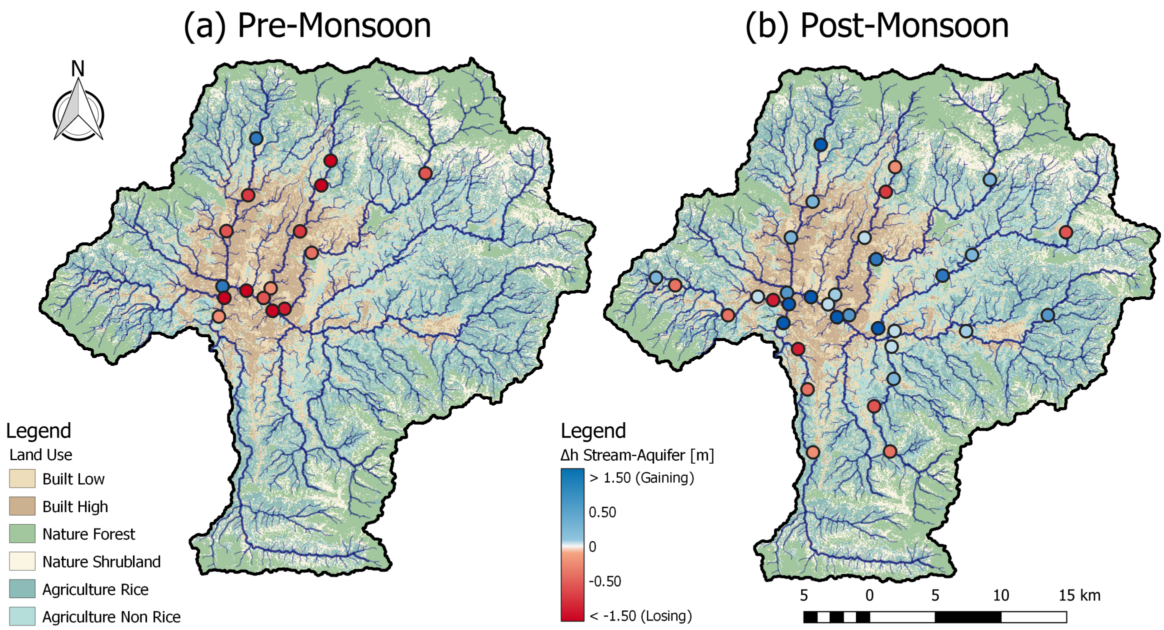

Figure 7: Maps showing the stream-aquifer water level differences [m] (a) pre-monsoon (n = 16) and (b) post-monsoon (n = 35) in the Kathmandu Valley with stream network layer and land-use as a base map. (Davids et al., 2018). Gaining stream locations are indicated with blue gradient circles (n = 2 pre-monsoon, n = 24 post-monsoon), losing stream locations are indicated with red gradient circles (n = 14 pre-monsoon, n = 11 post-monsoon). Darker colors represent a higher measured value for either gaining or losing.

(BM05) are gaining water from the aquifer. Looking at the 11 post-monsoon monitoring location which are gaining, 8 of those (DB02, DB03, MH01.A, GD02.A, GD03, GD04, NK03,A and NK03.B) have no gaining site further upstream. Upstream locations have a tendency to lose water while most downstream monitoring locations in the Valley appear to be gaining. All monitoring locations in the Nakkhu watershed are losing water.

A general trend from up- to downstream cannot be observed. Manohara, Godawari, and Dhobi streams become increasingly gaining when moving downstream, while Nakkhu, Hanumante, and Balkhu streams show a decreasing Δh trend. BM05 is the only site gaining more during post-monsoon than during pre-monsoon.

3.1.2. Short-term water level variation results

Regular measurements at BM05, BA07, and DB05 were performed to improve our understanding of short-term variations in the stream-aquifer water level difference. These sites cover a range of different types of wells as described in methods and materials (see Section 2.2.1).

The regular measurements have shown that when a stream was found to be gaining or losing at a certain day and time, the same conclusion would be reached when performing the measurement at a different day and time. Although the measurements are only a snapshot, it can be considered as reliable when it comes to the magnitude. Two out of three sites experience decreasing Δh values. One site, BM05 shows the opposite. This site was also the exception to the conclusion made earlier, since this site appears to be gaining more in the pre-monsoon. Short term temporal variations of the water level difference for both stream and well are shown in Figure 9.

Groundwater level changes contribute most to the temporal variations of the water level difference. Figure 9.2 shows that groundwater level decreases by 0.9 m and 1.0 m while stream water level decreases by 0.3 m and 0.1 m for BM07 and DB05 respectively. Monitoring location BM05 has proven to be an exception to observed trends in water level difference and water quality measurements. At BM05, the effect of a decreasing stream water level contributes more to the water level difference than the decreasing groundwater level, mainly due to the fact that the groundwater level seems more constant in comparison to the groundwater at BM07 and DB05.

3.2. Water quality results

3.2.1. Pre- and post-monsoon stream and aquifer water quality results

Measured EC values have a range between 0 and 2200 μS/cm while the concentration limit set by the Government of Nepal for drinking water is 1500 μS/cm. Only one measurement (BK04) exceeds this value. Ammonia levels range between 0.0 and 3.0 ppm. Many measurements exceed the concentration limit of 1.5 ppm. It should be mentioned that the range of the equipment used to measure Ammonia was limited by 3.0 ppm. Chloride values range between 0 and 212 ppm and hardness values range between 0 and 456 ppm. Both hardness and chloride measurements do not exceed the concentration limit. Alkalinity values range between 0 and 240 ppm. Phosphorus values range between 0 and 1 ppm. The limit of the equipment was 1.0 ppm. Values of measured water quality

