The future of water research:

Supporting the implementation of citizen science data collection by investigating the current water quality and quantity situation in the main water sources of the Kathmandu Valley

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Preface

This project was done in the context of the course CIE4300 - Multidisciplinary project. This course is a part of the Civil Engineering master's program of Delft University of Technology, in which knowledge of different disciplines is combined in a project. This report is the result of a project conducted by six Water Management students, operating in three different tracks, Hydrology, Water Resource Management and Sanitary Engineering, who researched the water quantity, water quality and land-use in the Kathmandu Valley, to help tackle the water supply problem.

The project tries to support the research of Jeff Davids, a PhD student of the Water Resource Group of the TU Delft. He is developing a citizen science-based network to gather data on the hydrology of the Kathmandu Valley through the Open Data Kit (ODK) app. Our research tries complement this part, with data on water quality which hopefully will also be gathered by citizen scientist in the future. Together we have worked on the development of the land-use classification forms for the app. Citizen science will allow researchers to gather data in data-limited area's and we are glad that we can be part of this relatively new way of collecting data.

First of all, we would like to thank Ir. J.C. Davids and his family for welcoming and helping us get around in Kathmandu. We also would like to thank the team of Smartphones4Water (S4W) for sharing their knowledge and showing us around. During our fieldwork, many citizen scientists have been interested and enthusiastic in informing us about the wells and assisting us in our measurements. We would like to thank them for their help and hospitality and hope they will continue their support for S4W and the goal it serves.

The project has been supported by many professors and experts that we would like to thank for sharing their expert knowledge with us. Above all, we would like to thank Dr. ir. Martine Rutten and Dr. Thom Bogaard to continuously support us throughout the process and giving us advice on how to shape our project. We would also want to thank Dr. Thom Bogaard and Mohammed Jafar for helping with the arrangement of most of our equipment. Without their help, it would probably not have been possible to gather all the data. Furthermore, we would like to thank the local professors Ram Devi Tachamo Shah and Deep Narayan Shah for supporting our project and showing us the best of Nepalese hospitality.

We would also like to thank Ashok Lama, our downstairs neighbour, for introducing us to the Nepalese culture. Besides, we would like to thank Rabin Malla (PhD, executive director at Center of Research for Environment, Energy and Water (CREEW) for sharing the book about the groundwater of the Kathmandu Valley. We would also like to thank the laboratory of Environmental and Public Health Organisation (ENPHO) for analysing part of our water quality samples.

Furthermore, we would like to thank our sponsors Wareco, Delft Global Initiative (DGI), Ford Schakel Autogroup and VP Delta for the financial support. Without them, the research couldn't have been this extensive. Last, but not least, we would like to thank our family and friends that have supported us through the obstacles we had to take during the project.

Abstract

Kathmandu is a prime example of a city exhibiting both rapid metropolitan region expansion and a population boom. This growth leads to a water stress and pollution of the surface and groundwater. The lack of proper waste management and sanitation results in the ongoing deterioration of the water quality in the Kathmandu Valley. The situation is worsened by the lack of a complete and safe drinking water network leading citizens to pivot on conventional water sources like stone spouts and bore wells. Consequently, groundwater extraction, from the aquifer under the Kathmandu Valley, is expected to keep increasing and the groundwater table to drop as the recharge is less than the extraction rate. This research aims to address the influences of land-use on the quantity and quality of water sources in the Kathmandu Valley and how the necessary data can be collected by citizen science in the future.

The fieldwork took place in August 2017 when groundwater level, water quality and land-use data were collected from seven watersheds within the Kathmandu Valley in Nepal. At the same time, existing citizen science precipitation data were processed and juxtaposed with respective satellite data, namely IMERG GPM. On the one hand, the results confirm our initial assumption that the quality of the river water dramatically deteriorates (except for nitrite, nitrate and phosphate) while flowing through the agricultural and urban areas. Another observation is that spout water quality (except E. coli, turbidity and iron) is also negatively influenced by human activities. On the other hand, there is no clear link between land-use and wells' water quality. Geology has a role to some extent as well. The Kalimati formation slightly increases phosphorus concentrations while EC and hardness are increased in areas where limestone rock is present. A strange finding is that spouts and wells water quality do not behave similarly showcasing that they do not originate from the same aquifer. A health risk analysis was conducted with the results indicating that some water quality parameters have values exceeding the WHO standards. The more upstream the site is located, the higher the chance is that water won't be contaminated. Nitrate, nitrite and phosphate concentrations did not exceed the WHO standard values anywhere in the valley, while turbidity is above acceptable levels. Iron concentration in wells is not hazardous for human health while in the mid-west region the concentration in rivers and spouts can cause adverse health effects. However, faecal contamination is present at most of the study sites indicating that people should consume water from neither spouts nor wells unless some treatment process is performed, filtering away the biological pollutants.

Regarding the option of implementing satellite data to facilitate citizen science, the contingency analysis shows that satellite products can detect the general temporal precipitation pattern although they perform poorly when it comes to estimating the correct amounts of rainfall. An extended network of rain gauges within the Kathmandu Valley is vital to establish a strong linear relationship between ground and satellite data which is, in turn, essential to enable GPM to enhance the temporal resolution of the citizen science measurements. Furthermore, the implementation of land-use and water quality measurements into citizen science shows increasing potential especially when taking into account the contribution of ODK. The accuracy of the citizen science ground truthing was found to be 33% when compared to the experts. Proper training of the citizen scientists is essential to improve performance. During research temperature, EC and turbidity were labelled as indication parameters. Those parameters are used to indicate the range of other water quality parameters which cannot be measured easily. The indication parameters, however, can be measured with affordable equipment and together with water quality strips prove to be powerful tools in the hands of citizen science.

Inter-relations between quality and quantity parameters were researched, and the resulting correlation matrices present that certain parameters (EC and turbidity) have substantial correlations with other parameters and can be hence used as, mentioned above, indication parameters. Correlations between parameters are stronger in wells and rivers than in spouts. Finally, the groundwater recharge for the monsoon period was determined, but it is expected to be drastically reduced the rest of the year. A solid conclusion about the relation between recharge and land-use cant be made unless a more substantial number of wells is regularly sampled.

Contents

1 | Introduction

Nepal, a country that is simultaneously the least urbanised country and the fastest urbanising country in Asia, has had an urban population growth rate of around six percent per year since the 1970s (Muzzini & Aparicio, 2016). The Kathmandu Valley represents 24 percent of Nepal's urban population and is the fastest growing metropolitan region in South Asia (Government of Nepal, Ministry of Urban Development, 2015). It is hard to give actual numbers for the population in the Kathmandu Valley because population numbers in literature fluctuate between 2.5 and 5 million people. This is due to the fact that the percentage of unregistered births in Nepal exceeds 50 percent (Unicef, 2013). The Central Bureau of Statistics has officially stated that there were 2.517.023 people in the Kathmandu Valley in 2011 (CBS, 2014).

Because of the population growth, the gap between water supply and demand keeps growing. Furthermore, the Kathmandu Upatyaka Khanepani Limited (hereafter mentioned as KUKL), the drinking water supply company, has an insufficient supply of drinking water, people are turning to traditional resources to meet their water demands (Shrestha et al., 2012). Traditional water sources, like stone spouts and wells, extract the groundwater from the aquifer. Groundwater is one of the most important sources of water and because of the growing population, increasing urbanisation and industrialisation, the groundwater tables have been dropping since the 1970s, but are still increasingly dropping (Shrestha et al., 2012). Also, due to the population growth in the Valley, the land-use in the Valley is rapidly changing, and the Valley is becoming more and more urbanised (Ishtiaque et al., 2017). This urbanisation influences the recharge of groundwater. Because of paved grounds, rain generally has more difficulty to reach the aquifer, decreasing direct recharge (Lerner, 1990).

Furthermore, the water quality is deteriorating in the Kathmandu Valley. Waste management, waste handling, and sanitation are handled inadequately in the valley right now (Warner et al., 2007), which affects both surface- and groundwater. Surface water is for example highly polluted because of the unregulated waste (water) management. But also shallow groundwater is contaminated, due to seepage of polluted water from the rivers (Gautam et al., 2013), septic failures and leaches from landfill sites among others (Shrestha et al., 2012).

Unfortunately, there is little information available to predict changes in the water quality and the hydrological system when land-use is changed. To have a better understanding of the current information, data is needed. But one of the leading challenges of research in Kathmandu is the fact that there is a trend of keeping data information to oneself. Also, the documentation of data is lacking, which leads to a lot of repetition in relevant research fields. Furthermore, the studies that are well documented aren't updated and revised regularly, but at a very slow pace (Shrestha et al., 2012). A needed improvement of data availability together with the rise of smartphone usage in developing countries gives excellent opportunities for the use of citizen scientists.

According to Silvertown (2009) a citizen scientist is "a volunteer who collects and/or processes data as a part of a scientific inquiry." Citizen science is a very old concept, which traces back to the beginnings of modern science, but citizen scientist usage has become more abundant last few years because of the rise of smartphone usage and other technologies (Silvertown, 2009). With a smartphone, a citizen scientist can , for example, record water data like precipitation, water height, and many other parameters.

One company that jumps in the gap of the opportunity of citizen scientist use in developing countries is Smartphones4Water, a company that recruits inhabitants of the Kathmandu Valley to become citizen scientists, to better understand the hydrological system.

A parameter to have a good understanding of the hydrological system in the Kathmandu Valley is precipitation data. Unfortunately, the data availability of precipitation in the Kathmandu Valley is very scarce, making rainfall a critical parameter to measure. These measurements are currently done by multiple citizen scientists of Smartphones4Water all over the Kathmandu valley, giving a great spatial resolution. One drawback of this is that the temporal scale of citizen scientist precipitation measurements is coarse. To improve the temporal resolution of citizen scientist measurements, it might be possible to use Global Precipitation Measurement (hereafter, GPM) data, which has a very coarse spatial resolution, but a better temporal resolution.

This project aims to understand the relationship between land-use, water quality and the hydrological system and how future data collection for understanding and monitoring these processes can be done by citizen scientists and local inhabitants. The desired result is that by making citizen science-based studies and data open and accessible to everyone who might need it, the household water availability and the inhabitants who depend on it will not be negatively influenced by land-use planning decisions in the future.

Research questions

Main question: What are the influences of land-use on the quantity and quality of water sources in the Kathmandu Valley and how can the necessary data be collected by Citizen Science in the future?

To answer these questions, multiple secondary questions were formulated:

1. What are the relations between land-use and water quality in stone spouts, wells, and streams?
2. What are the relationships between geology and water quality in stone spouts, wells, and streams?
3. What is the relation between land-use and groundwater recharge?
4. How does water quality in the Kathmandu water sources influence population health?
5. Is it possible to adjust spatially distributed but low frequency, noncontinuous citizen scientist precipitation data with GPM data that has a low spatial resolution but a high temporal resolution?
6. Can water and land-use measurements be successfully performed by citizen scientists?

First, project boundaries will be defined in 2. Here the fieldwork site, geology, and structure of the water supply system will be described. In the following chapters answers on the secondary questions will be given. These chapters will be presented as a set of small papers. Following the short papers, a conclusion will be made to answer the central research question. Lastly, recommendations will be given for further research and actions and on how to improve the study that was done.

2 | Project Scope

In this chapter, the boundaries of the research will be set. This study will be done concerning the research site, the geology and the stakeholder responsibilities regarding water supply in the research area.

2.1 Study area

First of all, the site that was used for the research is the Kathmandu Valley. The Kathmandu Valley is the most populated area in Nepal and consists of three districts; Kathmandu, Bhaktapur, and Lalitpur. To set clear project boundaries of what is meant with the Kathmandu Valley throughout this project, it is chosen, to use the watershed delineations of the Kathmandu Valley, which can be seen in the picture below. A further distinction between watersheds will be made in Figure 2.2 where will be explained how the different watersheds are researched regarding water quality and quantity.

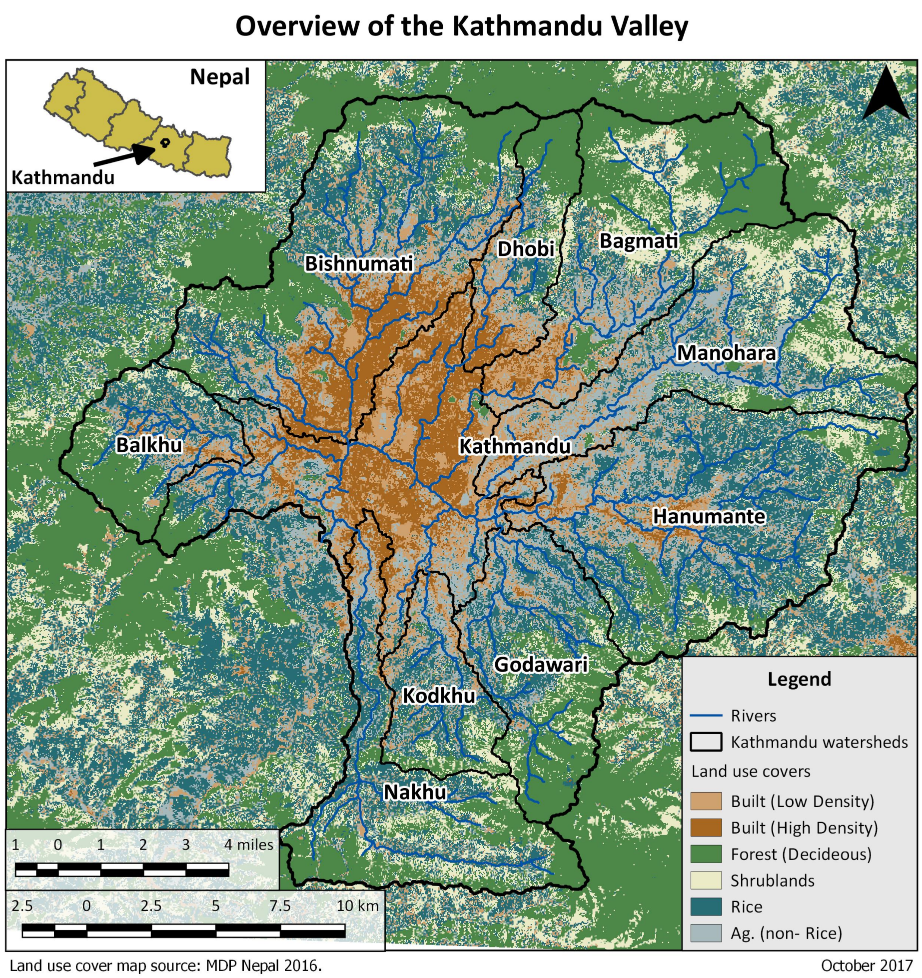


Figure 2.1: Geographical scope

The Kathmandu Valley is a very distinctive place in Nepal. It is lying in the central east of Nepal and situated in the Lesser Himalaya, with an area of 587 km^2[1]. In comparison with the mountains, the Kathmandu valley is surrounded with; it is a relatively flat area with an average height of 1350 meter above the Mean Sea Level (Regmi et al., 2003).

2.2 Fieldwork

To find answers to the research questions of this project, data is needed. A big part of this data is acquired by doing fieldwork measurements in the Kathmandu Valley. Before starting fieldwork measurement objectives were identified, and a distinction was made in geographical locations and sources. Firstly quantitative measurements are done on quantity (ex. discharge, water levels) and quality parameters (ex. E.coli, nitrate, iron) from three different sources: spouts, wells, rivers. These sources are distinctive in the way they work as a water source and from where the water originates. Rivers contain surface water, and spouts/wells contain groundwater. The geographical location of the measurements was chosen so that every source is evenly represented over the longitudinal direction of the watersheds with the goal of three measurements for every source in one main watershed. Every main watershed has a longitudinal land-use development that starts upstream with natural land covers and continues downstream increasing agriculture land covers in the middle and urban land covers at the most downstream watershed (see land-use development graphs in section 14.2. The longitudinal division of the measurements was directed so that every sub-watershed had a well, spout and river measurement near every pour point that more or less corresponds to the dominant land-use in that watershed; natural, agricultural or urban.

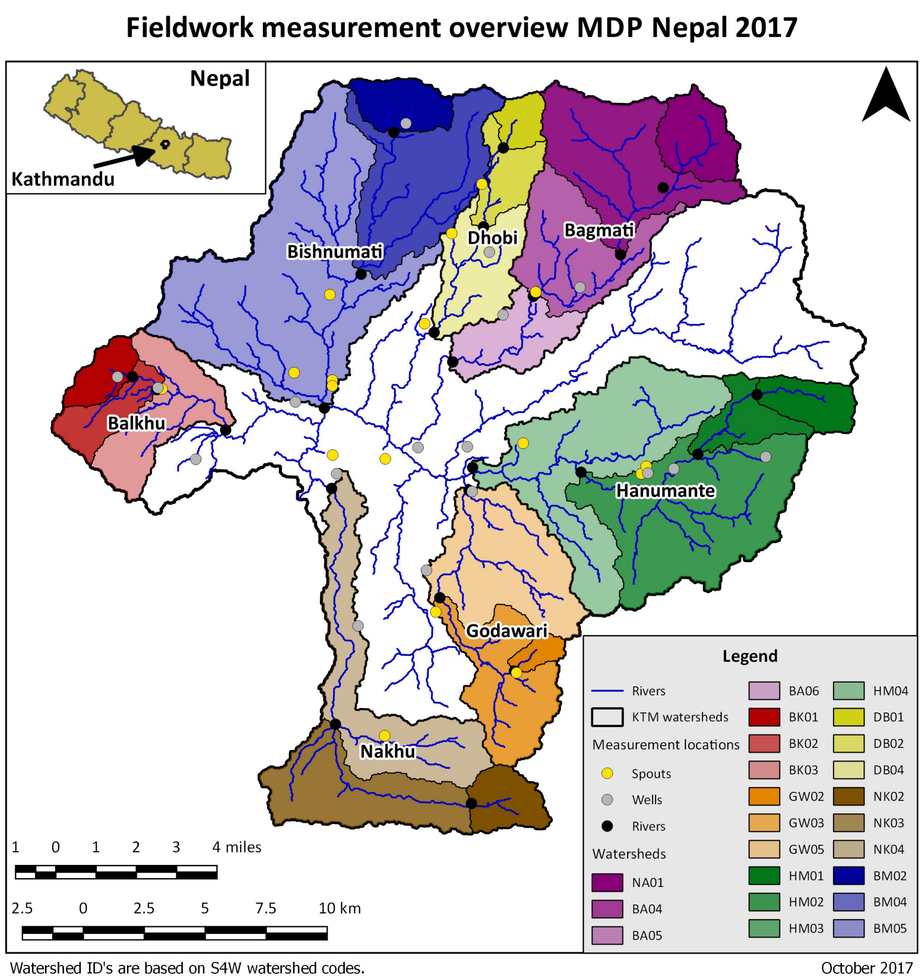


Figure 2.2: Geographical overview of the quantitative measurement locations and watersheds.

Because we had a measurement limit of 60 measurements due to limited measurement strips for the quality parameters, six of the nine main watersheds were chosen to investigate during fieldwork. Due to a positive development

[1] Measured by watershed delineation in QGIS & GRASS

during fieldwork, this could be extended to seven watersheds. They were chosen based on practical experience of the S4W team that they would probably provide the most useful data to use in this project. The exclusion of the Kodkhu river is mainly because of its small size and the lack of a clear transition between agriculture and urban area. The same transition reason stands for the Manohara river and its similar pattern as the Hanumante river, but without the clear anthropogenic activities, the Hanumante watershed contains. The quantitative, a select, measurement locations are shown in the Figure 2.2 and exist of 17 spout, 17 well and 23 stream measurements, concluding to a total of 57 water measurement locations.

Next, to quantitative measurements, qualitative ground-truth measurements were done for land-use validation which totals to 43 measurements, after checking false measurements, 42. The next chapter will elaborate on validation of the 2016 land-use classification and location-choice of ground-truth measurements.

2.3 Geology

2.3.1 Geology of Nepal

To understand how groundwater flows and how water quality is influenced by the subsurface, it is essential to know the geology of Nepal and the Kathmandu Valley. Nepal is situated in a tectonically, very active region. Plate tectonics, the process of large-scale movement of separate sections of the earth's crust, is responsible for this situation.

The separate sections of the lithosphere (the rigid outer shell of the earth), known as tectonic plates, move with different speeds (generally several centimetres per year) over the plastically moving asthenosphere. Based on the history of sea-floor spreading in the Indian Ocean, it can be derived that between 70 and 40 million years ago India moved about twice as fast with respect to Eurasia (Molnar & Tapponnier, 1977).

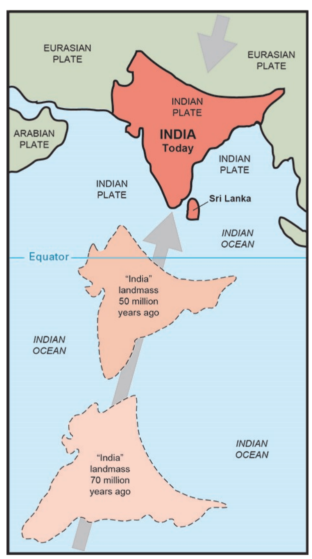


Figure 2.3: Movement of the Indian plate (USGS, 2015).

This movement of tectonic plates resulted in the fact that India approached the Eurasian plate and collided with it 40 million years ago, forming the highest mountain range in the world, known as the Himalayas (see Figure 2.3. This collision is still in progress, as proven by the last disastrous earthquake in Nepal in 2015. When two continental pieces of crust are colliding, unlike the situation with a continental and an oceanic plate colliding, neither of the two continental plates can easily plunge underneath the other into the asthenosphere. The continental crust is merely too thick (35 km unfolded) and too light (20% less dense than the underlying mantle). The buoyancy of the continental crust thus hinders subduction. The compressive force, however, is so large that the Indian plate is pushed underneath the Eurasian plate, suturing them to a more massive continent (Molnar & Tapponnier, 1977). As a result of the collision, the entire region became folded, faulted and deformed. In the Himalayan collision zone, strike-slip faults (where two sides of a fault slide horizontally past each other) are predominant (Molnar & Tapponnier, 1977). Thrust faulting (faults that result from compressive stresses, where one side of the fault slides over the other side) occurs only in limited areas. Normal faulting (where one side of the fault sinks) is rare in this part of Asia.

2.3.2 Geology of the Kathmandu Valley

In the Kathmandu Valley two crystalline nappes, sheetlike bodies of rock which move above a thrust fault from its original position overriding other stones, meet each other (Ganesh, 2011). The valley itself is surrounded by high mountain ranges up to 2700 m (Ganesh, 2011). They and the thick basin floor consist of intensely folded, faulted and fractured igneous and sedimentary basement rocks of more than 400 million years old (Devonian to the Precambrian era). The basement rock ranges from granite and gneiss to schist in the north. Intense weathering and erosion of these rocks over at least the past 542 million years, resulted in a significant amount of alluvial and colluvial deposits in the form of a fan (Shrestha et al., 2012). The eastern and western rims of the valley, phyllite, sandstone, and limestone are more prominent, and in the southern part of the valley sandstone, quartzite, siltstone and shale and crystalline limestone of the Phulchauki Group occur (Shrestha et al., 2012). This Phulchauki Group consists of several formations Table 2.1.

Stratigraphic subdivision of lithology in Kathmandu Valley				
Group	Formation	Main lithology	Thickness [m]	Age [Geological epoch & mln. years BP]
Phulchauki	Godavari Limestone	Limestone	300	Devonian (∼356 - ∼415)
	Chitlang Formation	Sand- and siltstone, slate	1000	Silurian (∼416 - ∼443)
	Chandragiri Limestone	Limestone	2000	Cambrian to Ordovician
	Sopyang Formation	Clayey and Marly slate and calc-phyllite	200	Cambrian (∼501 - ∼513)
	Tistung Formation	Sand- and siltstone and phyllite	3000	Early Cambrian to Precambrian (older than 513)
Bhimphedi	Markhu Formation	Marble, schist and granite intrusion	1000	Precambrian (Older than 542)
	Kulekhani Formation	Quartzite and schist	2000	Precambrian (Older than 542)

Table 2.1: Lithology in the Kathmandu Valley (Stocklin & Bhattarai, 1977).

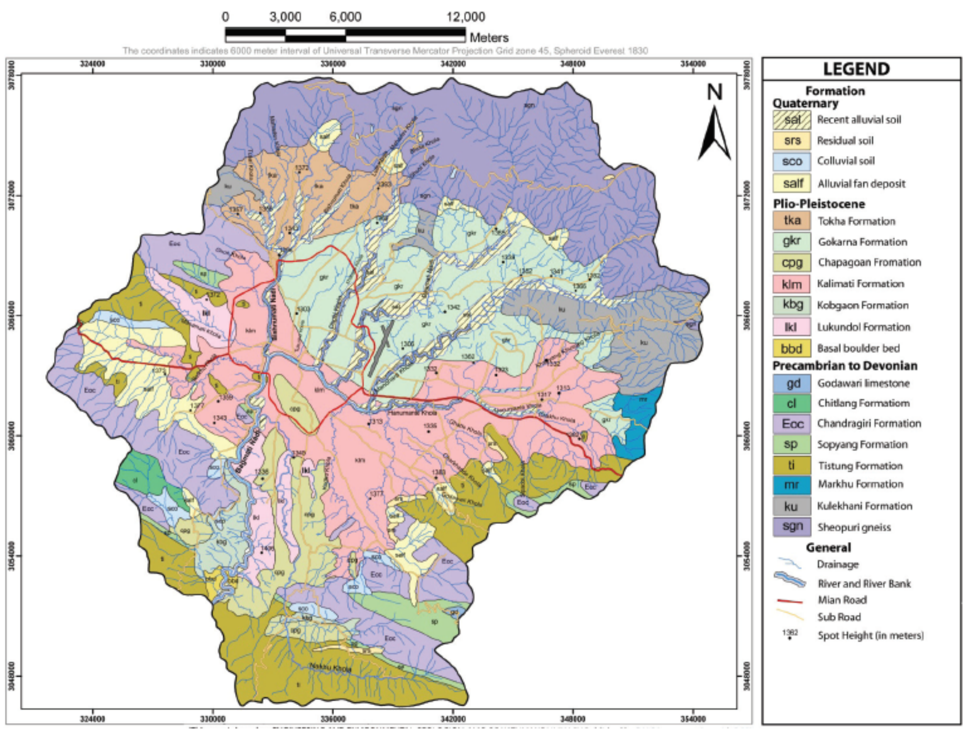


Figure 2.4: Geology of the Kathmandu Valley (Shrestha et al., 2012)

The centre of the valley is relatively flat and situated around 1300-1400 m altitude (Ganesh, 2011). However, the hard basement rocks are sometimes more than 550 m below the earth surface. They are covered by a thick semi-consolidated lacustrine and deltaic sediments from Pliocene to Pleistocene age (around 5 million to 10.000 years ago) (Stocklin & Bhattarai, 1977). During this time, a large lake was situated in the central part of the valley (Ganesh, 2011). Small sediments, originating from the surrounding mountains, could settle in this lake. Rivers drained towards it from the north and south and left their geological traces in the form of coarse sediments. Coarsening-upward sequences of residues show that deltas developed at the lake shore and proceeded into the water body. The sediments that were deposited during this time can still be found on the ground beneath the valley. Arenaceous fine to coarse sand is often composed of northern gneiss rocks, whereas argillaceous clay and silt result from erosion of limestone and phyllite in the eastern, southern and western rims of the valley (Ganesh, 2011). In the Plio-Pleistocene sediments, seven formations can be distinguished. They are displayed and explained in the table below. The cross-section through the valley, indicating thickness and location of different sediment formations is displayed in Table 2.2.

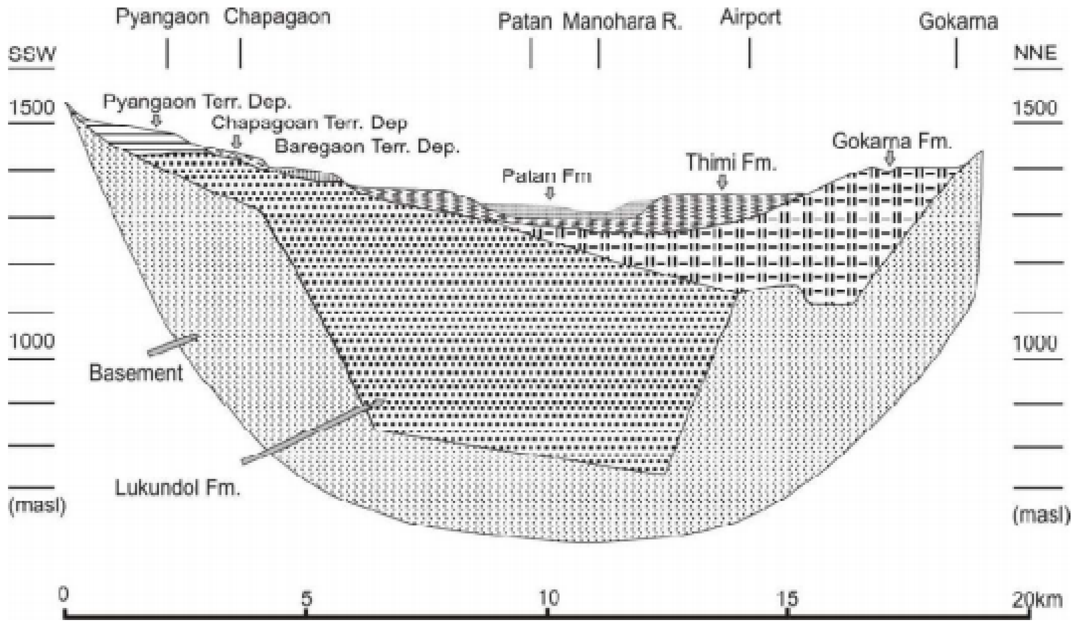


Figure 2.5: Cross-section of the Valley.

Classification of Plio-Pleistocene slightly consolidated sediments of the Valley			
Formation	**Lithology**	**Thickness**	**Aquifer Properties**
Tokha Formation	Dark grey clay, brownish grey and poorly sorted sub angular to rounded sandy gravel with occasional peaty clay and lignite layers.	up to 200m	Aquifer with high permeability, suitable for groundwater abstraction from shallow depth.
Gokarna Formation	Light grey, finely laminated and poorly graded silty sand, intercalation of clay of variable thickness as well as in the upper part diatomite (1 m). Considered to be of fluvio-deltaic faecies.	up to 300m	Medium groundwater potential and moderate to high groundwater infiltration.
Chapagoan Formation	Sub-rounded to rounded silty sandy gravel, occasionally with boulder beds, sometimes within (<1 m) clayey silt and silty sand and at places lignite pockets.	up to 110m	Good potential for groundwater recharge. Moderate to high permeability and high groundwater potential. Groundwater level is moderately deep and highly vulnerable to groundwater pollution.
Kalimati Formation	Grey to dark silty clay and clayey silt, at places calcareous and with phosphate minerals. Organic clay, fine sand beds and peat layers are common. Occasionally, lignite seams up to 20 m thick occur. In Kharipati area, quartzite and biotite schist boulder beds with sandy gravel and minor clayey and sandy silt layers are present. This formation shows purely a lacustrine (lake-sediment) faecies.	450m or more	Acts as an aquiclude or aquitard material having extremely low permeability.
Kobgoan Formation	Light grey to grey,laminated fine sand, occasionally with sandy clay, silty sand and sub rounded,to rounded, poorly graded gravel.	50m or more	Moderate groundwater potential with moderate to deep groundwater level and moderate to high,permeability.
Lukundol Formation	Semi-consolidated, sandy, clayey silt inbedded with gravel and carbonaceous clayey sand, peat, and lignite of up to 3 m thickness.	up to 80m	Low groundwater potential with deep groundwater table and low permeability.
Basal Boulder Bed / Tarebhir Formation	Semi-consolidated,sandy, clayey silt interbedded with gravel and carbonaceous clayey sand, peat and lignite of up to 3 m thickness.	1 to 350m	High groundwater potential and permeability.

Table 2.2: Sediments (Ganesh, 2011).

Different myths are famous about the draining of the Kathmandu paleo-lake. Hindus believe that Lord Krishna drained the lake by cutting the gorge at Chobhar, south of Kathmandu (Ganesh, 2011). Indeed, there is a massive gorge in the south of the valley, through which the Bagmati river is drained. This point is known to us as the pour point. A more scientific reason behind the drainage of the lake was suggested by (Sakai, 2001). He believes that this event could be clarified by a sudden movement along the active Chandragiri and Chobhar faults in the south of the valley. In the post-lake era, Plio-Pleistocene sediments described before, are partially overlaid by geologically young and unconsolidated quarternary deposits (max. 11,500 years old). These deposits consist of debris from the mountainous rims of the valley, transported by rivers (alluvial) and gravitational forces (colluvium). The quarternary unconsolidated sediments can be grouped in four formations (Shrestha et al., 2012), and are described in Table 2.3.

Quaternary unconsolidated sediments of the Kathmandu Valley		
Formation	Description Lithology	Aquifer properties
Recent Alluvial Soil	Recent sediments of, floodplains and lower alluvial terraces.In the northern , part of the valley, sand and gravel deposits up to boulder, size. In central and southern part, clay, sand and fine gravel.	Hydrologically this formation has a high potential of groundwater with periodic change of shallow groundwater level, high infiltration and high-risk of pollution of groundwater and surface water.
Residual Soil	Humic silty loam to sandy gravels of thickness 1-3m occurs on slopes.	High infiltration, and potential for groundwater
Colluvial Soil	Inhomogeneous, deposit at foot slopes with constituents of humic clay, silt and sand at places, boulders. Variable thickness, increasing towards the centre of the deposit.	High infiltration, and low potential for groundwater.
Alluvial Fan Deposit	Gravel, sandy, gravel, sand and silt. Thickness increases towards the centre of the fan. Finer grained material towards the margin of the fan.	High infiltration of surface water and perched water table may be present.

Table 2.3: Quaternary unconsolidated sediments of the Kathmandu Valley (*Barrier Sediments in the Kathmandu Valley*, 1998)

2.4 Water Supply and Demand Problems

In the Kathmandu valley, people take water in from multiple sources. The extraction and also the responsible institute for the different water sources will be described in this section.

2.4.1 Water Demand and Supply

The primary supplier of household water in the Kathmandu Valley is the KUKL. They have been the leading supplier since 2008, following up the NWSC (Nepal Water Supply Company). KUKL delivers water to almost 78% of the citizens in Kathmandu Valley (Pandey et al., 2016). The water demand in Kathmandu Valley is currently estimated to be 388.1 MLD (Million Liters per Day) (Saraswat & B.K. Mishra, 2017). Although the distribution network has a broad reach and a lot of connections, the water supply is minimal in both quality and quantity. First of all, the gap between supply and demand is huge. For example, in 2012, the supply was 139 MLD in the wet season and 90 in the dry season to a demand of 350 MLD (Chapagain, 2014). This demand has grown to 388.1 MLD and will only grow in the coming years due to a population growth rate of 5% and an expectation of more water use per capita due to changing lifestyles (Saraswat & B.K. Mishra, 2017). Secondly, the water supply system is heavily outdated. Leakages are estimated to make up a loss of 40% of the water supply (Shrestha et al., 2012), but might be higher in reality. The MDP project group found out that for 2010, hidden in the data from the Asian Development Bank, actual leakages are as high as 65 percent (Gonzalez Gonzalez et al., 2016). Also, there are illegal service connections.

Finally, the quality of the distributed water cannot be trusted. Although there are water treatment plants, the operation of those plants is not sufficient, as they are not very often maintained (Shrestha et al., 2012) and the treatment of the water is not continuously done, but only if supplies are in stock and there is a shortage of trained personnel. Furthermore, the water supply is intermittent and insufficiently pressurised. Even when treated, and the water has sufficient quality, the water gets polluted due to leakage points where contaminated water is infiltrating through (Kutawal & Bohara, 2011).

The problems described above lead to a water supply system that only supplies water for a few days per week and just for a couple of hours at most and with an unreliable quality. To supplement (or to even get access to water at all, in case of not being connected to the grid which is also true for a part of Kathmandu's population) their water supply, the people resort to traditional sources like local wells, water tanks, and stone spouts. These traditional sources supply water that is tapped from either the shallow aquifer, which are tube- and dug wells as well as stone spouts (also known as dhunge dharas). Other are deep aquifers, which are deep wells used by industries and companies like hotels, or water collected from other water agencies and then supplied by tankers (Shrestha et al., 2012).

Because of the extensive groundwater use, with a recharge rate lower than the depletion rate, the groundwater table is dropping (Shrestha et al., 2012). Next, to that, the wastewater from urban centres is managed inadequately, which altogether leads to a decrease in groundwater quality and the mentioned groundwater table drop.

With the before mentioned population growth and the attached land-use changes (more urban areas, which seal the ground due to pavement and buildings), make that the water demand and supply gap will increase even more in the following years, which gives even more urban wastewater and groundwater depletion. Because of the sealed grounds, rainwater will have more difficulty reaching the groundwater table, leading to even more groundwater depletion and ultimately threatens water security in the Kathmandu Valley even more.

2.4.2 The governing of water supply

One of the reasons for an unreliable supply of water in the Kathmandu Valley is because of the deteriorating quality of the distribution network, which is more a management problem than a water shortage problem. The deteriorating network is only one of the issues that are haunting the water supply market. Chapagain (2014) investigated this an came to the following vicious cycle of unsustainability, which can be seen in Figure 2.6. How this cycle applies to the Kathmandu Valley will be described below.

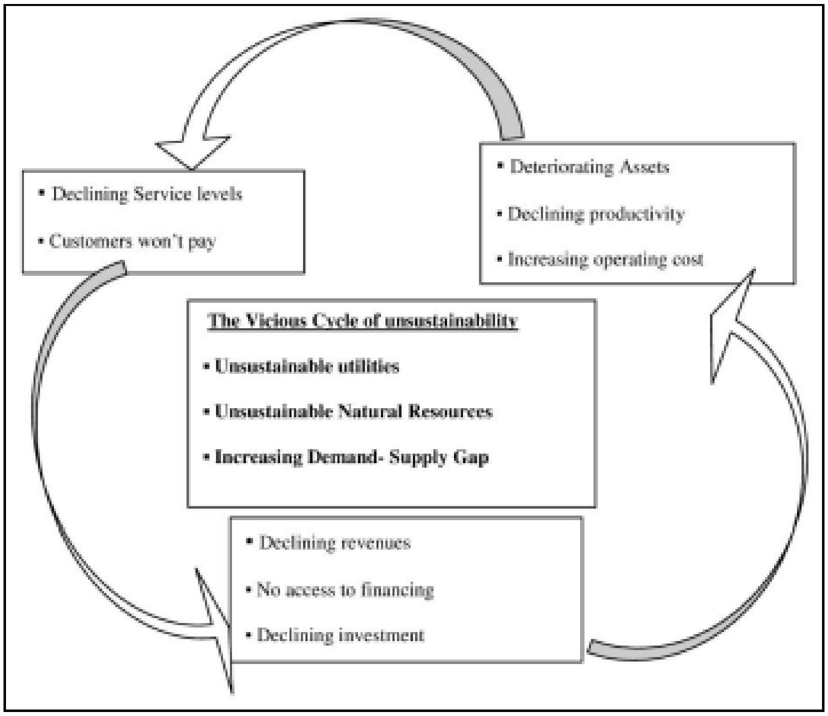


Figure 2.6: The Vicious Cycle of Unsustainability (Chapagain, 2014).

When formed in 2008, the KUKL immediately had to deal with assets that were deteriorating (Chapagain, 2014). Because of that, they also had to deal with a decline in both productivity and increasing production costs. The increased costs and decreased productivity led to an unacceptable service level which makes customers not paying their bills, making the revenues of KUKL decline so they cannot invest in assets, which lets the assets deteriorate even further every year. This vicious cycle of unsustainability leads to an increase in groundwater depletion and also the water demand and supply gap will not decline if the distribution system will not become more efficient. Also, it is impossible to expand services (Chapagain, 2014).

Ending this vicious cycle seems to be very difficult in practice. Not only because of political instability and frequent changes in government, because of which policy directions and decisions often change/Chapagain2014, but also because of a lack of collaboration between different responsible institutions /citepShrestha2012. It seems that there is no regulatory framework for groundwater extraction rates or groundwater rights in that matter /citepShrestha2012. Despite a non-existent regulatory framework for groundwater, Nepal is aware of the need for better groundwater management and thus has created a lot of institutions, policies and legislative instruments. Unfortunately, there is a lack of collaboration between these agencies, and because of that, a lot of roles and responsibilities are overlapping/citepShrestha2012.

3 | Discharge measurements

3.1 Introduction

sectionMethods and materials There are different methods to calculate the discharge of different types of water sources. For spouts, the discharge is measured with the Bucket method, while in streams both the salt dilution and flow tracker method can be applied.'

Salt dilution

Salt dilution is a discharge measure method for streams whereby a known volume of water and known mass of salt is injected into the stream, also known as a slug injection (Moore, 2005). Following the injection, the salt will mix with the base-flow (and rain flow during a rain event) which will cause a rise in electrical conductivity. Since the flow in the centre will be faster than at the boundaries, a longitudinal dispersion profile will be created. The electrical conductivity (EC) is measured downstream of the mixing point. The difference between the measured EC and the background EC is recorded over time (Moore, 2003). Together with the calibration factor (k) and the volume of the salt and the water (V) that is injected into the stream, the discharge can be calculated, see Equation 3.1.

$$Q = \frac{V}{k * \Delta t * \sum_n \left[EC(t) - EC_{bg}\right]} \tag{3.1}$$

The calibration factor (k) is equal to the gradient of the linear relationship between the salt concentration and the electrical conductivity. The method can only successfully be applied to turbulent streams with a lower background electrical conductivity. When this is done, dilution gauging can be precise to be within 5%, equivalent to the accuracy of current metering at a suitable cross-section (Day, 1977; Johnstone, 1988). The results can be found in Table 3.2.

Flowtracker

A flow tracker is a device that can measure the velocity with the Doppler effect. It measures the Doppler shift, which can tell the velocity of the source relative to the receiver. Determining the speed can be done by measuring the difference in the frequency that was received and was send ("FlowTracker Handheld ADV Technical Manual", 2007). In Equation 3.2 it is depicted how the velocity is calculated.

$$F_{doppler} = F_{source} * \frac{V}{C} \tag{3.2}$$

where:

$F_{doppler}$ = change in received frequency (Doppler shift)
F_{source} = frequency of transmitted sound
V = velocity of source relative to receiver
C = speed of sound

The flow tracker uses a Bistatic Doppler current meter. On a probe, two receivers and one transmitter can be found. The flow tracker measures the change in frequency for each receiver; therefore the device will know the velocity of the water in three dimensions. However, the flow tracker does not gauge the speed of the water, but the rate of particles travelling in the water. It is assumed that the velocity of the particles is equal to the velocity of the water. However, it the water is too clear, that no particles can be found, then the speed cannot be measured ("FlowTracker Handheld ADV Technical Manual", 2007).But since these conditions are almost non-existing in every natural water river, the ability to use the flow tracker to gauge the discharge in a river never depends on the water quality. The only reason why in some rivers the discharge could not be measured with the flow tracker was when the cross-section of the river was not suitable. It could be that the water level was not deep enough to place the probe beneath the water surface or that that the bottom was too irregular. A good cross-section is necessary to calculate the discharge since the device can only measure the velocity of the water. The discharge was measured with the Mean Section Method ("FlowTracker Handheld ADV Technical Manual", 2007). With this method, as can be seen in Figure 3.1, the velocity, depth, and width are measured at multiple locations in a stream. By dividing the river into multiple small sections, the discharge can be calculated with greater accuracy. The flow tracker can measure these two values, the device has an analogue depth meter, and with the help of a measuring tape, the width can also be measured("FlowTracker Handheld ADV Technical Manual", 2007). The working principle is as follows:

- Both values, height, and depth, are entered into the device for each section of the river.
- The probe is placed at a height where the distance between the probe and the floor of the river is 60% of the total height of the water at that spot.
- The average velocity is measured at the section.
- The three previous steps are repeated at every section.
- Finally the device will calculate the total discharge of the river.

This summation shows how the discharge can be measured with the help of a flow tracker.

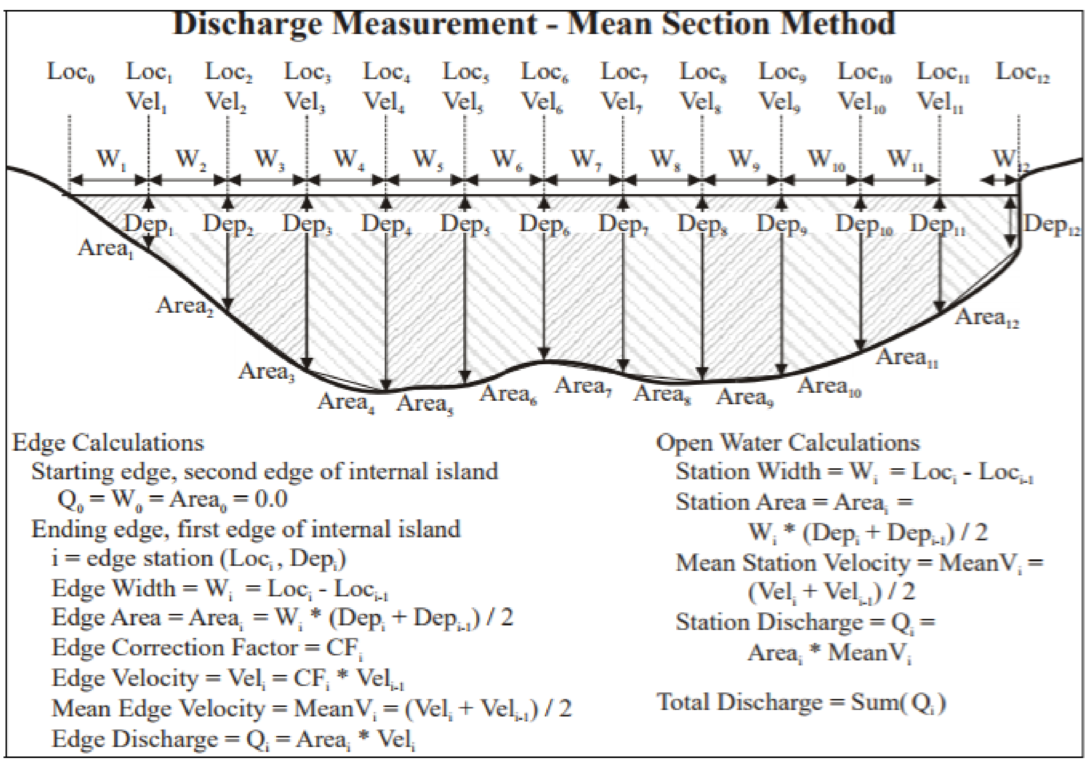


Figure 3.1: Mean Section Method to calculate discharge ("FlowTracker Handheld ADV Technical Manual", 2007)

3.2 Results

General results

Date	Time	Source	Watershed	Latitude	Longitude	Discharge [m^3/s]	Uncertainty [%]	Method
01/09/2017	03:00:00	River	Nagmati	27.77956383	85.43805179	1.460	-	Salt Dilution
11/09/2017	02:55:00	River	Hanumante	27.67287398	85.36444922	0.414	-	Flow tracker
11/09/2017	06:27:00	River	Hanumante	27.67306152	85.40955798	0.545	-	-
11/09/2017	05:54:00	Spout	Hanumante	27.68278105	85.3849651	0.520	-	Salt Dilution
11/09/2017	09:09:00	Spout	Hanumante	27.67355064	85.43458823	0.030	-	Bucket Method
11/09/2017	09:59:00	Spout	Hanumante	27.67636449	85.43653538	0.330	-	-
12/09/2017	02:12:00	River	Godawari	27.59846829	85.38586339	0.020	-	Salt Dilution
12/09/2017	03:22:00	River	Godawari	27.62422028	85.35343414	0.279	-	Salt Dilution
12/09/2017	05:37:00	River	Godawari	27.66438959	85.36339919	0.203	-	Salt Dilution
12/09/2017	10:21:00	River	Bagmati	27.71151036	85.35408975	3.903	2.4	Flow Tracker
12/09/2017	02:13:00	Spout	Godawari	27.59784219	85.38676747	13.510	-	Bucket Method
12/09/2017	03:10:00	Spout	Godawari	27.61887798	85.35204795	0.090	-	Bucket Method
12/09/2017	07:31:00	Spout	Kathmandu	27.67451538	85.32801763	5.320	-	Bucket Method
14/09/2017	02:30:00	River	Balkhu	27.70029191	85.22133408	0.063	3.5	Salt Dilution
14/09/2017	04:00:00	River	Balkhu	27.69595052	85.2317471	0.160	11.1	Salt Dilution
14/09/2017	07:36:00	River	Balkhu	27.68228216	85.26115134	0.199		Flow tracker
14/09/2017	04:52:00	Spout	Balkhu	27.69628479	85.23390788	1.450		Bucket Method
15/09/2017	02:31:00	River	Bishnumati	27.79530628	85.32496883	0.232	10.8	Salt Dilution
15/09/2017	05:03:00	River	Bishnumati	27.74227184	85.31423837	1.313	3.4	Flow tracker
15/09/2017	07:24:00	River	Bishnumati	27.692177	85.30168151	3.781	9.5	Flow tracker
15/09/2017	05:42:00	Spout	Bishnumati	27.73415294	85.30169268	0.350	-	Bucket Method
15/09/2017	07:47:00	Spout	Bishnumati	27.70261743	85.30441598	0.160	-	Bucket Method
15/09/2017	08:11:00	Spout	Bishnumati	27.70053585	85.3045331	0.15	-	Bucket Method
17/09/2017	04:04:00	River	Dhobi	27.79146044	85.37082543	0.184	8.1	Salt Dilution
17/09/2017	05:22:00	River	Dhobi	27.7619513	85.36420313	0.430	16.6	Salt Dilution
17/09/2017	08:32:00	River	Dhobi	27.7220896	85.34572868	0.549	-	Flow tracker
17/09/2017	03:57:00	Spout	Dhobi	27.77770626	85.36262572	0.110	-	Bucket Method
17/09/2017	06:26:00	Spout	Dhobi	27.75898389	85.35110818	0.240	-	Bucket Method
17/09/2017	08:26:00	Spout	Dhobi	27.72513285	85.3415953	0.02	-	Bucket Method
18/09/2017	03:12:00	River	Nakhu	27.54877062	85.37068029	0.151	3.8	Salt Dilution
18/09/2017	04:33:00	River	Nakhu	27.57560573	85.31264897	0.738	23.3	Salt Dilution
18/09/2017	05:22:00	River	Hanumante	27.70481689	85.48111226	-	-	-
18/09/2017	08:55:00	River	Nakhu	27.66259991	85.30631121	1.005	1.8	Flow Tracker
18/09/2017	01:51:00	Spout	Bishnumati	27.70469491	85.2884111	0.220	-	Bucket Method
18/09/2017	02:04:00	Spout	Nakhu	27.57224926	85.33333667	0.410	-	Bucket Method
18/09/2017	10:01:00	Spout	Kathmandu	27.67499258	85.30607077	3.370		Bucket Method
19/09/2017	02:23:00	River	Nagmati	27.75409598	85.4216803	1.613	12.7	Salt Dilution
19/09/2017	04:40:00	River	Bagmati	27.73719363	85.38621118	3.781	5.0	Flow tracker
19/09/2017	04:18:00	Spout	Bagmati	27.73881443	85.38717442	0.160		Bucket Method

Table 3.1: Overview of the general discharge results

Dilution gauging results

In this section of the appendix, all the results of all different salt dilution experiments will be displayed. All discharges that were calculated with the EC-meter were calculated at a time interval of 1 second. All discharges that were calculated with a diver were calculated at a time interval of 5 seconds.

As can be seen in Table 3.2, from the 7th of September, the electrical conductivity has also been measured with a "diver". This device can as told in The average ratio in the measured discharge between the diver and the EC-meter is 6.2% with a standard deviation of 3.8%. Since the diver was not calibrated and was placed on the bottom of the rivers, the measured discharge by the EC-meter is seen as the reference point. In Table 3.3 all the locations that were measured multiple times with a diver are shown. The average of those various measurements is also displayed as it the accuracy. The accuracy is defined here as 2.33 times the standard deviation divided by the mean value.

Date	Time	River	Latitude	Longitude	Discharge with EC-meter [m^3/s]	Discharge with Diver [m^3/s]	Ratio [%]
29/08/17	16:01	Nagmati	27.784891	85.44445	3.320	-	-
30/08/17	11:40	Nagmati	27.784835	85.44451	1.473	-	-
30/08/17	13:58	Nagmati	27.784958	85.44437	1.655	-	-
01/09/17	11:30	Nagmati	27.784916	85.44437	0.978	-	-
04/09/17	12:11	Hanumante	27.681006	85.45823	0.288	-	-
06/09/17	13:52	Nagmati	27.784861	85.44462	0.968	-	-
07/09/17	09:39	Nagmati	27.784844	85.44455	0.877	0.832	94.9
07/09/17	9:55	Nagmati	27.784820	85.44453	0.980	0.894	91.3
12/09/17	8:22	Godawari	27.598659	85.38584	0.020	0.017	84.6
12/09/17	9:25	Godawari	27.624371	85.36339	0.279	0.273	98.0
12/09/17	11:45	Godawari	27.664495	85.36339	0.203	-	-
14/09/17	8:46	Balkhu	27.70023	85.22136	0.064	0.062	97.4
14/09/17	10:03	Balkhu	27.695873	85.23209	0.181	0.169	93.3
14/09/17	10:15	Balkhu	27.695873	85.23209	0.163	0.157	95.8
14/09/17	10:22	Balkhu	27.695873	85.23209	0.168	0.156	92.8

Table 3.2: Overview of dilution gauging result measured with an EC-meter

Date	Time	River	Latitude	Longitude	Discharge [m^3/s]	Average [m^3/s]	Accuracy [%]
14/09/17	8:39 8:46 8:55	Balkhu	27.598659	85.38584	0.068 0.066 0.068	0.067	3.5
14/09/17	8:03 10:15 10:22	Balkhu	27.695873	85.23209	0.180 0.167 0.166	0.171	11.1
15/09/17	8:16 8:35 8:44	Bishnumante	27.795306	85.32497	0.220 0.241 0.235	0.232	10.8
17/09/17	10:01 10:07 10:12	Dobhi	27.791580	85.37076	0.191 0.181 0.179	0.184	8.1
17/09/17	11:17 11:22 11:27	Dobhi	27.761945	85.36412	0.404 0.463 0.421	0.430	16.6
18/09/17	9:07 9:12 9:17	Nakkhu	27.548604	85.37072	0.148 0.152 0.153	0.151	3.8
18/09/17	9:07 9:12 9:17	Nakkhu	27.575635	85.31264	0.797 0.656 0.762	0.738	23.3
19/09/17	8:21 8:27	Nagmati	27.754068	85.42165	1.551 1.675	1.613	12.7

Table 3.3: Overview of dilution gauging results measured multiple times at every location with a Diver instead of with a EC-meter

3.3 Discussion

3.3.1 FlowTracker

The flowtracker can be a convenient device to measure the flow of a stream or river, especially if that river is not suitable for other methods like Salt dilution. It has the option to be very precise, and it is a proven technique. There were, however, a few drawbacks. One of those is the fact that the duration of a measurement can be extremely long. Reason for this is that during a measurement the velocity of the water has to be measured multiple times (at least twenty times), at a different location. It is desired that the distance between these positions are equal. Also, the equipment has to be calibrated most of the times at every new position (input of the depth in the device and repositioning the sensor). Another drawback is that the measurement can only be conducted at a location where the depth of the water is not too big or too small and where the flow is uniform. A third setback is that the ergonomics are not that great. People have to place themselves sometimes in a dangerous situation (standing in a river with a high flow or a lot of pollutants), and the device can be difficult to handle if the user is not trained with it or has any previous experience. The last setback is the costs that are involved when using a flowtracker. The measuring tape has the be replaced multiple times, and the device itself is very costly.

Uncertainty Analysis

The salt dilution method is very prone to location errors because a few conditions have to be met. For example, you need a right mixing spot and a spot where the water is not too deep to stand where you can throw in the diluted salts. The salts can be thrown into the water in two ways: as a point load or as a perpendicular load. It is thus also prone to human errors. After dispatching in the salts, the EC needs to be measured after the mixing spot where all the water goes throw one point. Also, the EC has been measured with an EC meter but later on even with just a diver. Next, to the human and location errors, you can also have errors due to external errors like the weather. Salt dilution is, however, an excellent method to use in small stream especially since the flow tracker has difficulties here. In broader and deeper streams a flow tracker will probably give better results.

The following definition was maintained with defining the uncertainty within a salt dilution measurement where the discharge was measured three times at the same location in the sequence of each other. The uncertainty is the standard deviation divided by the calculated average of those three measurements. This uncertainty is expressed in percentage. The uncertainty given by a flow tracker has not the same definition.

3.4 Conclusion

Both methods have their advantages and disadvantages. For small streams, the salt dilution is better suited since a FlowTracker has difficulty with the banks. If, however, there is a lot of pollution in the river, the EC is already very high, and salt dilution will no longer work. In those streams, it is best to use a FlowTracker. Also, if the rivers are too broad the mixing will be affected, and thus the FlowTracker will be the better choice. If the discharge has to be measured by citizen scientist, the fact that the FlowTracker is expensive will make the salt dilution better suited. All in all, the best method to use mostly depends on the situation. It is essential to take the study site and the cost-benefit into account to find the best method for your purpose.

4 | land-use Validation and Statistics

An extensive land-use classification was performed by Gonzalez Gonzalez et al. (2016). This study resulted in a land-use classification map for the Kathmandu valley (figure 6.15 in Gonzalez Gonzalez et al. (2016)). This classification identifies six different land-use classes.

The 2016 land-use classification map is based on a supervised classification. The Gonzalez Gonzalez et al. (2016) report states that 'When selecting six land-use classes in combination with the eleven Landsat 8 bands, this gives some 660 training polygons as an absolute minimum and number of at least 6600 (pixels) as desired.' 305 polygons, obtained by visual inspection on Google Earth, and 77 polygons, obtained by ground observations, were used as training polygons for the training map. From these training polygons, forest and shrubland are underrepresented. 28 polygons obtained by ground observations were used for validation of the final classification map. The result of the validation was an 88% accuracy in the land-use classification map. These 28 validation points are however too few to make a reliable validation, as is also stated in the discussion of the Gonzalez Gonzalez et al. (2016) report. Also, it was found that the distinction between Low and High developed is difficult in the classification by GIS due to how Landsat intensity values are influenced by the surrounding area. Mixed planted was found difficult to identify by ground measurements.

Validation

Land-Use and the water system are closely connected. Different land-uses have their specific impacts on the water system, and the land-use needs are driven by the water systems deliverables (quality and quantity). To understand these interactions and make decisions on land development it is needed to have the right information. To make a reliable assessment of the land-hydro interactions, the parameter errors of both land-use data and the hydrological data needs to be known. Secondly, a proper evaluation of the allocation of the errors over the different land-use classes is beneficial for further ground truthing by citizens scientists. For land-use, this comes down to the accuracy of the land-use classification map. Creating a new, more accurate and/or a multi-temporal land-use classification is only useful when a lot of new training polygons are obtained continually (Tabak, 2015). Acquiring this was not possible in the 2017 fieldwork. For these reasons, there has been chosen to validate the classification map in the 2016 MDP report and produce a confusion table to identify the error of the land-use classification map. There has to be noted that between November 2016 and September 2017 land-use changes can have occurred, creating temporal errors. This difference is however not an obstacle to the goal of the validation is to statistically analyse the usability of the 2016 classification map (Gonzalez Gonzalez et al., 2016) for this 2017 project. For an actual validation of the 2016 land-use map, validation points from 2016 have to be used or have to be accounted for temporal changes.

The three main land-uses that are identified in the Kathmandu valley are urban areas, agriculture and nature. The differentiation between these classes will probably show the most different impact on the water system. This distinction is visible through a classification map. A classification map already exists from Gonzalez Gonzalez et al. (2016). To determine the accuracy and errors of this map for usage in 2017, 42 validation ground truth measurements were taken. To investigate the possibility of using citizen scientists for taking land-use ground truth measurements, eight measurements were done with volunteers. The ground truth measurements were done by so-called 'convenience sampling'. This method is explained by (Bryman, 2012) as a sample that is available due to its accessibility. The measurement locations are partly based on opportunism during the fieldwork over the seven main watersheds. An equal spread over the valley and the six different classes were kept in mind, which worked out well when observing the final measurement locations (Figure 4.2a) and comparing duplicate measurement locations from the MDP 2016 (Figure 4.2b). This comparison shows that increasing ground measurements in our watersheds will have little to no overlap with the Gonzalez Gonzalez et al. (2016) ground measurements. Therefore there will be a slight bias in measurements used for classification and validation measurements.

4.1 Methods

To obtain watershed statistics and validate the 2016 classification map spatial analysis and remote sensing methods were used. Watershed delineation is performed to obtain the hydrological watershed boundaries for the Bagmati tributaries. These barriers were needed measurement localisation and identifying the land-use statistics (% of each land cover type). To understand the land-use validation process, land-use classification itself is and the validation by using a confusion matrix is explained.

4.1.1 Watershed delineation

In 2016, watershed delineations on the rivers in the Kathmandu Valley were performed. The process of watershed delineation is used to compute an area that has a single pour point. The delineation for our research in watersheds was done again with the S4W RSA[1] points as pour points to not blindly trust on the delineation performed in 2016. For the watershed delineation, the Digital Elevation Model (DEM) is used as input. This DEM has a pixel resolution of 30x30 meters. The delineation is performed within QGIS with the GRASS plugin for its usefulness when working with raster files. With an already available stream layer for the Kathmandu Valley from the 2016 MDP project, the studied watersheds were generated. Only the main Dhobi watershed (DB04) was an addition to the 2016 watershed delineation.

GRASS commands - Watershed delineation

r.watershed input = DEM output = DrainDir/Accumulation/Streams/Basin
r.water.outlet input = KTM_DrainDir output = Watershed_# coordinates = "x, y" −− overwrite
r.to.vect input = Watershed_# output = Watershed_# type = area −s −− overwrite

4.1.2 land-use Statistics

The land-use statistics are produced with GRASS with the 2016 land-use map (Gonzalez Gonzalez et al., 2016) as land-use data input and watershed vectors as boundary vectors.

GRASS commands - Statistics

r.mask vector = # −− overwrite
r.stats input = KTM_LandUse output = "C : \...GRASS \ "Location" \ "Mapset" \ Watershed_Statistics \ Stats_LU_#.txt" −a −p −n −− overwrite

4.1.3 land-use validation

The method of land-use validation firstly requires some knowledge of classification in a GIS application. Secondly, the validation and gathering of ground truth validation points are required. Lastly, a statistical representation and analysis will be needed, which is done in the form of a confusion matrix. In the paragraphs below the used methods for these three subjects are given.

land-use classification

Land cover maps provide the basis for many applications and land cover classification is extensively studied within remote sensing (Zhu & Woodcock, 2014). A land cover classification identifies land-use classes in a specific area. For a classification in GIS applications, Landsat data is used as input. Landsat is satellite data consisting of spectral image bands that is gathered by the U.S. Geological Survey (2016) and has a resolution of 30 x 30 meters. With the intensity values in a Landsat image, several classifications can be used to produce a classification map. Figure 4.1 shows the process of classifying the intensity values into signatures. A supervised classification was used by the MDP 2016 to create the land-use classification map. A supervised classification consists of the following steps:

1. Class determination
2. Gather training polygons
3. Create class signatures[2]
4. Run the classification (probability model in GIS applications) based on the signatures

[1]RSA is a 'rapid stream assessment' which indicates the ecological state of the stream. 5 is the worst and one the best ecological condition.
[2]Signatures define which values assign a pixel to a certain class (Tabak, 2015).

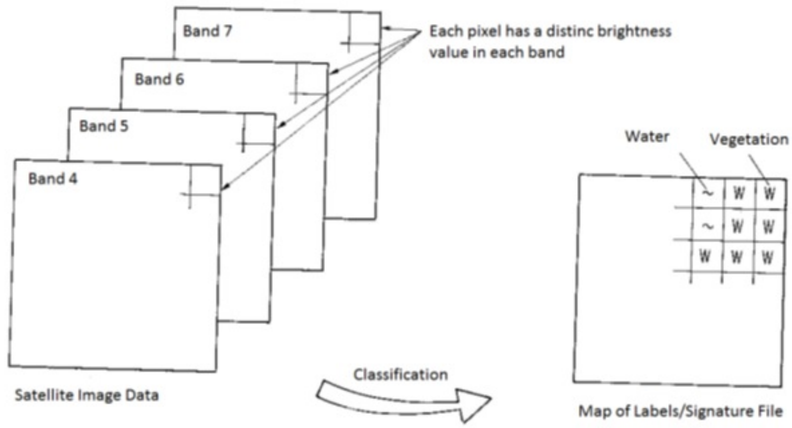


Figure 4.1: Classifying Landsat intensity values into signature files (Richards, 1999).

Confusion matrix

To validate a classification result like the classification map (Gonzalez Gonzalez et al., 2016) with ground truth measurements, a classification confusion matrix can be used (Stehman, 1997). This same method is used for validating expert ground truth measurements and citizen scientist measurements.

		Classification							
		c1	c2	c3	c4	c5	c6	A	E
Truth	c1	7	1	1	0	1	0	70%	30%
	c2	2	8	0	0	0	0	80%	20%
	c3	2	2	6	0	0	0	60%	40%
	c4	0	0	0	10	0	0	100%	0%
	c5	0	0	1	0	9	0	90%	10%
	c6	0	0	0	0	0	0	0%	0%
	ϵ	36%	27%	25%	0%	10%	0%	A_t: 80%	

Table 4.1: Confusion matrix example with classes c1-c6. A: Accuracy, ϵ: Commission error, E: Omission error, A_t: Total accuracy

The statistical quality assessment parameters are shown in Table 4.1 give an idea in how far the classification results agree with the ground truth data. The accuracy is defined as some pixels that is correctly classified. The omission error is the opposite which states the amount of wrongly classified pixels (Congalton, 1991). This accuracy is however not adjusted for Expected Chance, random classification errors. Mathematically, accuracy is denoted as follows:

$$A = 1 - E = \frac{n}{N} * 100\% \tag{4.1}$$

where n is the amount of correctly classified pixels and N is the total amount of pixels in a row class.
The commission error describes a number of pixels that are assigned to a class by the classification (Congalton, 1991). Mathematically denoted as follows:

$$\epsilon = \frac{n}{N} * 100\% \tag{4.2}$$

where n is a number of pixels where the classified class is not equal to the truth and N is the total amount of pixels in a column class.

4.2 Results

4.2.1 Watershed statistics

The watershed statistics obtained through GRASS are shown in Table 4.2. For every sub-watershed, the share of the six different land-use cover types is pictured by entire area and percentage of the total watershed area. The watershed ID's correspond with Figure 2.2. The ID's are ordered from low to high, corresponding with the upstream to downstream direction. Meaning for instance that that BK03 is the whole Balkhu watershed, while BK01 is the smallest Balkhu sub-watershed.

Land-Use in each watershed												
ID	Build (low density) [$10^3 m^2$]	Build (high density) [$10^3 m^2$]	Forest (decideous) [$10^3 m^2$]	Shrublands [$10^3 m^2$]	Rice [$10^3 m^2$]	Ag. (non-Rice) [$10^3 m^2$]	Build (low density) [%]	Build (high density) [%]	Forest (decideous) [%]	Shrublands [%]	Rice [%]	Ag. (non-Rice) [%]
NA01	0	0	8613	506	27	6	0.0	0.0	94.2	5.5	0.3	0.1
BA04	616	0	24488	8288	1853	269	1.7	0.0	69.0	23.3	5.2	0.8
BA05	3429	62	26768	12467	6797	6246	6.2	0.1	48.0	22.4	12.2	11.2
BA06	8765	2515	27821	12579	7088	8243	13.1	3.8	41.5	18.8	10.6	12.3
BK01	490	35	1280	824	1797	557	9.9	0.7	25.8	16.6	36.1	11.2
BK02	1426	197	4702	1162	3248	1424	11.7	1.6	38.7	9.6	26.7	11.7
BK03	4077	749	9288	2317	7744	3864	14.6	2.7	33.1	8.3	27.6	13.8
BM02	298	0	4166	1099	1538	125	4.1	0.0	57.7	15.2	21.3	1.7
BM04	5661	1826	10563	2942	8774	4632	16.5	5.3	30.7	8.6	25.5	13.5
BM05	18467	16032	24003	7022	23325	11882	18.3	15.9	23.8	7.0	23.2	11.8
DB01	0	0	3635	30	10	6	0.0	0.0	99.0	0.8	0.3	0.2
DB02	846	78	6586	1002	1334	750	8.0	0.7	62.2	9.5	12.6	7.1
DB04	5254	3259	7230	1733	3877	3488	21.2	13.1	29.1	7.0	15.6	14.1
GW02	8	0	1765	389	48	26	0.4	0.0	79.3	17.5	2.2	1.2
GW03	731	46	11760	2818	3475	1405	3.6	0.2	58.2	13.9	17.2	7.0
GW05	3515	259	16309	4733	12952	8469	7.6	0.6	35.3	10.2	28.0	18.3
HM01	152	0	3438	2229	784	101	2.3	0.0	51.4	33.3	11.7	1.5
HM02	672	2	3957	2926	4981	1403	4.8	0.0	28.4	21.0	35.8	10.1
HM03	5477	1099	9296	6981	22136	9032	10.1	2.0	17.2	12.9	41.0	16.7
HM04	12381	2869	12184	9000	37838	20486	13.1	3.0	12.9	9.5	39.9	21.6
NK02	306	0	3613	1192	1378	250	4.5	0.0	53.7	17.7	20.5	3.7
NK03	1914	2	11582	5662	6354	1496	7.1	0.0	42.9	21.0	23.5	5.5
NK04	5454	1811	16774	9544	15378	5867	10.0	3.3	30.6	17.4	28.1	10.7

Table 4.2: Land-use statistics for the researched watersheds. NA & BA = Bagmati watershed, BK = Balkhu watershed, BM = Bishnumati watershed, DB = Dhobi watershed, GW = Godawari watershed, HM = Hanumante watershed, NK = Nakkhu watershed.

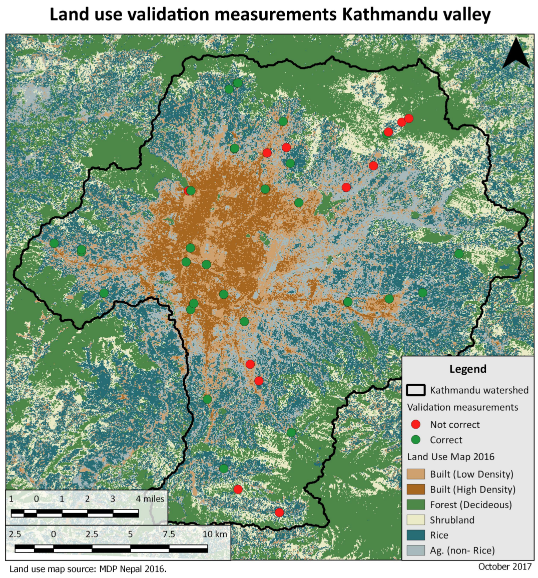
A more detailed look is shown in section 14.2 with the visualisation of longitudinal land-use development in the seven main watersheds.

4.2.2 land-use validation

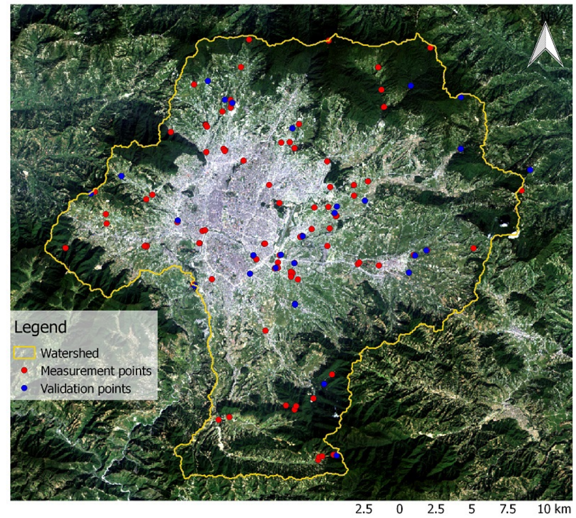
A geographical overview of the validation measurement locations and their correctness after validation is shown in Figure 4.2a. Table 4.3 shows a confusion matrix with the statistical parameters describing the accuracy and errors of the land-use classification map ((Gonzalez Gonzalez et al., 2016)) by validation points taken in 2017. The total accuracy of the classification map is 57%, which is lower than the 88% stated by the MDP 2016. The highest accuracy was found in the build classes and the lowest in the shrubland (0%), forest (33%) and agriculture (non-rice) (50%). These classes also have the lowest amount of validation points. The highest commission errors occur in shrubland (100%) and agriculture (non-rice) (71%). Figure 4.2a shows that there are a lot of miss-classifications in the Nag-/Bagmati basin, especially when classifying the agricultural and natural cover types. From photos, it can be seen that especially in Shivapuri park close to the river, shrubland and forest get classified as rice and agriculture (non-rice).

		Classification							
		BL	BH	Fo	Sh	Ri	Ag	A	E
Truth	BL	14	0	0	0	1	0	93%	7%
	BH	0	7	0	0	0	0	100%	0%
	Fo	1	0	1	0	1	0	33%	67%
	Sh	1	0	0	0	1	2	0%	100%
	Ri	0	0	0	0	6	3	67%	33%
	Ag	0	1	0	1	0	2	50%	50%
	ϵ	13%	13%	0%	100%	33%	71%	A_t: 57%	

Table 4.3: Confusion matrix of 42 land-use validation points. Ag = Agriculture (Non-Rice), Ri = Rice, Sh = Shrubland, Fo = Forest (Decideous), BH = Built (High Density), BL = Built (Low Density). A: Accuracy, ϵ: Commission error, E: Omission error, A_t: Total accuracy



(a) 2017 land-use validation measurements



(b) 2016 land-use classification and validation measurements (Gonzalez Gonzalez et al., 2016)

Figure 4.2: Comparison of land-use measurement locations MDP 2016 - MDP 2017

4.3 Discussion

There is a big difference in classification accuracy between 2016 and 2017 can have different causes. When visually inspecting the entire map, it seems quite accurate. The method of validation used however looks at individual pixels with a limited scope of the surrounding area. Secondly are the accuracy's of 2016 and 2017 both not adjusted for an expected chance (random classification) which can make our accuracy an underestimation and the accuracy from 2016 an overestimation. Lastly, this year's validation contains more temporal errors due to a higher possibility of land-use change than the 2016 validation. The inclusion of this error type will always decrease the accuracy of validation, certainly within an area as Kathmandu Valley where development is going rapidly. This causality is in line with what Congalton (1991) already stated that inaccuracies in reference data (ground truth) would automatically, be inaccurately blamed on the classification accuracy. All these are reasons to state the accuracy of the land-use map 2016 for use in 2017 will be between 57% and 88%. There can be discussed about the method of classification as this year's validation was done by pixel validation with a surrounding pixel check to identify a broader classification pattern. The 2016 validation, however, used a bigger validation area, taking more surrounding pixels into account when judging a classification pixel.

Geographically a clear error hotspot can be seen in Shivapuri national park. Here rice is classified in the bottom of the Nagmati valley while there is no noteworthy agricultural land. This occurrence means that shrublands and forest are classified wrongly as agriculture. These classification points have a notable negative impact on the overall accuracy, however. A more widespread problem that is noticed is that barren areas and dirt road areas are often classified as low-density buildings. However, this classification is understandable as the signatures, due to their closeness in brightness values, are similar. Gonzalez Gonzalez et al. (2016) removed the barren type signature classes and merged them with the six existing levels as they are difficult to distinguish.

4.4 Conclusion

Total land-use validation accuracy between 2016's classification and it's used in the 2017's project is at 57% while an accuracy of 88% was found in 2016. Geographically the most errors were found in Shivapuri National park as pixels depicting Nature (both Deciduous forest and shrubland) were falsely classified as Agriculture. Agriculture had the highest commission error with most pixels wrongly assigned to another class, while forest and shrubland were found to have the biggest classification error.

5 | Water Quality Parameters

The quality of the water can be measured by several parameters. These parameters are used to determine the quality of the water of the Kathmandu Valley of three primary water sources which are spouts, wells and rivers. The parameters are nitrate, nitrite, phosphate, hardness, EC (indirectly TDS), DO, pH, Temperature, Iron and E. coli.

5.1 Methods and Materials

The measurement of water quality parameters is needed to understand the state of water sources and how they probably relate to for example land-use and geology. Within the fieldwork period a total of 57 measurements over the three different water sources were done for pH, DO, nitrate & nitrite, phosphate, hardness, iron, E. coli, EC, turbidity and temperature. The next paragraphs will explain the used methods and materials for measuring these parameters.

5.1.1 Strips

Within the Kathmandu Valley, there are three main land-uses: natural, agricultural and urban. To identify the pollution caused by agricultural practices, the concentrations of nitrate, nitrite and phosphate are measured. Due to the use of fertilisers, there is a surplus in nitrogen forms like nitrate and nitrite and phosphate. Furthermore, the hardness (CaCO3) of the water will be measured. Hardness in itself is harmless, but it can have adverse effects when you heat the water or use soap. All the parameters are estimated with water quality test strips. The strips have a reagent which, if held into the water, will react and show a colour that corresponds to the water quality. Information on the specific strips can be found in Table 5.1. In this table, one can read the time the strip has to behold in the water and the time before readout of the results.

Parameter	Colour	Range (ppm)	Steps (ppm)	Time in water (sec)	Time of read out (sec)
Nitrate	Yellowish white to pink	0-50	0-1-2-5-10-20-50	1	60
Nitrite	Yellowish white to pink	0-30	0-0.15-0.3-1.0-1.5-3.0	1	30
Phosphate	Greyish pink to Greyish green	0-50	0-5-15-30-50	5	45
Total Hardness (CaCO3)	Green to Brown	0-425	0-25-50-120-250-425	1	15

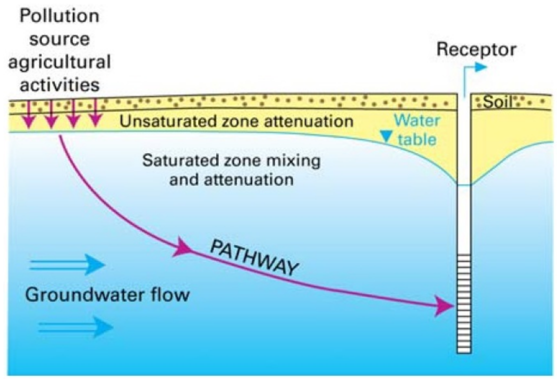
Table 5.1: Water Quality Test strips

Nitrate and Nitrite

In this report, the values of nitrate (NO3-), stable, and nitrite (NO2-), unstable form of oxidation of nitrogen are measured. They are both parts of the nitrogen cycle, and the nitrogen (N) is an essential nutrient for plants (Speijers & Fawell, 2011). Certain land-uses like agricultural fields, industries or domestic effluent increase the available nitrogen, making nitrate and nitrite a good indicator for the type of land-use. An increase in N availability negatively affects the biological diversity and changes the cycle. Within the cycle, the fertilisers and wastes containing nitrogen are first decomposed into ammonia which will then oxidise to nitrite and nitrate. The nitrate will be used by plants. However, the surplus of nitrate will leach through the soil depleting soil minerals and lead to losses of nutrient cations. Also, it will give rise to an increase in acidity of the soil and water bodies. (Vitousek et al., 1997; Speijers & Fawell, 2011).

Shallow groundwater has aerobic conditions allowing large amounts of nitrate to seep into the aquifer with almost no plant material to decrease it. Also, nitrate is highly soluble and mobile. (BGS, 2009) Natural nitrate values are a few milligrams of nitrate per litre. (WHO, 2016) How vulnerable the groundwater is to pollution to nitrate depends on the hydro-geological conditions. The source, pathway receptor model Figure 5.1 shows that shallow aquifers under a thin permeable, aerobic soil are very vulnerable to groundwater pollution. The risk of nitrate pollution depends on the vulnerability of the location and the pollutant load on the land (BGS, 2009). In the deep groundwater, the nitrate concentration will probably be lower due to anaerobic conditions allowing nitrate to be denitrified or degraded. In surface water, the amount of nitrate is dependent on temperature, pH and mostly on the uptake of nitrate by plants (Speijers & Fawell, 2011).

Figure 5.1: Source, pathway receptor model (BGS, 2009)



Furthermore, if nitrogen is found in drinking water, an over-consumption can cause lasting adverse impacts to humans. Studies indicate a concentration of 11% exceeding the WHO guideline in the groundwater at many locations in Kathmandu (Warner et al., 2007). A quantitative microbial risk assessment will give us a good overview of the health risks in chapter 9.

Phosphate

Like nitrate, phosphate loading occurs due to fertilisers used in agricultural practices. The difference, however, is that phosphate concentrations in fertilisers are much lower than those of nitrate and will thus be loaded on the land in lower quantities. Besides, high phosphate concentrations are rarely found in groundwater since they rarely leach down below the soil. This occurrence is because phosphate is often adsorbed by clay in the soil. Phosphate can, however, be a good indicator in steams for the agricultural land-use. The values will be especially high after a rain event when runoff is generated (BGS, 2009).

Phosphate comes naturally from weathered phosphorus from rocks and other mineral deposits. Phosphorus is needed for the growth of plants, and the low level of it limits the production of freshwater systems (Oram, n.d.). Phosphate has a very low toxicity and is only toxic if the concentrations are extremely high. An in-depth overview of the health hazards will be given in chapter 9.

Total hardness (CaCO3)

Total hardness is a unit of measurement that expresses the capacity of water to react with soap. Hard water requires more soap than soft. Total hardness does not exist out of one element, but a summation of elements. The most well-known elements are calcium and magnesium, but also other polyvalent metallic ions, like aluminium, barium, iron, manganese, strontium and zinc. Hardness is mostly expressed in the form of calcium-carbonate (WHO, 2011). When water moves through or over a limestone or chalk area, the amount of calcium and magnesium ions increases and so does the hardness of the water. The water hardness can be divided in temporary (carbonate) and permanent (non-carbonate) hardness. The temporary hardness increases the consumption of soap and scale deposition in water distribution system. Besides, carbonate will precipitate when the water is boiled which can damage your devices. (Utilities, n.d.) The optimal hardness for drinking water is from 80 - 100 mg/l. If the hardness is higher than 200 mg/l, the water has a poor quality, and if it is even higher than 500 mg/l, it is unusable for domestic purposes (*Hardness in Groundwater*, 2007). Within those boundaries, the carbonate is in equilibrium (Figure 14.16). The standard categories in which hardness is divided can be found in Table 5.2.

Hardness Category	Equivalent Concentration of CaCO3
Soft	< 60 mg/l
Medium hard	60 - 120 mg/l
Hard	120 - 180 mg/l
Very hard	> 180 mg/l

Table 5.2: Hardness standards (USGS, n.d.; *Hardness in Groundwater*, 2007)

Sample at 25 °C	EC (μS/cm)
Distilled water	0.5-3
Precipitation	5-50
Fresh water streams (general	100-2000
Streams running through silicate rock (granite)	10-50
Streams running through limestone formations	500-700

Table 5.3: Standard EC values for T=25 °C (*CIE4495-13: Module 1 Water Quality*, 2016)

The hardness of water can increase due to natural occurrences like weathering of limestone, sedimentary rock and calcium-rich minerals or due to human activities like chemical and mining industry effluent or the application of lime to the soil in agricultural areas.

5.1.2 Lab analysis

For the parameters of iron and E. coli, water samples are taken and brought to an external laboratory.

Iron

Iron is a natural element that can be found in the earth's crust. It is found in combination with mostly oxygen and or with sulphur. Iron concentrations are unnoticeable if they are below 0.3 mg/l. If it is higher, it will start staining the laundry but is however still acceptable as long as it stays under a maximum level of 3 mg/l. If aeration of iron-containing layer occurs due to lowering of the groundwater table or nitrate leaching takes place, the Iron concentration will affect the groundwater and surface water quality if dissolution takes place. This effect is, however, a result of oxidation and decrease in pH (WHO, 2003).

E. coli

E. coli or in other words Escherichia coli is part of a group bacteria that is called faecal coliform. These bacteria exist in the intestines of warm-blooded animals and humans. If E. coli is found in the water, this is an indicator of contamination of the water by human sewage or animal droppings. Since E. coli co-exists together with other bacteria, viruses or disease-causing organisms, there often will be more than just E. coli contamination. Small amounts can already pose a health risk, and thus the samples should have no E. coli in them (*Total, Fecal & E. coli Bacteria in Groundwater*, 2007). If E. coli is found in the groundwater there are three likely sources:

1. Agricultural runoff
2. Effluent from septic systems or sewage discharge
3. Infiltration of domestic or wild animal faecal matter

5.1.3 Electrical Conductivity (EC)

The electrical conductivity (EC) is a parameter which expresses the ability of water to conduct an electrical current (*CIE4495-13: Module 1 Water Quality*, 2016) . It relates directly to the concentration of ions in the water, indicating the presence of Total Dissolved Solids (TDS). Important to notice is that EC varies with temperature. Standard EC values for a temperature of 25 °C are given in Table 5.3. An adjustment is made to convert an EC measured during a different temperature with the following formula:

$$EC_{25} = EC_x/(1 + \beta * (T - 25)) \tag{5.1}$$

EC_{25} = Electrical Conductivity (μS/cm) at T = 25 °C
EC_x = Electrical Conductivity (μS/cm) at T = measured in Celcius
β = Correction factor (1.90%/°C
T = Temperature measured in Celcius

To measure the electrical conductivity an EC meter is used. Before usage, the meter has to be calibrated. For this, a fluid is used as the calibration standard for conductivity cells of 0.01 mol/l KCl. After the calibration, the EC meter is put in the water of which the EC has to be known. While using the EC meter, make sure to keep it stable and make sure the sensor is completely submerged.

Total dissolved solids (TDS)

Since the TDS and EC have a direct relationship, the EC value can be used to estimate the Total Dissolved Solids. The TDS is an indicator of pollution. In fresh water, where there is no pollution, the TDS should be equal to the salinity of the water. If the TDS is higher in the water, it is polluted. According to the US EPA standards, if a TDS > 500 is given, the water is contaminated as shown in Figure 5.3.

$$TDS = EC * K \tag{5.2}$$

TDS = Total Dissolved Solids [mg/L]
EC = Electrical Conductivity [(μS/cm)]
K = Correction factor ranging from (0.50-0.80)

Equation 5.2 gives the on-site rule of thumb rule to calculate the TDS with the EC. For this formula we need a correction factor, K, that is ranging from 0.50 to 0.80. The value of the correction factor depends on the ionic disposition. For the K-factor often a standard value of 0.7 is used. If however the fresh water has a high concentration of chloride and sulphate the value will be lower, and if the bicarbonate concentration is high, the factor should be higher as shown in Figure 5.2.

Figure 5.2: Correction factor K (Walton, 1989)

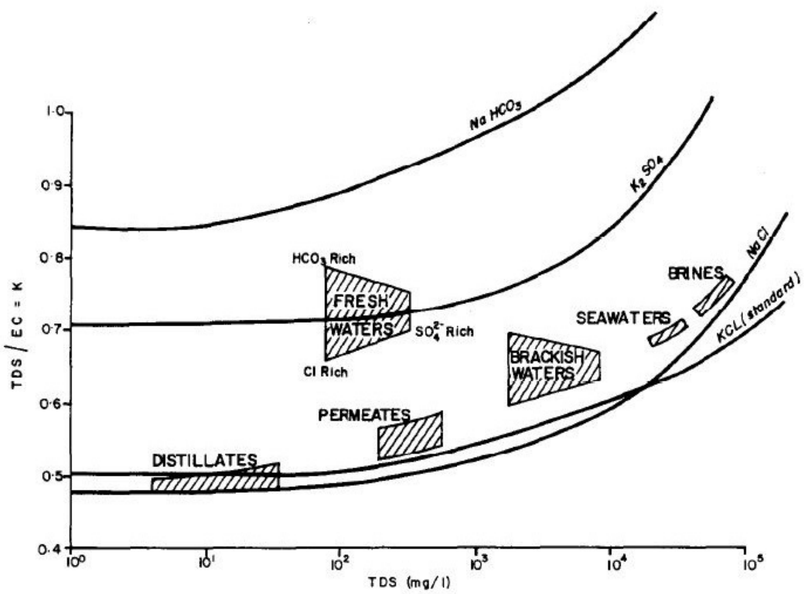
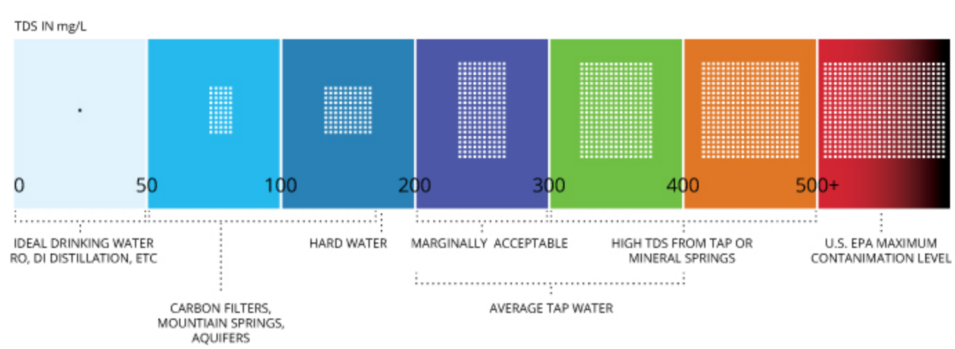


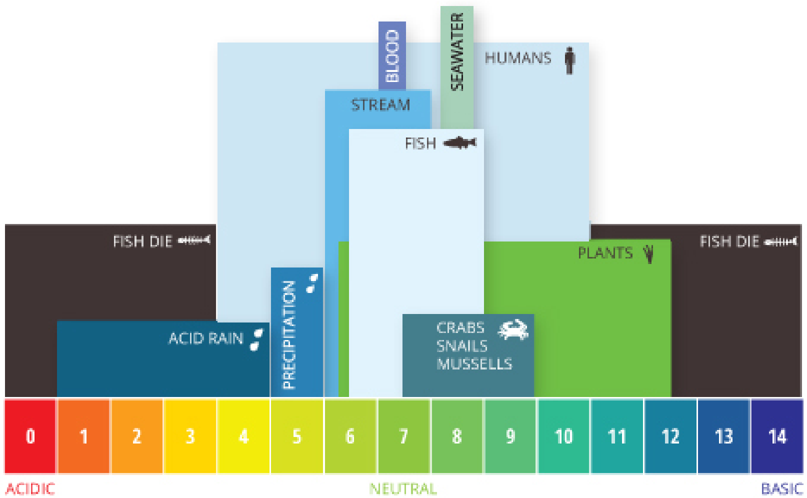
Figure 5.3: TDS Standards (Fondriest, n.d.)



5.1.4 Potential of hydrogen (pH)

pH indicates how acidic or alkaline a solution is. It influences organisms that consume or live in water and also affects the solubility of (toxic) compounds. The pH is an essential factor in understanding the reaction in targeted water. Depending on the normal pH of a watershed, a rainfall event could increase or decrease the pH. Other elements such like the DO or Nitrate concentrate would have a great influence on the pH of a watershed. The pH can increase by carbonate-rich soils like limestone or decrease by sewage outflow and aerobic respiration (Fondriest, n.d.). An overview of pH standards is given in Figure 5.4. The pH is measured with a pH meter which like the EC meter needs to be calibrated. For the calibration, two buffer solutions are used of 7.00 pH and 4.01 pH respectively.