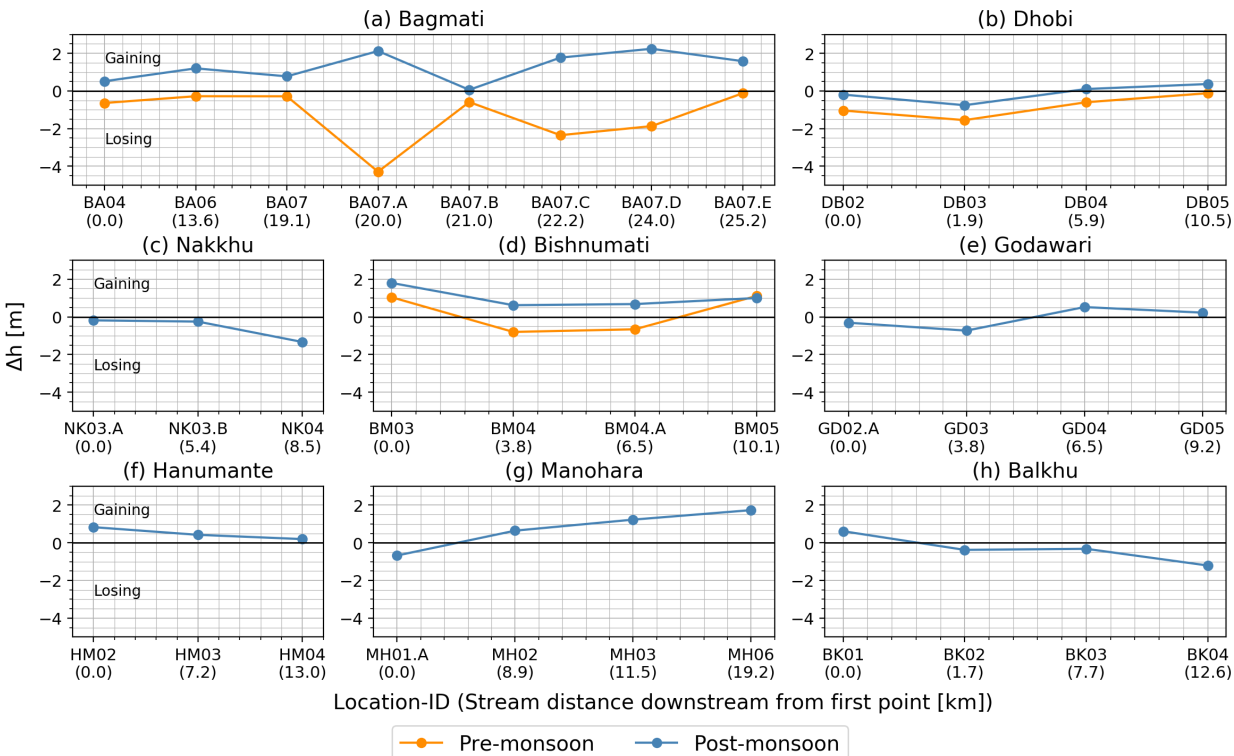

Figure 8: Graphs showing pre- (orange) and post- (blue) monsoon water level difference per monitoring location per watershed. For Bagmati (a), Dhobi (b), and Bishnumati (d) both pre- and post-monsoon data is available. On the horizontal axes the measurement locations and the distance from the most upstream location are shown. The vertical axes show the stream-aquifer water level difference and are all fixed at -4.5 to +3.0 m.

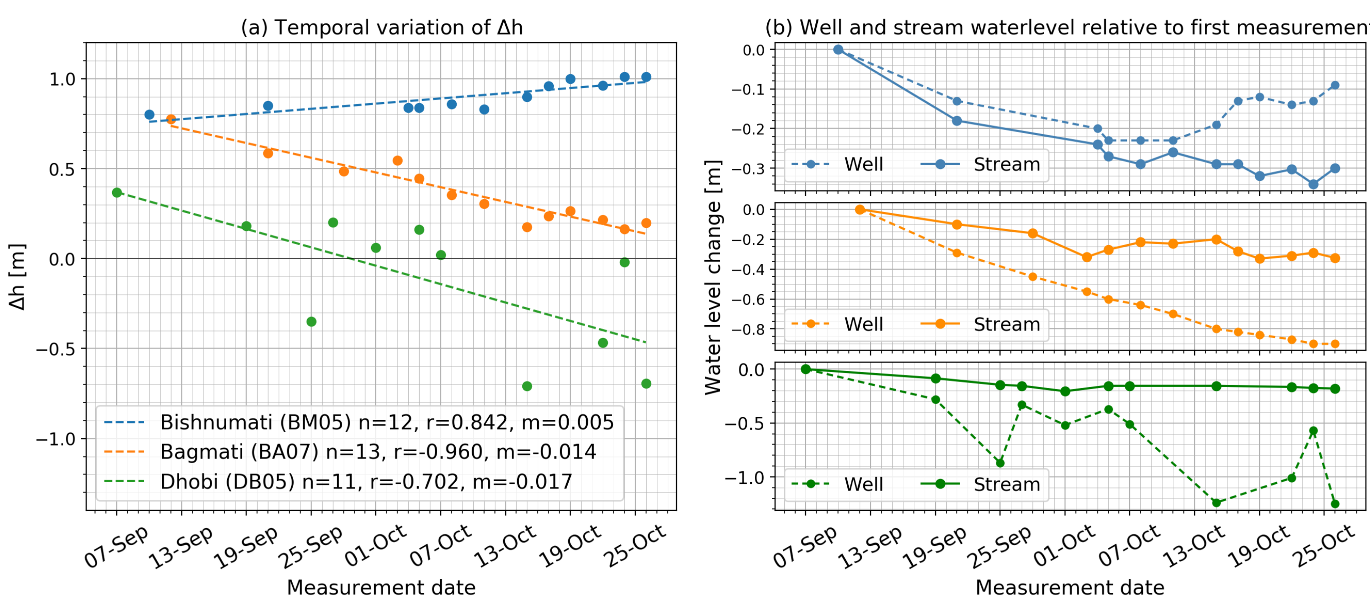

Figure 9: Graphs showing temporal variation of the stream-aquifer water level difference (a) and water level change for both well and stream (b) at Dhobi (n = 9, blue), Bagmati (n = 11, orange), and Bishnumati (n = 10, green). Measurements are indicated as points and in the left graph (a) the dashed lines represent the trendlines. The vertical axis represents the water level difference [m] and the horizontal axis the time variation [date]. The graph on the right (b) shows the variation of the well and stream water level over time in relation to the first measurement taken.