Figure 5.4: pH Standards (Fondriest, n.d.)

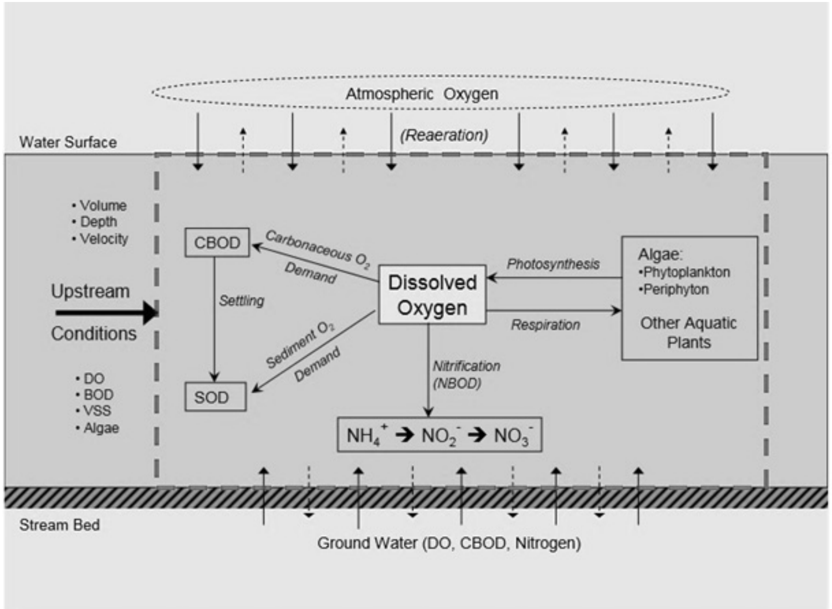


5.1.5 Dissolved Oxygen (DO)

DO is an indicator of the amount of free, non-compound oxygen in the water which is important for aquatic life. Depending on the life form, a certain amount of DO is needed to survive. For bottom feeders, crabs, oysters and worms this is about 1.6 mg/L and for shallow water fish about 4-15 mg/L. (Fondriest, n.d.) A deficiency in oxygen can lead to a decrease in aquatic life. Besides, DO is required to decompose organic materials which are important for the nutrient recycling. This demand for oxygen is called the chemical oxygen demand (COD). Also, you also have biochemical processes (BOD) which is the amount of DO consumed by bacteria to oxidise compounds. (*CIE4495-13: Module 1 Water Quality*, 2016) The total stream balance of DO can be found in Figure 5.5. Also, it must be taken into account that cool water can hold more oxygen than warm water. If the DO concentration is unsaturated, there is re-aeration or in other words a net transfer of atmospheric oxygen.

Dissolved Oxygen is also a good indicator in groundwater. Deep groundwater is often anaerobic and thus has low DO values. The values are often low since the soil organic matter (SOM) or minerals like (FeS_2) consume the DO. In shallow aerobic groundwater, the DO values should be higher than in deep groundwater, but still lower than in surface water. There are several processes taking place like iron $Fe(III)$ reduction and SO_4^- reduction due to forming of FeS_2, methanogenesis (dissolved CH4 gas) and decomposition of SOM (NH4 and PO4). (*CIE4495-13: Module 1 Water Quality*, 2016). DO concentrations are also important to constrain the bacterial metabolism of dissolved organic species.(Rose & Long, 1988).

Figure 5.5: DO stream balance (Fondriest, n.d.)



5.1.6 Temperature

Temperature has both a direct as an indirect influence on the water quality. Directly, the temperature affects aquatic organisms in their metabolic rates and biological activity. Also, the increase in temperature leads to an increase in solubility of heavy metals, which increases the toxicity of the water. A combination of higher toxicity and increased metabolic rates, more toxins get inside the aquatic organisms, raising the mortality rates. Indirectly it influences other parameters like EC, TDS, pH, DO and other parameters that are not taken into account in this report. (Fondriest, n.d.)

Figure 5.6: Temperature interactions (Fondriest, n.d.)

5.1.7 Turbidity

With turbidity, you measure the cloudiness of water. The water cloudiness can be very low due to suspended sediment, coloured organic compounds, and phytoplankton. The turbidity is measured based on the amount of light that is scattered by Total Suspended Solids in the water. The higher the number of particles, the higher the scattering and thus the higher the NTU value (Fondriest, n.d.). Turbidity is an important water quality indicator since the particles often have viruses, bacteria, and metals attached to them (*CIE4495-13: Module 1 Water Quality*, 2016). Also, the turbidity can reduce photosynthesis by blocking the sunlight, which can decrease the chance of survival of plants and a decrease in dissolved oxygen levels. If the plants die, the other aquatic organisms will have less food, and a reduction of aquatic life can be seen.

Turbidity is also a good indicator for conditions of the surrounding areas. If the water is very turbid, this can indicate high erosion rates, contamination, etc. Take into account that water flow and weather can influence the turbidity of the water. In the Kathmandu Valley, there is a lot of untreated sewer contamination, and the turbidity is expected to be quite high in the urban area of the valley. (Fondriest, n.d.) Turbidity is, however, an expensive parameter to measure and it often provides results which are more precise than necessary. One of the ways to measure turbidity on site is by using a Secchi disk. The Secchi disk is often used for lakes with stagnant water. For streams, wells, and spouts it is hard to use a regular Secchi disk, and a turbidity tube is used. This tube has at the bottom a Secchi disk. By filling the tube to the point you can no longer see the Secchi disk, you can measure the turbidity of the water. An average human can see a turbidity of about 5 NTU, and this is then also the minimum value of our turbidity tube that you can measure. The conversion chart of the water height (cm) in the tube and the NTU can be found in section 14.1. An overview of the turbidity of the regular water is shown in Table 5.4.

Water type	Turbidity (NTU)
Drinking water	<1 - < 5
Recreation	< 5 (cloudy)
Groundwater	<5
Streams	1- >1000
Sewage raw	80 - 200
Sewage treated	< 25

Table 5.4: Turbidity Standards (*CIE4495-13: Module 1 Water Quality*, 2016)

5.1.8 Fieldwork parameter interpolation

Interpolation of the parameter values of the water wells and stone spout is done due to their semi-consistent[1] locations. This means that all quality parameters will be interpolated for every single main watershed (see Figure 5.7 for the seven main watersheds), which consist most of the time of three sub-watersheds. The interpolation creates a raster file with interpolated values of the respective parameter. The combined (patched) interpolation maps (see Figure 5.7) for all parameters from spouts and wells are point sampled by pour-point location. This results in the spout, well and river parameter values that are all located at the pour point of every sub-watershed. This re-projection of the well and spout measurements makes a comparison between the quality and land-use parameters for the three different sources (wells, spouts and rivers) possible.

[1] The well and stone spout locations were chosen so that they can be assigned to a sub-watershed and a single pour-point. They can, however, be illogically located in the watershed in respect to the stream when visually inspected.

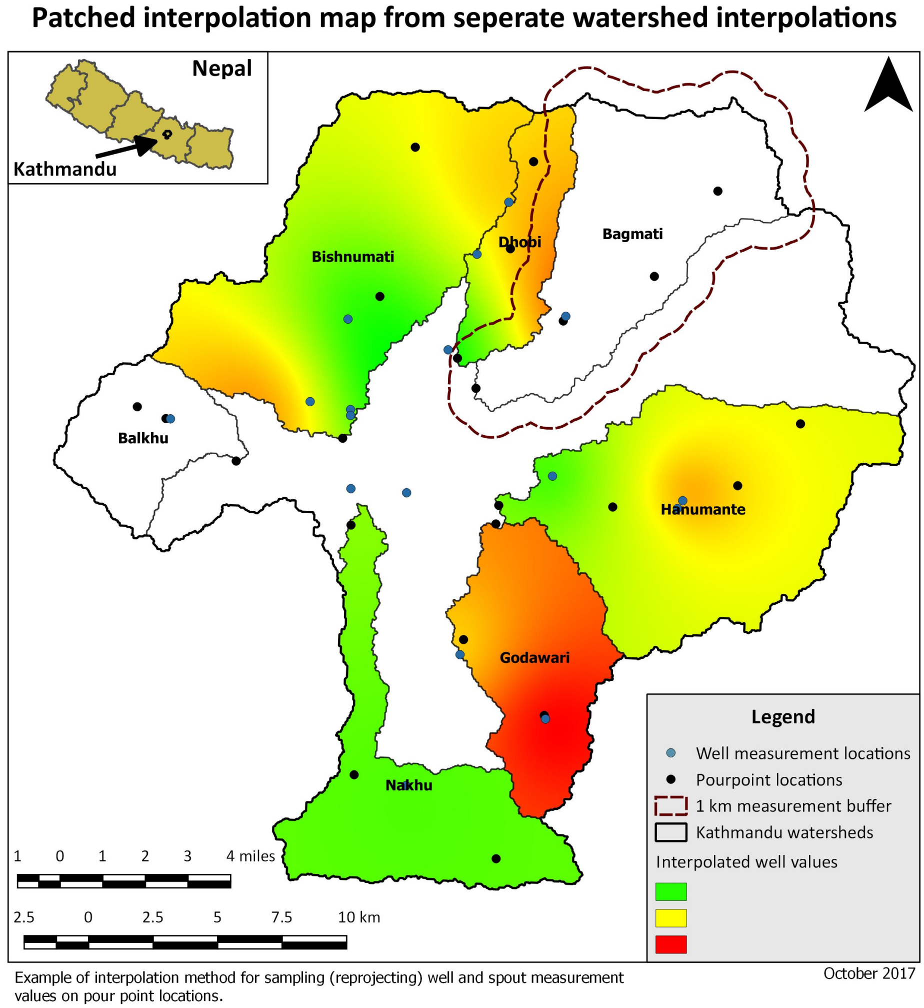


Figure 5.7: Visualization of methodical QGIS & GRASS steps for data interpolation.

The regularised spline with tension raster interpolation method was chosen from the QGIS and GRASS interpolation tools. It has the disadvantage, like every other interpolation method, that values located outside the area of the input data are extrapolated and thus not reliable. Interpolated values near boundaries of a watershed are therefore not useful. The method is, however, useful for the research purpose as the pour-point locations are more or less in the middle of the watersheds, staying away from the dubious boundaries. The spline method gives the most natural result in comparison to the inverse distance weighting (IDW) or neighbour interpolation (with averaging boundary cells) due to isoline creation. The IDW is mainly influenced by distance and has a dominant circular interpolation, which is counterproductive when interpolating watershed areas that have a dominating longitudinal upstream-downstream water flow interaction. The spline method can be seen as a rubber sheet that is stretched over the data points creating a surface that can have lower and higher values than the maximum or minimum measured values. An illustration is shown in Figure 5.8 Splines calculate surfaces by producing weighted averages of nearby locations while passing through known locations (Udmale et al., 2002). Splines are also known to work better with smaller data sets than IDW.

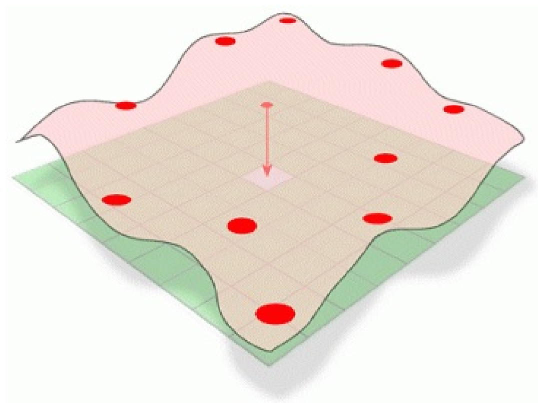


Figure 5.8: Illustration of the spline method as a stretched sheet over the data points (resources, 2015).

A limited amount of data points was available. In all interpolation methods, this means that data points in one watershed are always influenced by those of another catchment, even when the separating distance is considered significant. Because these interactions over vast distances seem wrong and the assumption is made that topography has a considerable influence on sub-surface water flow, every main watershed is interpolated separately from the others. To not wholly ignore cross-boundary water flow a buffer of 1 km is taken to include data points outside the watershed, that can have a possible influence on values within the watershed. In Figure 5.7 two watersheds, Balkhu and Bagmati, only one spout was measured., which makes interpolation not possible and these data points and watersheds are therefore not taken into account in spout analysis. Figure 5.9 shows the sequential steps that were taken in GRASS to create the parameter rasters for the well and spout data.

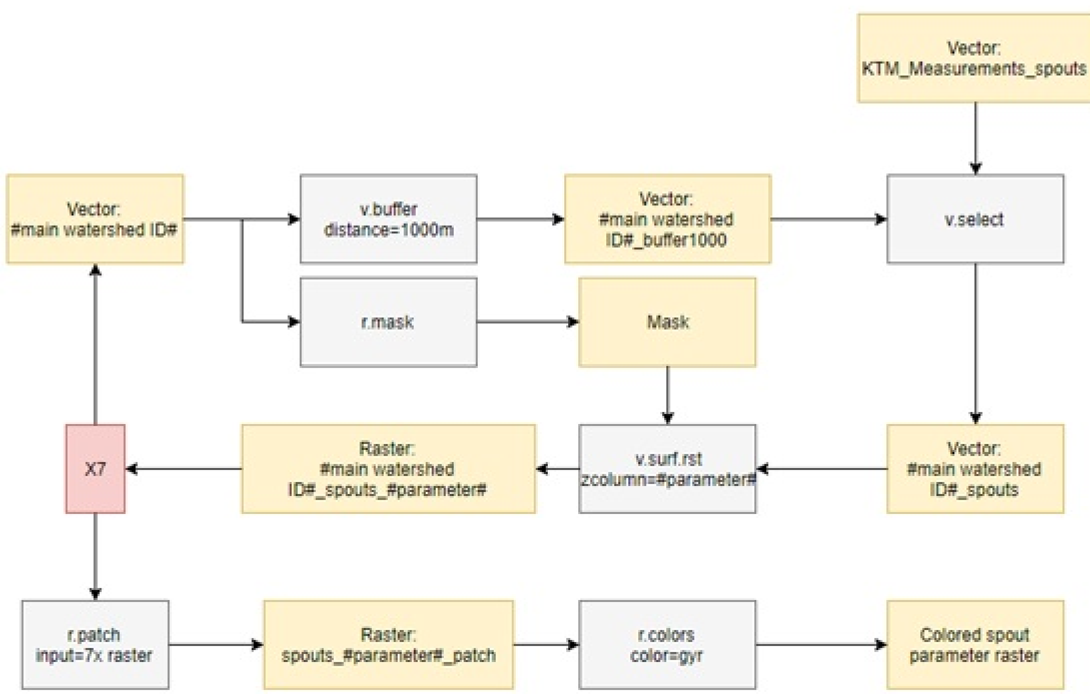


Figure 5.9: Grass steps for interpolation, per main watershed, with parameter rasters as result. All steps are run in 1 command script (see subsection 14.4.1) which is run for both spouts and wells.

5.1.9 Fieldwork parameter assignment

The values of the parameter rasters are assigned to their respective pour point with point sampling. The average value of the four closest raster cell values is assigned to the pour point. This way all watershed parameters are projected on one graphical location for every sub-watershed. The Grass command below is used for sampling raster values. It can be run directly with the parameter interpolation script from subsection 14.4.1.

GRASS commands - Raster value sampling
$v.what.rast\ -i\ map = Pourpoint\_"source"\_param\_output\ raster = "source"\_"parameter"\_patch\ column = "parameter"$

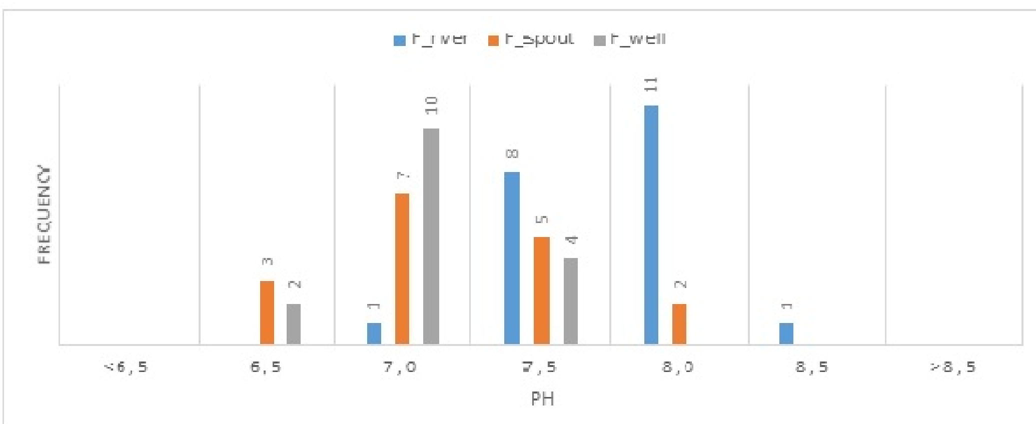
5.2 Results

In the results, we look at which values are found in which water sources and what those values mean for each of the parameters measured. This result will give an indication of which problems are found and also wherein the valley the issues arise.

5.2.1 Potential of hydrogen (pH)

The pH values within the rivers are slightly higher than in the stone spouts and wells. This is because the groundwater pH is lower than that of the rivers. Since all the values are between 6,5 and 8,5 as shown in Figure 5.10, the values are not endangering aquatic or human life as explained in subsection 5.1.5. There is, however, a distinctive geographical correlation between pH and land-use. For the streams, the pH is lowest in the area of the Kathmandu city centre as shown in Figure 14.13b, this is also where there is a high amount of sewage outflow. Sewage outflow can lower the pH. For the pH in wells, a clear correlation is seen with the geology of the Valley. In the Balkhu, Bishnumati, Godawari and Nakkhu watersheds limestone can be found as explained in chapter 7. Limestone increases the pH values and as shown on the map in Figure 14.14b the highest values can be found in limestone-rich areas. The spouts, however, show a complete different pH map as shown in Figure 14.14c and are probably not influenced by the formation or the land-use since they do not correlate. There is only a small correlation found with the land-use named Forest as shown in Table 6.4. It is, however, unclear why this is the case.

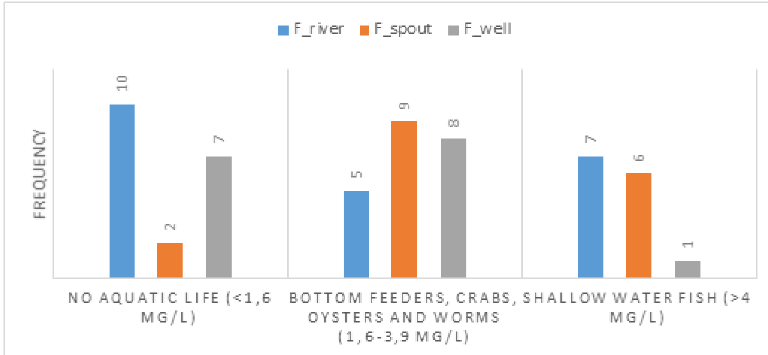
Figure 5.10: pH - Histogram



5.2.2 Dissolved oxygen (DO)

As shown in Figure 5.11, one-third of the samples taken is unable to hold aquatic life due to deficiency of dissolved oxygen. For the rivers, this is even a higher percentage. In addition, only one third can hold shallow water fish which can only survive if the dissolved oxygen levels are higher than 4 mg/l. The dissolved oxygen levels are most important for the river systems, and a little less than half of the river system are unable to hold aquatic life.

Figure 5.11: DO - Histogram



For most rivers, there is a clear trend in which the DO decrease the further downstream you get. One of the most extreme examples is that of the Hanumante as shown in Figure 5.12. Moreover, the decrease is very steep while the urban land-use increases rapidly. This suggests a strong relationship between urban land-use and reduction in DO. The only watershed that shows a different story is the Godawari. The Godawari already start with a very low DO (Figure 5.13) while there is almost no urban development in the watershed.

Figure 5.12: Hanumante DO comparison with land-use

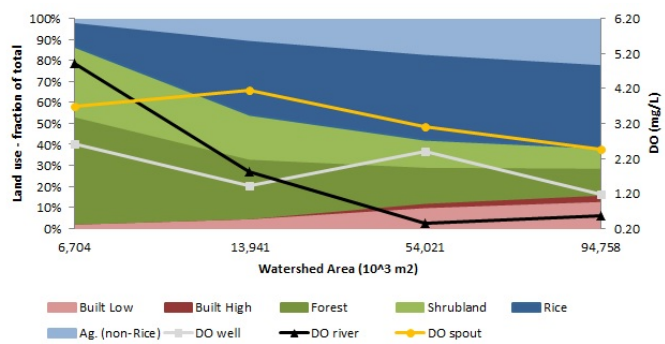
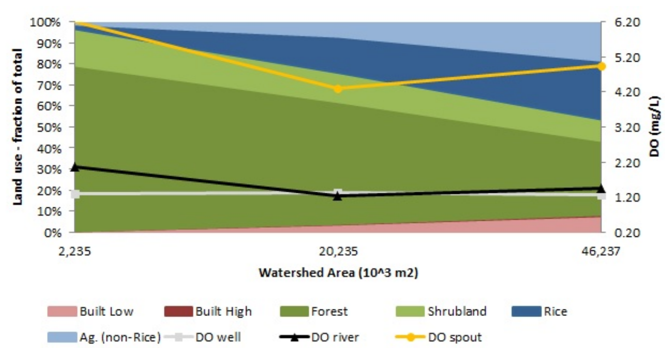


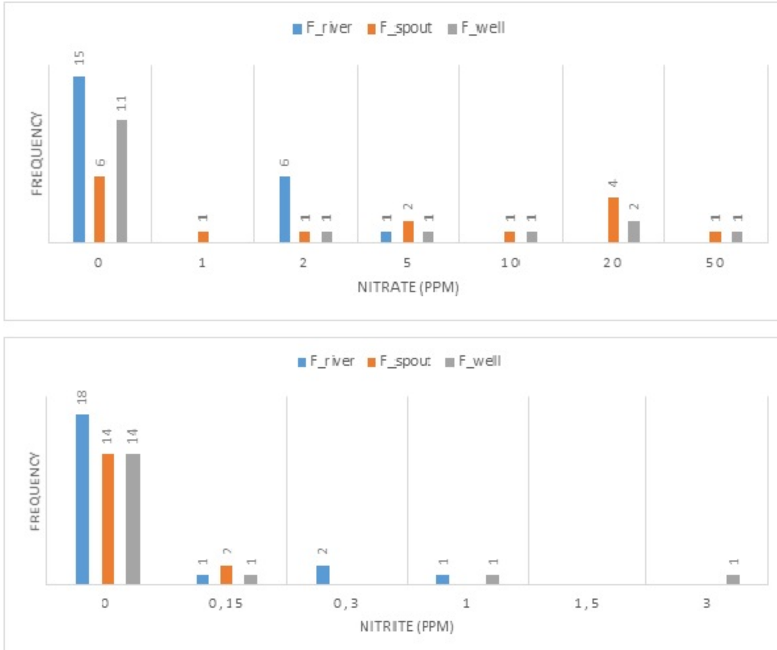
Figure 5.13: Godawari DO comparison with land-use



5.2.3 Nitrate and Nitrite

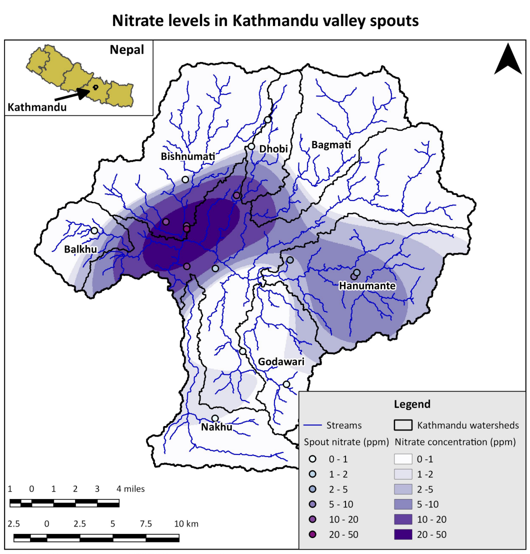
Both for nitrate as for nitrite, the values are most of the time zero.Figure 5.14 Especially for nitrite, the values are so low that, you cannot tell anything conclusive except that there is almost no nitrite in the valley according to the data gathered. In addition, the nitrite levels are very low, especially in the rivers. The rivers are loaded with direct sewer inflow.

Figure 5.14: Nitrogen - Histogram

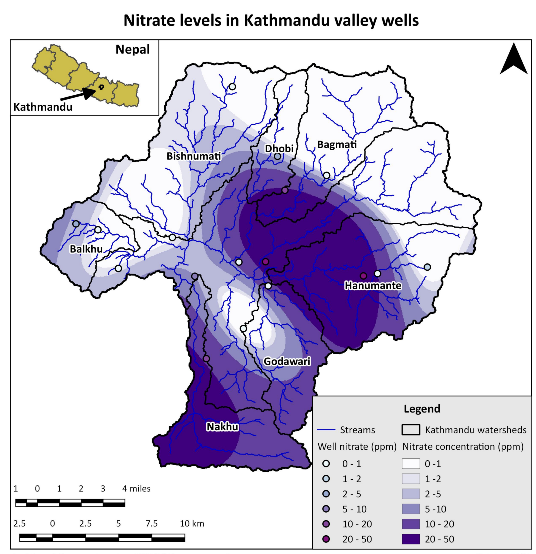


Geographical distribution

The nitrate levels in the rivers are very low and geographically of no interest. The spouts and wells, however, show some higher values. There is, however, no correlation between the location of the high nitrate levels of both sources. (Figure 5.15).



(a) Spouts



(b) Wells

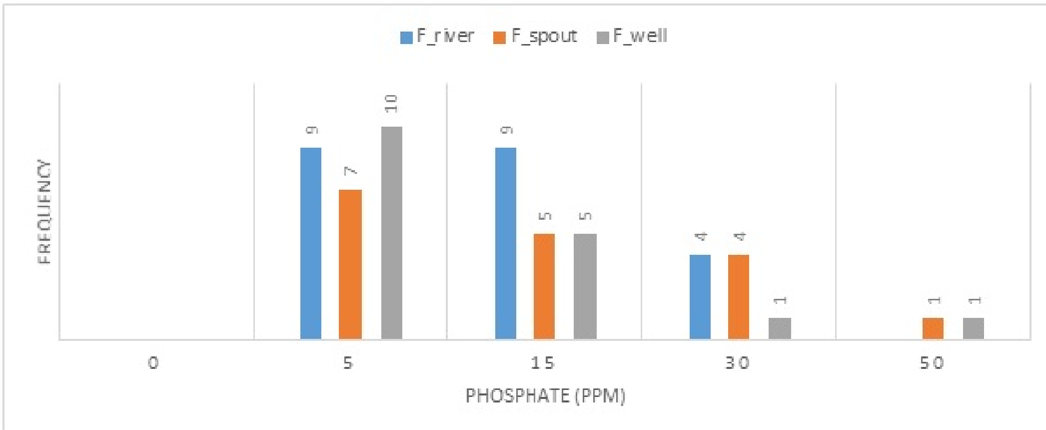
Figure 5.15: Nitrate levels in spouts and wells.

The correlation as will be explained in section 14.5 shows that there is only a bit of correlation between the nitrate levels found at the spout and the urban land-use. Both wells and spouts, however, show an increased nitrate concentration in the area of Bhaktapur where there is a lot of agriculture. Also, high level of nitrate has been measured in the Nakkhu basin. Here there is some agriculture, however, natural vegetation dominates.

5.2.4 Phosphate

Phosphate is only toxic in extremely high concentrations as explained in Figure 5.1.1. As shown in Figure 5.16, there are only a few samples with high phosphate levels, and even those are not dangerously high for humans. Geographically, it doesn't have a clear correlation with land-use either as shown in (Figure 14.21). Phosphate layers co-occur with the urban land-use in the centre of the valley. Therefore it is hard to tell if the high phosphate levels are the result of geology or that they occur because of human activities.

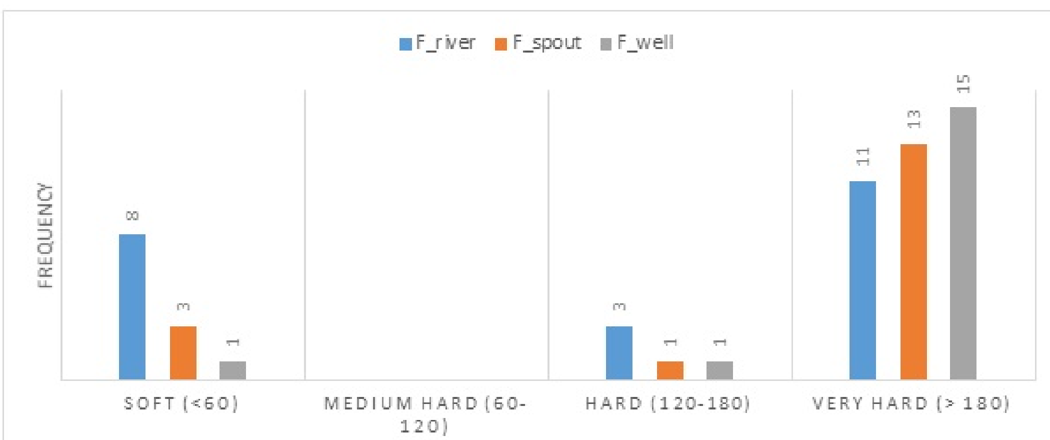
Figure 5.16: Phosphate - Histogram



5.2.5 Hardness

As shown in Figure 5.17, most hardness values fall in the highest hardness class measurable by strips. Hardness is strongly influenced by geology as explained in the geology chapter. More information

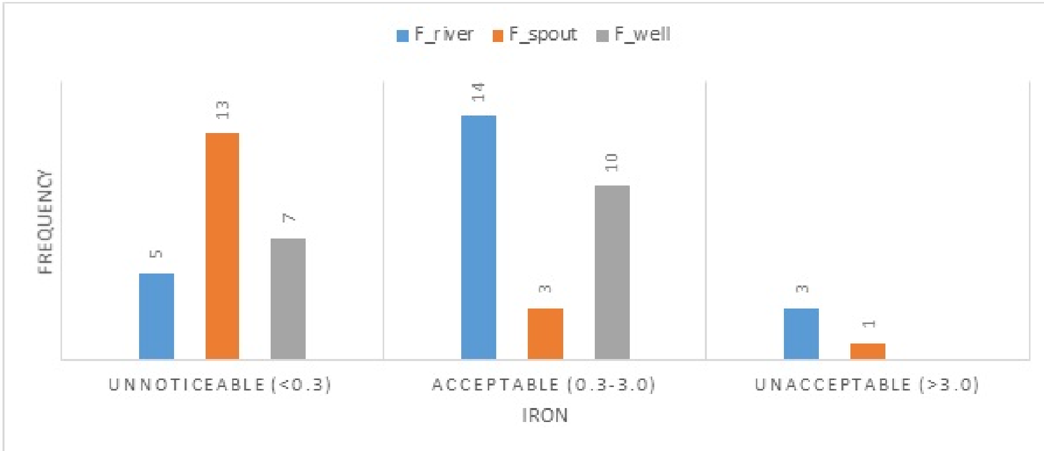
Figure 5.17: hardness - Histogram



5.2.6 Iron

According to WHO (2003), the level of iron is acceptable or unacceptable as shown in Figure 5.18. Only four of the iron samples contain unacceptable levels of iron. The rest is acceptable or barely noticeable. About half of the samples are acceptable but will give strains to laundry if the water is used and is thus not optimal.

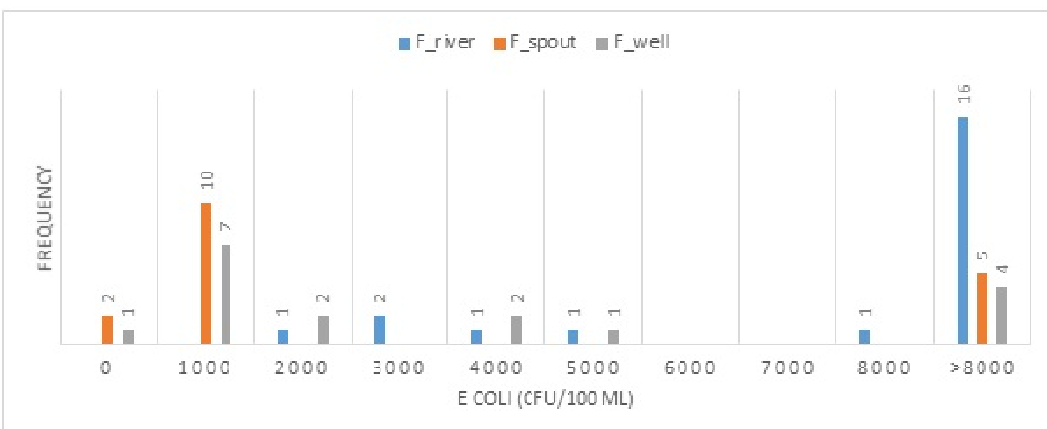
Figure 5.18: Iron - Histogram



5.2.7 E. coli

E. coli is an indicator for faecal pollution and as can be seen in Figure 5.19, there is either only a bit of contamination or a high level of pollution. In only three of the samples have not been contaminated with faecal matter. As E. coli is an indicator organism, when it is found, very likely, there will also be contamination of the water by other bacteria, viruses, which potentially are pathogenic. Samples taken from spouts are on average only lightly polluted. As shown in Figure 14.17, spouts are the least polluted sources while rivers are almost always polluted, except in areas with a lot of natural land-use. The wells show very high E. coli coliforms, especially in the populated areas. Noteworthy, are the high values found in the upstream part of the Nakkhu and Bishnumati.

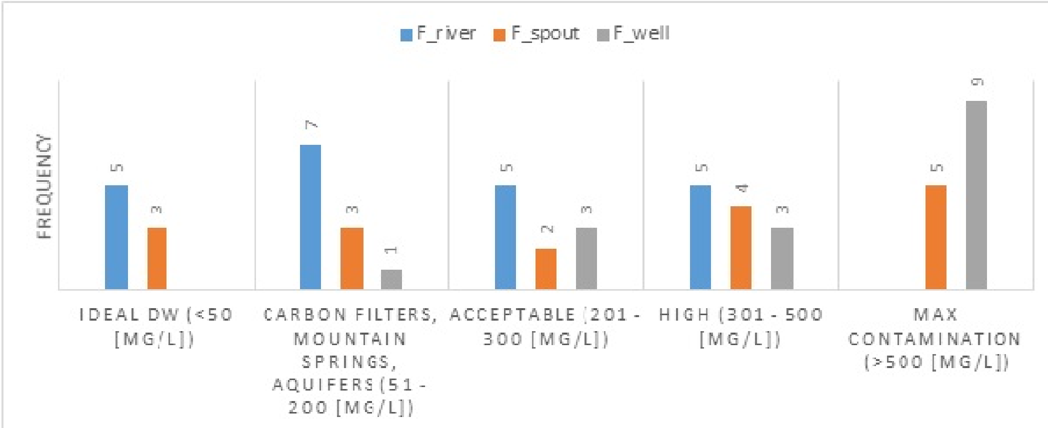
Figure 5.19: E. coli - Histogram



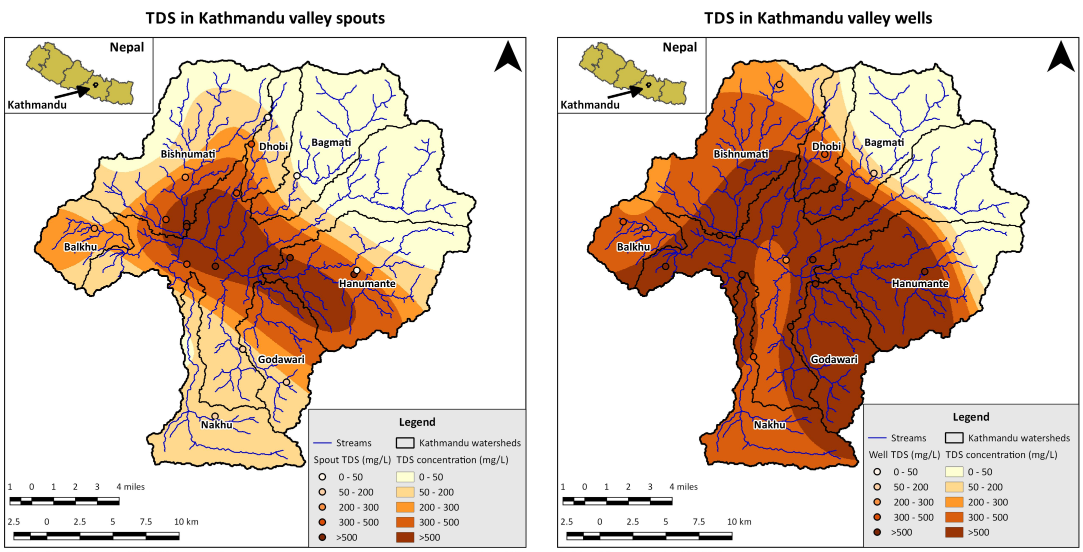
5.2.8 EC and TDS

By applying a rule of thumb to calculate TDS from EC as explained in Equation 5.1.3, the contamination of the water can be found. Five stone spout samples and ten well samples contained a concentration higher than 500 mg/l of total dissolved solids, the maximum allowable contamination level according to U.S. EPA (Fondriest, n.d.).

Figure 5.20: TDS - Histogram



In Figure 5.21, it is shown that the wells have higher levels of total dissolved solids than the spouts. The spouts show that the most senior TDS values are present the central part of the river at the downstream point of the watershed, whereas the TDS values in wells are very high in the more upstream parts where a fair amount of agricultural land can be found.



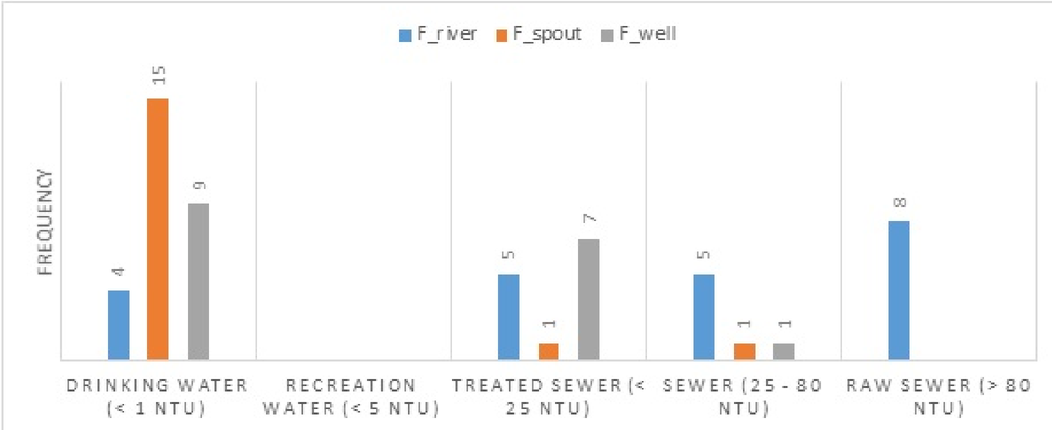
(a) Spouts (b) Wells

Figure 5.21: TDS levels in spouts and wells.

5.2.9 Turbidity

As shown in Figure 5.22, the turbidity in most stone spouts is sufficient for drinking water while only half of the wells show a similar result. As expected, some of the river samples have a very high turbidity and values that can be compared to treated or even raw sewer outflow.

Figure 5.22: Turbidity - Histogram



5.2.10 Overview data

Date	Time	Watersource	Watershed	Latitude	Longitude	Temperature [°C]	EC [$\mu S/cm$]	pH	DO [mg/L]	Turbidity [cm]	Nitrite [ppm]	Nitrate [ppm]	Phosphate [ppm]	Hardness [ppm]	Iron [mg/L]	E.coli [$CFU/100ml$]
12/09/2017	11:33:00	Well	Godawari	27.66400554	85.3647685	25.2	1016.0	6.88	1.25	58.40	0.00	0	5	425	1.30	3800
12/09/2017	13:16:00	Spout	Kathmandu	27.67451538	85.32801763	23.2	846.0	6.46	3.33	96.00	0.00	2	15	425	0.04	12
12/09/2017	16:06:00	River	Bagmati	27.71151036	85.35408975	25.1	67.8	3.90	1.13	6.80	0.00	2	15	3	7.30	8001
14/09/2017	08:15:00	River	Balkhu	27.70029191	85.22133408	21.9	311.0	7.56	1.22	49.90	0.30	2	15	250	0.84	8001
14/09/2017	08:32:00	Well	Balkhu	27.69994441	85.21514512	21.5	512.0	7.27	2.31	56.30	0.10	5	5	425	0.11	1612
14/09/2017	09:45:00	River	Balkhu	27.69595052	85.2317471	23.2	421.0	7.40	1.66	88.40	0.30	5	15	425	0.43	8001
14/09/2017	10:00:00	Well	Balkhu	27.696646	85.23218558	22.4	330.0	6.50	0.96	96.00	0.00	0	30	250	0.18	1714
14/09/2017	10:37:00	Spout	Balkhu	27.69628479	85.23390788	20.6	289.0	6.80	1.40	62.50	0.00	0	30	200	4.80	92
14/09/2017	13:21:00	River	Balkhu	27.68228216	85.26115134	27.1	508.0	7.35	0.81	21.50	1.00	2	30	250	2.00	8001
14/09/2017	14:03:00	Well	Kathmandu	27.67096043	85.24932438	20.9	857.0	6.60	1.11	96.00	0.00	0	7	250	0.00	600
15/09/2017	08:16:00	River	Bishnumati	27.79530628	85.32496883	19.5	575.0	7.71	2.41	33.70	0.00	0	30	25	0.37	8001
15/09/2017	08:18:00	Well	Bishnumati	27.79875952	85.32987184	20.9	319.0	6.60	2.13	96.00	0.00	0	5	250	1.10	8001
15/09/2017	09:47:00	Well	Bishnumati	27.76013687	85.32976921	23.6	1948.0	9.50	9.24	95.00	0.00	0	5	200	0.69	139
15/09/2017	10:48:00	River	Bishnumati	27.74227184	85.31423837	22.7	249.0	7.40	0.54	6.00	0.15	0	5	120	3.30	8001
15/09/2017	11:27:00	Spout	Bishnumati	27.73415294	85.30169268	19.6	342.0	7.30	1.71	96.00	0.00	0	5	350	0.26	8001
15/09/2017	13:09:00	River	Bishnumati	27.692177	85.30168151	25.4	667.0	8.08	0.21	3.00	0.00	2	15	250	4.10	8001
15/09/2017	13:32:00	Spout	Bishnumati	27.70261743	85.30441598	20.2	1123.0	6.70	1.80	96.00	0.00	15	30	250	0.00	8001
15/09/2017	13:56:00	Spout	Bishnumati	27.70053585	85.3045331	20.8	1056.0	6.65	2.58	96.00	0.15	50	25	250	0.00	514
17/09/2017	09:49:00	River	Dhobi	27.79146044	85.37082543	18.6	30.1	7.98	4.35	96.00	0.00	0	5	25	0.00	2352
17/09/2017	09:42:00	Spout	Dhobi	27.77770626	85.36262572	20.0	30.8	7.55	4.28	96.00	0.00	0	10	25	0.00	96
17/09/2017	11:07:00	River	Dhobi	27.7619513	85.36420313	23.1	106.5	7.14	2.68	32.40	0.00	2	5	50	0.23	8001
17/09/2017	11:22:00	Well	Dhobi	27.75271452	85.36709508	26.2	581.0	6.51	2.18	96.00	0.00	5	5	250	0.34	16
17/09/2017	12:11:00	Spout	Dhobi	27.75898389	85.35110818	23.9	455.0	6.99	3.55	96.00	0.00	0	5	425	0.00	30
17/09/2017	14:11:00	Spout	Dhobi	27.72513285	85.3415953	25.7	559.0	6.62	1.36	96.00	0.00	20	10	250	0.00	200
17/09/2017	14:17:00	River	Dhobi	27.7220896	85.34572868	28.9	391.0	7.15	1.08	8.30	0.00	0	5	120	1.40	8001
18/09/2017	07:36:00	Spout	Bishnumati	27.70469491	85.2884111	22.4	541.0	6.86	3.89	94.00	0.00	20	5	250	0.07	8001
18/09/2017	07:49:00	Spout	Nakhu	27.57224926	85.33333667	21.3	141.6	6.50	2.07	96.00	0.00	1	5	120	0.23	8001
18/09/2017	08:27:00	Well	Bishnumati	27.69389996	85.2895308	24.1	931.0	6.96	1.51	69.50	0.00	0	5	425	1.20	8001
18/09/2017	08:57:00	River	Nakkhu	27.54877062	85.37068029	17.2	186.9	7.80	5.62	96.00	0.00	0	5	250	0.05	2545
18/09/2017	10:18:00	River	Nakkhu	27.57560573	85.31264897	21.2	187.3	8.00	5.85	9.50	0.00	0	15	120	1.00	8001
18/09/2017	11:07:00	River	Hanumante	27.70481689	85.48111226	20.5	47.4	7.92	4.92	20.30	0.00	0	5	25	0.29	3282
18/09/2017	11:17:00	Well	Nakkhu	27.61235084	85.32004812	20.4	631.0	7.34	4.24	20.60	0.00	20	10	250	0.50	8001
18/09/2017	13:46:00	Well	Hanumante	27.68201396	85.48598549	-	-	6.68	3.07	54.10	0.00	2	5	120	0.08	40
18/09/2017	13:56:00	Well	Nakkhu	27.66816	85.3081759	23.3	862.0	6.74	1.50	29.00	0.00	10	15	250	1.10	8001
18/09/2017	14:40:00	River	Nakkhu	27.66259991	85.30631121	24.8	263.0	7.80	4.83	9.00	0.00	0	5	250	1.40	8001
18/09/2017	15:46:00	Spout	Kathmandu	27.67499258	85.30607077	21.8	559.0	6.45	2.68	96.00	0.00	20	10	250	0.69	176
19/09/2017	08:08:00	River	Nagmati	27.75409598	85.4216803	18.3	27.7	7.11	5.68	21.40	0.00	0	5	10	0.20	8001
19/09/2017	08:58:00	Well	Bagmati	27.74130559	85.40544168	22.6	127.0	6.24	1.32	96.00	0.00	0	5	50	0.06	700
19/09/2017	10:03:00	Spout	Bagmati	27.73881443	85.38717442	19.8	32.4	7.11	5.35	20.10	-	-	10	25	0.40	0
19/09/2017	10:25:00	River	Bagmati	27.73719363	85.38621118	20.6	56.1	7.03	4.67	14.20	0.00	0	10	25	0.61	8001
19/09/2017	11:21:00	Well	Dhobi	27.72979561	85.37402645	26.5	965.0	6.69	2.76	96.00	0.00	20	5	425	0.28	4500
19/09/2017	16:16:00	Well	Kathmandu	27.6792778	85.34139961	25.2	429.0	6.84	1.88	84.00	0.00	0	10	250	0.54	345

Table 5.5: Overview of all water quality parameter measurements.

5.3 Discussion

Some of the data show surprising outcomes like the different values for total dissolved solids that are higher in wells than in spouts which were expected to be from the same groundwater source. The difference is probably due to point pollution of the wells which are often open. During fieldwork, it was noticed that garbage was thrown in abandoned wells. In addition, the wells can be polluted during floods since they are not always closed off. The results also showed that the data gathered at wells and often spouts where not correlated. It is thus very likely that the spouts and wells do not directly tap into the same groundwater source. It is expected that spouts use preferential paths while wells tap into the aquifer. This would also explain why the nitrate levels are much higher in the wells than in the spouts since nitrate often increases over time due to loading.

Surprisingly, there was almost no nitrate or nitrite in the rivers. One of the reasons could be that the sewers use the dissolved oxygen in the water to such an extent that there is probably not enough dissolved oxygen left to oxidise the ammonia in the water. This can result, in very low nitrate and nitrite levels. Especially with some agricultural fields, the values should otherwise be higher. The fields are, however, mainly dominated by rice which has still standing water on the field. It could be that due to this, the nitrate doesn't flow off into the river but instead infiltrates into the groundwater. This could explain the high nitrate values found in the spouts and wells.

Another thing, is the low DO levels in the Godwari river, which was unexpected since it looked quite clean. In addition, the spout water flows into the river and micro-organisms can still be found while the DO values suggest otherwise. Upstream of the measuring point there was a fish farm which could have influenced the results. In general, the DO values were very low throughout the Kathmandu Valley which is probably due to the constant inflow of raw sewer. Especially in the Hanumante the DO levels where dramatically low which is probably because it is one of the most polluted streams that have been measured. A general trend in all the watersheds is that the further downstream you get, the more sewer has been put in and thus the lower the DO.

High E. coli values in the Nakkhu and Bishnumati are noticeable with an unknown cause. Since E. coli doesn't circulate through the groundwater, it is probably a local source.

Uncertainty analysis

In section 14.7, the errors for all the parameters are shown. For a few parameters which are prone to errors, an in-depth explanation will be provided of the uncertainties in the collected data. The parameters that will be discussed more in depth are turbidity and dissolved oxygen. As the TDS is calculated by using a rule of thumb based on the EC and temperature data, it also has a low confidence level.

The turbidity tube is a good instrument to measure the turbidity in the field. There are however some errors that are quite important to mention. The turbidity tube is very prone to human errors. The tube is depending on the eyesight of the one that looks through it. In addition, the boundary between being able to see and not being able to see the Secchi disk at the bottom of the tube differs by person. It is also essential to take into account that sunlight and shadow can change the readout. Besides, the device itself can even have some errors. For example, you have to put on the measuring tape as straight as possible and have everything the same for all three tubes. Other errors can be found in the weather. The rain itself has a direct impact on the turbidity as it will increase the flow, turbulence and sediment uptake of the stream. Furthermore, indirectly it will increase the erosion that enters the streams which were especially the case in the Nakhu river.

One of the main errors for the measurement of dissolved oxygen are device related errors. The DO is hard to measure. It is hard to find a right spot to measure the DO since you need flowing water to get an accurate value. In addition, the device has a hard time stabilising. The moment you think the DO is stable is dependent on the people that measure it since it fluctuates continuously and doesn't stabilize. Moreover, the time span in which the DO is measured differs between measurements since the DO was sometimes measured with the help of samples and later on directly in the field. Lastly, the rain can influence the re-aeration of the water and can also change the DO values measured.

5.4 Conclusion

Land-Use seems to mostly affect the water quality samples taken in rivers while geology is more important in the values found in wells. The spouts do not seem to have a strong relationship with either of the two.

The DO in rivers is strongly influenced by the urbanised areas. As the comparison between DO and land-use show in the watersheds of the Hanumante and the Godawari, an increase in the urban area strongly decrease the DO levels. 1/3 of the DO levels is so low that no aquatic life is possible. In addition, nitrate and nitrite concentrations in rivers are often zero or close to zero. The nitrate levels are probably influenced by the low DO levels. If there is no oxygen, the ammonia cannot oxidise into nitrate or nitrite. This also explains why there is no correlation between the nitrate levels found in rivers and the groundwater sources of spouts and wells.

Hardness and EC seem to be mostly influenced by geology. The value of hardness increase in calcium and magnesium-rich soils. Furthermore, phosphate shows both a relationship with urban land-use as it could be influenced by the geology. It is however likely that phosphate concentrations are higher in the centre of the valley due to geology since the Kalimati formation can increase them as will be explained in the chapter 7.

Important to notice is that most water quality parameters show that the quality of the water in spouts is better than in wells and that the rivers are highly contaminated with especially E. coli. In spouts and wells, the E. coli is mostly locally induced.

6 Relations between land-use and water quality

In this chapter, the correlations between land-use and water quality, as introduced in the previous chapters, will be discussed, aswell as the relations within the water quality parameters itself. It tries to answer the first research question: "*What are the relations between land-use and water quality in stone spouts, wells and streams?*".

6.1 Methods

To understand the relationship between different parameters, correlation matrices will be constructed based on the Pearson Product-Moment Correlation. The Pearson correlation provides the answer to the question if there is a linear based relationship between two parameters. The Pearson correlation coefficient r expresses this response. The value of this coefficient (r) can range between 1 and -1. A value of 1 or -1 indicates a perfect linear correlation, a value of zero shows that there is no correlation and everything between zero and one or minus one suggests that there is a correlation, but that is less strong, and that is a positive or negative correlation. How closer the absolute value is at one, the stronger the relationship is (Leard Statistics, n.d.).

However, even if the value of the correlation coefficient is not equal to zero, there is still a change that there is no correlation. That is when the correlation coefficient is so weak that you actually can assume that there is no correlation. To estimate that change, you can use the critical values table, see Table 6.1, with corresponding significance values. The significance values express how likely the chance is that there is no correlation if the absolute value (Elementary Statistics for Political Research, n.d.). Three classes will be formed to express how significant a result of the matrices will be. In these classes correlations will be placed who have a higher absolute value that corresponds to the value provided by Table 6.1 and the correct sample size. The following classes are defined:

- High Significant (HS). A significance of 0.05% (P = 0.0005).
- Medium Significant (MS). A significance of 0.5% (P = 0.005)
- Low Significant (LS). A significance of 2.5% (P = 0.025).

The results can be found in section 6.2.

N	0.025	0.005	0.0005	N	0.025	0.005	0.0005
4	0.95	0.99	0.999	24	0.404	0.515	0.629
5	0.878	0.959	0.991	25	0.396	0.505	0.618
6	0.811	0.917	0.974	26	0.388	0.496	0.607
7	0.754	0.875	0.951	27	0.381	0.487	0.597
8	0.707	0.834	0.925	28	0.374	0.479	0.588
9	0.666	0.798	0.898	29	0.367	0.471	0.579
10	0.632	0.765	0.872	30	0.361	0.463	0.57
11	0.602	0.735	0.847	35	0.334	0.43	0.532
12	0.576	0.708	0.823	40	0.312	0.403	0.501
13	0.553	0.684	0.801	45	0.294	0.38	0.474
14	0.532	0.661	0.78	50	0.279	0.361	0.451
15	0.514	0.641	0.76	60	0.254	0.33	0.414
16	0.497	0.623	0.742	70	0.235	0.306	0.385
17	0.482	0.606	0.725	80	0.22	0.286	0.361
18	0.468	0.59	0.708	90	0.207	0.27	0.341
19	0.456	0.575	0.693	100	0.197	0.256	0.324
20	0.444	0.561	0.679	200	0.139	0.182	0.231
21	0.433	0.549	0.665	300	0.113	0.149	0.189
22	0.423	0.537	0.652	400	0.098	0.129	0.164
23	0.413	0.526	0.64	500	0.088	0.115	0.147

Table 6.1: Pearson correlation critical values (*Table of critical values for Pearson correlation*, n.d.)

6.2 Results

In this section, the calculated correlations are displayed in the form of correlations matrices. All matrices have the same layout. In their first part, the calculated values are shown, and in section two the classification of these values are displayed. In subsection 6.2.1 the correlations between different land-uses and different water quality parameters can be found and in subsection 6.2.2 the relationships between various water quality parameters in each different source can be found. In this part, the result of the search for indicator parameters can be found.

6.2.1 Correlation between land-uses and interpolated parameters

In Table 6.2, 6.3 and 6.4 the correlation between the different measured water quality parameters and the land-use is displayed. The results are based on the value of a water-quality parameter that was measured at one location and the ratio of a specific land-use that was present. In the wells, only four times a correlation was strong enough to be placed in one of the three correlation classes, in rivers and spouts twenty-six and sixteen correlations respectively were found that were worthy to mention. It should be noted that in a lot of water samples, the E.coli count was too high to measure (higher than 8000 CFU/100ml). Those measurements are represented with the value of 8001. However, the value of those measurements can be higher than 8001. Therefore a distorted view with the E.coli correlations could be the case.

Wells

As can be seen in Table 6.2, there are only four correlations found that were sufficient to be placed in one of the three classes, and all four were found in one of the agricultural land-use classes. Between the land-use "Rice" and the parameter phosphate, a correlation was found that could be identified as LS (Low Significance, p=0.025) with a value of 0.426. The other three, found with the land-use named "Agriculture (non-Rice)", were with the parameter Hardness (LS, r = 0.500), with EC (MS, r = 0.544) and with TDS (MS, r = 0.054).

Wells											
	pH	DO [mg/l]	Nitrite [ppm]	Nitrate [ppm]	Phosphate [ppm]	Hardness [ppm]	Iron [mg/l]	E. Coli [$CFU/100ml$]	$EC_{25\,°C}$ [$\mu S/cm$]	TDS [mg/l]	Turbidity [NTU]
Built (Low Density)	0.063	-0.080	0.076	0.123	0.180	0.349	0.129	0.349	0.296	0.297	-0.053
Built (High Density)	0.027	-0.063	-0.025	0.000	-0.074	0.331	0.210	0.324	0.274	0.274	-0.110
Forest (Decideous)	-0.261	0.120	-0.293	-0.283	-0.301	-0.358	-0.274	-0.366	-0.410	-0.410	-0.192
Shrublands	0.059	0.273	-0.017	0.023	-0.097	-0.313	-0.047	-0.073	-0.260	-0.260	0.281
Rice	0.351	-0.175	0.395	0.304	0.426	0.324	0.321	0.344	0.406	0.406	0.287
Ag. (non-Rice)	0.135	-0.304	0.275	0.304	0.270	0.500	0.175	0.209	0.554	0.554	-0.058
Build (Low Density)											
Built (High Density)											
Forest (Decideous)											
Shrublands											
Rice					LS						
Ag. (non-Rice)						LS			MS	MS	

Table 6.2: Correlation between land-use and parameters within the wells.
$[HS >= |0.640| > MS >= |0.526| > LS >= |0.413|, n = 23]$

Rivers

Between the different parameters and land-uses in the rivers, a lot of correlations are found that can be placed in the various classes. Especially the parameters RSA, DO, and E.coli correlate with almost every land-use with the exception of DO which correlates with all different land-uses. In contrast, pH, nitrite, nitrate and phosphate do not have a single correlation that was strong enough to be placed in one of the three classes.

Rivers												
	RSA	pH	DO [mg/l]	Nitrite [ppm]	Nitrate [ppm]	Phosphate [ppm]	Hardness [ppm]	Iron [mg/l]	E. Coli [$CFU/100ml$]	$EC_{25\,°C}$ [$\mu S/cm$]	TDS [mg/l]	Turbidity [NTU]
Built (Low Density)	0.899	-0.235	-0.637	0.315	0.333	0.085	0.358	0.562	0.634	0.402	0.302	0.634
Built (High Density)	0.603	-0.073	-0.477	0.006	0.139	-0.098	0.173	0.508	0.322	0.424	0.362	0.698
Forest (Decideous)	-0.829	0.107	0.561	-0.213	-0.249	-0.252	-0.470	-0.354	-0.716	-0.318	-0.189	-0.426
Shrublands	-0.396	-0.115	0.449	-0.211	-0.153	-0.143	-0.284	-0.099	0.062	-0.500	-0.518	-0.179
Rice	0.726	0.118	-0.502	0.253	0.237	0.392	0.557	0.066	0.570	0.399	0.286	0.155
Agriculture. (non-Rice)	0.835	-0.213	-0.685	0.232	0.221	0.313	0.522	0.412	0.627	0.310	0.215	0.397
Build (Low Density)	HS		MS					MS	MS			MS
Built (High Density)	MS		LS					LS		LS		HS
Forest (Decideous)	HS		MS				LS		HS			LS
Shrublands			LS							LS	LS	
Rice	HS		LS				MS		MS			
Agriculture (non-Rice)	HS		HS				LS		MS			

Table 6.3: Correlation between land-use and parameters within the rivers.
$[HS >= |0.640| > MS >= |0.526| > LS >= |0.413|, n = 23]$

Spouts

In Table 6.4 sixteen correlations can be found that are classified to be placed in one of the classes. One can observe that the land-use "Shrublands" and "Rice" didn't have a single correlation that was strong enough to be significant. Also, the parameters like phosphate, iron, E. coli and turbidity had correlation coefficients that were not strong enough to be organised. Only one correlation had an absolute value that was high enough to be classified as HS; this was between nitrate and "Built (High Density)".

Spouts											
	pH	DO $[mg/l]$	Nitrite $[ppm]$	Nitrate $[ppm]$	Phosphate $[ppm]$	Hardness $[ppm]$	Iron $[mg/l]$	E. coli $[CFU/100ml]$	$EC_{25\,°C}$ $[\mu S/cm]$	TDS $[mg/l]$	Turbidity $[NTU]$
Built (Low Density)	-0.462	-0.694	0.443	0.638	0.382	0.624	0.093	0.174	0.715	0.714	0.035
Built (High Density)	-0.401	-0.490	0.536	0.869	0.356	0.396	-0.165	0.000	0.710	0.709	0.035
Forest (Decideous)	0.540	0.575	-0.471	-0.442	-0.454	-0.464	-0.404	-0.233	-0.663	-0.664	0.387
Shrublands	-0.278	0.090	-0.251	-0.204	-0.268	-0.242	0.302	0.076	-0.260	-0.260	-0.421
Rice	-0.361	-0.414	0.410	0.151	0.441	0.272	0.482	0.302	0.455	0.455	-0.438
Ag. (non-Rice)	-0.196	-0.356	0.392	0.264	0.486	0.533	0.240	0.022	0.609	0.609	-0.152
Build (low density)		MS		MS		MS			MS	MS	
Built (High Density)			LS	HS					MS	MS	
Forest (Decideous)	LS	LS							MS	MS	
Shrublands											
Rice											
Ag. (non-Rice)						LS			LS	LS	

Table 6.4: Correlation between land-use and parameters within the spouts.
$[HS >= |0.742| > MS >= |0.623| > LS >= |0.497|, n = 26]$

6.2.2 Correlations between parameters in different water-sources

In this subsection of the report, the correlation between different parameters is displayed. In Table 6.5 no distinction between the source of the water was made, but in Table 6.6, 6.7 and 6.8. It should be noted that the absolute value of correlations between the same parameters are of course always equal to one and these should be neglected since they have no meaning.

All data

In total sixteen correlations were statistically strong enough to be classified. Especially turbidity and EC have more than two correlations where the absolute value was relatively high:

- EC with turbidity: LS (r=0.296)
- EC with nitrate: HS (r=0.523)
- EC with hardness: HS (r=0.568)
- Turbidity with nitrate: LS (r=0.285)
- Turbidity with hardness: LS (r=0.305)
- Turbidity with iron: HS (r=-0.540)
- Turbidity with E.coli: HS (r=-0.503)

Another observation is that the correlation between DO and temperature was HS (r=-0.499), another one that could be classified as HS was between nitrite and phosphate (r=0.455). A side note is that the critical values of the classes are lower than in other tables since the number of measurements with each parameter is higher than in other tables.

All data												
	Temperature °C	EC [$\mu S/cm$]	pH	DO [mg/l]	Turbidity [cm]	Nitrite [ppm]	Nitrate [mg/l]	Phosphate [ppm]	Hardness [ppm]	Iron [mg/l]	E.Coli [CFU/100ml]	Discharge [m^3/s]
Temperature °C	1.000	0.230	-0.174	-0.449	-0.122	0.069	-0.033	0.103	0.278	0.256	0.153	-0.138
EC [$\mu S/cm$]		1.000	0.062	-0.055	0.296	0.242	0.523	0.256	0.568	-0.130	-0.060	-0.055
pH			1.000	0.461	-0.076	0.080	-0.212	-0.013	-0.053	-0.304	0.002	-0.183
DO [mg/l]				1.000	0.089	-0.153	-0.071	-0.225	-0.331	-0.349	-0.244	0.253
Turbidity [cm]					1.000	-0.025	0.285	0.029	0.305	-0.540	-0.503	-0.003
Nitrite [ppm]						1.000	0.348	0.455	0.093	0.022	0.144	-0.136
Nitrate [mg/l]							1.000	0.248	0.225	-0.211	0.017	-0.108
Phosphate [ppm]								1.000	0.016	0.104	0.145	-0.161
Hardness [ppm]									1.000	-0.107	-0.046	0.039
Iron [mg/l]										1.000	0.281	0.148
E.Coli [CFU/100ml]											1.000	-0.171
Discharge [m^3/s]												1.000

	Temperature °C	EC [$\mu S/cm$]	pH	DO [mg/l]	Turbidity [cm]	Nitrite [ppm]	Nitrate [mg/l]	Phosphate [ppm]	Hardness [ppm]	Iron [mg/l]	E.Coli [CFU/100ml]	Discharge [m^3/s]
Temperature °C	HS			HS					LS			
EC [$\mu S/cm$]		HS			LS		HS		HS			
pH			HS	HS						LS		
DO [mg/l]				HS					LS	MS		
Turbidity [cm]					HS		LS		LS	HS	HS	
Nitrite [ppm]						HS	MS	HS				
Nitrate [mg/l]							HS					
Phosphate [ppm]								HS				
Hardness [ppm]									HS			
Iron [mg/l]										HS	LS	
E.Coli [CFU/100ml]											HS	
Discharge [m^3/s]												HS

Table 6.5: Correlation in between all measured parameters.
$[HS >= |0.414| > MS >= |0.330| > LS >= |0.254|, n = 58]$

Rivers

Rivers												
	Temperature °C	EC [$\mu S/cm$]	pH	DO [mg/l]	Turbidity [cm]	Nitrite [ppm]	Nitrate [mg/l]	Phosphate [ppm]	Hardness [ppm]	Iron [mg/l]	E.Coli [CFU/100ml]	Discharge [m^3/s]
Temperature °C	1.000	0.504	-0.256	-0.729	-0.409	0.277	0.282	0.318	0.344	0.451	0.557	0.047
EC [$\mu S/cm$]		1.000	0.192	-0.654	-0.209	0.331	0.219	0.529	0.632	0.187	0.408	-0.172
pH			1.000	0.254	0.307	0.009	-0.226	0.003	0.246	-0.702	-0.293	-0.502
DO [mg/l]				1.000	0.157	-0.293	-0.362	-0.443	-0.419	-0.492	-0.388	0.024
Turbidity [cm]					1.000	0.006	0.223	0.052	0.162	-0.500	-0.583	-0.478
Nitrite [ppm]						1.000	0.450	0.379	0.308	0.058	0.204	-0.222
Nitrate [mg/l]							1.000	0.155	0.311	0.188	0.340	0.076
Phosphate [ppm]								1.000	0.259	0.069	0.164	-0.150
Hardness [ppm]									1.000	0.007	0.130	-0.390
Iron [mg/l]										1.000	0.323	0.621
E.Coli [CFU/100ml]											1.000	0.209
Discharge [m^3/s]												1.000
Temperature °C	HS	LS		HS						LS	MS	
EC [$\mu S/cm$]		HS		HS				MS	MS			
pH			HS							HS		LS
DO [mg/l]				HS				LS		LS		
Turbidity [cm]					HS					LS	MS	LS
Nitrite [ppm]						HS	LS					
Nitrate [mg/l]							HS					
Phosphate [ppm]								HS				
Hardness [ppm]									HS			
Iron [mg/l]										HS		MS
E.Coli [CFU/100ml]											HS	
Discharge [m^3/s]												HS

Table 6.6: Correlation in between measured parameters within the Rivers.
$[HS >= |0.640| > MS >= |0.526| > LS >= |0.413|, n = 23]$

Wells

In the correlation matrix between the parameters in the wells only six correlations were found that were strong enough to be classified. These correlations were between EC with nitrite (LS, r = 0.554), nitrate (MS, r=0.677) and hardness (LS, r = 0.509), but also between nitrite with nitrate (MS, r = 0.662) and phosphate (HS, r = 0.762), and finally also one between turbidity and iron (LS, r = -0.483).

Wells											
	Temperature °C	EC [$\mu S/cm$]	pH	DO [mg/l]	Turbidity [cm]	Nitrite [ppm]	Nitrate [mg/l]	Phosphate [ppm]	Hardness [ppm]	Iron [mg/l]	E.Coli [CFU/100ml]
Temperature °C	1.000	0.004	-0.169	-0.127	0.313	-0.326	-0.142	-0.284	0.226	0.012	-0.128
EC [$\mu S/cm$]		1.000	0.319	0.004	-0.062	0.554	0.677	0.290	0.509	0.050	0.301
pH			1.000	0.457	-0.386	0.417	0.127	0.271	0.356	0.082	0.096
DO [mg/l]				1.000	-0.390	0.154	0.222	-0.029	-0.204	-0.158	0.195
Turbidity [cm]					1.000	0.184	0.133	0.169	-0.079	-0.483	-0.259
Nitrite [ppm]						1.000	0.622	0.762	-0.088	-0.258	0.032
Nitrate [mg/l]							1.000	0.424	0.138	-0.350	0.434
Phosphate [ppm]								1.000	-0.197	-0.251	0.018
Hardness [ppm]									1.000	0.354	0.225
Iron [mg/l]										1.000	0.403
E.Coli [CFU/100ml]											1.000
Temperature °C	HS										
EC [$\mu S/cm$]		HS				LS	MS		LS		
pH			HS								
DO [mg/l]				HS							
Turbidity [cm]					HS					LS	
Nitrite [ppm]						HS	MS	HS			
Nitrate [mg/l]							HS				
Phosphate [ppm]								HS			
Hardness [ppm]									HS		
Iron [mg/l]										HS	
E.Coli [CFU/100ml]											HS

Table 6.7: Correlation between measured parameters in wells.
$[HS >= |0.640| > MS >= |0.526| > LS >= |0.413|, n = 23]$

Spouts

In the spouts, eight correlations were strong enough to be classified, from which five involved the EC. There is one with the pH and two with nitrite. They have the following classes and values:

- EC and pH: LS (r=-0.403)
- EC and Nitrite: LS (r=0.543)
- EC and Nitrate: LS (r=0.602)
- EC and Phosphate: MS (r=0.655)
- EC and Hardness: LS (r=0.590)
- pH and DO: LS (r=-403)
- Nitrite and Nitrate (r=0.603)
- Nitrite and Phosphate (r=0.673)

Spouts												
	Temperature °C	EC [$\mu S/cm$]	pH	DO [mg/l]	Turbidity [cm]	Nitrite [ppm]	Nitrate [mg/l]	Phosphate [ppm]	Hardness [ppm]	Iron [mg/l]	E.Coli [CFU/100ml]	Discharge [m^3/s]
Temperature °C	1.000	0.350	-0.332	-0.270	0.298	0.060	0.040	0.197	0.292	-0.147	-0.154	-0.282
EC [$\mu S/cm$]		1.000	-0.501	-0.403	0.365	0.543	0.602	0.655	0.590	-0.155	0.262	-0.086
pH			1.000	0.584	-0.070	-0.029	-0.432	-0.183	-0.299	-0.144	-0.061	0.064
DO [mg/l]				1.000	-0.225	0.080	-0.226	-0.232	-0.314	-0.352	-0.232	0.451
Turbidity [cm]					1.000	0.116	0.185	-0.034	0.435	-0.400	0.229	0.098
Nitrite [ppm]						1.000	0.603	0.673	0.049	-0.131	0.171	-0.174
Nitrate [mg/l]							1.000	0.255	0.056	-0.183	0.019	-0.207
Phosphate [ppm]								1.000	0.103	0.290	0.234	-0.183
Hardness [ppm]									1.000	-0.070	0.117	0.224
Iron [mg/l]										1.000	-0.179	-0.009
E.Coli [CFU/100ml]											1.000	-0.248
Discharge [m^3/s]												1.000

	Temperature °C	EC [$\mu S/cm$]	pH	DO [mg/l]	Turbidity [cm]	Nitrite [ppm]	Nitrate [mg/l]	Phosphate [ppm]	Hardness [ppm]	Iron [mg/l]	E.Coli [CFU/100ml]	Discharge [m^3/s]
Temperature °C	HS											
EC [$\mu S/cm$]		HS	LS			LS	LS	MS	LS			
pH			HS	LS								
DO [mg/l]				HS								
Turbidity [cm]					HS							
Nitrite [ppm]						HS	LS	MS				
Nitrate [mg/l]							HS					
Phosphate [ppm]								HS				
Hardness [ppm]									HS			
Iron [mg/l]										HS		
E.Coli [CFU/100ml]											HS	
Discharge [m^3/s]												HS

Table 6.8: Correlation in between measured parameters within the spouts.
$[HS >= |0.725| > MS >= |0.606| > LS >= |0.482|, n = 17]$

6.3 Discussion

As can be seen in Table 6.2, 6.3 and 6.4, the land-use does influence the water quality of the different water sources, but some water sources are more heavily influenced than others. As can be seen in Table 6.2, the wells are less influenced by the land-uses then the other two sources, as only four times the correlation was statistically significant, and none was strong enough to be classified as "High Significance" (HS). It seems that "Agricultural (non-rice)" land-use has the largest influence on water quality parameters, but most land-uses appear to have a negligible influence.

In contrast, rivers are most influenced by land-use, see Table 6.3. Especially DO, hardness, E. coli and turbidity are profoundly affected by the land-uses they cross. In contrast nitrite, nitrate and phosphate are least influenced by the land-uses. Especially between the ecology (RSA) and the different land-uses, strong correlations can be found; same can be said about DO. This existence of strong relationships with these two water quality parameters is logical since land-use is strong defined by upstream and downstream characters. The same is true for ecology and DO. Hence, the association is more geographically based than that these parameters have a real direct influence on each other. Other parameters that are strongly influenced by the land-uses are the water quality parameter E. coli and turbidity. It was observed that the E. coli count and the "Built (Low Density)", Rice and "Agricultural. (non-Rice)" land-uses have a strong positive correlation, but "Forest (Deciduous)" has a negative correlation. The reason for these correlations is probably that the presence of E. coli is heavily influenced by human and agricultural (livestock farming) activity. In a forest, these activities are low or non-existent, therefore a negative correlation is present. In the other land-uses classes, these activities can be expected to be high(er). Unexpected is the fact that the correlation between the presence of E. coli and the "Built (High Density)" land-use is very weak, too weak to be statistically significant. An explanation for this can be that in this land-use class the existence of sewer systems is higher; therefore the pollutants enter the river less gradually and act more like a point release. This explanation could potentially clarify the weaker correlation but remains, however, speculation. It could also be the case that the land-use "Built (High Density) is not represented extensively and the limited availability of data, therefore, makes it difficult to find a correlation.

In spouts also a couple of correlations can be found, not as much as in rivers, but more than in the wells. It looks like especially the parameters associated with groundwater are greatly influenced by the land-uses (hardness, EC and TDS), which make sense since spouts get their water from groundwater. However, the presence of DO is also greatly influenced by the land-use "Forest (Deciduous)" and "Built (low density)". Why precisely these land-uses have a strong enough correlation to be classified, is open for interpretation. Maybe there is a direct link, or perhaps the correlation exist based on a connection with the geographic location)

It should also be taken into account that correlations are profoundly influenced in the way the observer looks at the interactions between parameters. For example, from the correlation matrices, it can be seen that there is a low negative correlation between river pH and the land-uses. From the geographical overview, however, can be seen that Kathmandu city centre, covered by mainly build land-uses, is an acidic hot spot in the valley. This result shows that correlation factors do not explain the whole story and that visual inspection (graphs, trends, distribution) of parameter interaction data is highly is needed.

All in all, the presence of some land-uses predicts the expected water quality for some parameters. Although the correlation between them is stronger for some water-sources, none of the correlations is strong enough to derive a linear relationship with negligible errors. Land-uses can be used to predict the range of a parameter value (higher or lower), but quantification is very difficult if not impossible.

6.4 Conclusion

Water quality parameters of wells are the least correlated to land-use. Correlation of medium significance was found between non-rice agriculture and both TDS and EC. In the case of rivers, pH, nitrite, nitrate and phosphate are not correlated with any land-use while the rest of the parameters are correlated with all 3 of them to some extent. Lastly, for spouts, EC and TDS are correlated with all three land-uses while the rest, except for E. coli, turbidity and iron, correlate at some extent with some of the land-use cover types.

From the correlation matrices, it is showcased that EC and turbidity have the most substantial correlations with other parameters. The water quality parameters have the most relationship with turbidity, EC, hardness and nitrate. Out of the three water sources, spouts have the least correlated parameters with EC and nitrite correlating with medium significance with nitrate and nitrite, phosphate respectively. The correlations are more frequent and stronger in wells and secondly in rivers. Therefore, turbidity, EC and to some extent temperature can be used as indication parameters to estimate ranges of values of the water quality parameters they are most strongly related.

7 | Influence of geology on groundwater and stream composition

In this chapter, the consequences of geology on groundwater and stream composition will be discussed. This chapter will focus on finding an answer for the research question: "*What are the relations between geology and water quality in stone spouts, wells and streams?*".

Quantifying geological influence on the chemical composition of water, is quite hard, just because one cannot only open the ground and analyse the small-scale processes, exact lithological composition and inhomogeneities in detail. However, geology is considered as one of the leading factors influencing water quality. Therefore, we have tried to say something useful about its influence. Based on literature research, the consequences of geology will be discussed per sub-catchment. Some findings are however cross-boundary, and will, therefore, be addressed first.

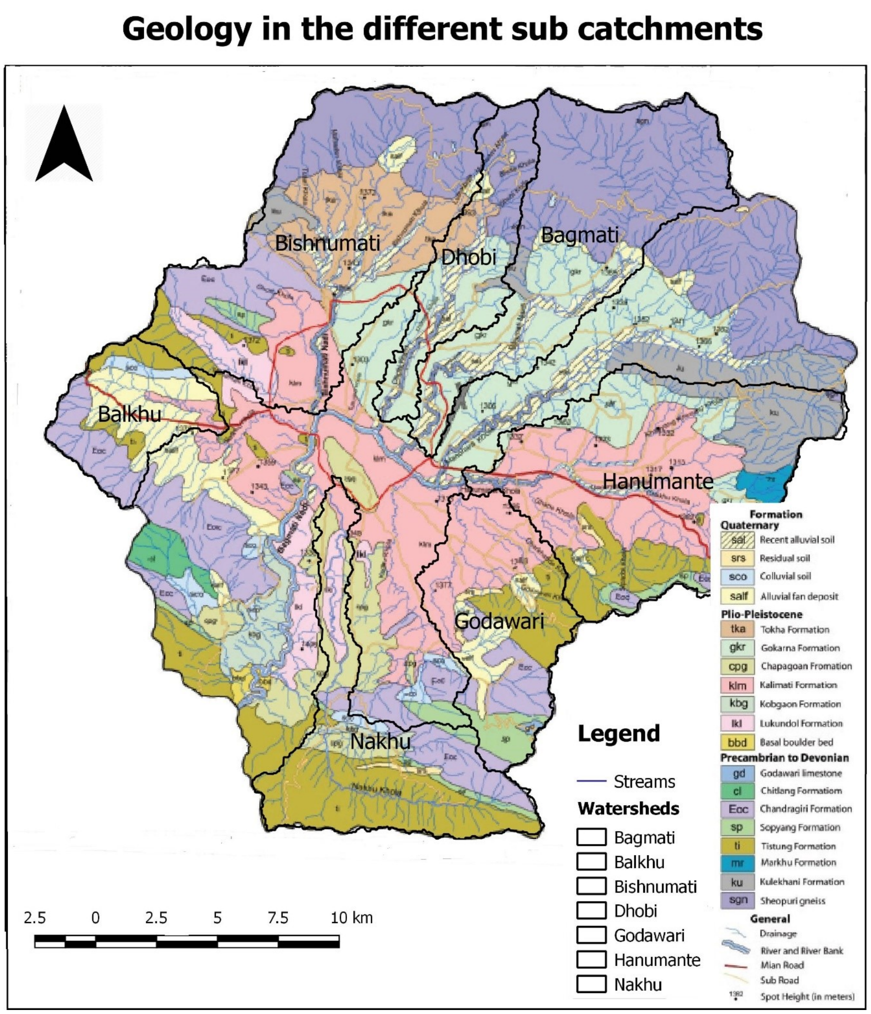


Figure 7.1: Geology in the main research watersheds

The central part of the valley has relative high phosphate concentrations in its spouts and especially streams, but not as extreme as in the upstream Balkhu and Hanumante areas. This presence coincides perfectly with the appearance of the Kalimati clay, which contains at places phosphate minerals. When those are dissolved in the water, the phosphorus concentrations in the water will rise. Iron peaks seem to follow streams, rather than geology and also nitrate and nitrite concentration cannot be linked to the geological subsurface. Peaks occur over all types of lithology and are other different for spouts, wells and rivers. EC levels peak in different regions for the various sources. For wells, an EC peak around Bhaktapur can be noticed from the interpolation map, which coincides with the Kalimati formation. However, the maximum was too local to blame geology for it. The pattern resembles point pollution instead that following lithology. Only for streams, it seems that the EC is correlated with geology as will be described below.

7.1 Geology of main watersheds

7.1.1 Bagmati

The Bagmati originates from an area where Sheopuri gneiss can be found at the surface. In the upstream region, some sidestreams flow through an alluvial fan with presumably more or less the same (but loose) composition. Downstream the stream continues into the Gokarna formation, formed by sand and sometimes silt. The high turbidity in spouts, halfway the Bagmati, might be clarified by the presence of only moderately consolidated sand and silt, which can release sediment particles to the water. It is however strange that the turbidity in wells and rivers is rather low in the area. Maybe a pocket of strongly consolidated sediment is present within the formation close to the spout whereas other parts are less well kept together. Finally, the Bagmati flows through the Kalimati clay, which is sometimes calcareous and/or containing phosphate minerals) towards the pour point of the valley. As described before, the slightly elevated phosphate concentrations in this part can be clarified by the occurrence of this formation.

7.1.2 Balkhu

Chandragiri limestone can be found in the source area of the Balkhu. Limestone is quite soluble and can increase EC and hardness significantly. This increase was indeed measured for the sub-catchment of the Balkhu stream (especially for interpolation maps based on the stream measurements). The relatively high phosphate concentrations here cannot be explained by geology. After Chandragiri limestone, the Balkhu flows over sand- and siltstone and phyllite of the Tistung formation and consequently over quarternary alluvial fan deposits. Here the hardness considerably drops, as a consequence of dilution by the extra amounts of water fed to the stream. Finally, the river merges with the Bagmati in the clays of the Kalimati formation, which at places is high in calcareous and phosphate minerals.

7.1.3 Bishnumati

At its source, the Bishnumati follows more or less the same pathway through the geology as the Bagmati (and Dhobi). First, it starts in the Sheopuri gneiss. The phosphate concentration in streams in this region is quite high, but cannot be clarified by the gneiss geology, as gneiss is simply too hard to weather at such a high rate. After flowing a small distance through quarternary alluvial fan deposit, it, however, ends up in the Tokha formation (unconsolidated clay and sandy gravel, which might explain the high turbidity). The region in the north-western part of the valley, where a high hardness in the interpolated maps is assigned based on the hardness of spouts, coincides with the occurrence of the Tokha formation. Not much information is known about the chemical composition of the Tokha clay and gravel. Based on the geology of surrounding hills (gneiss), which most probably forms the source of this material and which is quite insoluble, it is doubtful that the Tokha geology is causing the high hardness in this region. A little more downstream of the Tokha formation, the Chandragiri limestone can be found, which due to its high solubility, releases calcium in the groundwater (according to our measurements not in streams), resulting in quite a high hardness. Finally, the Bishnumati merges with the Baghmati in the Kalimati formation, made of clay, that sometimes is calcareous with phosphate minerals, slightly elevating phosphate concentrations.

7.1.4 Dhobi

The source area of the Dhobi river is located in Sheopuri gneiss. This high-grade metamorphic rock is tough to weather, and therefore, the EC and hardness here are relatively low compared to other parts of the valley. The stream travels only a small distance through quarternary alluvial fan deposits, which, considering the fact this sediment is rather young and since they are directly downstream of the gneiss region, will probably hardly leave any chemical traces in the water either. The final part of its flow path continues through the Gokarna formation, which is made of sand and sometimes silt but doesn't seem to influence the chemical composition of the water flowing in and over it.

7.1.5 Godawari

Clayey and marly slate and calc-phyllite can be found in the source area of the Godavari. A little further towards the centre of the valley, the stream drains the Chandragiri limestone, which naturally increases the hardness of the groundwater as indicated by interpolation maps for wells (surprisingly not for spouts), and an alluvial fan deposit area. Presumably, the spouts get their water from a deeper aquifer, with different geological properties, than the wells. However, in its downstream half, the Godawari flows through Kalimati clay (sometimes containing calcareous and phosphate minerals) and finally ends up in the Hanumante.

7.1.6 Hanumante

The Hanumante river's most upstream area is mostly covered with Kulekhani formation quartzite and schist. Some small side streams originate on the Markhu marble, schist and granite and a few others on Tistung sandstone, siltstone, and phyllite. All of them are very unlikely to be the source of the high phosphate concentrations in the different water sources of the region. Over a small stretch, the river flows through sand and sometimes silt of the Gokarna formation. Afterwards, it's road continues over the Kalimati formation's clay, which contains irregularly patches of calcareous and phosphate minerals, which is reflected in water composition.

7.1.7 Nakkhu

In the most upstream part of the Nakkhu river, Tistung sand and siltstone with phyllite ca be found. A relatively large side stream flows through Chandragiri limestone and Kobgoan sand (with clay, silt and gravel). A little more downstream the river travels over silty, sandy gravel from the Chapagoan formation, and later over Likundol sandy, clayey silt with carbonaceous gravel. Finally, just before draining into the Baghmati, the clays of the Kalimati formation (which can be containing calcareous and phosphate minerals), are crossed. Except for the Chandragiri limestone and Kalimati clays, none of the lithologies in this subbasin seems to affect the chemical parameters we measured.

7.2 Conclusion

Geology only seems to affect the hardness and EC to a certain extent. The more limestone rocks were present in our measurement areas, the higher the values of these parameters were. Striking is the fact that often the EC and hardness did not seem to correlate, even not within only the groundwater sources (spouts and wells), which should both display more or less the same values, considering the fact they probably originate from the same aquifer when they are located close to each other. This discrepancy is an indicator for local (point) pollution from the surface or that the hypothesis, of a similar groundwater source for wells and spouts, is false. Phosphate concentrations seem to be slightly increased by the Kalimati formation but are mainly influenced by pollution from above (agriculture and urban). Iron, turbidity, nitrate and nitrite did not display any correlation with the present geologies.

8 | Groundwater Recharge

As mentioned in the introduction, in recent years, the groundwater depletion in the Kathmandu Valley has increased significantly. One of the leading causes of the groundwater depletion in the shallow aquifer is the use of groundwater wells, which are located in backyards of a lot of Nepalese houses. They use it for almost everything, except as drinking water. Because wells are directly in contact with the shallow aquifer groundwater table, measuring the depth of wells is an easy way to gain knowledge about the well. As explained, the groundwater table gets depleted by the extraction of water from the ground through, for example, the use of wells. During the monsoon, the groundwater level gets recharged with precipitation. Unfortunately, because of urbanisation, more and more land surfaces get paved, which makes direct recharge of the groundwater table increasingly more difficult in the future. This situation is the reason why it is essential to monitor the groundwater level and to see how the groundwater level recharges and what the impact of the land-use is on recharge. This information can also be relevant in making decisions about groundwater management in the future.

8.1 Methods and Materials

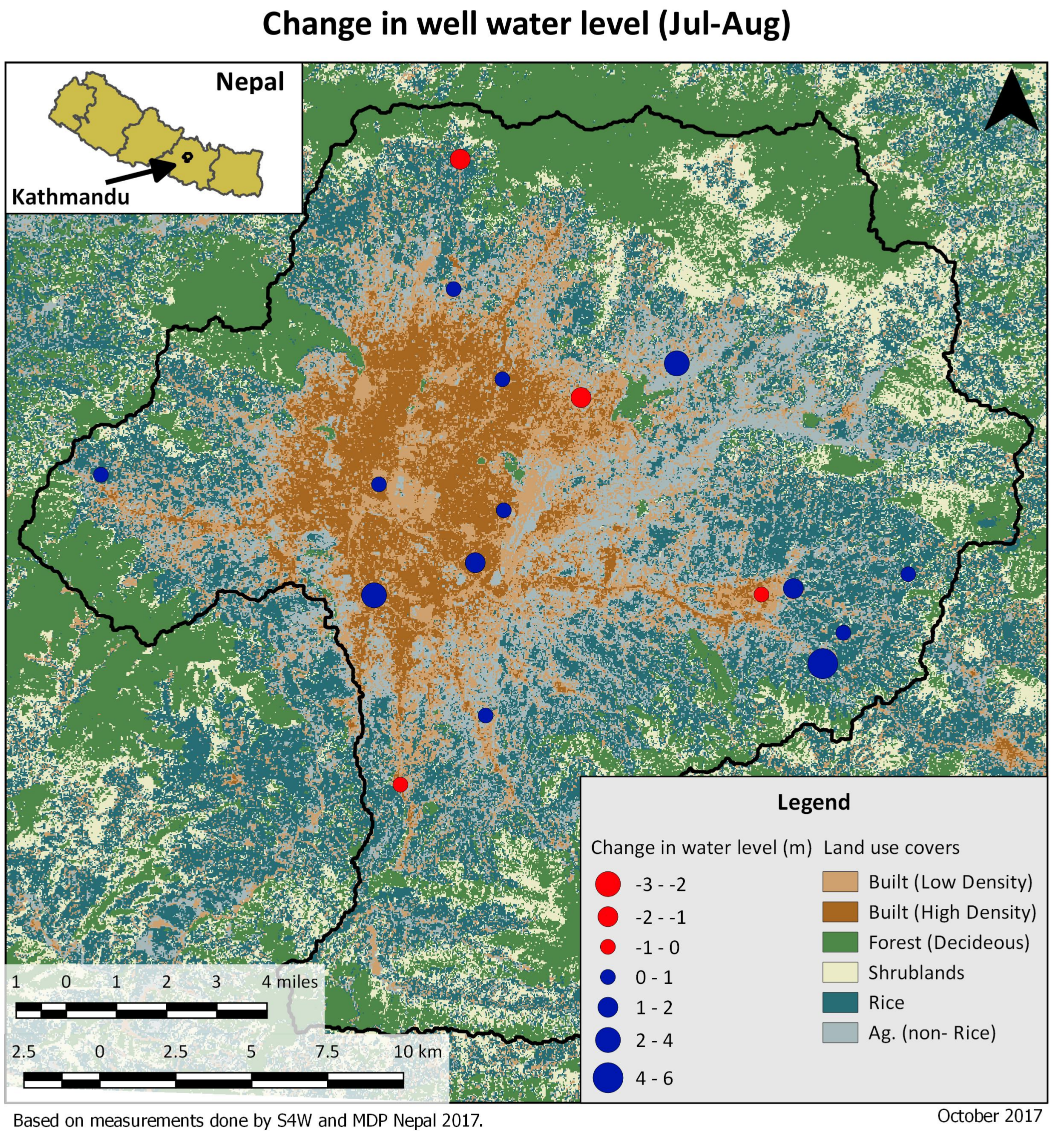
First, a map was made of all the wells in the Kathmandu Valley, and 23 wells were selected that had a proper spatial distribution over the valley. To see what the recharge or depletion was in the pre-monsoon, monsoon and just after the monsoon of 2017, water tables were measured in September. Furthermore, data of the water depth in wells were available for July and August from the Smartphones4Water database (not all wells were measured before, or in July or August, those wells had to be excluded from the research, having a total of 18 wells to compare in the end). Wells were measured with a multi-meter, of which the usage is explained below. From the water table depths of July, August and September the water height difference (hereafter mentioned as Δh) for July-August and August-September could be calculated. These Δ h values were then put on a land-use map, to see if there was a clear connection between land-use and Δ h. To see if there is a significant relationship between the water table depth fluctuation (Δ h) during the monsoon and the land-use types, ultimately a correlation matrix was made.