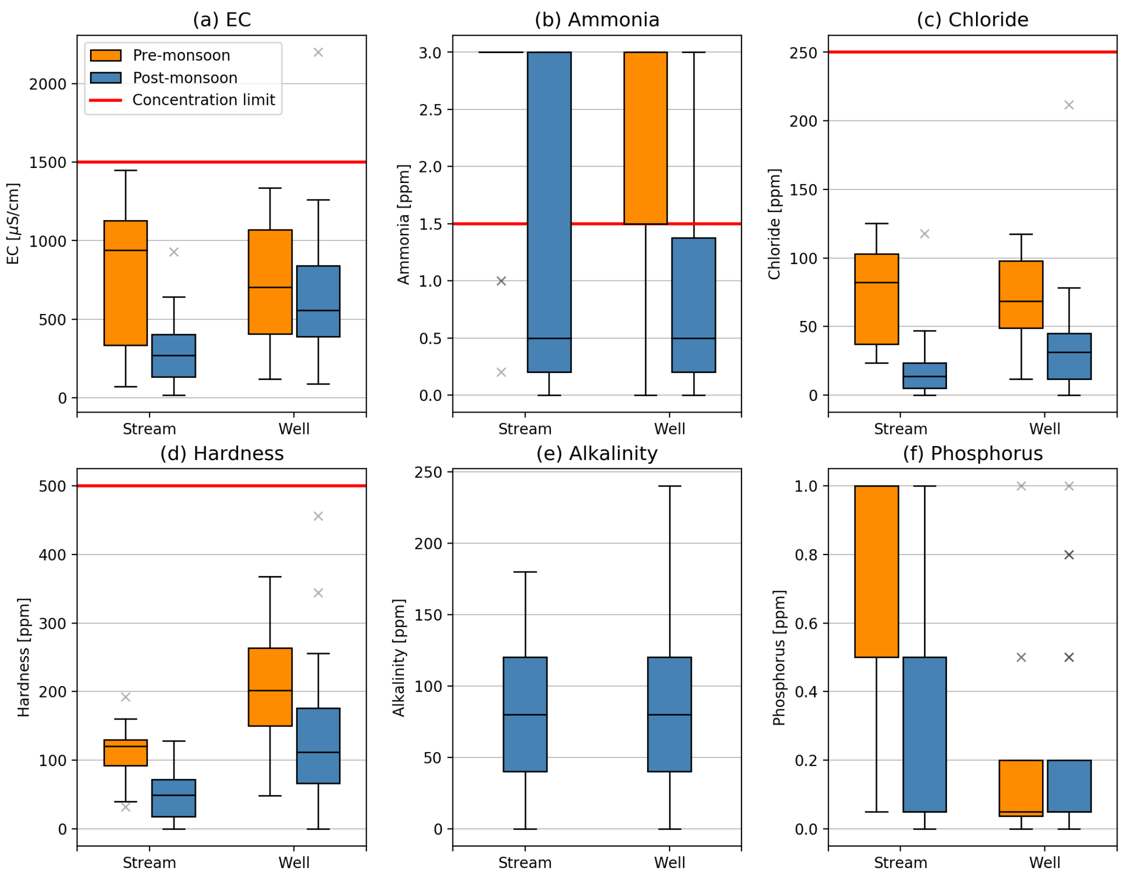

Figure 10: Box plots showing the distribution of water quality parameter values. The Nepal government concentration limit is shown as a red line for EC, ammonia, chloride, and hardness (**?**). Outliers have been made transparent to show the presence of identical values. Boxes show the inner-quartile range between the first and third quartiles of the dataset, while whiskers extend to show minimum and maximum values of the distribution, except for points that are determined to be "outliers" using a method that is a function of 1.5 times the inter-quartile range (Waskom, 2018)

parameters in the Valley are presented in Figure 10 using box plots.

Although most EC, chloride and hardness values are below the concentration limit for safe drinking water by the government of Nepal, the presence of organic pollutants and E.coli disqualifies many water samples as drinking water. The measured E.coli values can be found in Table 2. Untreated sewage is discharged into the streams at many locations in the Valley. Apart from the observation that E.coli counts increase in downstream direction, no other trends could be observed.

In general, water quality deteriorates from upstream to downstream in both stream and well in the pre- and post-monsoon. This trend can be observed in Figure 11 for the electrical conductivity values. EC is chosen to show this trend because EC values show significant correlation with many other water quality parameters as mentioned in the methods and materials (see Section 2.2.2) (Kumar and Sinha, 2010). The parameter is measured with the great precision (1 μS/cm) and is therefore very suitable for showing small changes.

In both seasons, a strong depleting trend can be observed in the water quality longitudinally moving upstream to downstream. Pre-monsoon, EC values measured in the stream and well show similar values. In the post-monsoon season, EC values of groundwater generally exceed the stream EC value at the same monitoring location. EC values measured in the well at BM05 do not follow the general trend. This monitoring location also differed from the general trend in the water level results (see Section 3.1.1).

3.2.2. Water quality correlation analysis results

In general, all water quality parameters vary similarly in the stream and well in pre- and post-monsoon seasons. This trend can be observed in Figure 11. Due to this general trend, correlation values between all water quality parameters are relatively high, as can be seen in Table 3.

Most parameters have a statistically significant correlations, indicating a strong overall link between stream and groundwater quality. Phosphorus measured in the groundwater has an insignificant correlation with most other parameters measured in the stream, including phosphorus itself, indicating its independence of the stream-aquifer interactions. Similarly but to a smaller extent, stream alkalinity values show insignificant correlation to other groundwater parameters, except to groundwater alkalinity.

Next to the significant correlation between all parameters in both seasons, there is a seasonal difference between the rela-

Season	Sites	Number of wells	E.coli pollution percentage
Pre-monsoon	Pre- and post-monsoon sites (Figure 5)	16	75 %
Post-monsoon	Pre- and post-monsoon sites (Figure 5)	16	63 %
Post-monsoon	All sites post-monsoon (Figure 5)	35	41 %

Table 2: Percentage of wells in which E.coli is found for sites on which both pre- and post-monsoon measurements were conducted (n = 16) and for all post-monsoon sites (n = 35).

		Stream					
		EC	Ammonia	Chloride	Hardness	Alkalinity	Phosphorus
Well	EC	**0.622**	**0.582**	**0.597**	**0.476**	0.276	**0.651**
	Ammonia	**0.671**	**0.534**	**0.660**	**0.559**	0.222	**0.596**
	Chloride	**0.730**	**0.615**	**0.792**	**0.548**	0.219	**0.705**
	Hardness	**0.694**	**0.673**	**0.683**	**0.592**	0.211	**0.725**
	Alkalinity	**0.571**	**0.565**	**0.458**	0.422	**0.605**	**0.590**
	Phosphorus	0.079	0.081	0.078	0.075	0.172	0.132

Table 3: Pearson's correlation coefficients for the water quality parameters measured in the stream and well, presented in a matrix. These values are calculated using combined pre- and post-monsoon data. Statistically significant values are highlighted green and shown in bold. For all correlations with alkalinity (only post-monsoon data available): $n = 34, p = 0.01, r > 0.437$. For other correlations with chloride: $n = 49, p = 0.01, r > 0.465$. For correlations with EC, Ammonia, Hardness and Phosphorus: $n = 50, p = 0.01, r > 0.361$.

tions. The scatter plots in Figure 11 show this difference.

The only two parameters with significant correlations for both seasons, EC and chloride, show similar pre- and post-monsoon correlations. The stream values for these two parameters decrease greatly pre- to post-monsoon, while the groundwater values decrease only slightly. This causes a shift in the slope of the trendline, indicating a seasonal shift. Pre- and post-monsoon trendlines for ammonia show a similar slope, but a big downward shift. Ammonia concentrations in the well decrease while stream ammonia levels remain approximately the same. It should be noted that the maximum value that could be measured with our equipment was 3.0 ppm. Almost all streams had a measured concentration of 3.0 ppm so actual values are likely to be higher. Hardness decreases both in stream and groundwater from pre- to post-monsoon. Phosphorus concentration correlations are not statistically significant.

4. Discussions and recommendations

This section is organized using the same subsections as the Results (Section 3): (1) water-level interactions, (2) water quality interactions.

4.1. Water level discussions

4.1.1. Pre- and post-monsoon stream and aquifer water level discussion

Our first research question was: *For the primary tributaries to the Bagmati River within the Kathmandu Valley, what is the pre- and post-monsoon status of surface water-groundwater interactions?*

Answer: In general, streams lose water to the aquifer during the pre-monsoon season and streams gain water from the aquifer in the post-monsoon season.

The second research question was: *How does this change longitudinally from upstream to downstream?*

Answer: Pre-monsoon, no recurring trend in water level difference was seen longitudinally from upstream to downstream. Post-monsoon, most losing monitoring locations were found upstream, away from the valley floor and most gaining locations in the Valley Floor were gaining

Due to in part groundwater extraction, groundwater levels in the shallow aquifer decrease in the pre-monsoon season. Monsoon rainfall recharges the aquifer, increasing groundwater levels in the shallow aquifer. This impact is predominantly visible in the Valley floor. Upstream sites still have a tendency to lose water to the aquifer during the post-monsoon, indicating a continuous recharge of the shallow (and potentially deep) aquifer(s).

Pre-monsoon, two monitoring locations indicate a gaining stream: BM03 and BM05. We cannot find a reasonable explanation for BM03. BM05 seems to be influenced by an external water source (i.e. leaky pipe) since the groundwater level in this well is inexplicably high and the EC value in this well is very low compared to adjacent wells (see Section 4.2).

In the Northern Groundwater District, a recharge area is located which consists of a highly permeable soil, three monitoring locations here (DB02, DB03 and MH01.A) lose water to the aquifer (Shrestha et al., 2012). From our results, it seems that the aquifer is also recharged in the Southern Groundwater District. All monitoring locations on the Nakkhu watershed (NK03.A, NK03.B and NK04) were losing water to the aquifer. The Nakkhu watershed had a geology which differed a lot from the other watersheds. It composed of very permeable rock and gravel and we observed many rock and gravel mining activities. High permeability explains why all locations on this stream are losing during post-monsoon season.