To measure the water level for streams and wells, two different methods are used. For the wells, a 30 m long measuring tape is used in combination with a multimeter. Most wells are too deep, to see the tip of the measurement lint touching the water. To increase the accuracy, the multimeter is used. The multimeter will start giving a value the moment the sensor reaches the water, giving the depth of the well. The sensor can tell it touched the water because the water has a higher conductivity than the air above it and this difference is measured. In streams, the water level can easily be measured with a staff gauge, for which the water level is read off where the water touches the staff gauges.

8.2 Results

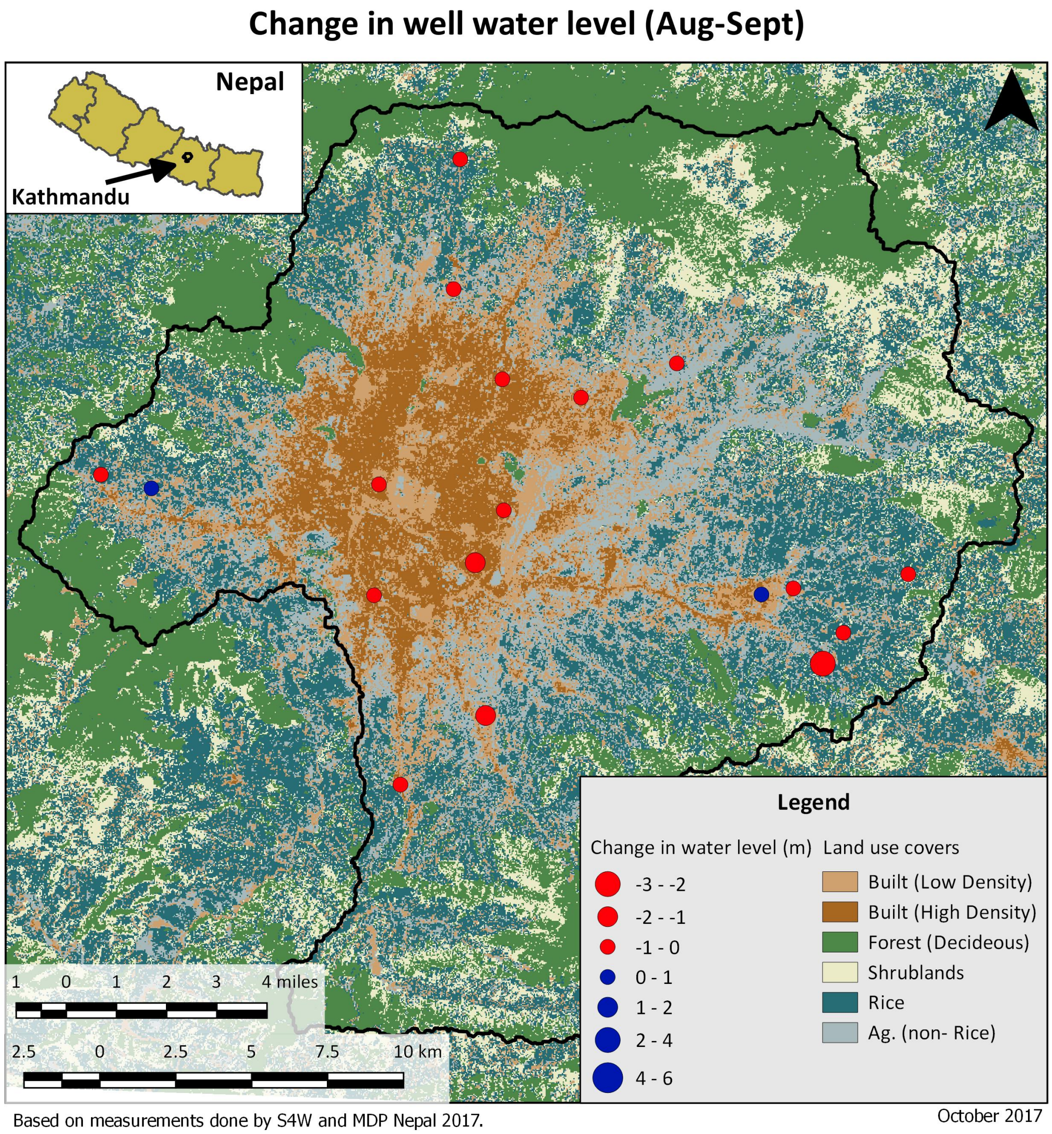
With the collected data of September and the data extracted from the Smartphones4Water database for July and August, delta h was calculated, as can be seen in 14.10. The Δ h for July-August and August-September were transferred in a QGIS map to give the results a background of land-use, as can be seen in Figure 8.1 and Figure 8.2. In the maps, recharge is given by blue dots, and depletion is showed by the use of red dots. The bigger the dots, the bigger the recharge/depletion.

Figure 8.1: land-use - Water depth change July - August



In 8.1, it can be seen that the dots are mostly blue, which means that in those months recharge of the aquifers occurred. Although the spatial distribution of the wells covers all the land-use types, from this map it cannot be concluded if the land-use has a significant impact on the water table fluctuation.

Figure 8.2: land-use - Water depth change August - September



In 8.2, the dots were mostly red, which means depletion of the groundwater table was happening in these months. Again, it cannot be concluded from this map if the land-use has a significant impact on the water table fluctuation. Therefore, a correlation matrix was made of the whole period of July - September and the land-use of Kathmandu Valley Table 8.1.

Recharge in wells						
	Built [(Low Density)]	Built [High Density]	Forest [(Decideous)]	Shrublands	Rice	Ag. [non-Rice]
Delta H	-0.200	0.084	-0.375	-0.250	0.031	0.312
Delta H	NS	NS	NS	NS	NS	NS

Table 8.1: The correlation between land-uses and recharge during the monsoon
$[HS >= |0.725| > MS >= |0.606| > LS >= |0.482|, NS(NoSignificance) > |0.000|, n = 17]$

The land-use-Δh correlation matrix shows that there is no significant correlation between land-use and Δh.

8.3 Discussion

The results of the research showed no correlation between Δh and land-use, although this correlation was expected, since the ongoing trend of urbanisation results in a lot of paving, making recharge more difficult.

One of the reasons that there is no correlation can be that there were not enough measurements conducted. In the results, only 18 wells were shown, although more measurements were conducted. Reason for this is that GPS coordinates in the database from Smartphones4Water were sometimes not very accurate and therefore it was hard to find the right well. This situation leads to wrong well measurements a few times, which meant the well depth could not be compared with earlier measurements. Also, when trying to pair the well measurements, the classification was sometimes very hard. In the ODK app, it was optional to make a picture of the measurement site, but this was often not done, and therefore it is hard to entirely be sure if the right wells were compared to each other.

On the other hand, some measurements occurred that seemed to be off, but when double-checking them, they were entered in ODK in the right way. One well was measured in a time span of two days (on the 17^{th} and 18^{th} of September), and the water depth on the 18^{th} was 2 meters lower than was measured on the 17^{th} (Figure 8.3. Because the well did not have a pump, it couldn't have been a recent pumping in that well so that the aquifer might have been emptied due to a significant industry or hotel. Because it was assumed big water users like industries and hotels are pumping from the deep aquifer, this wasn't taken into account before and could have interfered with more shallow groundwater measurements.

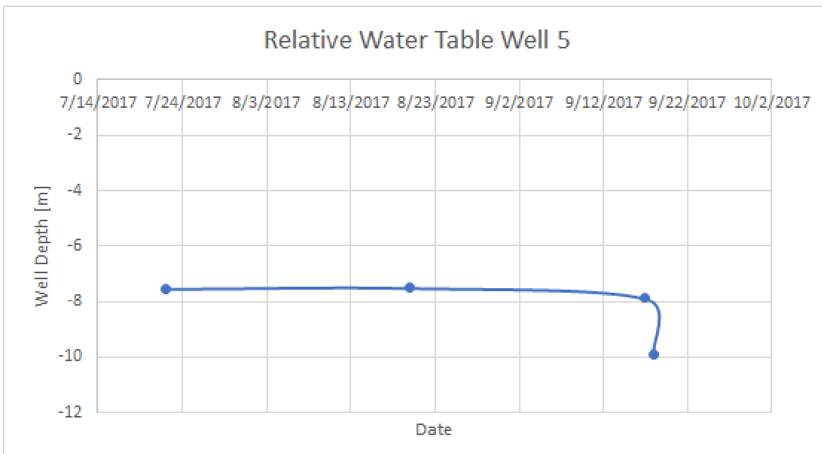


Figure 8.3: Water Table Depth Well 5

Another option to explain the absence of correlation between land-use and recharge is that the percentage of unpaved land-use in urban areas is still big enough for recharge to happen in those areas. Because the maps were showing merely blue dots in the July-August period, they show that there is recharge, matching the monsoon period and the red dots showing in August-September, match the post-monsoon period. Concluding, this can be the reason, but literature shows otherwise.

8.3.1 Uncertainty Analysis

The groundwater level was measured with the help of a simple multimeter. The moment the electrodes touch the water, the multimeter will give a value. This is the moment where the measurement tape has to be held as straight as possible, and the value for the groundwater level can be read out. The measuring tape is however never utterly straight since it is turned around the electric wires, making the measured well seem deeper than it was. Also, the reference point can be taken at different locations. The reference point has to be set relatively to the ground level. If the reference levels differ, the groundwater level will be measured and compared to a different reference point. This difference can lead to errors if you compare the data. Moreover, the moment the water is hit by the electrodes is not always very accurate since you get a different value if you pull it up then the moment it hits the water. It is therefore prone to human errors, and the equipment could be better as well. The measurements give a subtle indication, but for more accurate values a different type of material should be used.

8.4 Conclusion

What is the impact of land-use on groundwater recharge?
According to the conducted research, there is no correlation between land-use and groundwater recharge, although literature mentions otherwise. To reach a more solid conclusion in the future, regarding recharge and determining the possible correlation with land-use, a more significant sample group with consequent measurements is needed, so the measurements of wells can be paired with each other to find Δh.

9 | Quantitive Health Risk Assessment

As Paracelsus said already in the Renaissance: 'Sola dosis facit venenum' (The dose makes the poison). By this, he meant to say, that potentially every compound is venomous, as long as a person is exposed to a dose that is high enough.

In this chapter, the different health risks are evaluated, based on a comparison to the exposure, for the various water quality parameters that have been measured in the numerous rivers, wells, and spouts in the valley. First, the methods are discussed, see section 9.1, then secondly an exposure assessment is done, see section 9.2. The third part is the hazard identification, see section 9.3. The fourth part is the dose-response, see section 9.4. In section 9.5 the results are displayed and in the section after that, section 9.6, the results are discussed which lead to a conclusion which can be found in section 9.7

9.1 Methods

Risk can be defined as the result of frequency times the effect. A risk assessment process will be conducted over the water sources of the Kathmandu Valley. A standard risk assessment exists out of four basic steps. First a hazard identification, secondly an exposure assessment, thirdly a dose-response assessment and last a risk characterisation is conducted. The risk characterization is displayed in section 9.5. To quantify the risk, first, the daily exposure model will be used. If the result of this model with a parameter is positive (the acceptable daily intake is surpassed), then a dose-response will be conducted to quantify the risk further, but only if that is possible to do. The daily exposure model is defined in Equation 9.1. If the Acceptable Daily Intake (ADI) is lower than the value the people are exposed to, a higher risk than deemed acceptable by drinking water standards is reached. Both the Nepali standards and the standards of the World Health Organization will be displayed in the dose-response sections, however, for the sake of simplicity, any further analysis will be based on WHO standards only when possible.

$$RQ = \frac{ADI}{E} \tag{9.1}$$

where:

RQ = Risk Quotient [%]
ADI = Acceptable Daily Intake [mg/kg]
E = Exposure [mg/kg]

9.2 Exposure assessment

The inhabitants of the Kathmandu Valley depend for 50% of their water supply on groundwater sources (mostly wells or spouts) (Warner et al., 2007). Some people might also use surface water as the main source, but no statistics on this assumption are found. Further is sanitation and waste management non-existing in the valley (Warner et al., 2007). We assume that a lot of people drink their water unfiltered. However, some people boil their drinking water first (Warner et al., 2007) or use disinfection methods with the use of tablets or chlorine. The presence of the last two methods for preparing drinking water was derived by talking with the inhabitants of the valley. However, how many people use disinfection methods is not known, and therefore the assumption is made that most do not use it. Another assumption that is made is that all people who use the wells, spouts or rivers as a water source for drinking water only depend on one particular source. Another main assumption is that adults drink 2 litres every day and that infants drink 0.75 litres every day. This assumption is based on the guidelines of the World Health Organization (Speijers & Fawell, 2011).

9.3 Hazard identification

9.3.1 Nitrite and Nitrate

As told in section 5.1.1, nitrate ($N0_3^-$) and nitrite ($N0_2^-$) are two ions that naturally occur in nature and are part of the famous nitrogen cycle. Nitrate is a stable form of a combined nitrogen while nitrite exists in a more unstable oxidation state. In this unstable form, it can easily be oxidised to nitrate, or it can be further reduced by chemical or biological processes. Nitrate can also be reduced, although it is chemically more difficult to do so(Speijers & Fawell, 2011). Nitrate is mainly used in inorganic fertilisers, but also in explosives or glass making. Nitrite is used as sodium nitrite as food preservers. As told in Table 5.1.1 nitrates also occur naturally in plants. Plants naturally absorb them for their growth. A surplus of nitrate in groundwater and surface can occur because of the presence of fertilisers and manure. A surplus can happen by mismanagement of farmers or the absence of sewer treatment. Also, mismanagement of septic tanks (leakage or overflowing) can provide a surplus of nitrogen in the environment. A surplus of nitrate can easily move with the flow of the groundwater which enables a larger pollution potential (van Duijvenboden & Loch, 1983; USEPA, 1987).

Since a lot of the residents don't use any water treatment, see (Warner et al., 2007), they can be exposed to this surplus nitrate. A surplus can be very hazardous. However, the element nitrate itself is harmless, but nitrate is reduced to nitrite in the body. The nitrite is decreased further to N-nitroso compounds (NOCs) which are widely considered to be carcinogenic. Nitrite is therefore also deemed to be more dangerous. Multiple studies have concluded that an overdose of nitrate and nitrite can lead to congenital disabilities, bladder cancer or thyroid cancer (IEC, n.d.), but it can also cause methemoglobinemia, also known as the blue-baby syndrome. This disease causes that the red blood cells lose the capacity to transport oxygen, which can slowly lead to suffocation (IEC, n.d.; Speijers & Fawell, 2011).

9.3.2 Phosphate

High concentrations of nutrients like phosphate in the water result in eutrophication, which is characterised by an algae bloom. Some blooms are created by cyanobacteria, a type of bacterium that carries out photosynthesis (Paerl et al., 2011). Cyanobacteria can produce toxins, which can be harmful to human health. Those effects will however not be discussed in further detail in this section, as they are indirect and depend on the presence of a special type of algae that form and not solely on the phosphate concentration.

No direct health risks are known for phosphate ions. Phosphates are not toxic to people or animals unless they are present at very high levels. The digestive problem could occur from extremely high levels of phosphate (Kumar & Puri, 2012).There is, however, information about the health risks formed by phosphorus, one of the constituents of phosphate together with oxygen. Phosphorus is present in every body cell. This mineral is a structural component of bones and plays a vital role in energy production and storage in the body. Moreover, it functions as a building block for numerous enzymes and hormones (WHO, 2005). Since phosphorus is present in many food products, a phosphorus deficiency is very rare. When high-dose calcium supplements are taken, however, all the phosphorus people receive through their food may be bound and hence unavailable for absorption (Heaney, 2004), leading to osteoporosis.Studies do yet confirm that high phosphorus intake in combination with low calcium intake, which occurs primarily in senior women, can also form a risk to develop osteoporosis (Calvo, 1994). People with osteoporosis experience a decrease in the density of bone, decreasing its strength. This condition is getting more prevalent in society because of the growing use of phosphorus-containing food additives. Although phosphorus is an essential nutrient, in excess it could be linked to tissue damage, renal failure, cardiovascular diseases, and osteoporosis (Calvo & Uribarri, 2013). An excess phosphorus intake can also impede the absorption of iron, copper and zinc by the body (VIB, 2015).

9.3.3 Hardness

As has been said in Figure 5.1.1, hardness expresses the capacity of water to react with soap. Hardness is a summation of different dissolved polyvalent metallic ions like calcium, magnesium, aluminium, barium, iron, manganese, strontium and zinc, but it is expressed most of the time as calcium carbonate(WHO, 2011). Groundwater can usually have a high hardness since the water has been in contact with a lot of minerals, concentrations higher than 100 mg/l can be found (60 mg/l is considered soft; 60-120 mg/l moderately hard; higher is considered very hard (McGowan, 2000))

People are daily exposed to calcium and magnesium. Most exposure occurs when food is consumed. The dietary intake is a contribution of more than 80 % of calcium and magnesium. However, only 30% of the calcium and 35% of the magnesium is absorbed by the body. The daily intake of calcium and magnesium by water is between 5-20%. Is this directly dangerous? No, both calcium and magnesium are essential minerals for the human body and health. Of course, there are health hazards, but most of them occur with an inadequate intake (WHO, 2011).

However, there are also some cases known of adverse health effects when an overdose of one of these minerals occurs. Hypermagnesaemia is one of the adverse health effects that can happen when an overdose of magnesium occurs. Neuromuscular symptoms (muscle weakness etc.) is one of them, but also the loss of blood pressure, a decrease of certain hormones, shortness of breath, nausea, vomiting and cutaneous flushing can be observed by a person with Hypermagnesaemia. However, with a good functional liver, the excess magnesium is eliminated immediately (Tibor, 2017). Acute myocardial infarction is another possibility, but no association between drinking water rich in magnesium and acute myocardial infarction has been found. Other studies can be found about health hazard with excesses intake but in none a correlation between hard water and these health hazards where found (WHO, 2011).

9.3.4 Turbidity

As has been told in subsection 5.1.7, turbidity is a useful indicator for the presence of pollutants in the water. People can see turbidity only when the NTU (unit of turbidity) level is higher than four. Turbidity is caused by suspended chemical and biological particles, this can be sediment particles (clay, sand etc.), but on these sediments bacteria or viruses could be found. Therefore it can be used as a convenient indicator of the quality of the drinking water since it is easy to measure, but turbidity itself does not present a danger to the public health (WHO, 2017). One could argue, when a presence of a lot of pollutants is found, one can be sure that the water has a high turbidity, but when the water has a high turbidity, one doesn't know which pollutants one will find. Therefore it is very difficult to impossible to quantify health risks that correlate to the level of NTU. It should also be noted that raw water with a low turbidity does not direct have any health hazards. The only thing one can be sure is that if one lowers the turbidity of the water during the treatment process, the pathogens are probably removed from the water, but did doesn't mean that no pathogens remain in the water(WHO, 2017).

9.3.5 Iron

Iron is an essential element in human nutrition. The daily requirement for iron varies between 10 to 50 mg/day (WHO, 2008). Iron is one of the building blocks for the formation of the protein haemoglobin, which transports oxygen within the body. Moreover, iron fulfils a critical function in cellular metabolism and is needed for the construction of enzymes. Low iron stores in the body can result in iron deficiency, anaemia and can make a person more susceptible to infections (Garvin, 2015). One should however not depend solely on the iron in drinking water as the only source of iron in one's diet. This amount of iron can quickly be consumed by merely eating green vegetables.

Although iron deficiency is a common problem for human health, high levels of iron in drinking water can cause adverse health effects. When large amounts of iron are ingested chronically, a medical condition called iron overload can be created. Iron overload is linked to a mutation in the C282Y gene. This mutation most often occurs in Caucasian people (As et al., 2005). When this mutation is left untreated, iron overload can lead to hemochromatosis, a severe disease that can damage organs in the human body and can eventually lead to heart disease, liver problems and diabetes before clinical symptoms develop Garvin (2015). When detected, the consequences of iron toxicity can be attenuated or prevented (Fleming & Ponka, 2012). Unfortunately, no articles have been found that discuss a safe daily intake of iron to prevent iron overload from developing. There is, however, information on the average lethal dose of iron in humans. This dose is between 200–250 mg/kg of body weight, but there are cases known that resulted in death after ingestion of doses as low as 40 mg/kg of body weight (National Research Council (NRC), 1979).

9.3.6 Escherichia coli

Coliform bacteria like E. coli are hard to detect since they have no taste, smell or colour (*Facts on drinking water, coliform bacteria - Total coliforms & E. coli*, n.d.). E. coli is the only bacteria from the total coliform group that is found only in the intentions of mammals. Due to this, E. coli is as mentioned in subsection 5.1.2 a good indicator of faecal contamination in water due to human sewage or animal droppings (*Total, Fecal & E. coli Bacteria in Groundwater*, 2007). E. coli itself doesn't cause illness but can cause infection in the gastrointestinal tract area, leading to nausea, vomiting, diarrhoea and fever. E. coli only causes illness when it gets into the blood or the kidneys, and this is called E. coli poisoning (Rock & Rivera, 2014). The most harmful E. coli strains can be found in Table 9.1. The most significant health risk is, however, not the E. coli itself but are other pathogens that can be detected in the faecal of mammals that can be transported through the water.

Strains of E. coli	Modes of Transmission	Disease
Enterotoxigenic (ETEC)	Food of water ingestion	Diarrhea (common in infants and travellers)
Enteropathogenic (EPEC)	Food or water ingestion, direct and indirect human contact	Watery/bloody diarrhea (common infantile in underdeveloped countries)
Enterohemorragic (EHEC)	Food/ingestion, direct or indirect human contact	Bloody diarrhea, possible damage kidneys and progress to fatal hemolytic uremic syndrome (HUS).
Enteroinvasive (EIEC)	Food and water ingestion	Watery, dysentery like diarrhea and fever.

Table 9.1: Harmfull E. coli strains (Rock & Rivera, 2014)

9.4 Dose Response/WHO Standards

9.4.1 Nitrate and Nitrite

Both the Nepali standard and the WHO standard guidelines for nitrate are set at 50 mg/l in drinking water. This guideline is based on evidence for methemoglobinemia in infants (Speijers & Fawell, 2011; WEPA, 2008). However, multiple studies have concluded that adverse effects can be observed at lower concentrations:

- Women who are drinking water with a concentration of 3.5 mg/l or greater are 1.9 times more likely to have an NTD-affected pregnancy than women exposed to lower levels of nitrate in their water (Brender et al., 2004).
- People exposed to concentrations of 5 mg/l of nitrate or higher for more than four years had a higher prevalence of bladder cancer (Jones & Dellavalle, 2016).
- At nitrate concentrations of 2.46 mg/l or greater, it was found that woman had three times more likely chance to develop bladder cancer (Weyer et al., 2001)

Many more comparable studies can be found. However, the question that arises is how reliable are these studies. Did they just found a correlation based on the geographical location where the study was conducted or is there a real correlation? It should be noted that the EU and the Dutch government hold up the same guideline for nitrate for drinking water as the WHO (*Drinkwaterbesluit*, 2015; *Council directive 98/83/EC*, 1998).Thus, the maximum nitrate concentration for drinking water consumption is 50 mg/l

The WHO standard instruction for nitrite of 3 mg/l is based on data showing that methemoglobinemia in infants when they are exposed to nitrite in the range of 0.4 to more than 200 mg/kg of body weight. When assumed that an infant drinks 0.75 litres of water and has a mass of 5 kg, a guideline of 3 mg/l can be derived.

9.4.2 Phosphate

Official maximum allowable intakes of phosphate have not been found in the WHO database, nor in the Nepalese drinking water guidelines. However, compounds containing phosphate, like the pesticide glyphosate, do have ADI's, but since we did not measure concentrations of those chemicals in the water ourselves, we leave those out of our analysis.

Since there is no official WHO guideline for phosphate in drinking water, we calculated the maximum allowable intake based on the ADI of phosphorus, because for that compound an upper limit of daily dietary intakes is established (WHO, 2005). For children till the age of 8, this restriction was the lowest, namely 3000 mg per day. For older people, a maximum of 4000 mg per day was established. This maximum is equal to the amount of phosphorus in two kilos of meat or four kilos of spinach (VIB, 2015). Based on differences in molecular and atomic weight, 3000 mg of phosphorus is equal to 9200 mg of phosphate per day. The majority of people consume most phosphorus through food, meaning that only a small amount of the acceptable daily intake should be 'reserved' for consumption via drinking water (NRCSDW, 1980), however, not a single article quantified how much on average people consumes via drinking water. Concentrations in food, however, are in general considerably higher than in water (NRCSDW, 1980). When we assume that people typically consume no more than 3% of their daily phosphorus intake via 2 litres of drinking water, that means that the maximum allowable concentration of phosphate in drinking water is 138 mg/l.

9.4.3 Hardness

The World Health Organization has the following conclusion about hardness in drinking water: "Although there is some evidence from epidemiological studies for a protective effect of magnesium or hardness on cardiovascular mortality, the evidence is being debated and does not prove causality. Further studies are being conducted. There are insufficient data to suggest either minimum or maximum concentrations of minerals all this time, and so no guideline values are proposed"(WHO, 2011).Therefore there is no dose-response or WHO standard guideline to do a health assessment. According to the Nepalese guidelines, however, the hardness shouldn't be higher than 500 mg/l (WEPA, 2008).

9.4.4 Turbidity

The WHO has the following to say about turbidity and diseases:
"Achieving low turbidities in drinking-water is a proven indicator of pathogen removal and hence of drinking-water safety. Incidents of elevated turbidity have been associated with several outbreaks of disease. However, a directly proportional relationship between removal of turbidity and pathogens has not been demonstrated. Similarly, investigations of potential links between levels of turbidity in drinking-water and rates of endemic gastrointestinal disease in communities have produced mixed results. Some studies have reported a relationship between turbidity and endemic disease, but others have not; thus, although correlations may exist in individual drinking-water supplies, a uniform relationship has not been established" (WHO, 2017).

The WHO does not have direct standards, but it says that ideally drinking water should have a turbidity of an NTU lower than one (WHO, 2017). Nepali standards are less strict, with a maximum of 5 NTU (WEPA, 2008). Therefore this standard will be upheld. However, this doesn't mean that there is no risk with water sources where the turbidity is lower than one. The only thing one probably can say about it is that there perhaps fewer pollutants present in the water source.

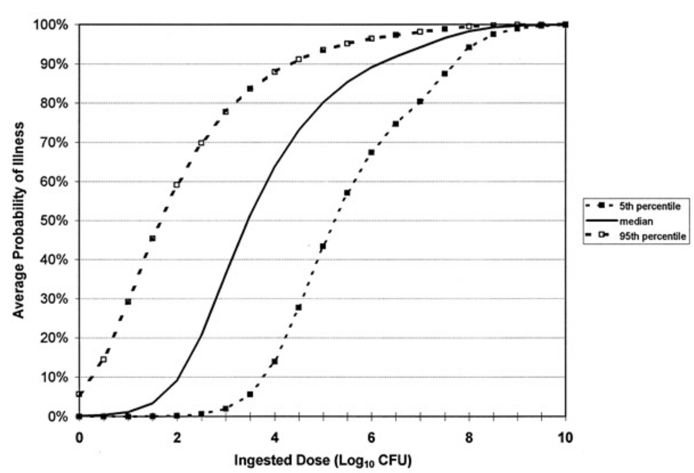
9.4.5 Iron

Studies on the acceptable daily intake (ADI) of iron are unknown. Finch & Monsen (1972) found that an intake of 0.4–1 mg/kg of body weight per day is unlikely to cause adverse effects in healthy people. An expert panel of the FAO/WHO Expert Committee on Food Additives (1983) opted an ADI of 0.8mg/kg of body weight as a precaution against storage of excessive iron in the body. Allocation of 10% ADI to drinking water gives an acceptable value of about 2 mg/litre for a person of 50 kg who drinks two litres of water a day. Nepali standards are set at 3 mg/l (WEPA, 2008). This intake does not present a hazard to health. The taste and appearance of drinking water will usually be affected below this level, what hopefully will alert people and will trigger them to look for better wells to extract their drinking water.

9.4.6 E.coli

As can be seen in Figure 9.1, half of the people had 0% chance of getting sick until a dose of 10 CFU. At that same dose, 5% of the people already experience an average probability of illness of 30%. Only after ingesting around 1 billion CFU, 100% of the people are projected to become ill for sure. The presence of E. coli is undesirable, first of all, because at a low dose (10 CFU) is causing a considerable chance (30%) of getting sick in the 5% (mostly weak) people in the population. Secondly, no E. coli should be tolerated, because it is an indicator for other forms of faecal microbiological contamination, which can have way more severe effects than E.coli itself. Therefore, both the WHO (1971) and the Nepalese standards (WEPA, 2008) stated that no concentration of E. coli, higher than 0 CFU/100ml should be allowed in drinking water.

Figure 9.1: The Binomial dose–response model for E. coli is shown. Uncertainty in average probability of illness vs. ingested dose of E. coli. Cassin et al. (1998).



9.5 Results Health Risks

In this section, the results of the Health Risk Assessment will be displayed for each researched parameter.

9.5.1 Nitrate and Nitrite

Since none of the measured values of nitrate and nitrite is above the WHO standard, the risks do not exceed the acceptable level as stated by the WHO.

9.5.2 Phosphate

None of the phosphate values measured in the valley was higher than 138 mg/l (see, Figure 5.16).Therefore, we do not consider phosphate to cause unacceptable health risks in this area.

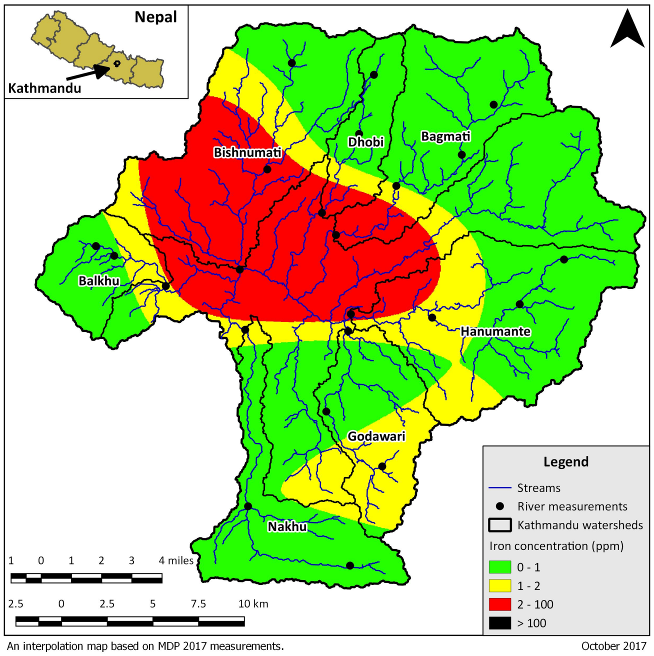
9.5.3 Hardness

Since there are no standards set by the WHO considering hardness in drinking water, health hazards caused by this parameter can only be tested using the Nepali standards. It was found that nowhere in the valley the hardness concentration exceeded the guideline of 500 mg/l, meaning that no unacceptable health risk is imposed on the inhabitants of the valley through high calcium and magnesium concentrations.

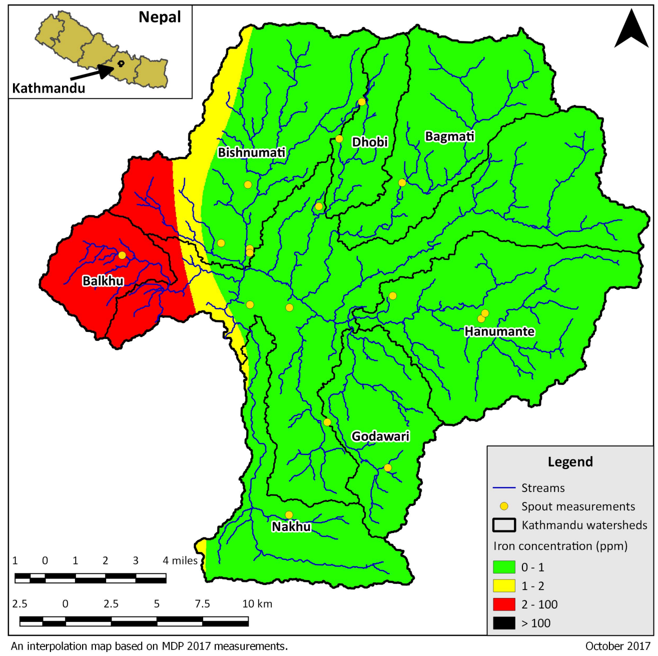
9.5.4 Iron

In none of the sources, the lethal dose of iron will be reached via drinking 2 litres of water a day. In the mid-west of the Kathmandu catchment, however, the rivers are containing a concentration which can cause severe adverse health effects. The spouts in the western Balkhu region seem to be polluted to an unhealthy extent as well. The wells contain slightly elevated iron values (1-2 mg/l) only in the Bishnumati catchment, but overall the concentrations in this type of source remain under the WHO standard.

Iron levels in Kathmandu valley rivers



Iron levels in Kathmandu valley spouts



Iron levels in Kathmandu valley wells

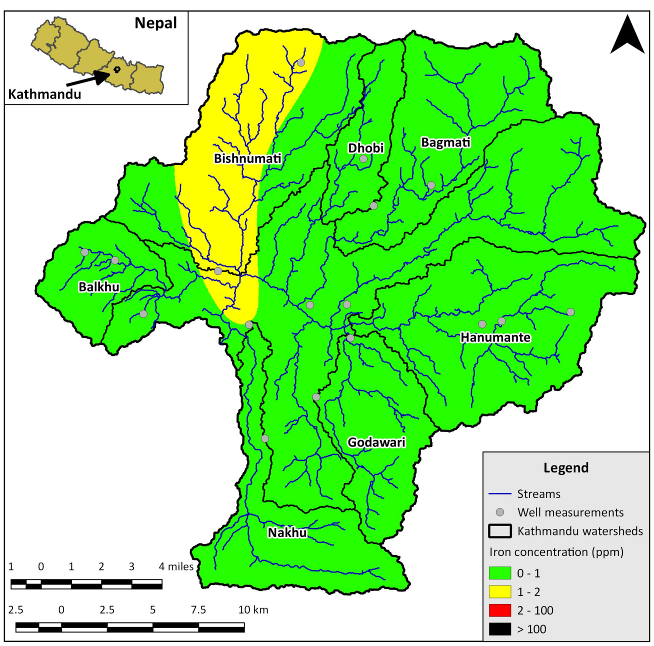


Figure 9.2: Risk analysis of iron in wells, rivers and spouts. Data is based on interpolation results.

9.5.5 Turbidity

As can be seen in Figure 9.3, the turbidity in almost all rivers doesn't comply with the ideal turbidity for drinking water and has, therefore, an RQ value higher than one. Half of the wells and spouts has an RQ lower than one. A curious observation is that the area where the RQ for wells is smaller than one, the RQ of the spouts is almost higher than one.

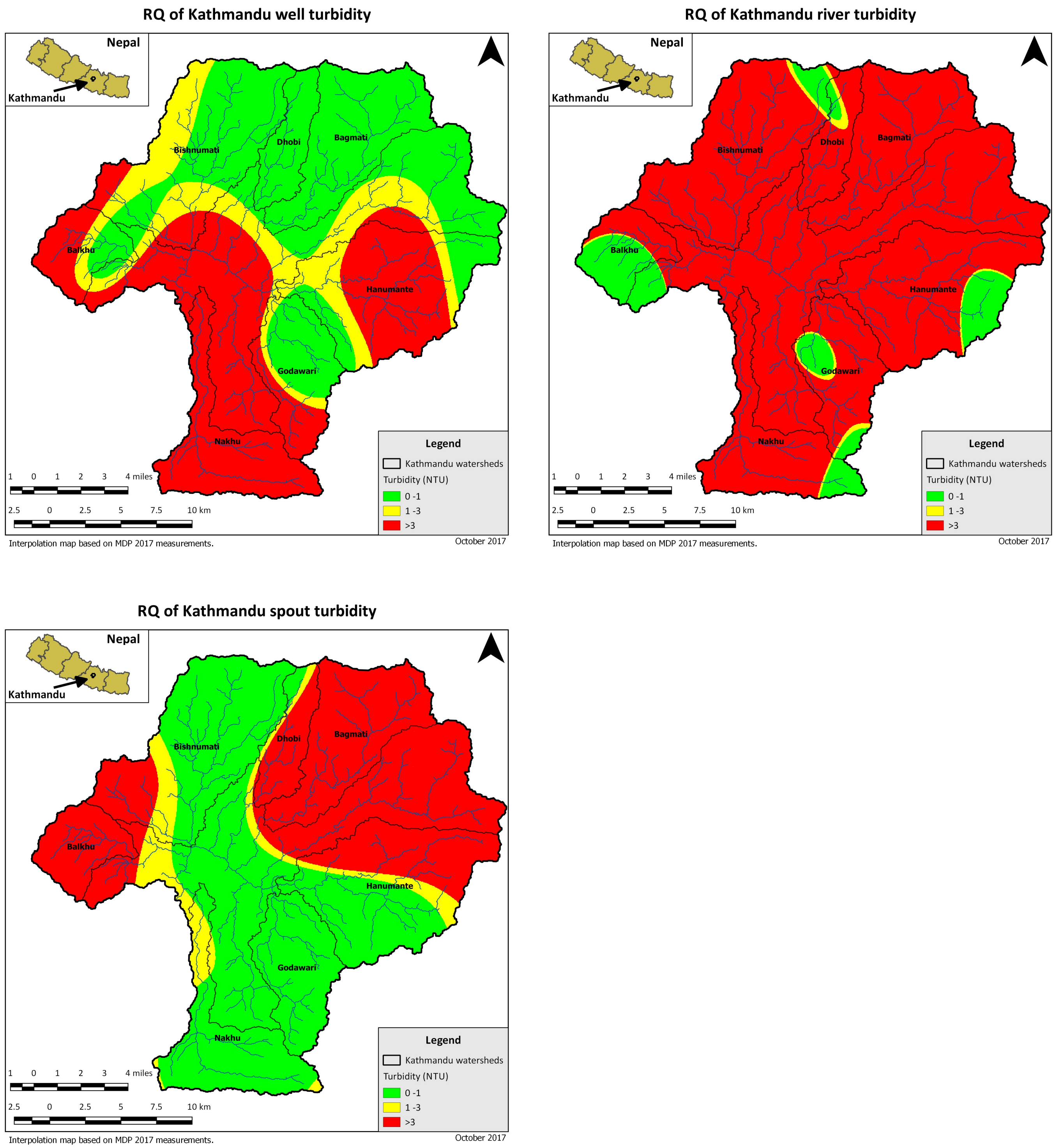
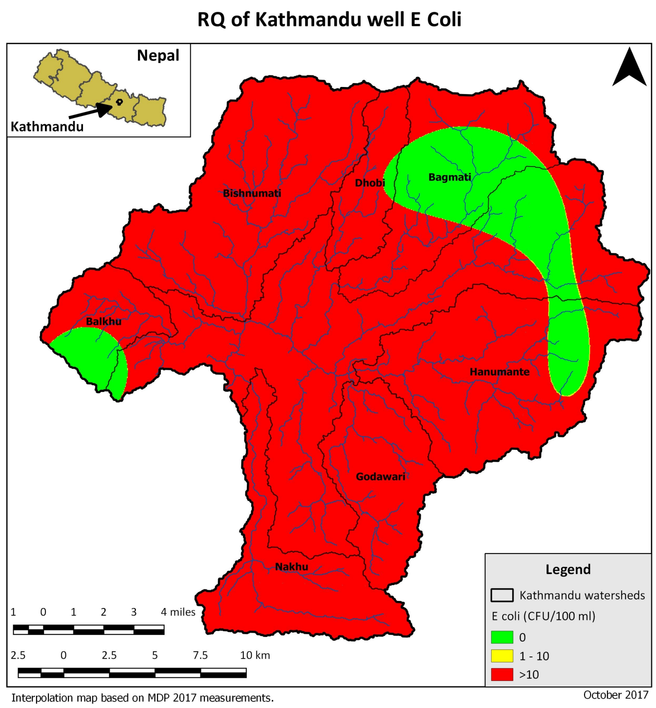
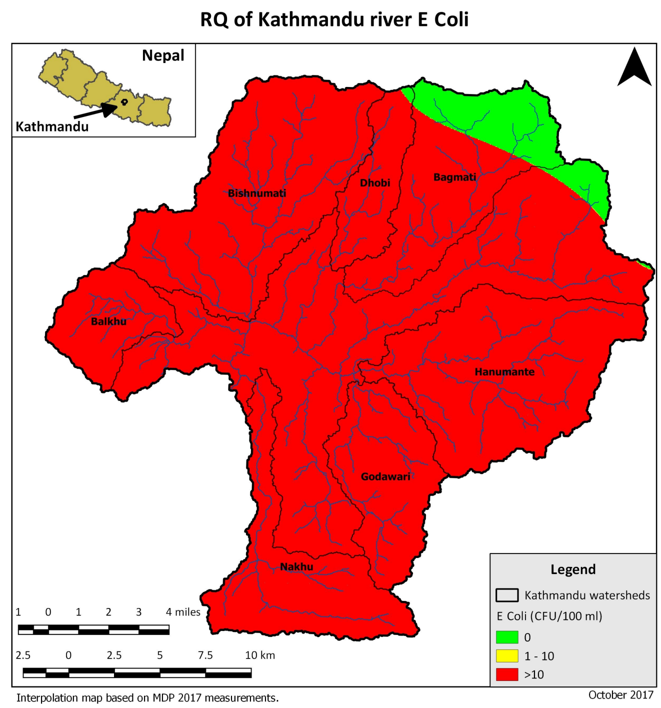


Figure 9.3: Risk analysis of the turbidity's in wells, rivers and spouts. Data is based on interpolation results.

9.5.6 Risk Analysis Results: E. coli

Only four wells in the valley did not contain E. coli. The interpolation maps based on the measurements did result in the maps displayed below. All sites with an (interpolated) value of more than 0 colony-forming units per 100 ml are shown as red. Wells in the upstream area of the Bagmati, Hanumate and Balkhu rivers are E. coli free. Of all streams, only the most upstream part of the Bagmati is not contaminated with faecal matter, and just the spouts in the east of the valley and the middle (in the urban centre of Kathmandu) are not exceeding the WHO standard.





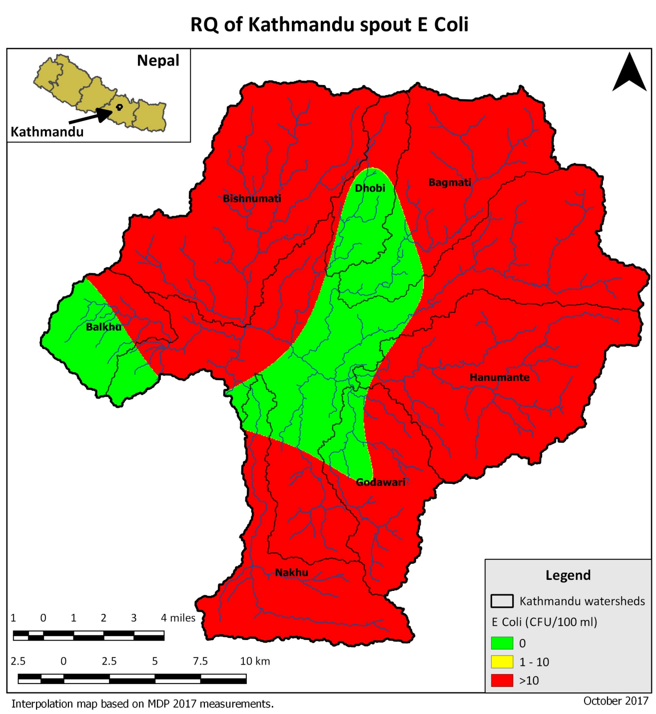


Figure 9.4: Risk analysis of the E. coli. in wells, rivers and spouts. Data is based on interpolation results.

9.6 Discussion Health Risks

The only parameters that can create a health hazard in the Kathmandu Valley are the turbidity, iron and E. coli. Of these three water sources, especially the rivers are the most significant threat to human health. The probable cause for this is that surface water is easier polluted than groundwater. Therefore, people should never use surface water as drinking water without advanced treatment.

The spouts and wells in the valley seem to because of lesser health risks in general, but it depends on the location of the well or spout how significant the risk is. A curious observation is that at a lot of places where a well contains unacceptable pollution levels for human consumption, the spout usable and reverse. Luckily, this provides people with the possibility to take water from a nearby good source, giving them a choice. However, it is always advised to boil the water to get rid of the biological pollutants, as at almost every location the E. coli count is too high for safe drinking water consumption. There were some locations where E. coli was absent, but these were very rare. Based on the measured iron, the Balkhu and Bishnumati watersheds and Kathmandu City have spouts and wells that are not suitable for consumption.

There are a lot more pollutants out there that could pose a risk to human health, but unfortunately, we didn't have the means to measure them. Calculating the real health risk is, therefore, difficult, but one can theorise that inhabitants who live not in rural areas or the Balkhu watershed, can probably safely use the wells and spouts as a source of drinking water as long as they boil the water or/and disinfect it. To answer the question if the treatment had any effect, they could measure the change in turbidity with the help of a turbidity tube as an example. If the turbidity has decreased, you can safely assume that also fewer pollutants are present. However, to quantify a number of contaminants still present is impossible with the use of turbidity tubes. Inhabitants of rural areas can also better not drink the water directly from spouts or wells without any proper treatment, mainly since there can be a great risk for biological pollutants, but also chemical contaminants can have an abundant presence here. They can better not rely on local ground or surface water for human consumption without any advanced treatment.

A side note is that the wells which were measured in this research, probably aren't fueled by a deep water aquifer. For wells which have a very deep water aquifer as a source, the situation could be different.

9.7 Conclusion Health Risk

Measured values for nitrate, nitrite and phosphate did not exceed the WHO standard. Consequently, there is no direct concern about them posing a health risk for human beings. The turbidity in most of the measured rivers does not comply with the standards for drinking water quality, however. Turbidity in wells located in the Nakkhu and Hanumante watersheds and spouts in the Balkhu, Dhobi and upper Bagmati watersheds does not comply with the drinking water standards either. In most of the valley, the iron concentration in the water sources is acceptable and non-threatening for human health. The wells contain slightly, elevated iron values in the Bishnumati catchment only. In the mid-west of the catchment, the rivers are containing a concentration which can cause adverse health effects and spouts in the western Balkhu region seem to be polluted to an unhealthy extent as well. In most areas of the valley, it is unsafe to drink water from rivers, wells and even spouts, based on the faecal pollution that is indicated by the presence of E. coli. The more upstream the site is located, the larger the chance that the water is uncontaminated. However, in the city centre of Kathmandu, most spouts can be considered micro-biologically safe as well. Overall, it is advised that people do not consume water from spouts and wells unless they use some form of barrier or at least first boil it to get rid of the biological pollutants.

10 | Capitalizing on Global Precipitation Measurement mission's data

10.1 Introduction

Comprehensive information about precipitation in Nepal and specifically in the Kathmandu Valley is very scarce. Smartphones4Water set to fill in that void by implementing citizen science to create a grid of continuous precipitation measurements. These citizen science measurements give a great spatial distribution of rainfall. The only drawback of having people manually collecting data as a side activity means that the temporal resolution is coarse (minimum one day). Our goal is to improve that temporal resolution by researching whether satellite precipitation data correlate to ground measurements and if they do, then employ them to sharpen the temporal resolution of citizen science measurements. The satellite measurements, for which in this case GPM is used, lag behind the respective ground measurements but offer a uniform data source over large areas. Consequently, a perfect match between satellite and ground measurement data is a far-fetched expectation. GPM data are very coarse, but the data are available in different temporal resolutions with a minimum of 30 minutes. The goal of implementing GPM data into our project is to try and fill in the temporal and possibly spatial gaps of the citizen science measurements for July and August. The most exceptional temporal resolution logistically able to process within the given duration of the project is the 3 hours one.

10.1.1 Global Precipitation Measurement Mission

Currently, satellite-based precipitation products are based on microwave-only, calibrated infrared (IR) and microwave plus IR observations from various satellite missions using a variety of merging technology. Further advances in global precipitation product development require more accurate and more frequent microwave measurements within a unified observational framework (Hou et al., 2014). There is a wide variety of such satellite products like TRMM, GPM, METEOSAT, GSMAP, CMORPH, PERSIAN-CSS etc. Global Precipitation Measurement (GPM) constellation satellites are an international mission to provide next-generation observations of rain and snow. NASA and the Japanese Aerospace Exploration Agency (JAXA) launched the GPM Core Observatory satellite on 27 February 2014, carrying advanced instruments that will set a new standard for precipitation measurements from space. GPM offers global coverage from 60°N to 60°S which is improved compared to its predecessor's (TRMM) 37°, and it has a spatial scale of 0.1 arcsec degrees (10 x 10 km grids on Nepal latitude). The enhanced global coverage is achieved by building upon existing satellite programs and new mission opportunities from a consortium of partners (Hou et al., 2014). A primary merit of GPM's data is that they are available Near Real Time meaning they are open to the public with minimum latency. Latency is the amount of time that passes between an observation being collected by the satellite and a data product being produced. There are three flavours of IMERG, each with a different latency. These three flavours are called Early, Late, and Final and their associated latencies are approximately 6 hours, 18 hours, and four months. For this study, Late IMERG GIS files were used.

10.1.2 Ground validation of GPM data

Validation of the data collected by satellite measurements is an integral procedure to assess the quality of satellite products. It is almost always considered that the ground data represent the "truth" which is a false assumption. Ground measurements do not necessarily represent the "truth" but rather have their own set of uncertainties which have to be carefully monitored and quality controlled. The comparison of satellite estimates with rain-gauge measurements is often frustrating because satellites can attempt at best to measure rain amounts over areas many kilometres in size around a gauge, whereas rain-gauges can only record what falls in an area some tens of centimetres in diameter. However, recently released IMERG is going to reduce this sampling issue such that GPM constellation satellites will have improved spatial and temporal resolutions (Sharifi et al., 2016). In the Himalayas, precipitation varies according to a wide range of spatial scales, from small-scale ridge-valley gradients to large-scale orographic effects over the whole mountain. Ideally, the validation of any remotely sensed product from gauge stations is only possible if the resolution of the products is sufficient to take into account the scale of spatial variability of precipitation (Andermann et al., 2011).

10.2 Methods

10.2.1 GPM Analysis Method

Because the correlation of the GPM products is very coarse, the whole area of the Kathmandu Valley is represented with just six pixels. To go on with the correlation procedure, the appropriate GPM values (those at the two tipping bucket locations) from the three-hour products have to be collected and stored in a single spreadsheet. The GIS IMERG products include information about precipitation in a global scale as shown in Figure 10.1 and consequently need to be cropped to the study area to reduce computation time.

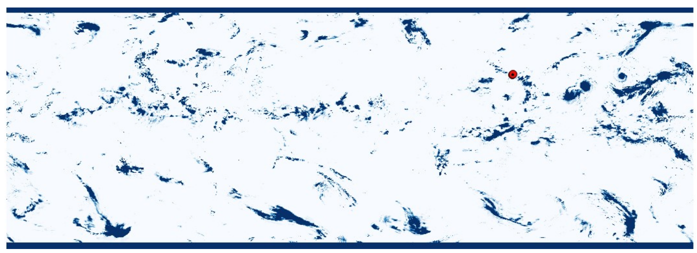


Figure 10.1: Global Precipitation

GRASS integrated QGIS was used to group the satellite data, then re-project them on the tipping bucket locations and finally extract them. A uniform temporal resolution is required to compare ground and satellite data, and as GPM's resolution cannot get sharpened to tipping bucket standards, the latter had to be downgraded to a temporal resolution of 3 hours. To facilitate the creation of TIFF (raster) files of Early or Late GIS products precipitation data are multiplied by 10 and then rounded off, meaning the units of the GIS files are 0.1 mm. It is essential to take into account the units of the GPM files and act accordingly (unit is 0.1 mm, so it needs to be divided by 10 to get the values in millimetres). Microsoft Visual Basic for Applications was employed and an algorithm was scripted to transform the tipping bucket dataset to a 3-hour time-series (subsection 14.4.2). The datasets will be evaluated by the methods of statistical analysis and dichotomous evaluation. In addition to the numerical precipitation data, the categorical data (the distribution of rainfall events) will be statistically analysed as well. For the dichotomous analysis, a contingency table will be produced.

10.2.2 Evaluation Indicators for Satellite Precipitation Products

It is essential first to correlate the GPM data with reliable ground data. A tipping bucket was installed in each of the following two locations: Bhaisepati, Lalitpur and Okhreni within Shivapuri Nagarjun National Park. Those tipping buckets record precipitation events representing 0.2 mm of precipitation. When no precipitation takes place, the tipping buckets log readings with a 15-minute timestep. The IMERG (GPM) products were acquired from the NRT PPS server of the GPM mission. The IMERG precipitation estimates were compared with the respective tipping bucket data from July 4th to August 31st 2017. The first four days of July were rejected as the available GPM data of those days were corrupt.

A comprehensive study was performed on the correlation of IMERG-GPM with the station precipitation data over the Kathmandu Valley. The timestep of the analysis was 3 hours and all recordings (zero and non-zero were taken equally into account) The three following indices were implemented for the statistical analysis:

- The Pearson correlation coefficient (CC) describes the agreement between satellite precipitation estimates and gauge observations (Equation 1). A perfect positive fit is reflected by a CC value of 1, whereas a weak linear correlation is indicated by CC that is close to zero.
- The relative bias (BIAS) represents the systematic bias of satellite-based precipitation (Equation 2). A positive BIAS indicates an overestimation of satellite precipitation, whereas a negative value implies an underestimation.
- The root means square error (RMSE) measures the average absolute error of satellite precipitation (Equation three). The smaller RMSE is, the closer the satellite precipitation estimates are to the observations.

$$CC = \frac{\sum_{i=1}^{n}(P^S - \overline{P}^O)(P^S - \overline{P}^S)}{\sqrt{\sum_{i=1}^{n}(P^O - \overline{P}^O)^2}\sqrt{\sum_{i=1}^{n}(P^S - \overline{P}^S)^2}} \quad (1)$$

$$BIAS = \frac{\sum_{i=1}^{n}(P^S - \overline{P}^O)}{\sum_{i=1}^{n} P^O} \quad (2)$$

$$RMSE = \frac{\sum_{i=1}^{n}(P^S - P^O)^2}{n} \quad (3)$$

Where n is the sample size of the satellite or the gauge-based precipitation time series; $P^S i$ and $P^O i$ represent the satellite precipitation and gauge-based precipitation amounts at the ith time step (mm); and $\overline{P}^S$ and $\overline{P}^O$ are the mean values of satellite precipitation and gauge-based precipitation (mm). It should be mentioned at this point that, a perfect correlation between averaged areal values(GPM) and point measurements(tipping buckets) is a utopic expectation and should not be expected.

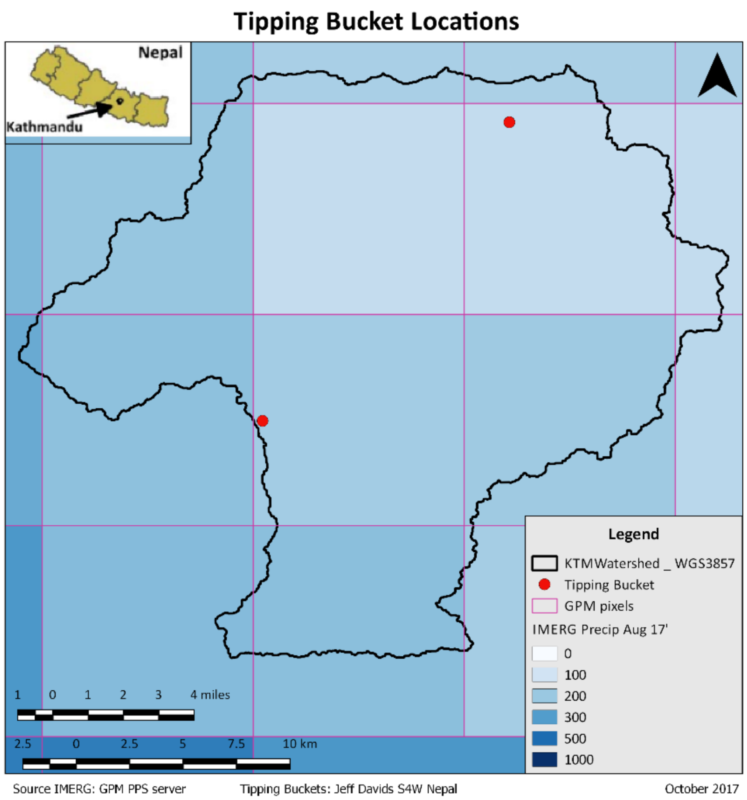


Figure 10.2: Tipping Bucket Locations

Another assessment technique of satellite estimation/model forecast is using a contingency table that reflects the frequency of "Yes" and "No" of the satellite estimation/forecast model. Table 10.1

A/A		Satellite	
		Yes	No
Tipping Bucket	Yes	Hits (H)	Misses (M)
	No	False alarms (F)	Correct Negative (N)

Table 10.1: Contingency Table

The four following indices will be implemented for the dichotomous analysis:

- The probability of detection (POD), also known as hit ratio, describes the fraction of precipitation events correctly detected by the satellite among all real precipitation events (Equation 4).

- The false alarm ratio (FAR) denotes the fraction of false events among all the events detected by the satellite (Equation 5).
- The critical success index (CSI) answers the question of how well the estimated/forecasted events correspond to the observed events (Equation 6).
- The Accuracy index (ACC) measures the fraction of correct estimates/forecasts (Equation 7).

$$POD = \frac{H}{H + M} \tag{4}$$

$$FAR = \frac{F}{H + F} \tag{5}$$

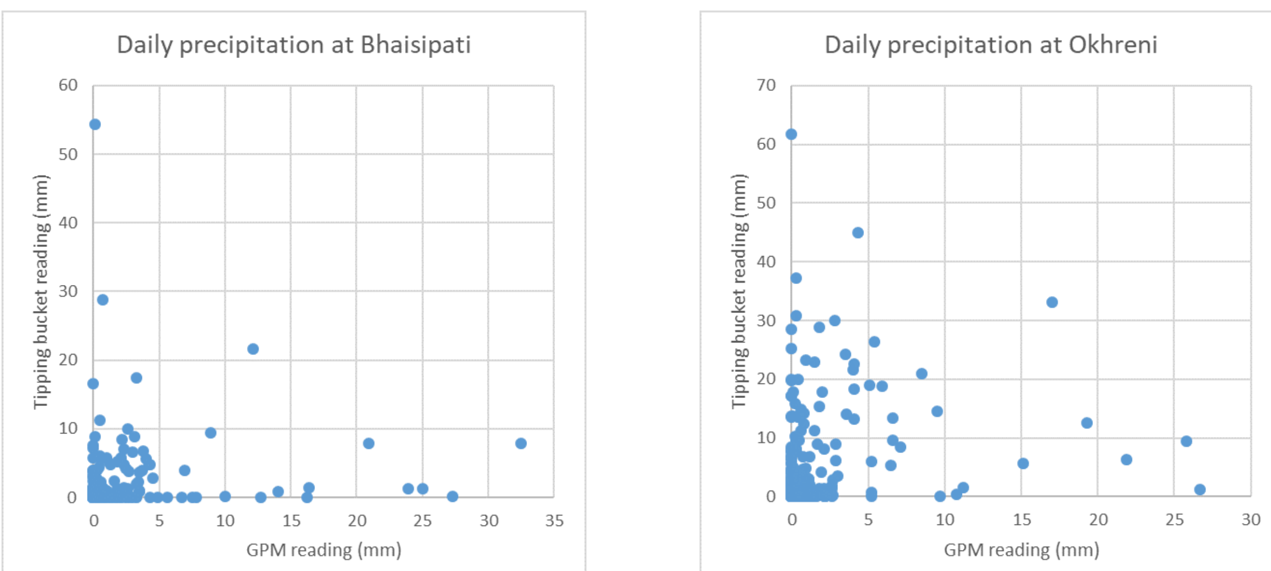
$$CSI = \frac{H}{H + M + F} \tag{6}$$

$$ACC = \frac{H + N}{H + M + F + N} \tag{7}$$

The factor H denotes the number of real rain events correctly detected by the satellite, M represents the number of actual rain events failed to be identified by the satellite. F is the number of rain events detected by the satellite that does not occur, and N is the number of adverse events correctly detected by the satellite. The perfect scores of POD, FAR, CSI and ACC are 1, 0, 1 and one respectively (Yuan et al., 2017). Last but not least, the Nash-Sutcliffe coefficient was estimated for each tipping bucket coupled with the respective GPM dataset. Nash-Sutcliffe coefficient (NSE) has been widely used in rainfall-runoff modelling to assess the predictive power of hydrological models (Bajracharya et al., 2017). NSE = 1 would mean that the product agrees precisely with the station observations, while NSE = 0 indicates that the mean square error of the product is as significant as just using the mean observed value as the predictor. Unlike the correlation coefficient, CC, between a precipitation product and station observations, NSE penalises systematic bias in the product's precipitation estimates, as well as irregular discrepancies (Krakauer et al., 2013). In our case, it was implemented to compare with CC and notice possible discrepancies.

10.3 Results

The initial goal of introducing GPM into the current project is enhancing the temporal resolution of citizen science data by capitalising on the more frequent GPM data. Consequently, the daily data will be distributed into the eight 3-hour time slots issued from the statistical analysis of the GPM data to determine the diurnal variation of precipitation in the study area. The scatter plots (Figure 10.3) of the two different data types are clustered at the axis' intersection meaning a trend line cannot be produced without a big error. This observation is a first indication that there is a low correlation between the satellite data and the continuous tipping buckets ground measurements.



(a) Daily Precipitation at Bhaisepati

(b) Daily Precipitation at Okhreni

Figure 10.3: Precipitation scatter plots

Figure 10.4 presents the average temporal distribution of daily precipitation in the two study areas for the months of July and August. It is observed that there is not a uniform distribution, but it slightly varies between different months and areas. The results suggest that in most cases the frequency and the amount of precipitation are minimised in the morning. The precipitation peaks are in the evening (18-21 h), except Bhaisepati in August where there is a second peak in the night (3-6 h). Overall precipitation follows a parabolic curve throughout the day where the gradient of the curve varies depending on the respective month and location.

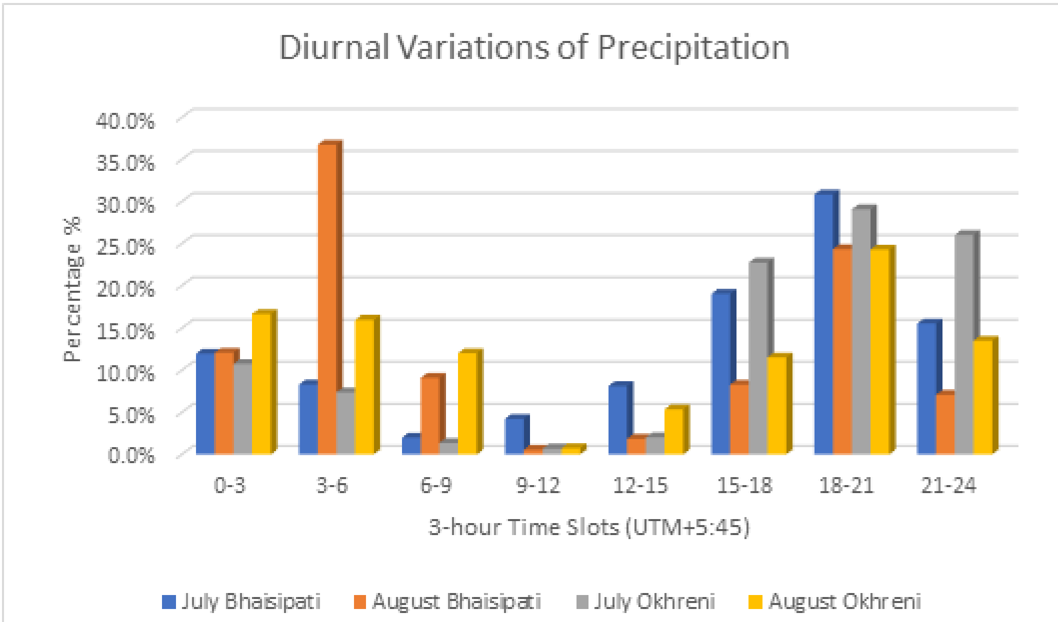


Figure 10.4: Diurnal variations of precipitation

Table 10.2 shows the results of the correlations of the precipitation over the Kathmandu Valley for July and August in the monsoon season of 2017. The correlation is very low for all sets of data with the greatest correlation observed at Okhreni for the month of July. It was expected that the correlation would be low due to the fact that the spatial resolution between ground and satellite data is vastly different. The BIAS is remarkably high indicating over/underestimation of precipitation by GPM.

Numerical Evaluation				
Month	July		August	
Location	Bhaisepati	Okhreni	Bhaisepati	Okhreni
Pearson	0.17	0.41	0.20	0.18
BIAS	0.55	-0.56	-0.30	-0.84
RMSE	3.83	5.66	5.20	8.34

Table 10.2: Numerical Evaluation

It is also observed that there is a relationship between the level of under-/overestimation and the amount of precipitation as presented in Figure 10.5. GPM values consist of 10x10km areal averages which are bound to differ significantly from point measurements, hence the underestimation. A grid of continuous ground measurements in the Kathmandu Valley would be ideal to assess the correlation more accurately. However, the absence of such data compromised the quality of the results.

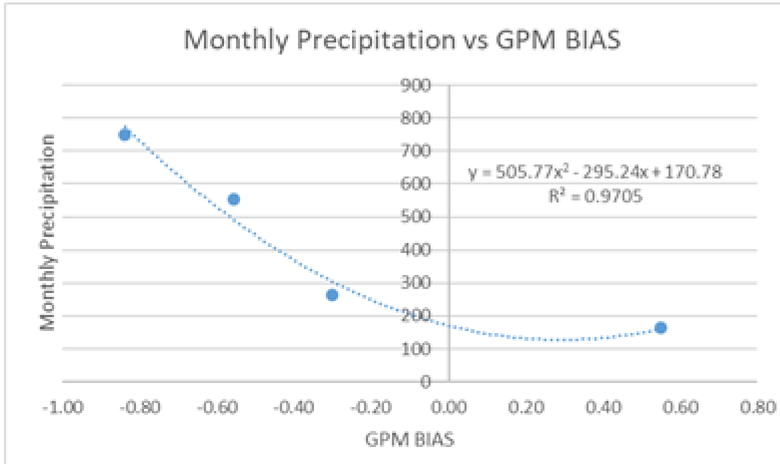


Figure 10.5: Monthly precipitation versus GPM BIAS

Table 10.3 shows the results of the statistical analysis of the categorical precipitation data over the Kathmandu Valley for the same period. The Pearson correlation factor is slightly increased for all datasets in comparison to the analysis of the numerical data while the absolute values of BIAS are decreased as well. There is a definite relationship between the outcomes of the numerical and the categorical evaluation, which indicates that the over/underestimation of precipitation is caused by the innate weakness of the satellite data to detect every rainfall event due to its coarse spatial resolution.

Categorical Evaluation				
Month	July		August	
Location	Bhaisepati	Okhreni	Bhaisepati	Okhreni
Pearson	0.35	0.41	0.29	0.38
BIAS	0.38	0.06	0.36	-0.34
RMSE	0.55	0.53	0.60	0.59

Table 10.3: Categorical Evaluation

The results of the dichotomous evaluation are presented in Table 10.4. Based on the POD results it can be deduced that GPM was less successful at detecting rainfall events in mountainous Okhreni. The reason behind this might be the weakness of GPM to accurately estimate precipitation in areas where precipitation is dominated by orographic events (Duncan & Biggs, 2012). However, less false rainfall events were logged in Okhreni compared to Bhaisepati as shown by the FAR values. Furthermore, the critical success index (CSI) indicates that the level of correspondence of the rainfall events detected by the satellite is below 50% and is noticeably worse in the case of Bhaisepati. Finally, all four sets of data showed a similar accuracy with an average value of 0.7 meaning almost 70% of the conditions Rain/No Rain is correctly detected by the GPM constellation measurements.

Evaluation of Contingency				
Month	July		August	
Location	Bhaisepati	Okhreni	Bhaisepati	Okhreni
POD	0.67	0.67	0.63	0.50
FAR	0.52	0.37	0.54	0.23
CSI	0.39	0.48	0.36	0.44
ACC	0.69	0.72	0.66	0.68

Table 10.4: Evaluation of Contingency

Table 10.5 presents a summary of the contingency table, showing that 68.6% of all precipitation events recorded by the tipping buckets are registered by the satellite constellation as well.

A/A		Satellite	
		Yes	No
Tipping Bucket	Yes	22.5%	14.9%
	No	16.5%	46.1%

Table 10.5: Summary of the Contingency Table

Last but not least, the Nash-Sutcliffe coefficient offers a reasonable overall metric of relative quality, and thus it was estimated for the monthly precipitation values. According to the estimated NSE coefficient, precipitation at the second location (Okhreni) is better estimated than at the first position, though both are below zero. NSE coefficient values below zero indicate that the mean observed value is a better predictor than the mean squared error.

Nash-Sutcliffe Correlation				
Location	Bhaisepati		Okhreni	
A/A	Numerical	Categorical	Numerical	Categorical
July-August	-0.510	-0.518	0.096	-0.120
July	-2.260	-0.479	0.196	-0.143
August	-0.170	-0.553	0.041	-0.103

Table 10.6: Nash-Sutcliffe Correlation

Figure 10.6 shows an overview of the daily precipitation at Okhreni in July as documented by the GPM constellation and the tipping bucket. GPM succeeds in detecting the majority of the temporal variability of the rainfall. However, it underestimates precipitation considerably.

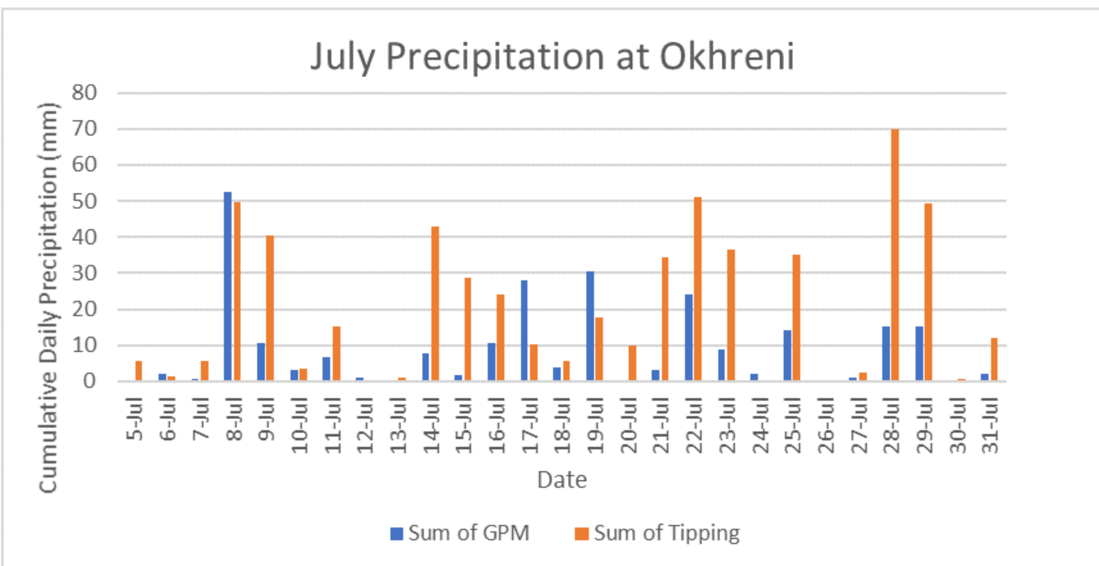


Figure 10.6: July Precipitation at Okhreni

Overall, all results should be taken with a grain of salt, because averaged precipitation of a 10x10 km^2 area is compared to point measurements. Ground measurements record precipitation over the very small surface area of the rain gauge, whereas they are being compared with satellite precipitation products which nominally represent precipitation averaged over a much more extensive grid cell that includes the rain gauge location (Krakauer et al., 2013). Assuming the satellite and the ground precipitation data were highly correlated. Thus there is a clear and strong linear relationship, then GPM could assist in enhancing the temporal resolution of the citizen science measurements, as it correctly illustrates the diurnal distribution of the rainfall. This is accomplished by dividing the total daily precipitation by the ratio estimated by GPM as shown in the Table 10.7 for the interpolated recordings of July in Bhaisepati.

Row Labels	0-3	0-6	0-9	9-12	12-15	15-18	18-21	21-24
5-Jul	-	-	-	-	-	-	-	-
6-Jul	-	-	18%	82%	-	-	-	-
7-Jul	-	-	-	-	100%	-	-	-
8-Jul	-	-	-	11%	31%	40%	13%	4%
9-Jul	13%	-	-	42%	26%	17%	-	2%
10-Jul	3%	15%	69%	11%	-	1%	1%	0%
11-Jul	10%	35%	11%	30%	4%	2%	-	8%
12-Jul	83%	17%	-	-	-	-	-	-
13-Jul	-	-	-	-	-	-	-	100%
14-Jul	-	-	2%	3%	1%	5%	3%	85%
15-Jul	-	-	-	23%	-	-	10%	67%
16-Jul	-	-	7%	4%	-	2%	66%	21%
17-Jul	5%	-	-	7%	81%	7%	-	-
18-Jul	-	-	-	94%	6%	-	-	-
19-Jul	-	51%	21%	21%	1%	5%	-	-
20-Jul	-	-	-	-	-	100%	-	-
21-Jul	-	-	-	-	0%	-	84%	13%
22-Jul	-	-	-	28%	25%	43%	4%	-
23-Jul	-	-	-	21%	36%	26%	15%	2%
24-Jul	-	-	-	-	-	76%	24%	-
25-Jul	-	-	-	8%	92%	-	-	-
26-Jul	-	-	-	-	-	-	-	-
27-Jul	-	-	-	-	-	-	-	100%
28-Jul	-	-	-	48%	2%	10%	28%	12%
29-Jul	-	-	3%	31%	18%	36%	1%	1%
30-Jul	-	-	-	-	-	-	-	-
31-Jul	-	-	-	89%	-	5%	-	5%

Table 10.7: Total daily precipitation ratio

By overlaying a DEM raster file with the location of citizen science measurements Figure 10.7 the spatial gaps of citizen science are addressed. Most of the Kathmandu Valley is covered, especially the urbanised-low elevation areas. There are only two areas which lack an adequate number of citizen scientists, north-east and north-west. In those areas, however, two National parks are situated (Shivapuri and Nagarjun respectively) and consequently, they are sparsely populated.

10.4 Discussion

Realistically, until the accuracy of satellite-derived precipitation estimates can be increased for use at finer spatial and temporal scales, reliance will remain on utilising ground-based data products in Nepal (Duncan & Biggs, 2012). The present form of satellite-derived precipitation products can be used to complement existing citizen science measurements. Previous studies suggest that IMERG products underperform in areas with complex terrain and associated warm-rain process since passive microwave algorithms depend primarily on scattering by ice, but orographic rains might not produce much ice aloft (Tang et al., 2016). This overestimation in rainfall over mountainous regions indicates that accurate estimation by satellite-based precipitation products remains a challenging issue (Andermann et al., 2011). Such inaccuracy may be rooted in the inadequate number of gauges, provided by the Global Precipitation Climatology Centre and used for bias correction in satellite products (Krishna et al., 2017). The climatology of the region should be taken into account when comparing ground and satellite data. The reason behind that is that meteorological processes are relevant: uncertainty is substantial under convective storm cells, which can produce significant rainfall volumes with insufficient spatial and temporal extent. Such events are significant for hazards such as flash flooding but may be missed altogether from point gauge records and cause difficulties for gauge-radar comparisons (McMillan et al., 2012).

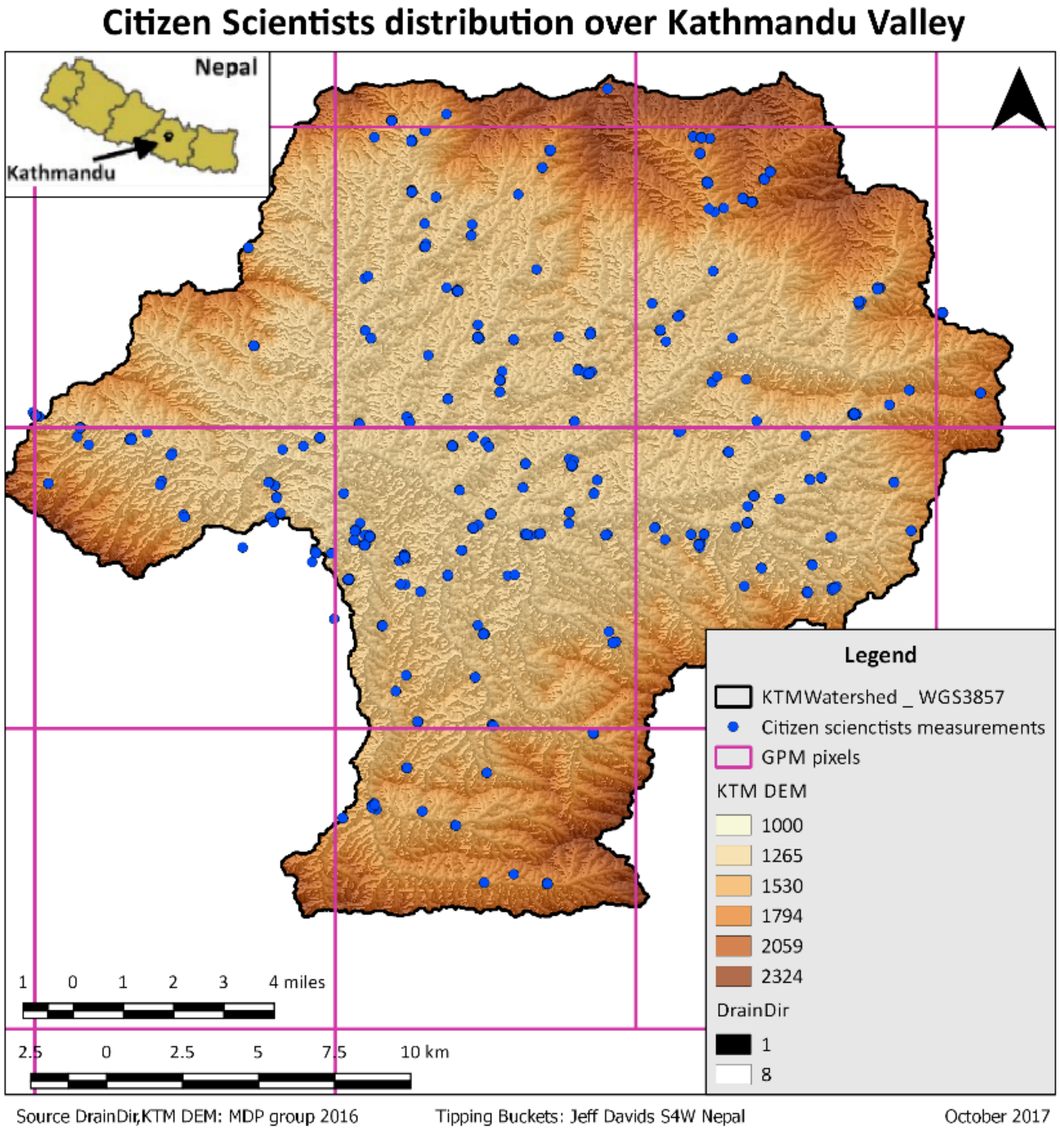


Figure 10.7: Citizen scientists distribution over Kathmandu Valley, including the GPM pixels grid

10.5 Conclusion

Is it possible to adjust the citizen scientist precipitation data with a low, non-continuous temporal resolution with GPM data that has a high temporal resolution?

The statistical analysis indicates that the correlation between ground and satellite data is not high enough meaning there is not a clear linear relationship. However, the contingency table shows that GPM manages to detect the general pattern of rainfall regarding duration even though it lacks in identifying the correct amount of rainfall, often underestimating it. The temporal gaps of the citizen science recording can be filled in by GPM data under the condition that a stronger linear correlation is established between ground and satellite precipitation data. The coarse temporal resolution of citizen science measurements will then be sharpened from 1 or 2-day up to 3-hour or even 30-minute. The citizen science locations are uniformly distributed in the Kathmandu Valley, and the GPM data should be able to complement the spatial gaps between the sparsely populated areas. It is safe to assume that an extended grid of rain gauges would improve the quality of the data and thus the quality of the analysis, indicating a higher correlation between satellite and ground records.

11 | Citizen science possibilities

Citizen scientists can come into play when a big amount of data needs to be collected. Collection of ground truth data is a huge task, and the burden of this can be lifted by using citizen scientists to obtain the ground truth data on a broad scale in space and time. This way of data collection has been reviewed for a couple of subjects which will be discussed in this chapter.

11.1 Methods

Two methods are highlighted as necessary for citizen science application. The ODK tool is the perfect tool to gather data on a large scale using smartphones in an easy way. The method of ground truth of classification by citizen scientists can be an essential next step in gathering a significant amount of land-use data with the help of citizen scientists.

11.1.1 Open Data Kit

The Open Data Kit, hereafter ODK, is an app with which you can measure the field using an Android phone. On the computer, you can create an ODK form where you can make a guideline which users will have to follow while filling in the form. You can give the users the option to fill in a multiple choice, open question, value or picture. Pictures are often used to verify the answers or values filled in by the users. All the data gathered in this report have been collected using the ODK app. One of the advantages of using the ODK app is that the measurements cannot be lost as easily as when they are written down on paper. The data will be stored on the phone if users connect to the internet the forms will be uploaded to the Google cloud. Users can use the options menu to upload the forms to the cloud manually. In this way, they can check the forms for mistakes before they will be stored on an online server. The data will be safely stored, and can afterwards be exported to an excel sheet for analysis.

11.1.2 Ground truth classification

To obtain an overview of the errors found by validation a confusion table can be created (Tabak, 2015). Ground measurements from our fieldwork are used to produce these point samples. Due to human observation uncertainties and the error of the GPS location, a buffer and human interpretation will be used to validate the validation points with the classification map. To ensure human validation is possible, multiple options are implemented in the ODK form to let the observer 1) capture the surrounding area (every 90-degree turn) and thus pixels (figure 2) and 2) inform on the important area features by giving textual comment options.

11.2 Results

Citizen scientists can be useful in increasing validation and classification land-use ground truth measurements for a land-use classification map. A promising tool is ODK for Android smartphones. A demo has been started to see where the ODK difficulties and errors can be found in the classification of land-use by volunteers. The six main classes, from the MDP 2016 map, are the only land-use classification possibilities.

The demo was started with the ODK land-use form v1.2 with two volunteers. Based on these observations some changes have been made in the ODK form, resulting in v1.3 that is used by six volunteers. The final result is v1.4 which is used by S4W at the moment. All interface versions of the ODK can be seen in the appendix. The changes between the versions are:

- V1.2 → v1.3
  - GPS location question was put after the question to find a good classification location.

- V1.3 → V1.4 (continued)

  - Textual changes to clarify questions. More explanation was given for the 90 degrees figure.

- V1.3 → V1.4

  - Almost no difference, except for more extensive explanation on spinning and not moving while taking pictures in all four locations.

There are a few difficulties that were experienced with the ODK app, that citizen scientist encountered and commented on in the ODK.

- The 'GPS localisation' option has to be after the 'find a classification location' option
- The ODK app is hard to understand for new users
- The app is only usable for Android and not for iPhone.
- Standing in the same location during the classification is not natural for most citizen scientists.

The tutorial, however, was found to be clear and helpful, but training in how to use the ODK app and on how to localise a 'good spot' to do the land-use classification, is still needed to get the required results. Figure 11.1 shows a heterogeneous environment. To get a 'good' classification, a homogeneous environment is desirable.

Figure 11.1: Example: Heterogenous classification environment

Within Figure 11.1, a total of four different land-use covers is found. In this picture brick factories, rice fields, barren land and greenhouses can be seen. Two of these land covers cannot be classified with the current classification scheme. Since greenhouses are very different from other agricultural non-rice fields in the satellite images, it would be wise to make a separate class for this cultivation type. The overview picture in Figure 11.1 was classified as natural shrublands. At the left side of the image some shrubs can be noticed, however, if there will be looked behind the shrubs, as the small picture shows, there is rice cultivation. Shrubland is hardest to classify.

(a) Citizen scientist

(b) Expert

Figure 11.2: Comparison citizen scientist and expert

In Figure 11.2a, you can see another example of how citizen scientists need to be trained to make an overview picture of the land-use so that you can quickly recognise the land-use at that location. To be able to identify low and high development classes, the height of the building has to be known, as wells as if there is pavement or not. Some citizen scientist had difficulty with classifying the different types of development.

		Citizen Scientist							
		BL	BH	Fo	Sh	Ri	Ag	A	E
Expert	BL	10	3	0	0	0	0	77%	23%
	BH	3	2	0	0	0	0	40%	60%
	Fo	0	0	0	0	0	0	0%	0%
	Sh	1	0	0	0	0	1	0%	100%
	Ri	1	0	0	1	0	0	0%	100%
	Ag	1	0	0	1	1	3	50%	50%
	ϵ	38%	60%	0%	100%	100%	25%	A_t: 33%	

Table 11.1: Confusion matrix of 28 land-use classifications by citizen scientists and an expert. Ag = Agriculture (Non-Rice), Ri = Rice, Sh = Shrubland, Fo = Forest (Decideous), BH = Built (High Density), BL = Built (Low Density). A: Accuracy, ϵ: Commission error, E: Omission error, A_t: Total accuracy

As shown in Table 11.1, the high and low build land-use classes are often confused for each other. 10 times, the citizen scientist and expert classified low build the same, and high build was recognised similarly twice. Six times, however, the land-uses were classified wrongly. Furthermore, shrublands have almost not been classified, and if classified it is classified incorrectly as shown in Table 11.1.

11.3 Discussion

11.3.1 land-use ground truthing

Our research has a small sample size. This small sample size makes the quantitative parameters, like accuracy, less reliable, while still providing a good overview of the qualitative comments on, and adjustments were done, to the ODK classification app. Difficulty in understanding land classes and lack of training seems to be one of the most significant problems in CS land-use classification. It seems that volunteers who find a class hard to define at a particular spot will walk to the next place where they do know the land-use cover type. This behaviour is connected to the other primary factor that causes wrong classifications with volunteers, a lack of training. From our own experience, we can conclude that classifications were done more smooth and confident when the demo pictures and approach was seen multiple times. That the lack of training decreases accuracy (in our case as low as 33%) is in line with studies from Fitzpatrick et al. (2009) and Fuhrman et al. (2014) that conclude that there is an increase in accuracy when more guidance and training are given.

The shrubs are one of the hardest classes to identify, and training is needed on how to classify shrubland. That it is hard to classify is probably since people do not understand how to classify this land-use class. So, they walk to the next spot where they do know the land-use type. This behaviour shows once more the importance of training since shrublands are an essential land-use class and classification of the land-use type are also necessary. Since shrubland is a natural land-use, you can even name it as nature non-forest. Training will make sure they will not classify agricultural land-uses as natural shrubs.

11.3.2 Indication parameters

Indication parameters can be instrumental, especially for the use of citizen science. They can be instrumental because for citizen scientists some parameters are easier to measure than others. The existence of indication parameters can cut down the costs and can make data gathering easier. Table 14.5 shows that the prospect looks bright. In this table where no distinction between water-sources was made, there are not a lot of correlations that were strong enough to be classified, but still, sixteen possible indication parameters can be found. However, since the number of data points is quite high (n=58), the critical values for each class is quite low compared to other correlation matrices. Therefore, even when a correlation is classified, it doesn't mean that one parameter can be used as an indicator parameter for the other parameter. However, when you look to the correlation matrices where a distinction is made by water source, another view arises, see Table 6.6, 6.7 and 6.8.

For example, Table 6.6, shows a promising view. The parameters temperature, EC and turbidity, have a lot of correlations with another parameter (10 of the 16). Those correlations were strong enough to be classified. The fact that those three parameters have is promising since these three are probably most easy to be measured by citizen scientists. These parameters could be used as follows:

- Temperature to estimate DO (HS, r = -0.729)
- EC to estimate phosphate (MS, r = 0.529)
- EC to estimate hardness (MS, r = 0.632)
- Turbidity to estimate iron (LS, r = -0.500)
- Turbidity to estimate E. coli (MS, r = -0.538)
- Turbidity to estimate discharge (LS, r = -0.478)

One should take into account that turbidity is here expressed in cm instead of in NTU (in Table 6.6 but also in 6.7, 6.8 and 6.2, therefore the negative correlations are positive if the unit is transformed from centimeter to NTU. All in all, when the turbidity increases, so does the iron, E. coli and discharge (or the other way around).

In the wells, the EC could be used to estimate nitrite (LS, r =0.554), nitrate (MS, 0.677) and hardness (LS, r=0.509). Also turbidity could be used to estimate iron (LS, r -0.483), see Table 6.7. The EC could also be used to estimated five different water quality parameter in spouts:

- EC to estimate pH (LS, r = -0.501)
- EC to estimate nitrite (LS, r = 0.543)
- EC to estimate nitrate (LS, r = 0.602)
- EC to estimate phosphate (MS, r = 0.655)
- EC to estimate hardness (LS, r = 0.590

However, it should be taken into account with all these correlations that, just like in section 6.3: "none of the correlations is so strong that you can derive a linear relationship formula with negligible errors. Land-uses can be used to predict the range of a parameter (higher or lower value), but quantification is very difficult to impossible". The indicator parameters can be used to estimate if the value of other parameters would increase or decrease, maybe it is even possible for some parameters to calculate the range the values can be expected. Probably the best use for indication parameters is that a significant change in the parameters temperature, EC and turbidity can be a signal that the other settings have changed as well, and therefore it would be wise to visit the location to measure the additional parameters by professionals.

11.3.3 Discharge measurements

During the research, two different methods were used to measure the discharge in the rivers: Salt dilution and flow-tracker. The flowtracker is an expensive piece of equipment for which people need extensive training; therefore it is not very suitable for the use citizen science. The salt dilution method, in contrast, can be used very easily by citizen scientist in combination with the ODK. A citizen scientist just has to evaluate a package of salt in a bucket, mix it with stream water and throw it at the right location in the river and then measure downstream with an EC-meter and the video camera of a phone (a video is made of the screen of the EC-meter). This video feed can be transformed into a data set which can be used to calculate the discharge. The question that arises is: how reliable is this method and can it measure the real discharge? As told in section 3.1, a salt dilation measurement has on average an error of 5% of the real discharge. But what is the accuracy? In Table 3.3 a mixed view is displayed. In this table, all measurements that were done multiple times at one location are shown. What can be seen that some measurements have consistently the same value with a small difference, whereas at different locations measurements can be less consistent.

Why the salt dilution measurements at certain places sometimes have a lower consistency than experiments done at other research locations can have varied reasons. The most logical reasons for low consistency are that there was not enough mixing taking place and/or that there were too many stagnant water pools. If locations with stagnant pools are avoided and only places where sufficient mixing takes place, salt dilution measurement can be done with a relatively high accuracy.

11.3.4 Turbidity tubes

Turbidity tubes can be an excellent solution for citizen scientist to measure turbidity, which is a water quality parameter that is very suitable for citizen science. A drawback of this tool that is that it is less objective than other methods to measure turbidity since people use their eyesight to measure the turbidity. Somebody with better vision could read a different value of a turbidity tube than some with a worse sight. However, since the change in turbidity is maybe more interesting than the actual value, see subsection 9.3.4, this problem is less critical as long as the same person keeps doing the measurement at the same location. In the end turbidity, tubes can be a real asset for citizen scientist. They can be a useful tool to indicate a significant change in water quality in the area where it is used.