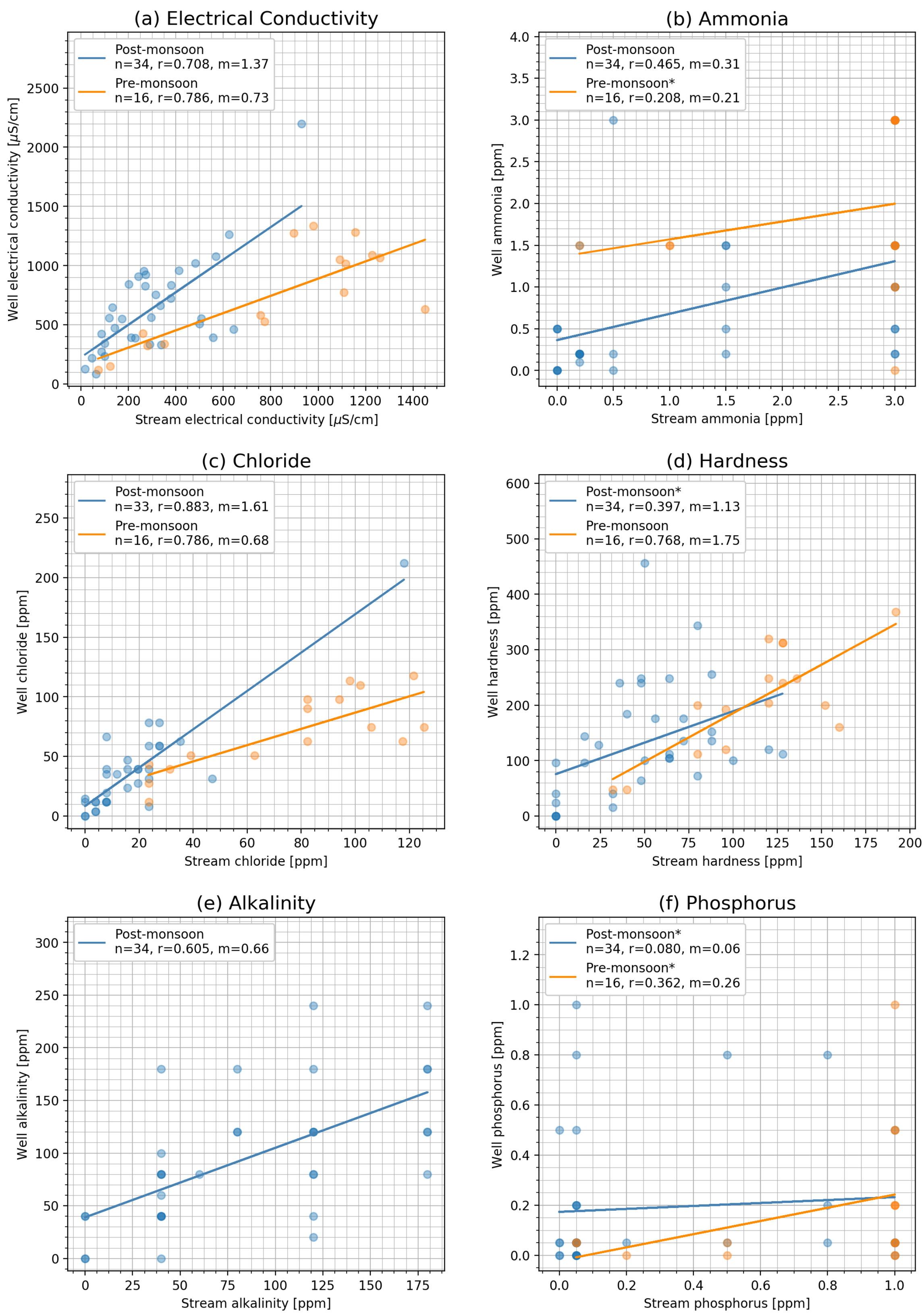

Figure 11: Stream vs well scatter plots (a to f) with corresponding linear trendline of EC, ammonia, chloride, hardness, alkalinity, and phosphorus for pre- and post-monsoon. The water quality parameter value in the stream and the well are shown in the horizontal and the vertical axes respectively. The number of measurements (n), correlation coefficient (r), and the slope of the trendline (m) per parameter and season is shown in the legends. Markers have been made transparent to give an insight in the presence of identical values. Note that labels marked with an asterisk (*) are correlations that are not statistically significant for $p = 0.01$. All other correlations are statistically significant. The following critical values were used: $n = 16, r_{critical} = 0.623; n = 33, r_{critical} = 0.430; n = 34, r_{critical} = 0.437$.

Although the methods used gave a good insight in the direction of interactions (i.e. gaining or losing), understanding their magnitude has not been possible with the current methodology. Including a survey on the hydraulic conductivity (K) at the different monitoring locations would lead to information about the specific discharge between the stream and the aquifer. Eventually this information would be key to setting up a water balance. However, the determination of hydraulic conductivity is generally characterized by large uncertainties, due to the fact that the outcomes may vary over some order of magnitudes and are highly variable in space and time (Kalbus et al., 2006). The K value changes in time due to scour from high flows, deposition, and degree of saturation of the soil, therefore long-term monitoring would be needed (Kalbus et al., 2006). Also the anisotropy of the soil has to be taken into account as the vertical (Kv) and horizontal (Kh) hydraulic conductivity may differ if the soil not structure-less (Stibinger, 2014). Previous research has shown that the K value differs from 12,5 to 44,9 m/day in the Kathmandu Valley (Pandey et al., 2010). Taking into account the vertical component in groundwater flow would give additional information about the interactions between the stream and the aquifer. To construct a flow field map, a piezometer nest will have to be installed with one or more piezometers installed at the same location at different depths (Kalbus et al., 2006).

4.1.2. Short-term water level variation discussion

Regular measurements have shown that a snapshot of a water level difference is an accurate estimation of the actual situation of the interactions. Each of the three point shows the same magnitude of the Δh when the measurements are taken within some days. A clear decreasing trend of the Δh over time can be seen at DB05 and BA07. DB05 even changes from gaining to losing at the end of September. This is as expected since the monsoon has ended and thus the groundwater in the shallow aquifer is going down, faster than the water level of the stream.

The short-term water level measurements in Figure 9 have shown that the gaining streams slowly transition back to losing. The water level difference at locations DB05 and BA07 decreases by 0.014 m per day and it took one or two months respectively to transition to losing. At some point during monsoon, the shallow aquifer recharges and streams again become gaining, but this doesn't last long as the shallow aquifer is quickly depleted below stream water levels after monsoon rainfall stops (see Figure 9). The dry season (8 months) lasts much longer than the monsoon period (4 months). This suggests that the streams lose water to the aquifer much longer than they gain.

Once again, BM05 seems to be an exception to the general trend. EC values measured in this well are very low and do not follow the downstream trend. Due to these suspicious measurements we performed EC measurements in 4 wells close to the initial well, which all indicated much higher EC values. These findings, together with the constant high water level in pre- and post-monsoon suggest the presence of an alternative water source that is feeding the well, such as a leaking water supply pipe.

Measurements performed as BA07 and DB05 will be continued by S4W staff and citizen scientists. Measurements at BM05 will be discontinued due to the impact of the external water source.