11.3.5 Water quality strips

The water quality strips that were used in the research can be easily used by citizen scientists. They are easy to utilise as one only needs to dip them in the water and find the corresponding colour on the package. There are, however, a few concerns on their implementation in data gathering. First of all, the initial cost of these strips is relatively high. A second matter is the discontinuous scale that is used to measure the parameter, which makes this method less accurate. The last concern is that this measuring process depends on the way people perceive colour, which can differ between persons and this can create a situation where errors are made when the colour is not very clear or differs from the colour presented on the package. However, this strip method does enable citizen scientist to measure the water quality more comfortably. The only thing that must be kept in mind is that the method is more suitable to indicate the range of the values, than the precise concentration.

11.4 Conclusion

There is a lot of potential for implementing water quality and land-use measurements by citizen scientists answering the research question '*Can water and land-use measurements be performed by citizen scientists?*'. There are parameters which can be easily measured by citizen scientists, known as indication parameters. Temperature, EC and turbidity emerged as possible indication parameters, however not all water sources have the same level of suitability for the use of these indication parameters. Another factor that should be taken into account is that indication parameters are not able to express the precise value of another parameter, but they can indicate the range and the direction (in-/decreasing) of the value. Specific water quality parameters can be easily measured by citizen scientists under the condition that they have the appropriate equipment, like turbidity tubes and water strips. Turbidity tubes are excellent devices for citizen scientist to indicate a big change in water quality. To quantify the change in the water quality, methods using water quality strips can be used. However, this technique is only precise enough to quantify the range of the value of a parameter. Another drawback could be the cost, but these are probably still considerably lower than other methods (like lab analysis) and depend on the financial means a study needs to work with.

The total accuracy of the citizen science ground truthing compared to expert ground truthing is 33%. The qualitative conclusion, mostly based on comments of volunteers, is that lack of training negatively influences the ground truthing conducted by citizen scientists and that the shrubland class is challenging to identify and thus to classify. With that said, land-use measurements can be performed by citizen scientists. However proper training is required to diminish possible errors.

12 | General Conclusion

This report has tried to answer the secondary research questions throughout the research chapters in order to formulate a conclusion on the main research question: **What are the influences of land-use on the quantity and quality of water sources in the Kathmandu Valley and how can the necessary data be collected by Citizen Science in the future?**

Based on the current research it can be concluded that different land-uses negatively affect various water parameters. In the case of rivers, the water quality (except nitrate, nitrite and phosphate) deteriorates to hazardous levels from upstream to downstream. Different parameters are affected differently, as dissolved oxygen deteriorates rapidly in non-rice Agriculture and low density urban and is depleted in high density urban (downtown areas), while turbidity is mainly affected by urban areas. In the case of spouts, deterioration of most water quality parameters is linked to urban areas, while forested areas and non-rice agriculture also play a role. Wells' water quality, however, does not show any correlation with any significant correlation with any of the land-uses except for non-rice agriculture which seems to affect TDS slightly. This absence is an indication that the relationship between land-uses, and the pollution of the wells' water source is still not firmly established. Research on the groundwater level showed that there is no significant correlation between groundwater recharge-depletion and land-uses. It can be observed that monsoon period provides a much-needed recharge of the groundwater table which gets depleted after monsoon is over, but more measurements and more frequent ones are needed to reach a solid conclusion. A study of the geology of the Kathmandu Valley indicated the geological formations, in fact, affect specific water quality parameters. Limestone rock is associated with a slight increase in EC and hardness while the Kalimati formation (containing phosphorus minerals) seems to be associated with increased phosphorus levels, even though surface pollution (waste holding soap products) plays a more critical role in this.

Citizen science can be a great tool for areas like the Kathmandu Valley where data collection can be difficult. Citizen science can be implemented in three different areas of interest, and the results have the potential to be quite fruitful. ODK is an integral part of the citizen science as it is the building block for the coordinators to interact with the citizen scientists and provides a structured form of data gathering and processing. First of all, citizen science can provide much-needed insight into the quality of the water sources within the Kathmandu Valley. Our research showed that there are three indication parameters: temperature, electrical conductivity and turbidity which can be measured with affordable equipment and can give results regarding other parameters which would require expensive and high-end equipment, like phosphate, TDS, nitrate, E. coli etc. The only drawback is, however, that indication parameters provide ranges of the other parameters and not absolute values. Moreover, citizen science has the potential to provide information about land-uses which can be consequently used to enhance the land-use classification. It is required to properly train the citizen scientists into clearly depicting a single land-use in their pictures to provide meaningful input for the land-use ground truthing and map training. Finally, our study proved that satellite precipitation measuring products, in our case GPM, can be utilised to improve citizen science precipitation measurements. GPM precipitation data can sharpen the temporal resolution of the respective CS data on the condition that the first ones are validated with high precision ground data (tipping buckets and similar rain gauges). The GPM paradox is that although its accuracy in detecting rainfall was determined to be 69%, its correlation with the ground measurements (tipping buckets) was not as high as required to establish a strong relationship. This paradox indicates that the potential of GPM is there, but it still needs to be validated for the Kathmandu Valley.

13 | Recommendations

13.1 Where does water from spouts and wells originates from?

Considering that our assumption that water wells and spouts drew from the same water source has been shot down by our findings, we propose that more research has to be conducted on identifying and determining what the origin of the water for both wells and spouts is. The updated assumption is that stone spouts draw from a shallower aquifer which responds faster to the surface environment and is hence susceptible to pollution caused by different land-uses. Accordingly, wells draw water from a deeper aquifer, which response in an unidentified way to surface contamination as well's water is polluted yet uncorrelated to land-use. Nonetheless, further research and mapping of the groundwater table below the Kathmandu Valley are required to shed light on this topic.

13.2 GPM

More continuous rain measurement data with tipping buckets are needed to correlate satellite and ground truth data accurately. A well-distributed network of rain gauged will provide the necessary grid of measurements.

GPM data are available in two formats: TIFF and HDF5 files. This research was conducted by using TIFF files which have the merit of visualisation of results and the drawback of being too bulky for long time series of data. HDF5 data are stored in database style meaning they are handy for situations when large amounts of data need processing, but they are also however plagued by performance issues and needless complexity. Consequently, it is recommended to experiment and familiarise with HDF5 data to possibly reduce the operational time, which was impossible in our study due to the time constraint.

13.3 Recharge

First of all, to say something about a possible correlation or not between land-use and recharge, it is recommended to use a bigger sample group. A sample group of eighteen is simply not enough. Within the fieldwork, more measurements were done, but as was explained in Figure 8.3, a lot of results couldn't be included due to wells not being measured before or that it was not possible to pair wells together. Pairing was difficult, firstly due to the proximity of a lot of wells (monitored and not). In QGIS, with the latitude and longitude data, a separation can be made well, but it was seen that often when wells are a little closer to each other, it was hard to separate them. Another reason it was difficult to pair wells was the low accuracy of certain smartphone GPS systems. To avoid these difficulties in pairing the good measurements, it should be obligatory to document photographs in the Open Data Kit, to avoid confusion.

In one measurement it could be seen that someone wrote his name on a well, this was a convenient way of making sure the same wells were paired because on every picture of the well, the name of the citizen scientist could be seen. It's understandable not everyone wants to write his or her name on a well, but if the citizen scientist can make sure a distinctive feature of the well or the surroundings is photographed, the good pairing would be made a lot easier. For this, it is needed, to either make a very clear description of the Open Data Kit that a photo of the well and its surroundings are required, or that citizen scientists receive training to get this information.

13.4 Citizen science

13.4.1 Land-use ground truthing

Training for citizen scientists has been identified in this research and other literary studies as a critical aspect of obtaining usable ground truth data. From the ground truth demo as executed in this project can be recommended that such training should focus on understanding the cover types, especially the shrubland class, and the localisation of a uniform, classifiable land cover type.

13.4.2 Indication parameters

Further research on the implementation of the indication parameters by citizen scientists is recommended. The default equipment to measure all three is a turbidity tube and an EC meter. However, the latter is not affordable for citizen scientists, and thus alternatives are needed. Multimeters measure resistance which is the inverse of conductivity. Consequently, multimeters can be used as an affordable alternative to indirectly but accurately measure EC. It is hence recommended to investigate developing an easy to replicate method to estimate EC by utilising multimeters. Such a hands-on method is described by (Hirsch, 2017). Temperature measurements have a level uncertainty due to the diurnal variation during a day. To use temperature effectively as an indicator parameter of DO further research is needed to diminish the effect of diurnal variation. To use temperature as an indicator parameter for DO Last but not least, we propose to research the three indication parameters with a goal to reduce the range of the indicated parameters' values and hence increase the efficiency of this method.

14 | Appendices

14.1 Appendix I: Table turbidity conversion

Turbidity conversion chart	
Height (cm)	Turbidity (NTU)
< 6	$>$240
6 - 7	240
7 - 8	185
8 - 9	150
10 - 12	120
12 - 14	100
14 - 16	60
16 - 19	48
19 - 21	40
21 - 24	35
24 - 26	30
26 - 29	27
29 - 31	24
31 - 34	21
34 - 36	19
36 - 39	17
39 - 41	15
41 - 44	14
44 - 46	13
46 - 49	12
49 - 51	11
51 - 54	10
54 - 57	9
57 - 60	8
60 - 70	7
70 - 85	6
> 85	< 5

Table 14.1: Turbidity conversion chart

14.2 Appendix II: Watershed land use development vs water quality parameters

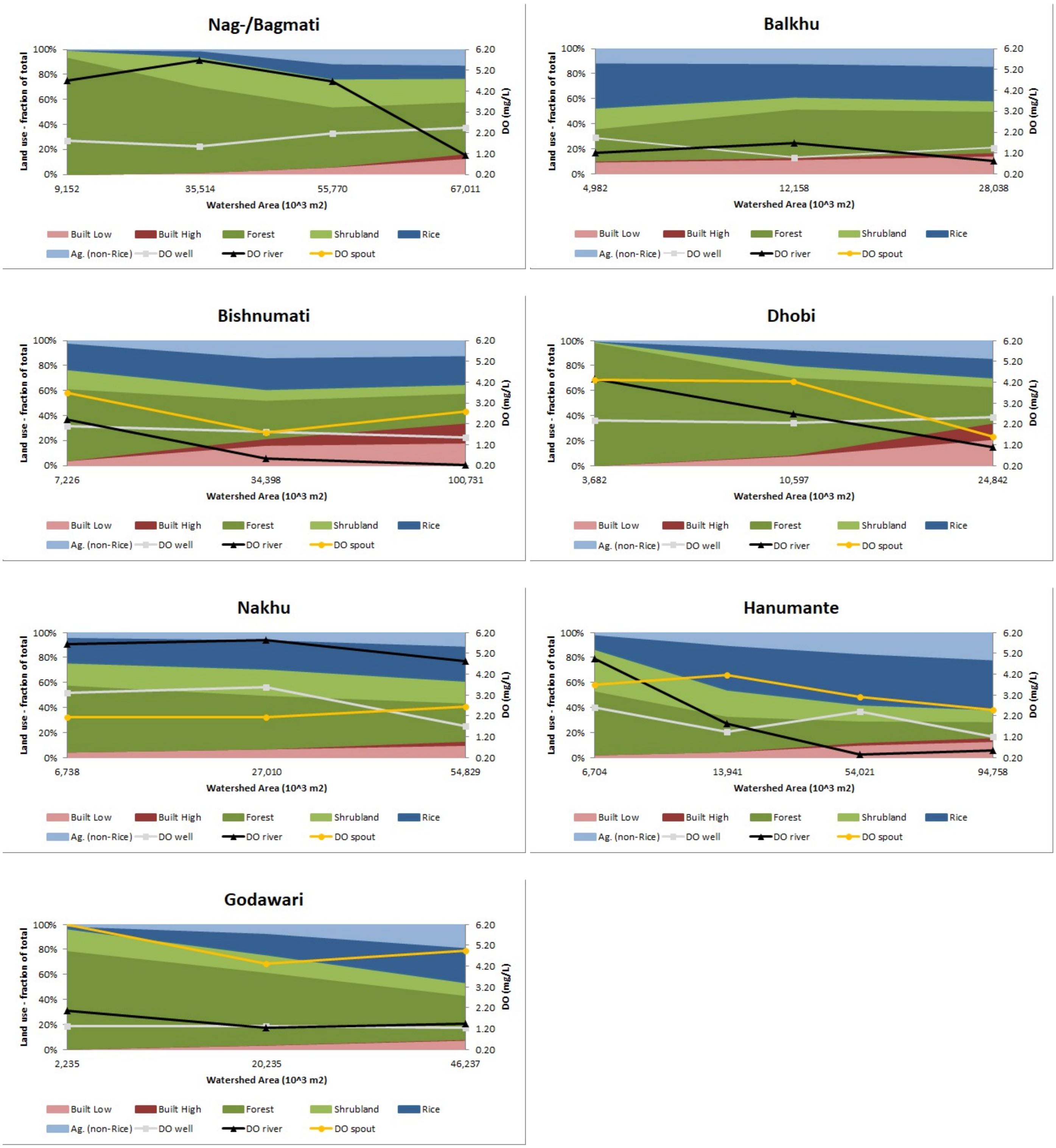


Figure 14.1: Comparison of land use development with the measured dissolved oxygen values, from the upstream to downstream watershed pour points.
Note: For the Nag-/Bagmati and Balkhu watershed only 1 spout measurement per watershed is available which is insufficient to create a longitudinal graph.

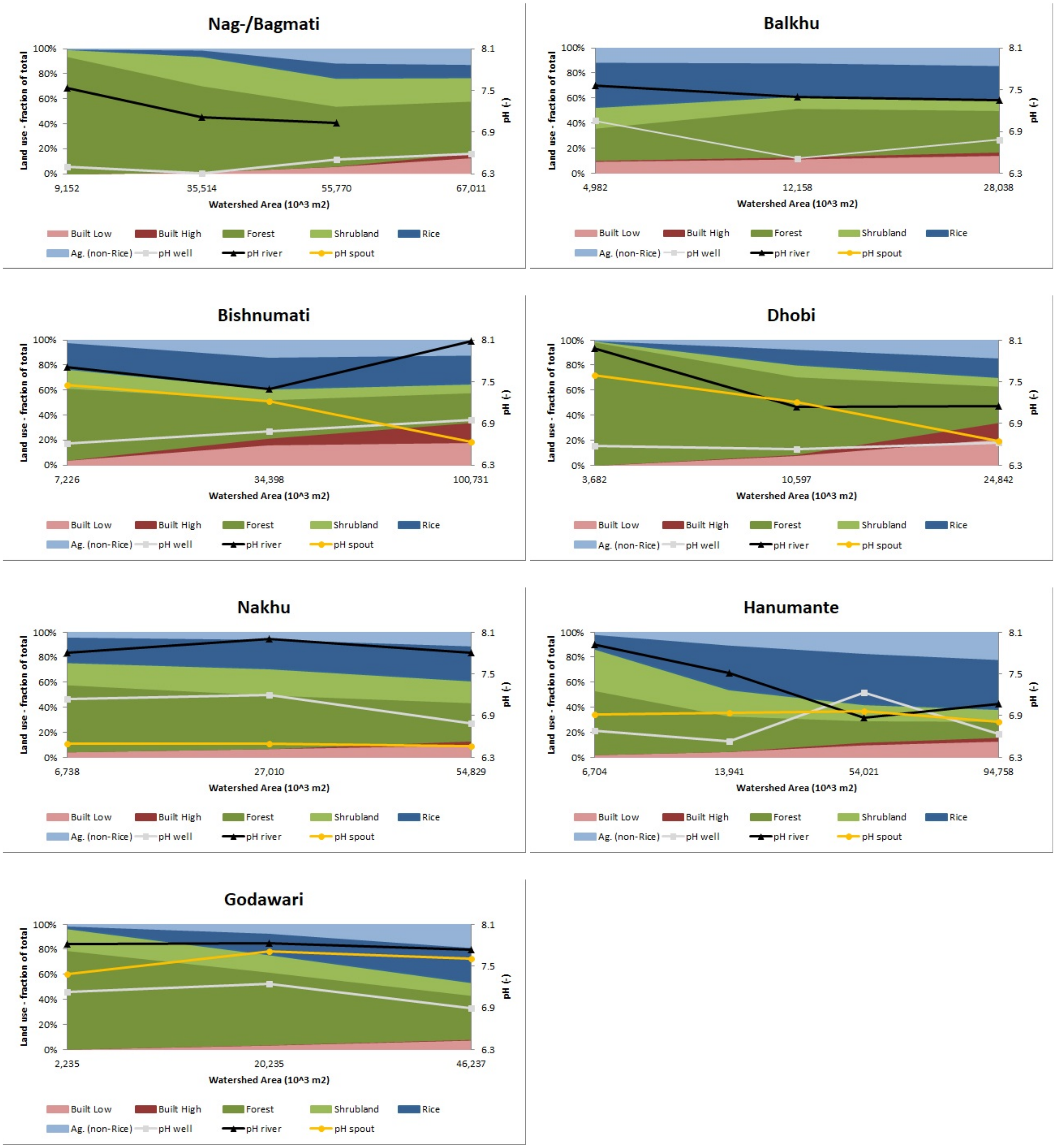


Figure 14.2: Comparison of land use development with the measured pH values, from the upstream to downstream watershed pour points.
Note: For the Nag-/Bagmati and Balkhu watershed only 1 spout measurement per watershed is available which is insufficient to create a longitudinal graph.

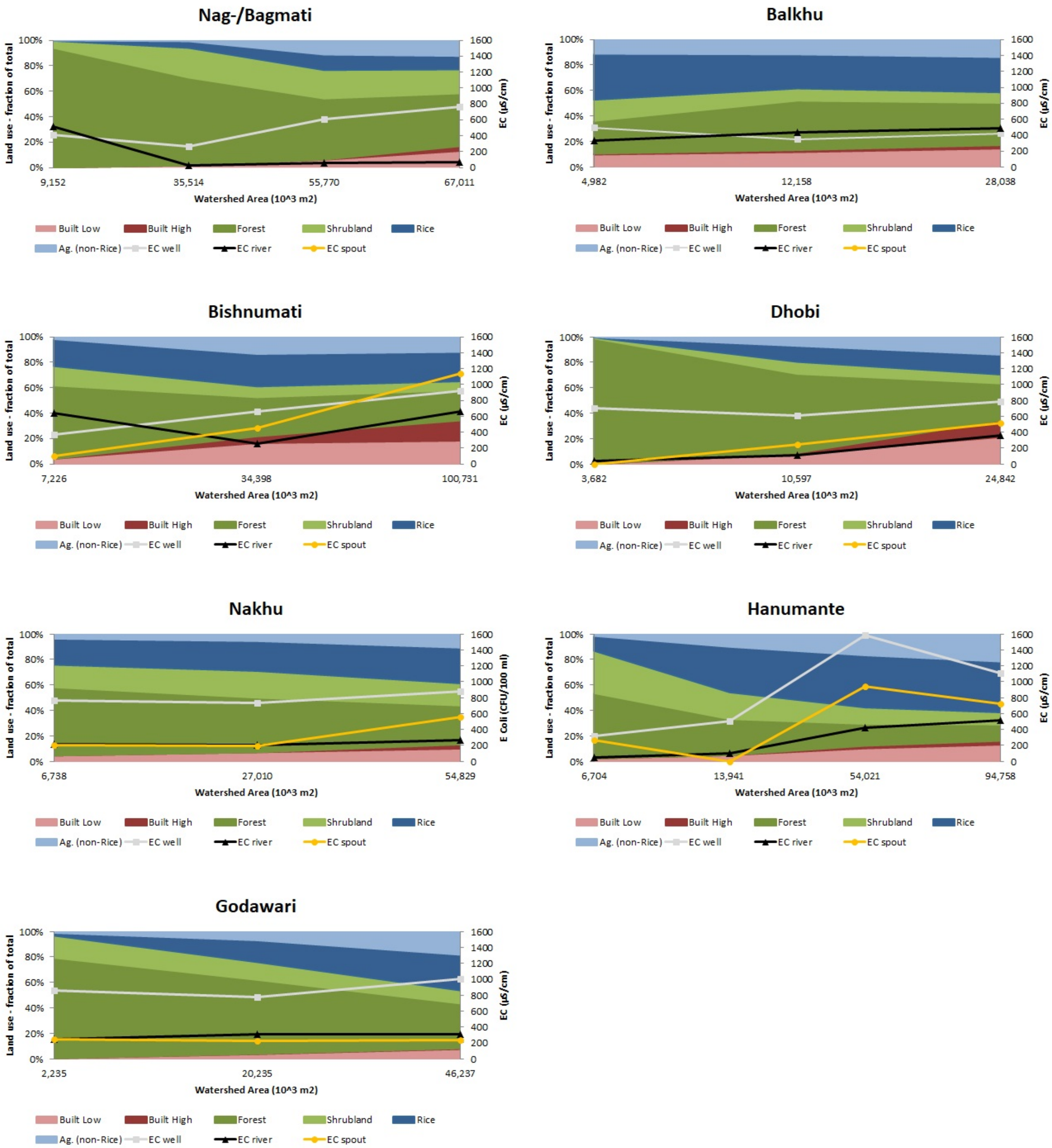


Figure 14.3: Comparison of land use development with the measured EC (25 °C) values, from the upstream to downstream watershed pour points.
Note: For the Nag-/Bagmati and Balkhu watershed only 1 spout measurement per watershed is available which is insufficient to create a longitudinal graph.

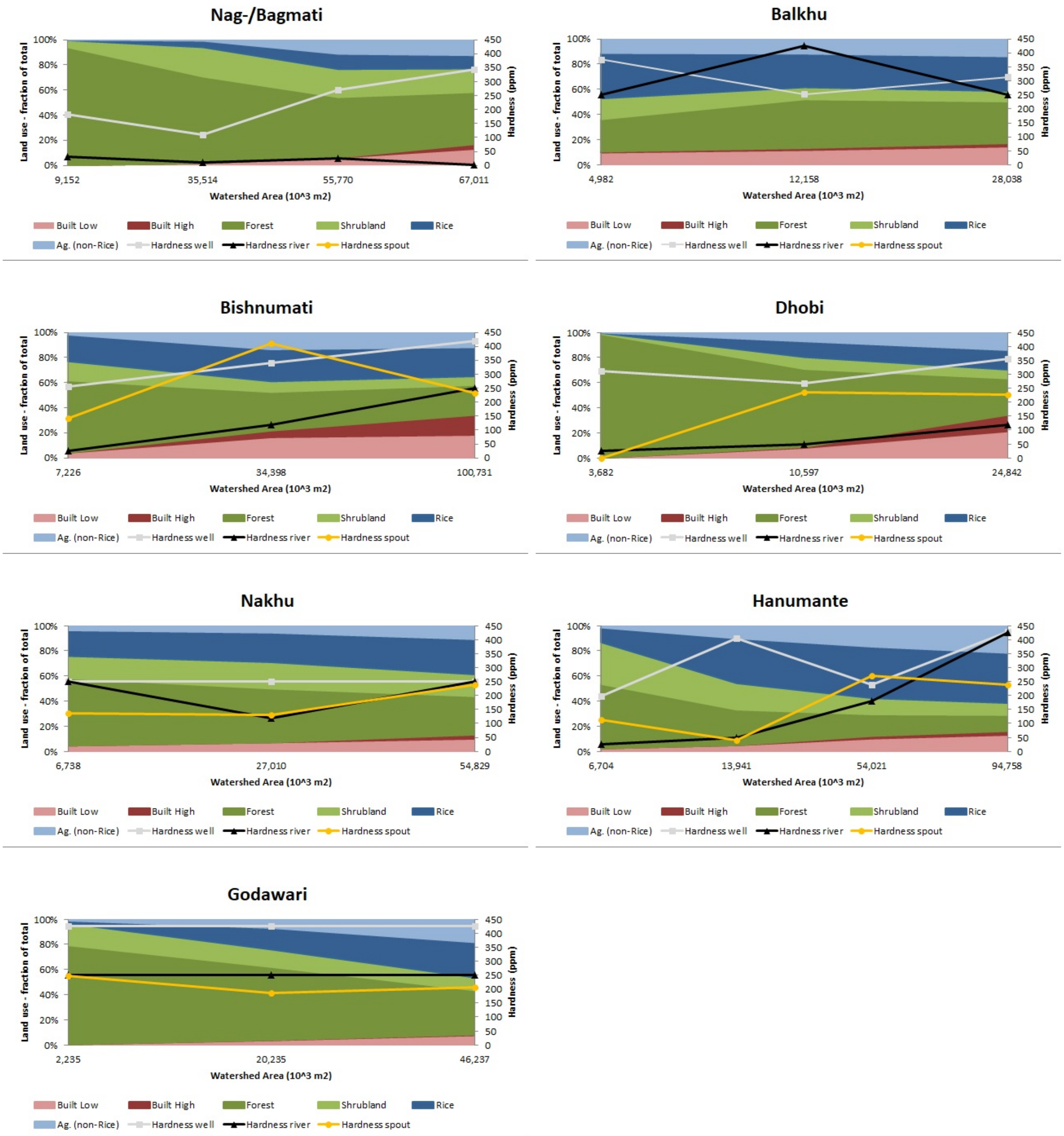


Figure 14.4: Comparison of land use development with the measured hardness values, from the upstream to downstream watershed pour points.
Note: For the Nag-/Bagmati and Balkhu watershed only 1 spout measurement per watershed is available which is insufficient to create a longitudinal graph.

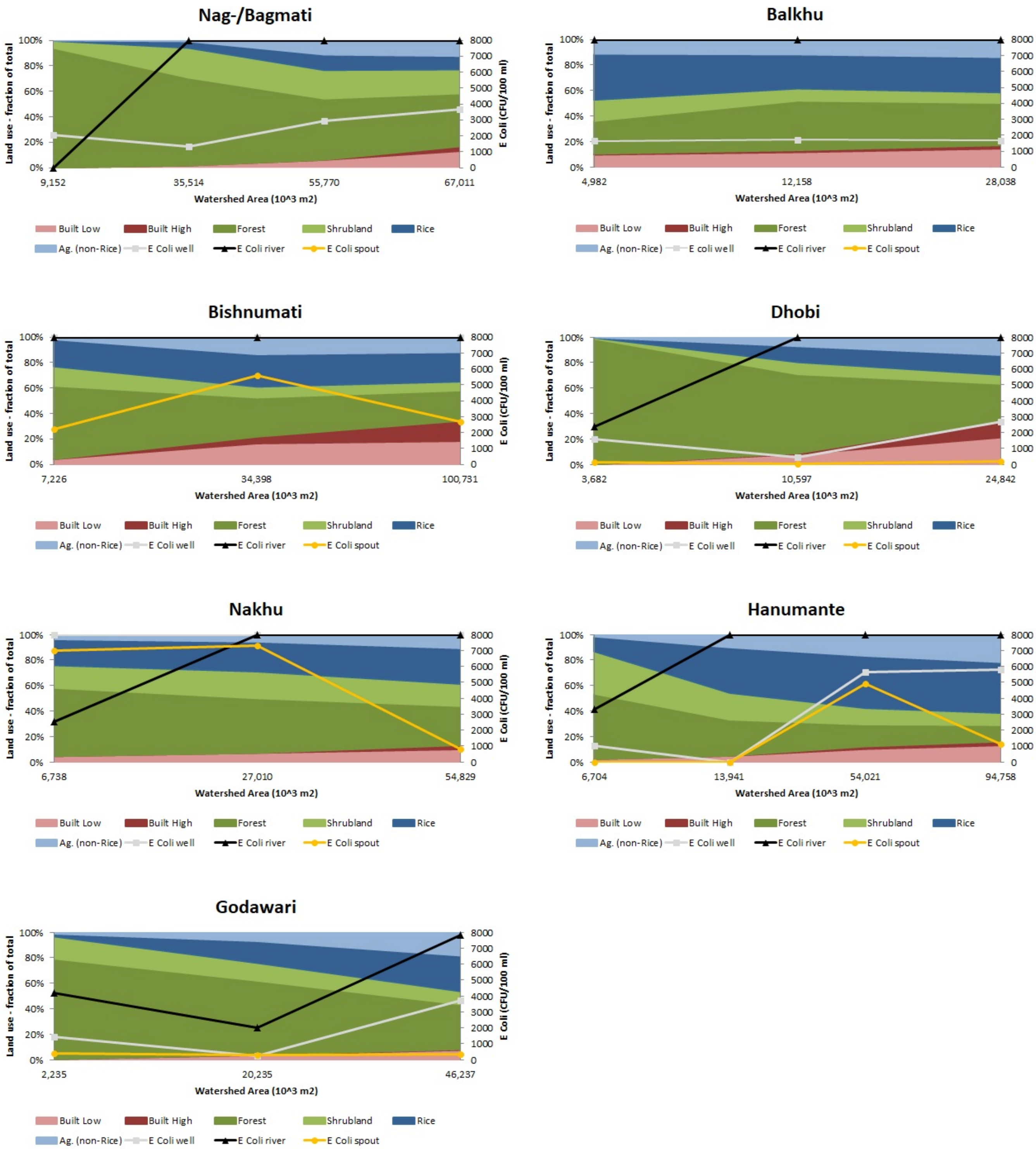


Figure 14.5: Comparison of land use development with the measured E Coli values, from the upstream to downstream watershed pour points.
Note: For the Nag-/Bagmati and Balkhu watershed only 1 spout measurement per watershed is available which is insufficient to create a longitudinal graph. The graphs that are barely visible on the top edge of the figures are out of range measurements.

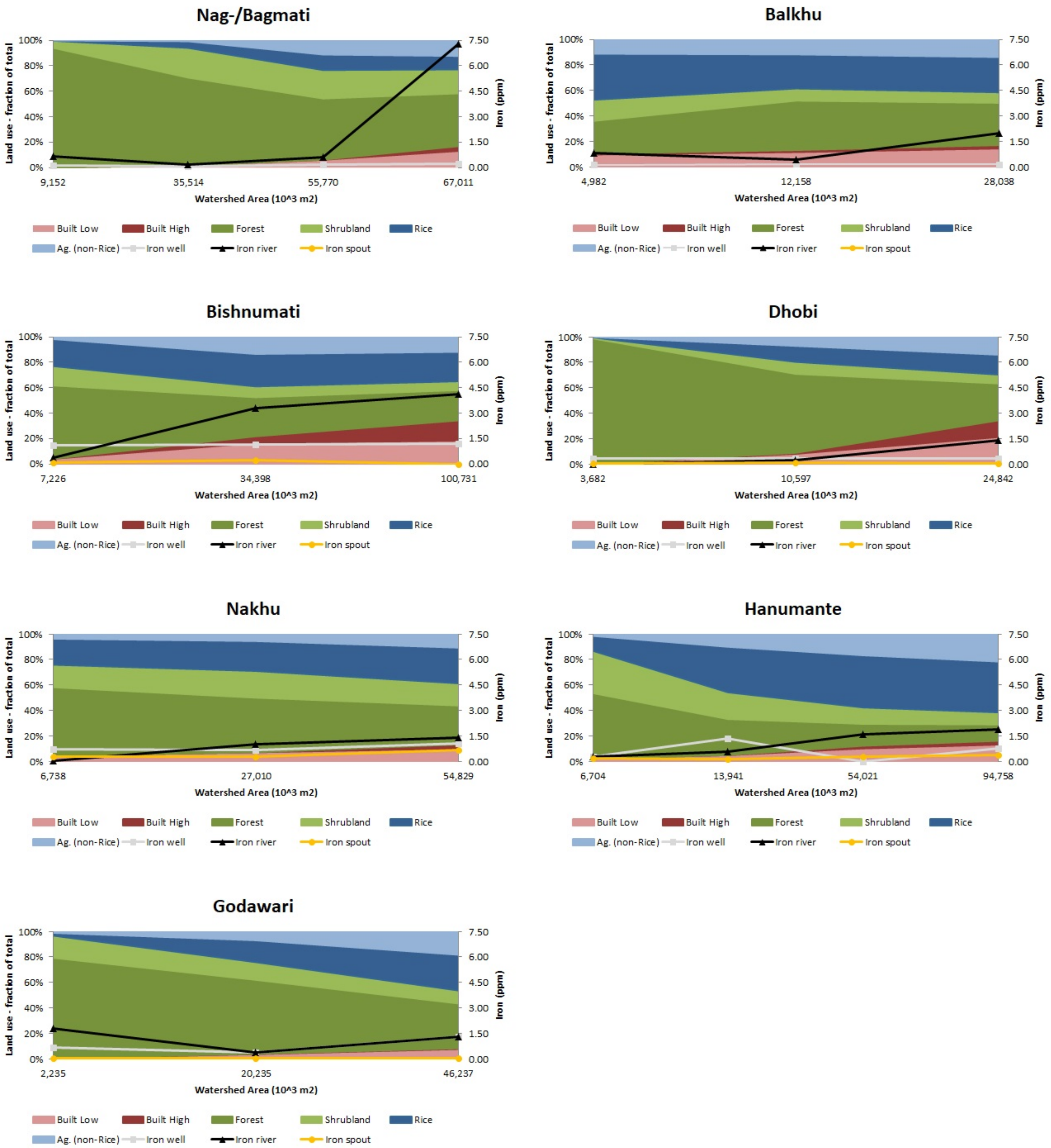


Figure 14.6: Comparison of land use development with the measured iron values, from the upstream to downstream watershed pour points.
For the Nag-/Bagmati and Balkhu watershed only 1 spout measurement per watershed is available which is insufficient to create a longitudinal graph.

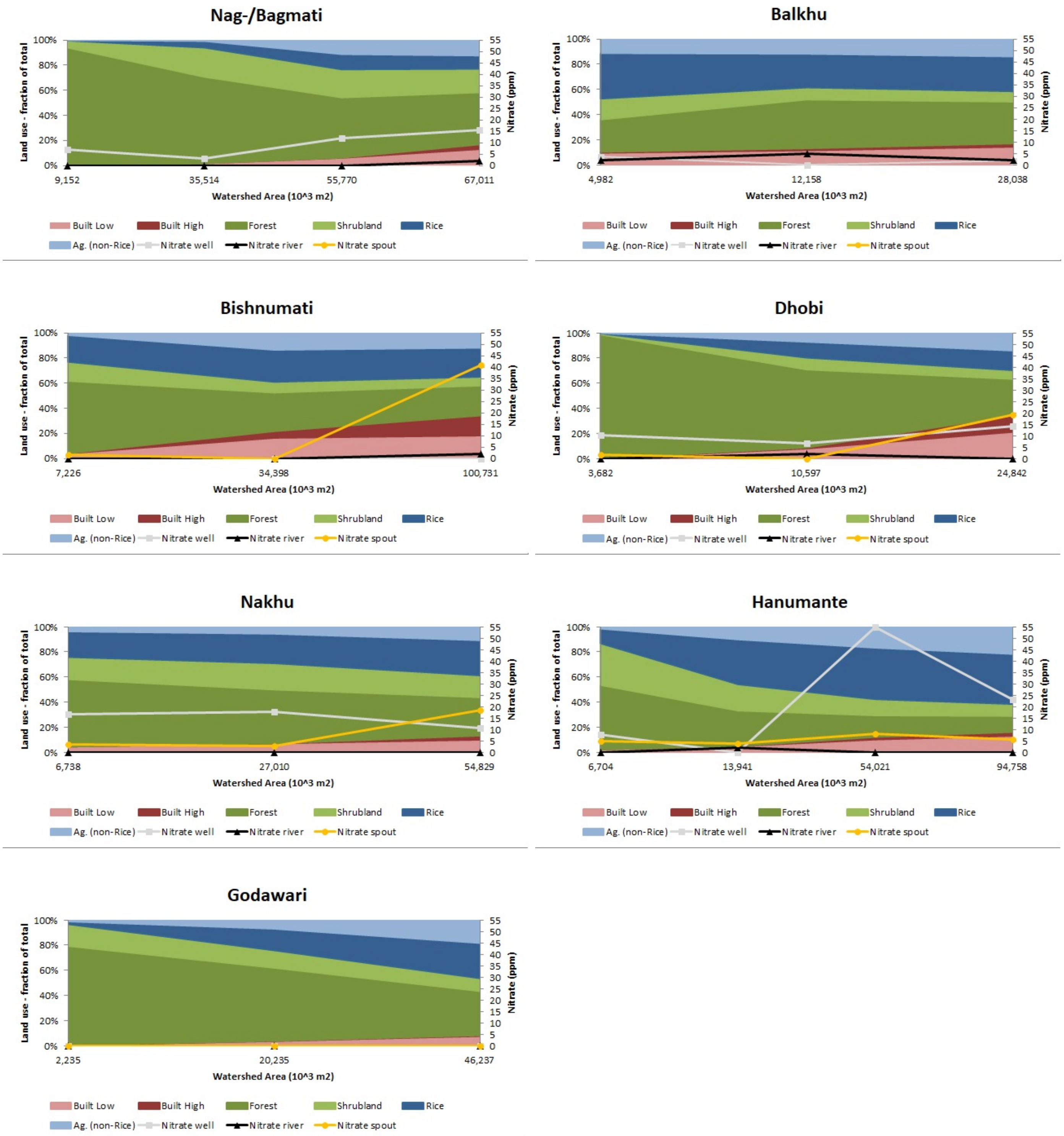


Figure 14.7: Comparison of land use development with the measured nitrate values, from the upstream to downstream watershed pour points.
Note: For the Nag-/Bagmati and Balkhu watershed only 1 spout measurement per watershed is available which is insufficient to create a longitudinal graph.

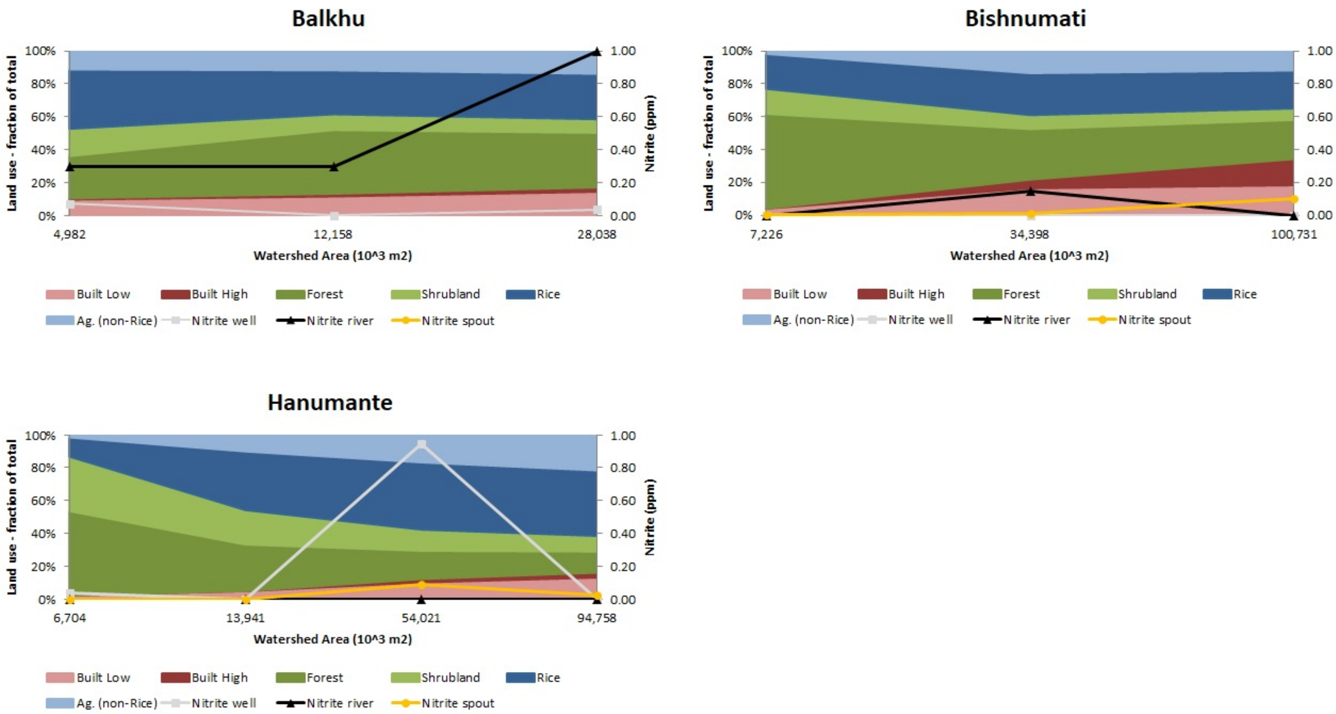


Figure 14.8: Comparison of land use development with the measured nitrite values, from the upstream to downstream watershed pour points.
Note: Only three watersheds are depicted here due to the absence of nitrite in the other watersheds. For the Balkhu watershed only 1 spout measurement pis available which is insufficient to create a longitudinal graph.

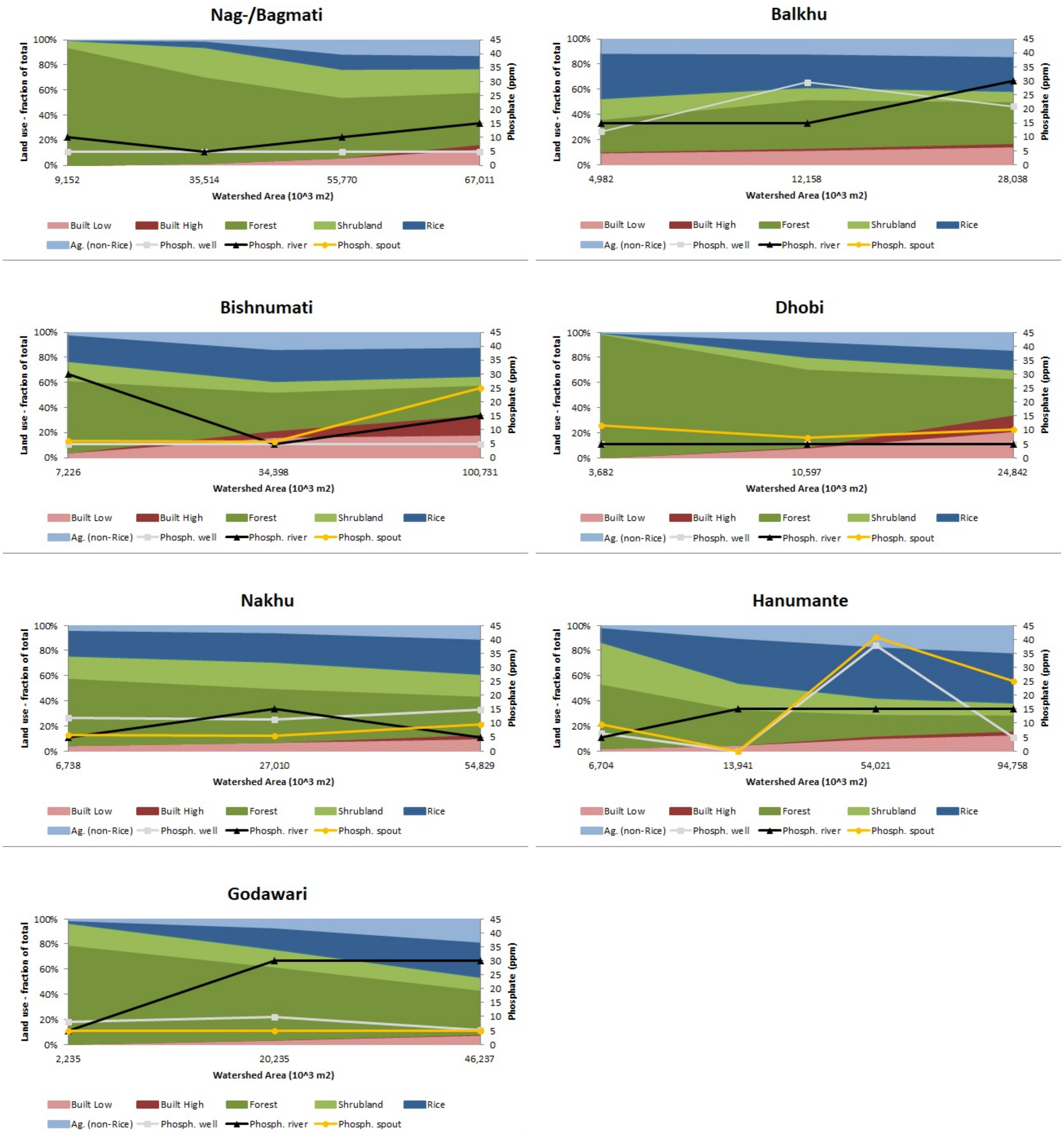


Figure 14.9: Comparison of land use development with the measured phosphate values, from the upstream to downstream watershed pour points.
Note: For the Nag-/Bagmati and Balkhu watershed only 1 spout measurement per watershed is available which is insufficient to create a longitudinal graph.