4.2. Water quality discussion

4.2.1. Pre- and post-monsoon stream and aquifer water quality discussion

Our third research question was: *How do the pre- and post-monsoon interactions relate to the stream and groundwater quality?*
Answer: Stream and well water (shallow groundwater) quality in the Kathmandu Valley deteriorate significantly longitudinally from upstream to downstream. Pre-monsoon, most monitoring locations were losing and observed well water quality is similar to stream water quality. Post-monsoon, most monitoring locations were gaining and stream water quality was much higher than well water quality.

Pre-monsoon, the stream-aquifer interactions suggest that polluted stream water infiltrates into the aquifer. Post-monsoon, stream water quality increases more than the well water quality. During the monsoon, streams are diluted by increased water discharge, thus improving water quality. Measurements were performed during base-flow conditions (avoiding rainfall events) so increased discharge is likely caused by additional water flowing from the mountains, not by run-off from inside the Valley. There is a significant difference in water quality entering the watersheds from the mountains, and the water quality of the runoff in the Valley (Davids et al., 2018). Since the shallow aquifer is recharged mainly by polluted runoff water in urban or agricultural areas, dilution does not occur to the same extend. This explains the seasonal shift in the slopes of the trendlines in the scatterplots (see Figure 11). In other words, stream water quality improves during and after monsoon because of increased high quality baseflow from the upper catchments, whereas shallow groundwater does not show as large of an improvement.

In addition, the response time of the groundwater is much longer than that of the streams. The water flow velocity in the streams is much higher than that in the shallow aquifer. This would suggest that the stream water quality responds faster to increased water discharge than the groundwater.

The link between stream and groundwater quality can partly be explained by the stream-aquifer interactions. However, many other factors such as land-use likely impact the water quality also. Davids et al. (2018) concluded that land-use is one of the main reasons for the deteriorating stream water quality longitudinally. Nonetheless, we did not expect to see this same trend in the groundwater to the extent that we observed. Even though there are other probable causes for water quality correlations, stream-aquifer interaction is an important one and should therefore not be neglected when managing natural water sources in the Kathmandu Valley. Upstream sites tend to recharge the aquifer continuously so effort should be made to improve the water quality upstream. When building a sewage collection system, we suggest starting upstream and moving downstream, since upstream sites are most important for recharging the aquifer.

More accurate water quality measurements should be performed in the future. The ENPHO test kit and the 9-in-1 Baldwin water test kit provide insight in various parameters, but the precision of the tests is not sufficient for establishing profound values for stream-aquifer interactions. Ammonia values are limited to 3 ppm, phosphorus values are limited to 1 ppm, and the measuring scales for alkalinity were not precise. The values from the ENPHO water test kit are an approximate estimation of drinking water quality and can be used as an indicator for stream-aquifer interactions. For more accurate analysis on the drinking water quality laboratory analysis is required.

4.2.2. Water quality correlation analysis discussion

The correlation analysis suggest yearly cyclic behavior of water quality in the streams and wells. Pre-monsoon, EC values measured in the stream and well are high and their correlation is high (r=0.786). After the monsoon, the stream water quality increases due to increased discharge, but the groundwater is partly recharged by polluted runoff water. Therefore, the slope of the trendline changes seasonally. Most water quality parameters have significant correlation with themselves in the stream and well, proving a strong link between the stream and groundwater quality.

The correlations calculated for ammonia were likely not a good representation of the actual correlations because of the 3.0 ppm measurement limit. Although ammonia concentrations in the groundwater experience a downward shift in the trendline, concentrations in the streams appear to remain the same. Ammonia concentrations in the stream have likely exceeded 3.0 ppm in both seasons but this could not be measured. Sewage is discharged into the streams throughout the whole Kathmandu Valley, which is indicated by the high ammonia concentrations.

5. Summary and Future Work

The water level difference analysis illustrates a significant interaction between the stream and aquifer at all monitoring locations. Based on pre-monsoon measurements, we found 88 % of water levels in wells lower than adjacent streams, indicating a loss of stream water to the aquifer. Water level difference analysis illustrates a significant interaction between the stream and aquifer at all monitoring locations. The average pre-monsoon water level difference in between wells and streams was -0.82 m. Post-monsoon, only 31 % of wells had water levels lower than adjacent streams with an average water level difference of 0.44 m, indicating that monsoon rainfall recharged the shallow aquifer. For some watersheds, water level differences increase (losing streams transition to gaining) longitudinally from upstream to downstream while others show the opposite. There is a significant correlation between water quality parameters such as electrical conductivity, chloride, hardness, and alkalinity measured in streams and adjacent wells, suggesting the presence of intense stream-aquifer interactions. Water quality in the streams and wells clearly deteriorate longitudinally. The population of Kathmandu will become increasingly dependent on the government for water supply, potentially increasing the cost of living. In order to prevent further deterioration of groundwater resources, stream-aquifer interactions should be taken into account in water resource management strategy.

This research is based on measurements from two measurement campaigns in one year. Although a clear trend can be observed, it is important to continue doing research to improve insight on long-term trends. Additional work should focus on collecting more data. Several measurement locations have been set up in such a way that Citizen Scientists can continue taking measurements on water level differences. Continued effort of S4W will realize this data collection, pre- and post-monsoon measurement campaigns will be continued.

Future work should also focus on assessing this method (measuring water level difference) to determine the direction and magnitude of the groundwater flow and therefore the stream-aquifer interactions. Computer modeling might be helpful for making detailed flow maps of the groundwater at the monitoring locations. In situ cone penetration test would be valuable to determine local soil conditions.

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Appendix B: Timeline

The timeline below will give a rough overview of the activities, summarized as bullet points.

6 months before departure: Form a group

- Formation of the MDP group by contacting fellow students and Dispuut.
- Discuss interests and possible topics.
- Contact with companies and TU Delft staff members.

6 months before departure: Finding a project + funding

- Contact with Thom Bogaard about possibilities MDP (supervisor in Delft).
- Contact with Jeffrey Davids about subject of the MDP (supervisor in Nepal).
- Start looking for funding (Delft Global, FIS Grant, Waterbouwfonds).
- Book flights to Nepal (take into account monsoon season).

1 month before departure: Preparations

- Occasional meetings with team and supervisors.
- Finish project proposal in close contact with Jeff Davids.
- Gather necessary equipment with help of Thom Bogaard and Armand Middeldorp (Lab technician Sanitary Engineering).
- Organize practicalities like housing and transport options in close contact with local S4W team members (Eliyah Moktan).
- Literature review on research by previous MDP groups and specifically on our topic.

Week 1-2: Settling & fieldwork preparations

- Settle in Kathmandu and meet S4W team.
- Organize transport together with Eliyah.
- Organize and test & calibrate measuring equipment.
- Make a fieldwork planning with S4W team taking into account local conditions like other fieldwork that the local staff has to do and festivals.

Week 2-3: Fieldwork: measurements at existing monitoring locations

- These locations were already measured during the pre-monsoon, so no need to look for suitable monitoring locations.
- The first few days, we did 3 monitoring locations in a day.
- Near the end, we managed to do 7 locations in a day.
- First two weeks were spent on the Northern Tributaries: Bishnumati, Dhobi and Bagmati.
- During this period we had some problems with the traffic during monsoon season.
- Some days were spent in the office to process results and to review literature.

Week 4-5: Fieldwork: measurements at new monitoring locations

- For these locations, we had to find suitable monitoring locations

- At each location, we performed a survey and marked the benchmark for measuring water level.
- Most locations were based on prior knowledge of Nischal and Citizen Scientists in the neighborhood.
- We did approximately 3-5 locations per day depending on the distance between them.

Week 6: Conference

- We analyzed the results of the first weeks of fieldwork to prepare the “Mountains in a Changing World” conference held annually in Kathmandu.
- Our results were matched to the results of the literature review we conducted during previous weeks.
- We had a meeting with all the S4W staff to check progress of the preparations for the conference.
- We made the presentation for the conference and helped other S4W staff members with their posters.

Week 7-8: Analysis, reporting

- We focused on writing the research paper, this was done in close cooperation with Jeff and Nischal.
- After the first draft of the paper was finished, we worked on the final presentation and this document.
- We made documents for future measurement campaigns/MDP groups consisting of: this document, our research paper, our data sheet, a survey summary sheet, a photo album, a map and other documents.

Appendix C: Data

Table 1: Pre-monsoon data

				Stream					Well					
Monitoring Location	Latitude	Longitude	Date	Ammonia [ppm]	Chloride [ppm]	EC [µS/cm]	Hardness [ppm]	Phospho-rus [ppm]	Ammonia [ppm]	Chloride [ppm]	EC [µS/cm]	Hardness [ppm]	Phospho-rus [ppm]	Δh [m]
BA04	27.75519	85.42146	6-4-2018	0.2	23.52	72	40	0.05	1.5	27.44	119	48	0.05	-0.640
BA06	27.71155	85.35398	6-4-2018	3	39.2	351	96	0.5	0	50.96	340	120	0.05	-0.280
BA07	27.68126	85.33742	6-4-2018	3	82.32	774	96	1	1	62.72	529	192	0.2	-0.285
BA07.A	27.68025	85.33027	18-4-2018	3	82.32	897	152	1	3	90.16	1276	200	0.2	-4.290
BA07.B	27.68677	85.32457	18-4-2018	3	98	1157	128	1	3	113.68	1282	240	1	-0.590
BA07.C	27.69086	85.31404	18-4-2018	3	82.32	980	192	1	3	98	1338	368	0.5	-2.350
BA07.D	27.68687	85.3008	18-4-2018	3	121.52	1227	128	1	1.5	117.6	1091	312	0.05	-1.870
BA07.E	27.67663	85.29769	18-4-2018	3	101.92	1261	128	1	3	109.76	1065	312	0.5	-0.120
BM03	27.7732	85.31911	20-4-2018	1	23.52	123	32	0.05	1.5	11.76	151	48	0.05	1.040
BM04	27.74259	85.31451	20-4-2018	3	62.72	757	120	1	1	50.96	580	204	0	-0.800
BM04.A	27.7229	85.30138	20-4-2018	3	125.44	1117	120	1	1.5	74.48	1017	320	0.2	-0.660
BM05	27.69296	85.29983	20-4-2018	3	117.6	1451	160	1	3	62.72	631	160	0.05	1.110
DB02	27.76148	85.36422	9-4-2018	1	23.52	261	80	0.2	1.5	43.12	427	200	0	-1.040
DB03	27.74754	85.35848	9-4-2018	3	31.36	280	80	0.5	1.5	39.2	323	112	0	-1.550
DB04	27.72328	85.34605	9-4-2018	3	105.84	1108	136	1	1.5	74.48	774	248	0	-0.600
DB05	27.6917	85.32844	9-4-2018	3	94.08	1091	120	1	3	98	1053	248	0.05	-0.120

Table 2: Post-monsoon data

				Stream						Well						
Monitoring Location	Latitude	Longitude	Date	Ammonia [ppm]	Chloride [ppm]	EC [µS/cm]	Hardness [ppm]	Alkalinity [ppm]	Phospho-rus [ppm]	Ammonia [ppm]	Chloride [ppm]	EC [µS/cm]	Hardness [ppm]	Alkalinity [ppm]	Phospho-rus [ppm]	Δh [m]
BA04	27.75543	85.42178	12-9-2018	0.2	3.92	17	0	0	0	0.1	11.76	128.2	40	0	0.05	0.515
BA06	27.71169	85.3534	12-9-2018	0.5	11.76	85.3	16	40	0.05	0.2	35.28	425	96	40	0.05	1.200
BA07	27.67944	85.33631	12-9-2018	1.5	19.6	172	32	80	0.05	1	39.2	551	16	120	0	0.775
BA07.A	27.68009	85.33012	13-9-2018	3	23.52	380	88	180	0.8	0.2	58.8	836	152	120	0.8	2.120
BA07.B	27.68697	85.32458	13-9-2018	3	27.44	482	48	180	1	3	58.8	1021	240	240	0.5	0.060
BA07.C	27.69076	85.31413	13-9-2018	3	23.52	378	72	180	0.5	1.5	39.2	723	136	180	0.8	1.770
BA07.D	27.68674	85.3008	13-9-2018	3	27.44	412	72	120	0.8	1.5	58.8	959	176	240	0.05	2.240
BA07.E	27.67656	85.29764	13-9-2018	3	35.3	568	64	120	1	1	62.7	1080	248	120	0.05	1.580
BM03	27.7731	85.31882	10-9-2018	0		63	0	40	0.05	0.5		87	0	40	0.5	1.801
BM04	27.74234	85.31438	10-9-2018	1.5	15.68	142	0	40	0.05	0.5	23.52	474	96	40	0	0.620
BM04.A	27.72283	85.30148	10-9-2018	1.5	19.6	270	40	40	0.05	0.2	39.2	827	184	100	0.2	0.680
BM05	27.69292	85.29958	10-9-2018	3	0	557	64	120	0.5	0.2	14.64	395	104	40	0.05	1.000
DB02	27.7616	85.36415	6-9-2018	0	0	98.8	0	0	0.05	0	0	237	0	40	0.05	-0.194
DB03	27.7482	85.35868	6-9-2018	0.2	3.92	100.4	0	40	0.05	0.2	3.92	345	0	0	0.05	-0.757
DB04	27.72321	85.34616	7-9-2018	1.5	0	241	48	40	0.05	1.5	0	908	248	180	0	0.102
DB05	27.69223	85.32879	7-9-2018	1.5	23.52	265	88	40	0.05	1.5	78.4	957	256	80	0.2	0.367
BK01	27.70003	85.22005	24-9-2018	0.5	23.52	337	80	180	0.05	0	7.84	330	72	80	0.05	0.615
BK02	27.69611	85.23168	24-9-2018	0	19.6	500	128	180	0.05	0.5	27.4	508	112	120	0.2	-0.376
BK03	27.68029	85.26401	24-9-2018	3	47.04	644	120	120	0.2	1	31.36	462	120	80	0.05	-0.322
BK04	27.68886	85.29122	24-9-2018	3	118	930	50	80	1	3	212	2200	456	180	0	-1.207
GD02.A	27.6079	85.36336	25-9-2018	0	7.9	289	0	120	0	0	11.7	336	0	80	0	-0.310
GD03	27.6322	85.35332	25-9-2018	0.2	7.84	296	50	120	0.05	1.5	35.3	564	100	120	0.05	-0.730
GD04	27.64716	85.36498	25-9-2018	0.2	15.68	315	100	180	0.05	0.2	47.04	756	100	180	0.05	0.522
GD05	27.66454	85.36344	26-9-2018	0.2	7.84	334	88	120	0.05	0.2	39.2	663	136	20	0	0.225
HM02	27.68268	85.45796	26-9-2018	0.2	7.84	132	16	80	0.05	0.2	19.6	649	144	120	0.8	0.830
HM03	27.67346	85.40852	26-9-2018	3	23.52	507	64	120	1	0.5	31.4	555	112	120	0.05	0.423
HM04	27.67304	85.36517	26-9-2018	3	27.4	624	80	120	1	1.5	78.4	1262	344	180	0.05	0.197
MH01.A	27.72757	85.46836	27-9-2018	0	0	46	0	0	0	0	11.76	221	24	40	0.05	-0.675
MH02	27.71468	85.41153	27-9-2018	0.2	3.92	86	32	0	0.05	0.2	11.8	274	40	0	0.05	0.645
MH03	27.70329	85.39378	27-9-2018	0.2	7.84	118	24	40	0.05	0.2	11.8	560	128	80	1	1.230
MH06	27.67438	85.35513	27-9-2018	3	15.7	201	36	40	0.8	0.5	39.2	842	240	80	0.2	1.735
NK03.A	27.60689	85.31666	28-9-2018	0	3.9	211	64	40	0	0	3.9	392	104	40	0	-0.185
NK03.B	27.64087	85.3128	28-9-2018	0	7.8	229	48	40	0	0.5	11.8	390	64	60	0.5	-0.251
NK04	27.66257	85.30678	28-9-2018	0.5	7.84	272	56	60	0.05	3	66.64	926	176	80	0	-1.335

Table 3: Short-term variations data

Measurement location	Date	RP_GWSE [m]	BM_WSE [m]	Δh [m]
DB05	7-9-2018	1.55	-1.927	0.367
DB05	19-9-2018	1.83	0.47	0.182
DB05	25-9-2018	2.42	0.41	-0.348
DB05	27-9-2018	1.88	0.4	0.202
DB05	1-10-2018	2.07	0.35	0.062
DB05	5-10-2018	1.92	0.4	0.162
DB05	7-10-2018	2.06	0.4	0.022
DB05	15-10-2018	2.79	0.4	-0.708
BA07	12-9-2018	4.93	0.65	0.775
BA07	21-9-2018	5.22	0.55	0.585
BA07	28-9-2018	5.38	0.49	0.485
BA07	3-10-2018	5.48	0.33	0.545
BA07	5-10-2018	5.53	0.38	0.445
BA07	8-10-2018	5.57	0.43	0.355
BA07	11-10-2018	5.63	0.42	0.305
BA07	15-10-2018	5.73	0.45	0.175
BM05	10-9-2018	2.37	-2.64	0.8
BM05	21-9-2018	2.5	0.66	0.85
BM05	4-10-2018	2.57	0.6	0.84
BM05	5-10-2018	2.6	0.57	0.84
BM05	8-10-2018	2.6	0.55	0.86
BM05	11-10-2018	2.6	0.58	0.83
BM05	15-10-2018	2.56	0.55	0.9