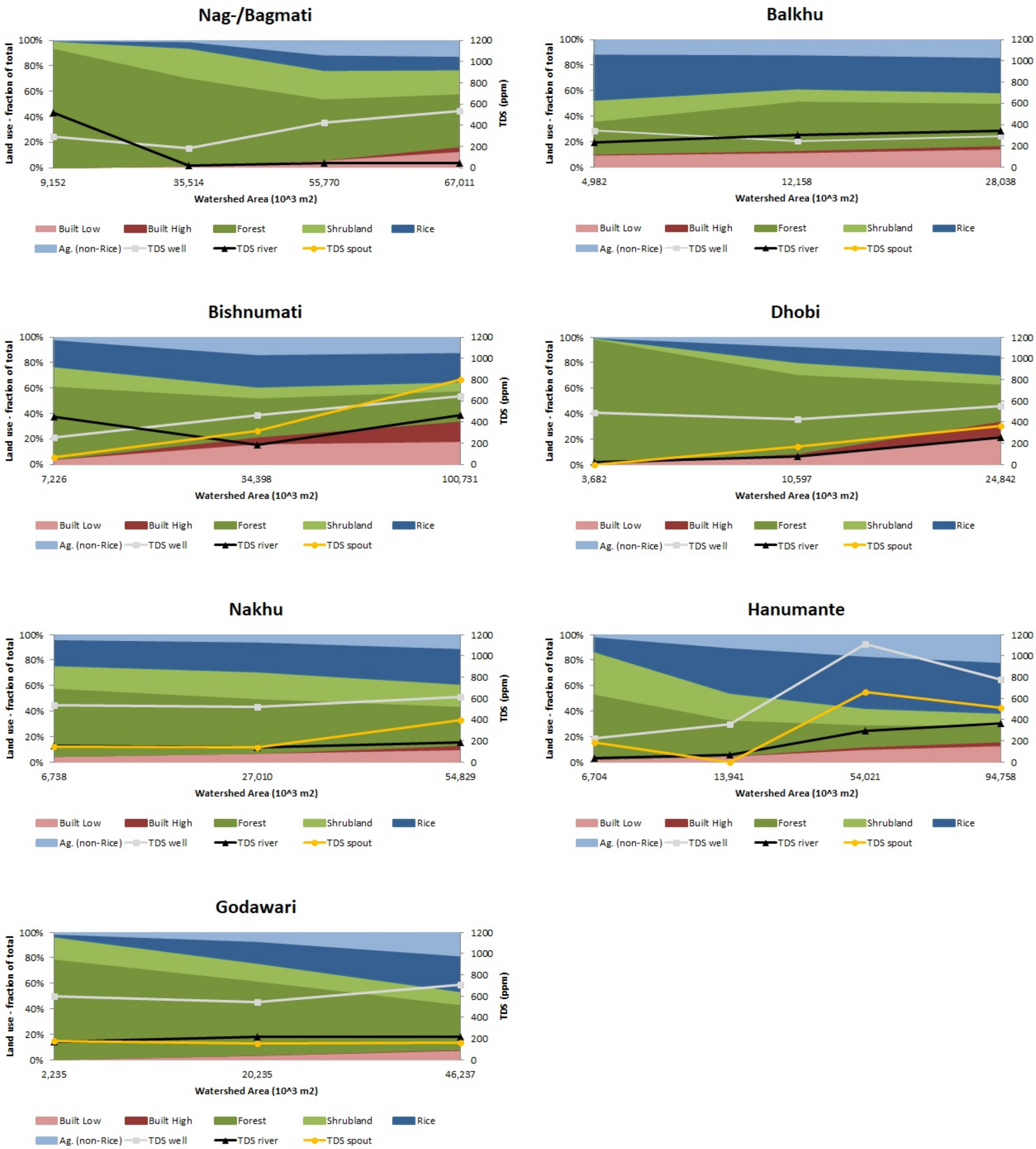


Figure 14.10: Comparison of land use development with the measured TDS values, from the upstream to downstream watershed pour points.
Note: For the Nag-/Bagmati and Balkhu watershed only 1 spout measurement per watershed is available which is insufficient to create a longitudinal graph.

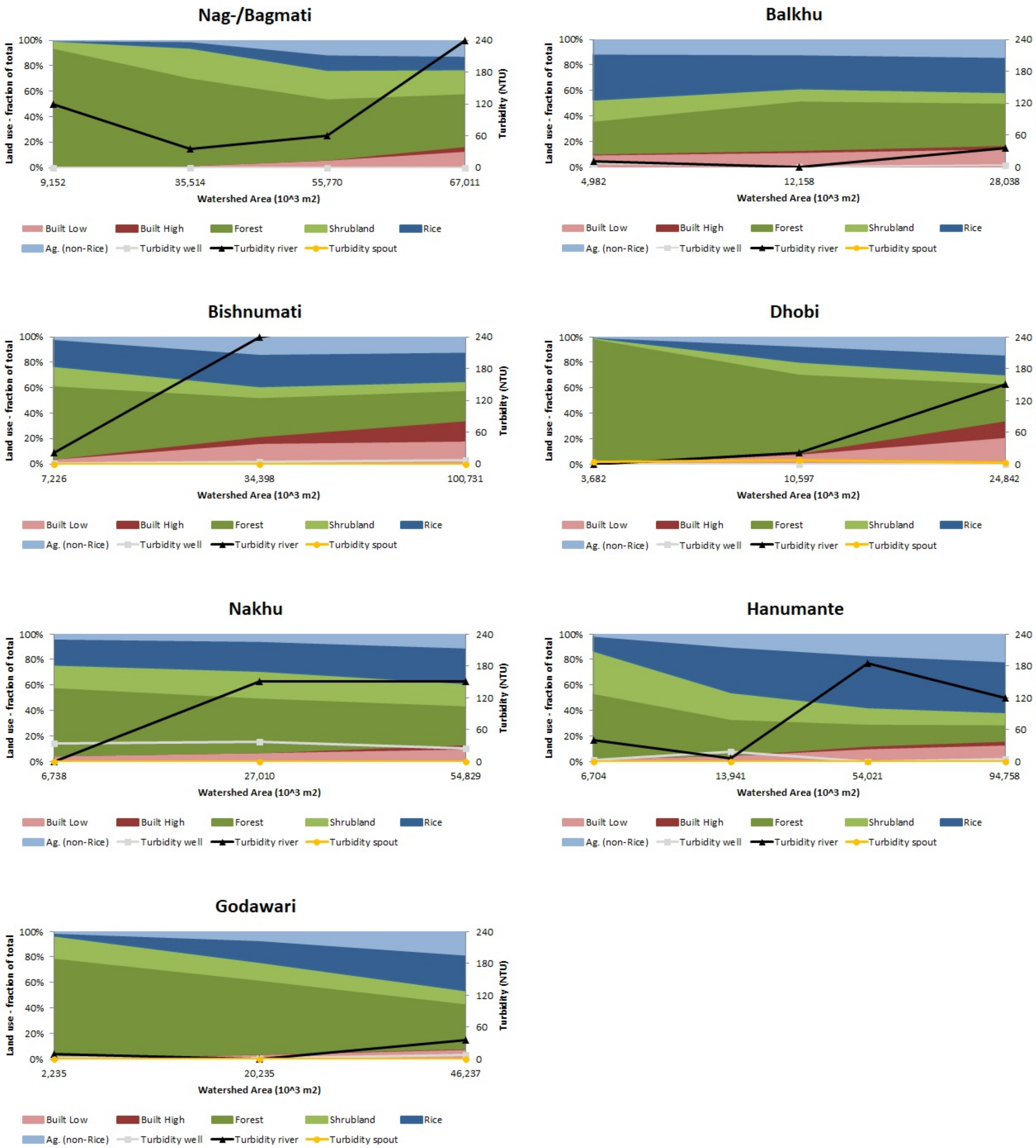


Figure 14.11: Comparison of land use development with the measured turbidity values, from the upstream to downstream watershed pour points.
Note: For the Nag-/Bagmati and Balkhu watershed only 1 spout measurement per watershed is available which is insufficient to create a longitudinal graph.

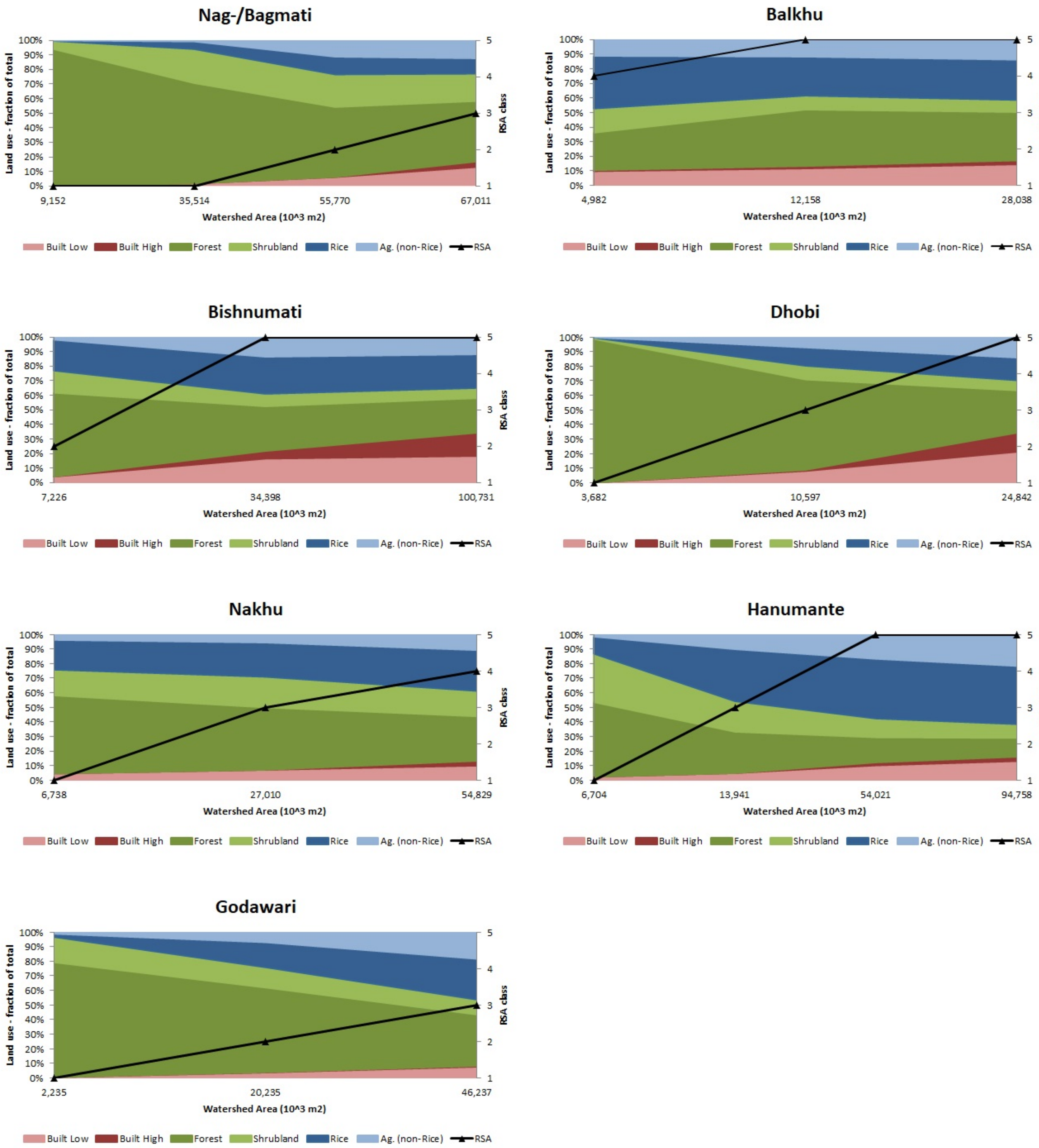
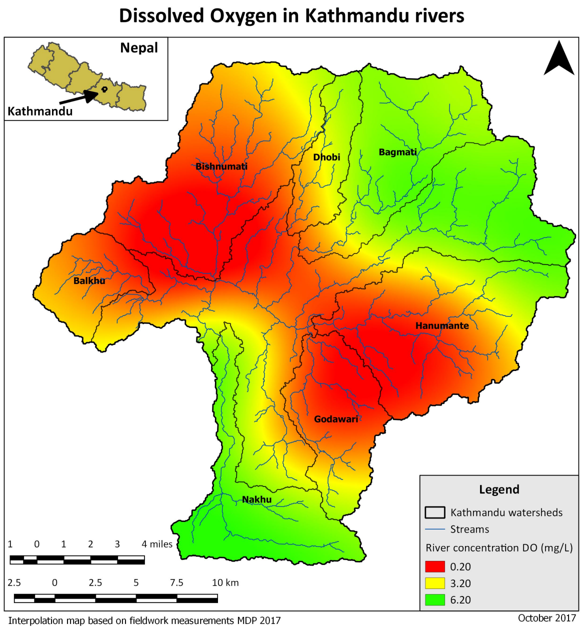
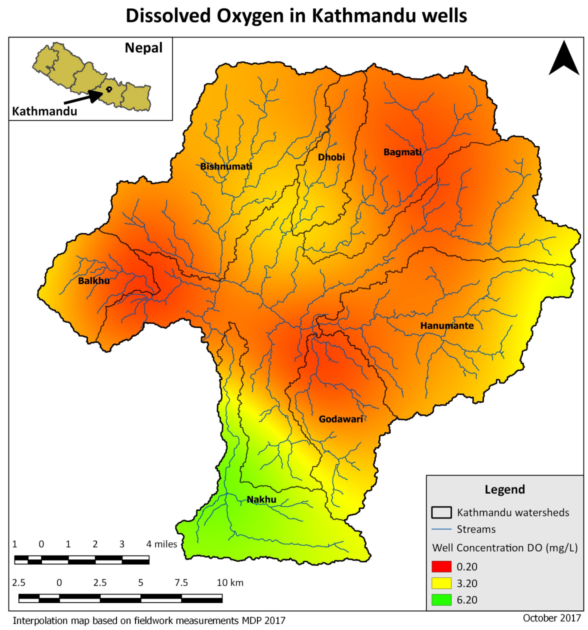


Figure 14.12: Comparison of land use development with the 2016 RSA classes, from the upstream to downstream watershed pour points.
Note: For the Nag-/Bagmati and Balkhu watershed only 1 spout measurement per watershed is available which is insufficient to create a longitudinal graph.

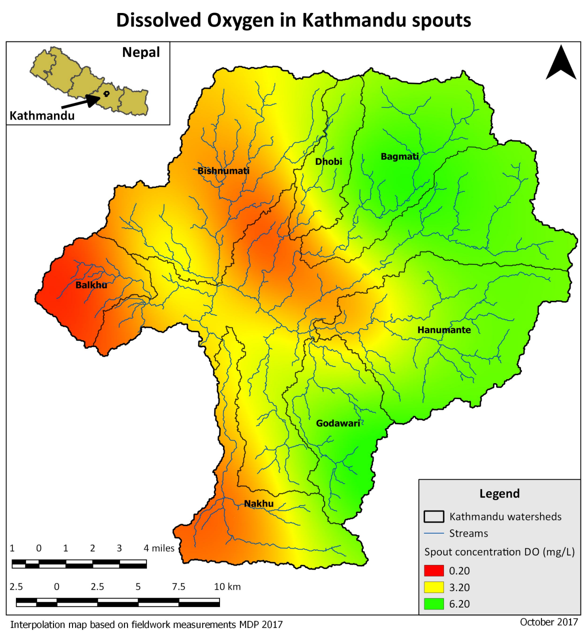
14.3 Appendix III: Spatial distribution of water quality parameters in the Kathmandu Valley



(a) Distribution of the DO over the rivers

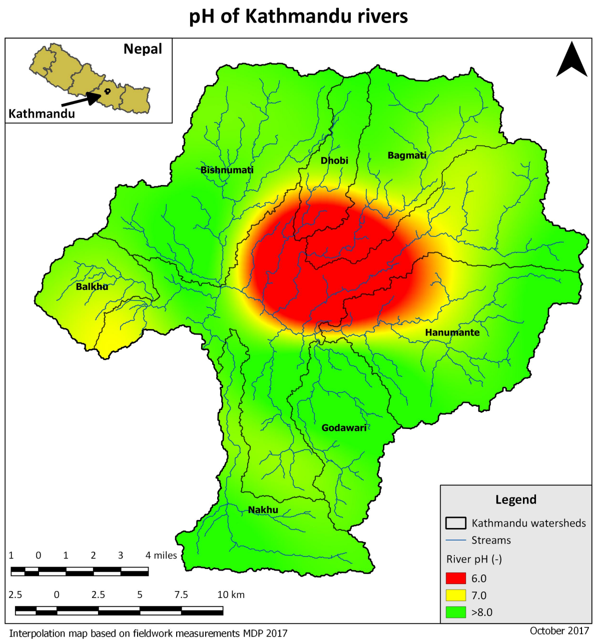


(b) Distribution of the DO over the wells

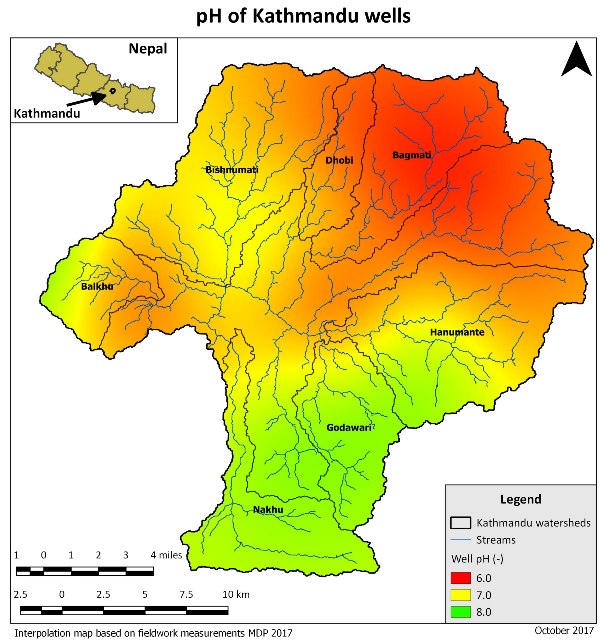


(c) Distribution of the DO over the spouts

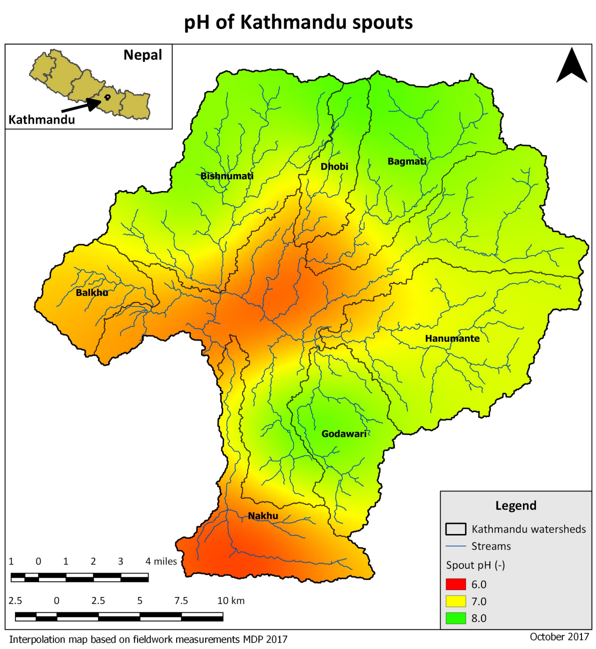
Figure 14.13: Spatial distribution of dissolved oxygen, from 3 different sources, in the Kathmandu watershed. Note: Caution is recommended when using values near the edges of this map. The interpolation maps are based on 17 well measurement points, 17 spout measurement points and 23 river measurement points. These are mainly located around the main river branches, which makes interpolated values near the edge of the Kathmandu basin not representative of the actual values.



(a) Distribution of the pH over the rivers

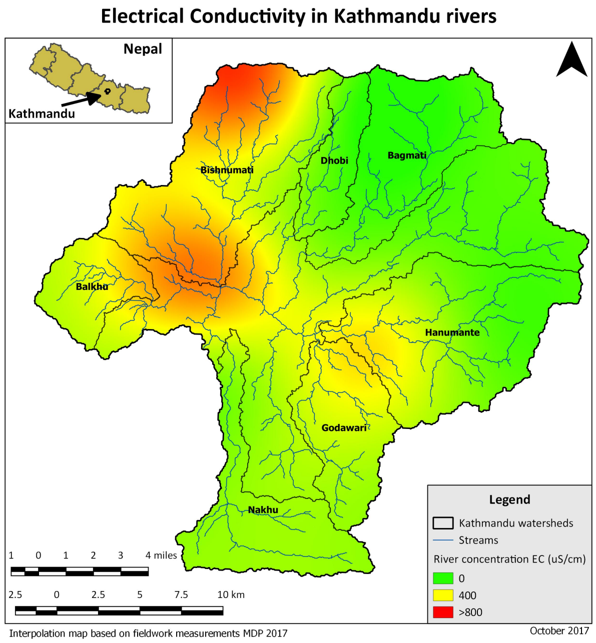


(b) Distribution of the pH over the wells

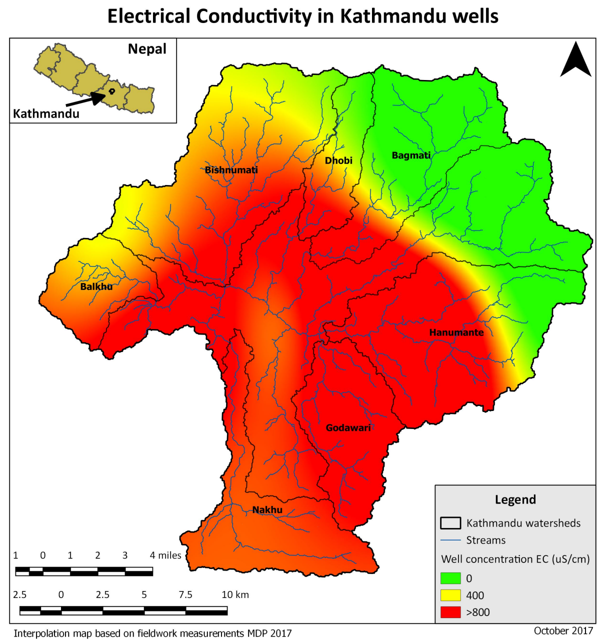


(c) Distribution of the pH over the spouts

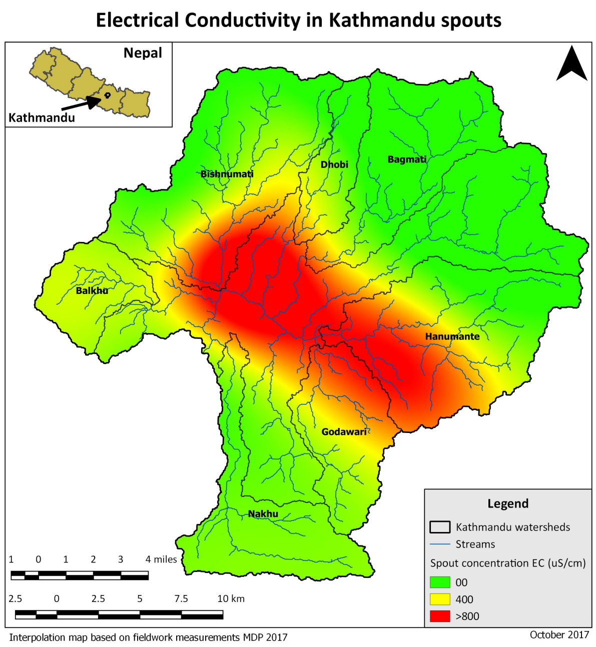
Figure 14.14: Spatial distribution of pH, from 3 different sources, in the Kathmandu watershed.
Note: Caution is recommended when using values near the edges of this map. The interpolation maps are based on 17 well measurement points, 17 spout measurement points and 23 river measurement points. These are mainly located around the main river branches, which makes interpolated values near the edge of the Kathmandu basin not representative of the actual values.



(a) Distribution of the EC over the rivers



(b) Distribution of the EC over the wells



(c) Distribution of the EC over the spouts

Figure 14.15: Spatial distribution of electrical conductivity, from 3 different sources, in the Kathmandu watershed. Note: Caution is recommended when using values near the edges of this map. The interpolation maps are based on 17 well measurement points, 17 spout measurement points and 23 river measurement points. These are mainly located around the main river branches, which makes interpolated values near the edge of the Kathmandu basin not representative of the actual values.

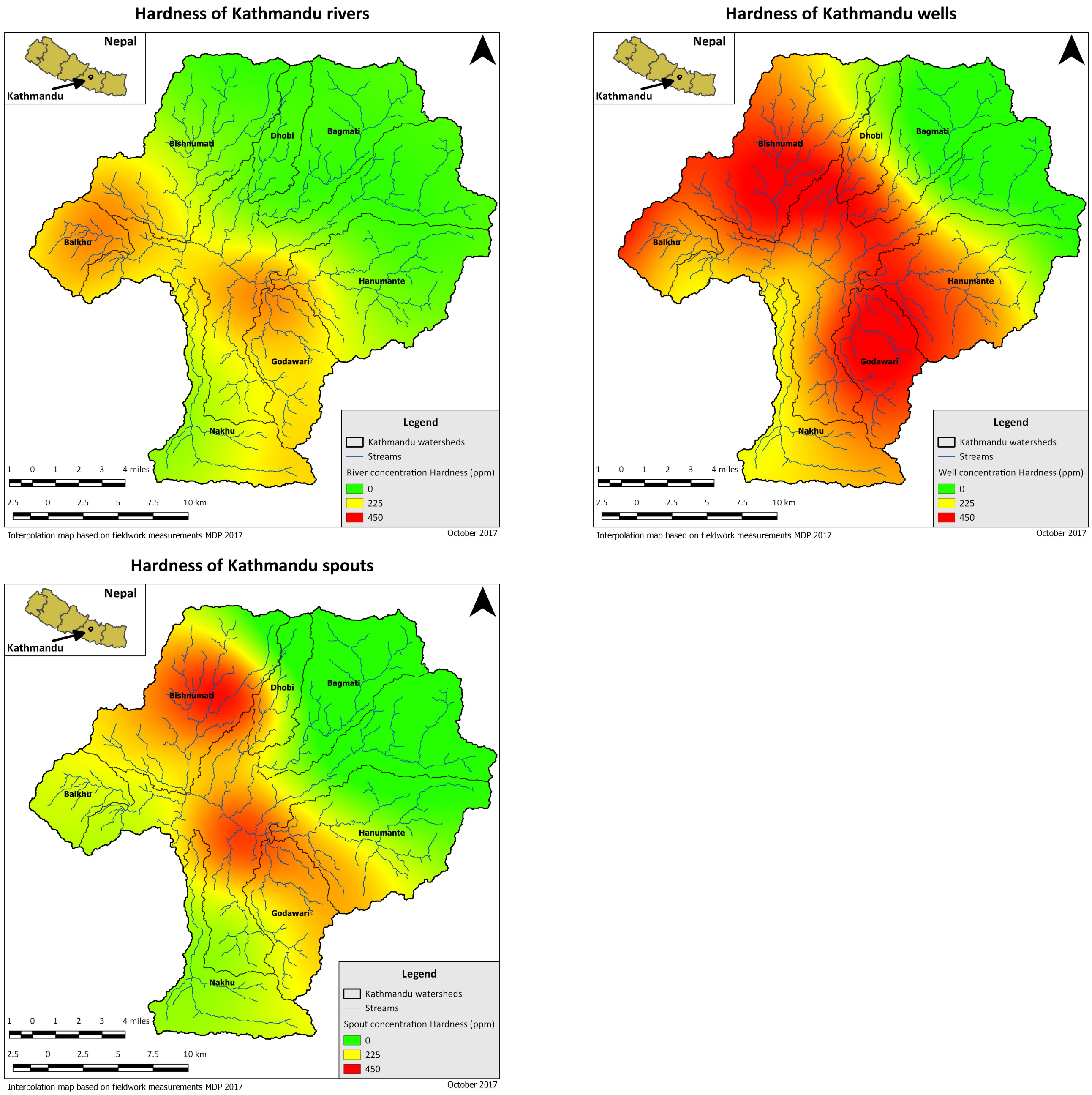


Figure 14.16: Spatial distribution of hardness, from 3 different sources, in the Kathmandu watershed. Note: Caution is recommended when using values near the edges of this map. The interpolation maps are based on 17 well measurement points, 17 spout measurement points and 23 river measurement points. These are mainly located around the main river branches, which makes interpolated values near the edge of the Kathmandu basin not representative of the actual values.

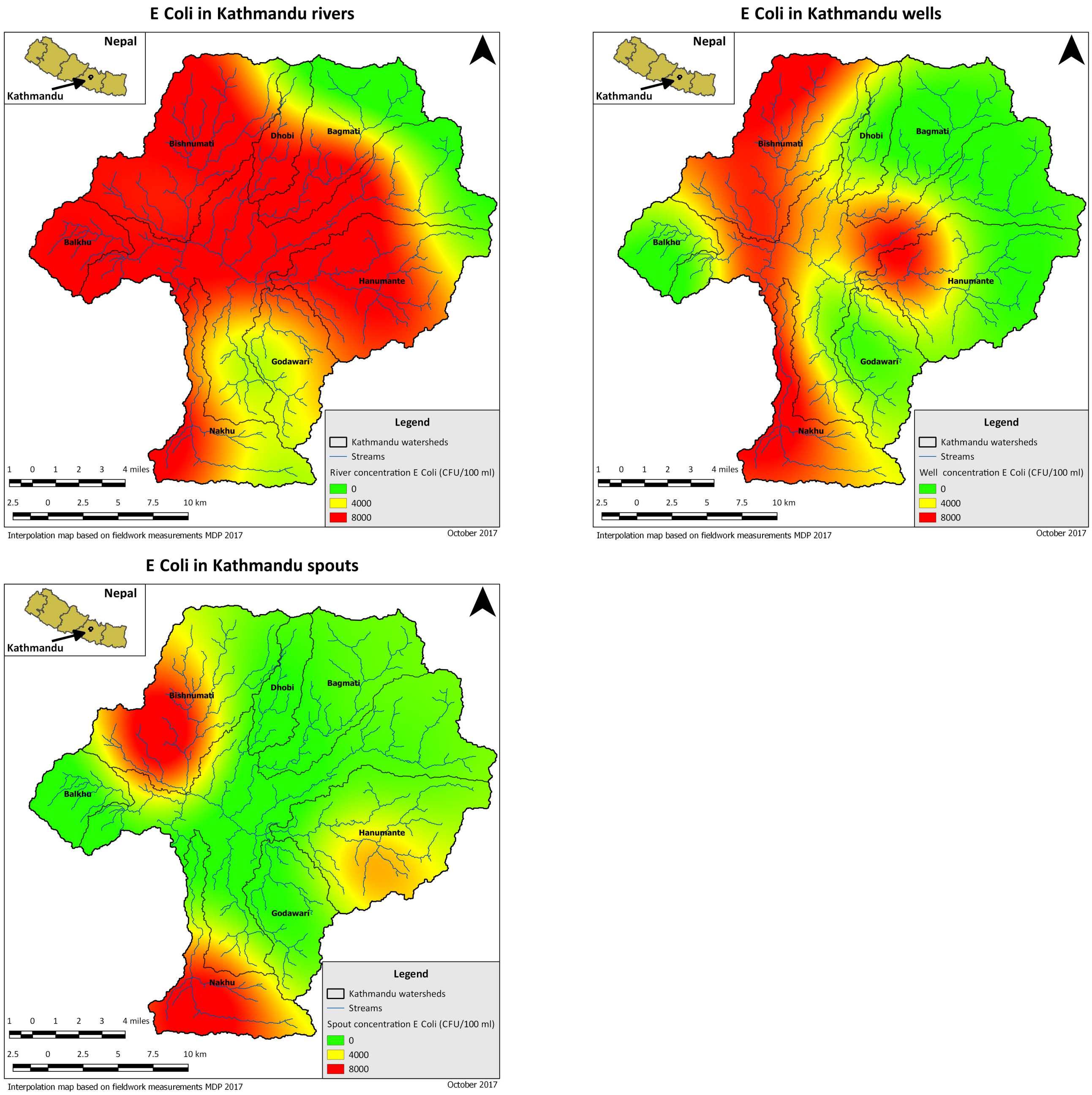


Figure 14.17: Spatial distribution of electrical conductivity, from 3 different sources, in the Kathmandu watershed. Note: Caution is recommended when using values near the edges of this map. The interpolation maps are based on 17 well measurement points, 17 spout measurement points and 23 river measurement points. These are mainly located around the main river branches, which makes interpolated values near the edge of the Kathmandu basin not representative of the actual values.

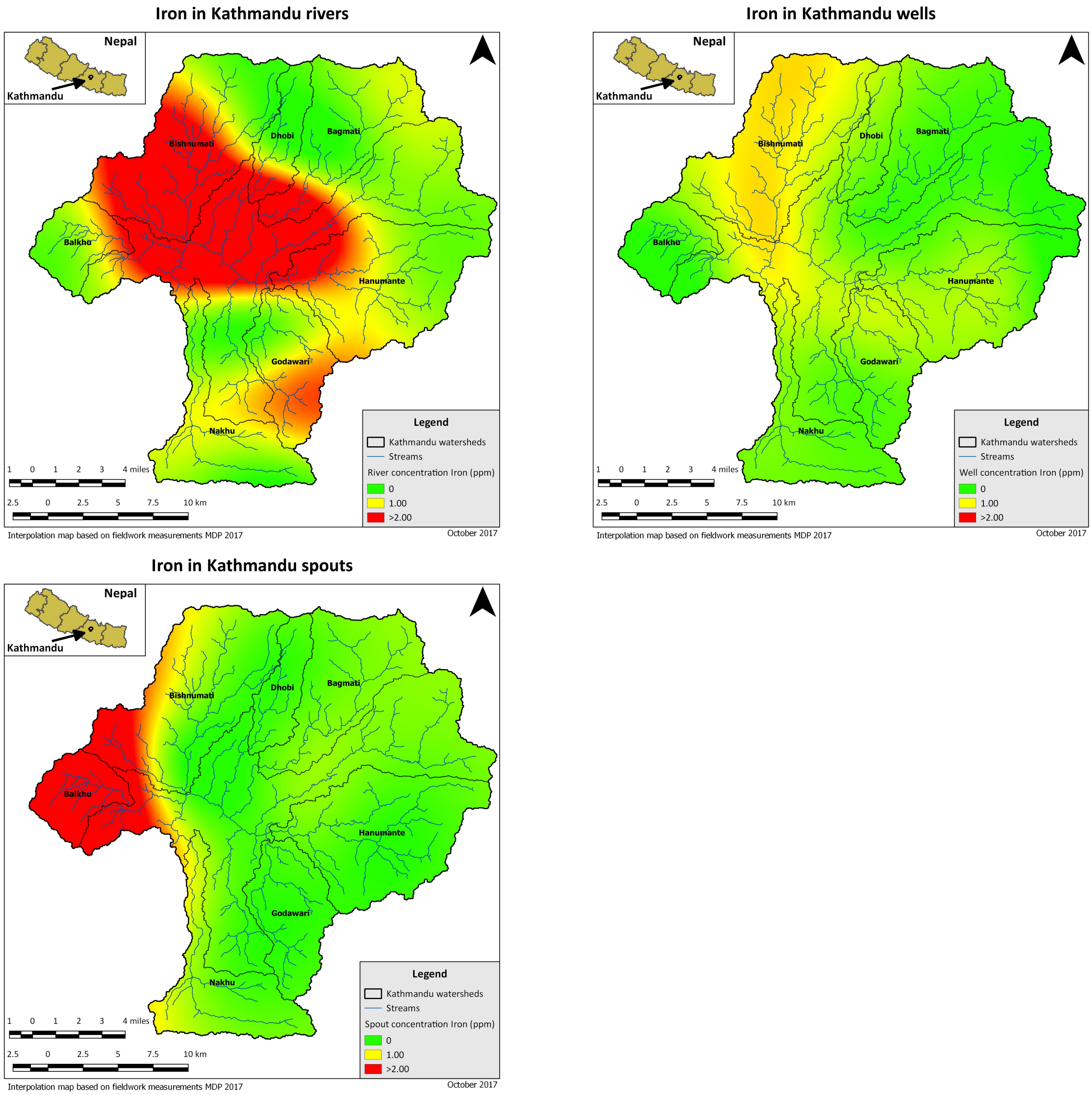


Figure 14.18: Spatial distribution of iron, from 3 different sources, in the Kathmandu watershed. Note: Caution is recommended when using values near the edges of this map. The interpolation maps are based on 17 well measurement points, 17 spout measurement points and 23 river measurement points. These are mainly located around the main river branches, which makes interpolated values near the edge of the Kathmandu basin not representative of the actual values.

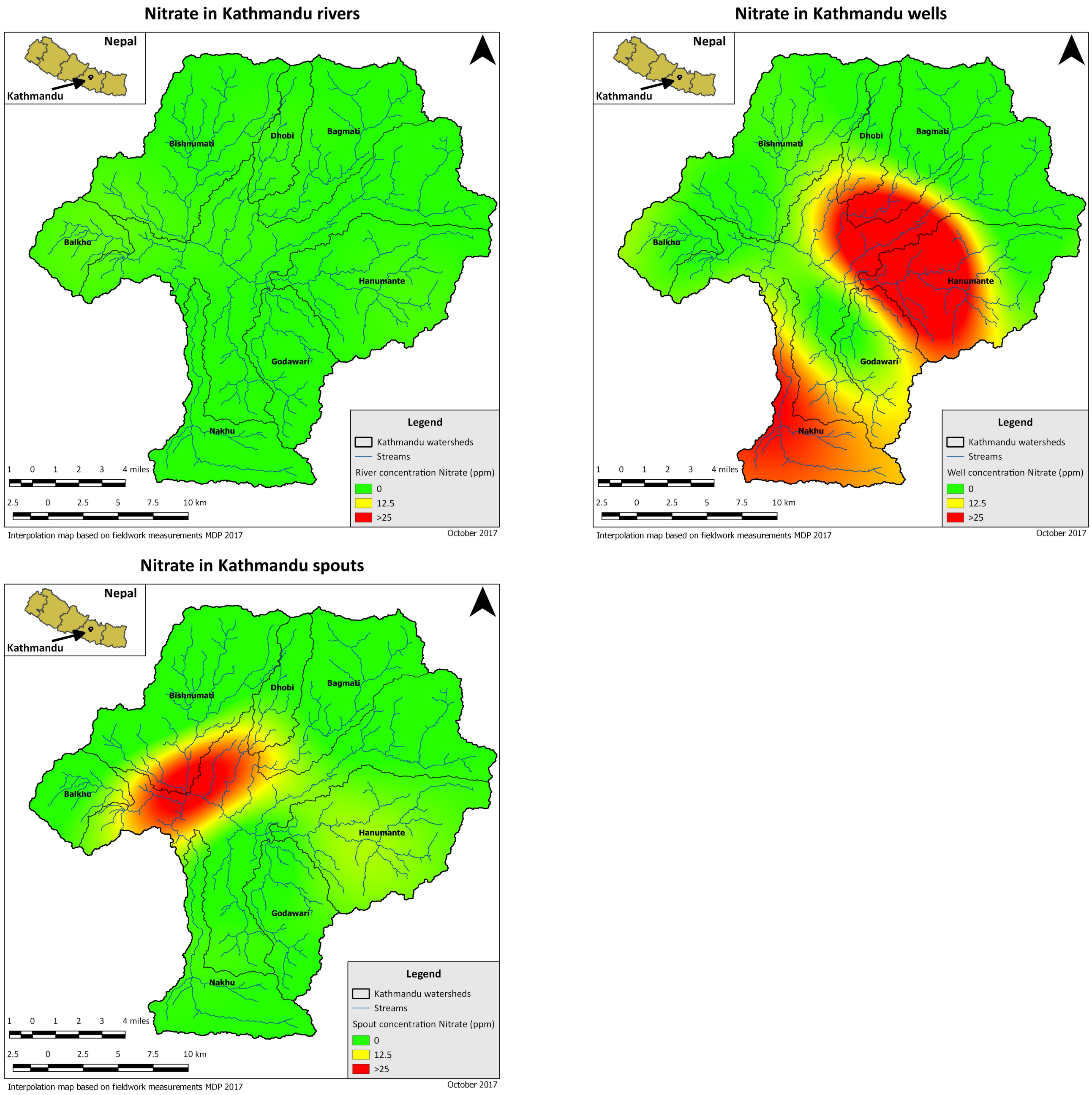
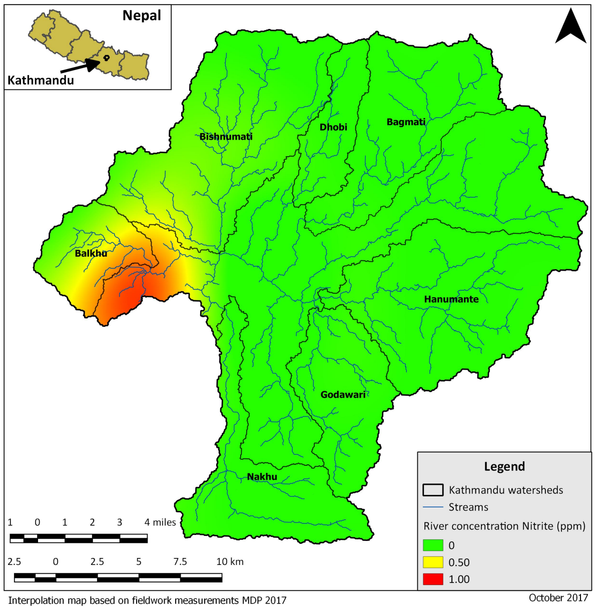
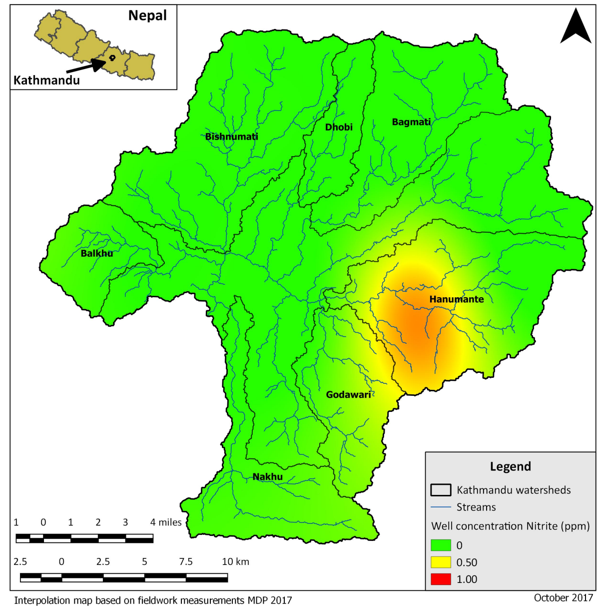


Figure 14.19: Spatial distribution of nitrate, from 3 different sources, in the Kathmandu watershed. Note: Caution is recommended when using values near the edges of this map. The interpolation maps are based on 17 well measurement points, 17 spout measurement points and 23 river measurement points. These are mainly located around the main river branches, which makes interpolated values near the edge of the Kathmandu basin not representative of the actual values.

Nitrite in Kathmandu rivers



Nitrite in Kathmandu wells



Nitrite in Kathmandu spouts

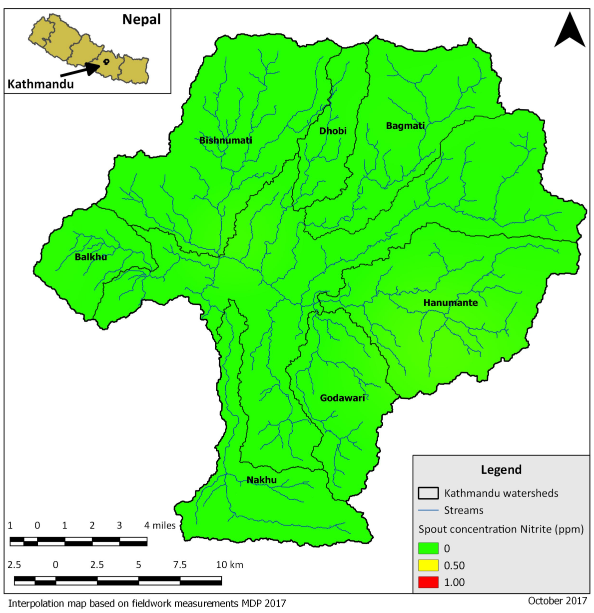
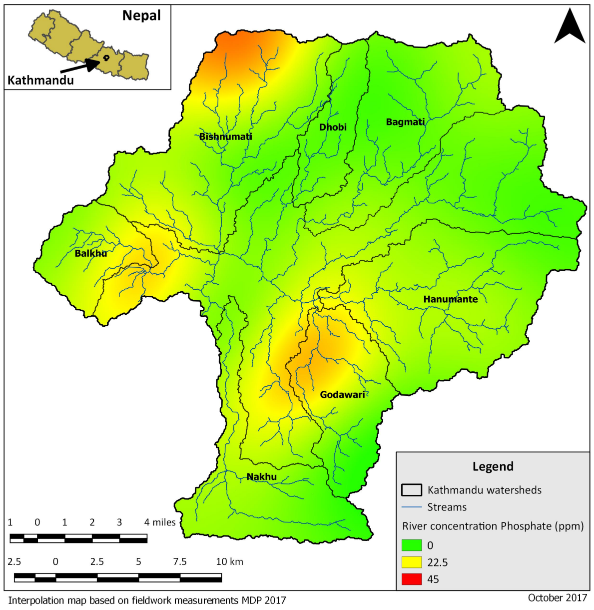
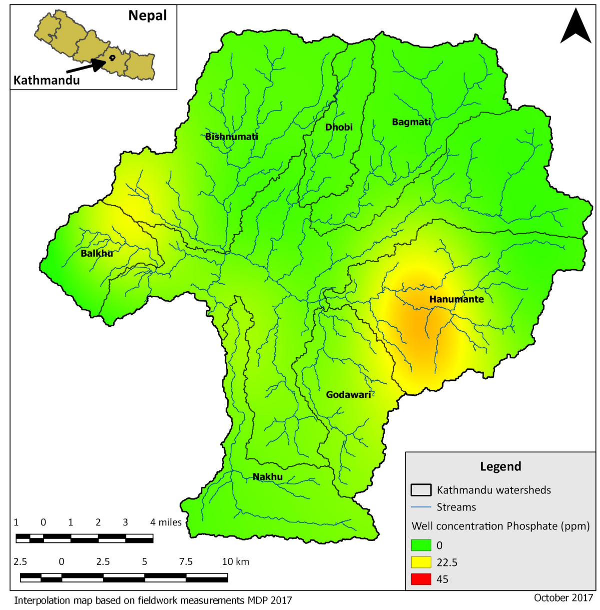


Figure 14.20: Spatial distribution of nitrite, from 3 different sources, in the Kathmandu watershed. Note: Caution is recommended when using values near the edges of this map. The interpolation maps are based on 17 well measurement points, 17 spout measurement points and 23 river measurement points. These are mainly located around the main river branches, which makes interpolated values near the edge of the Kathmandu basin not representative of the actual values.

Phosphate in Kathmandu rivers



Phosphate in Kathmandu wells



Phosphate in Kathmandu spouts

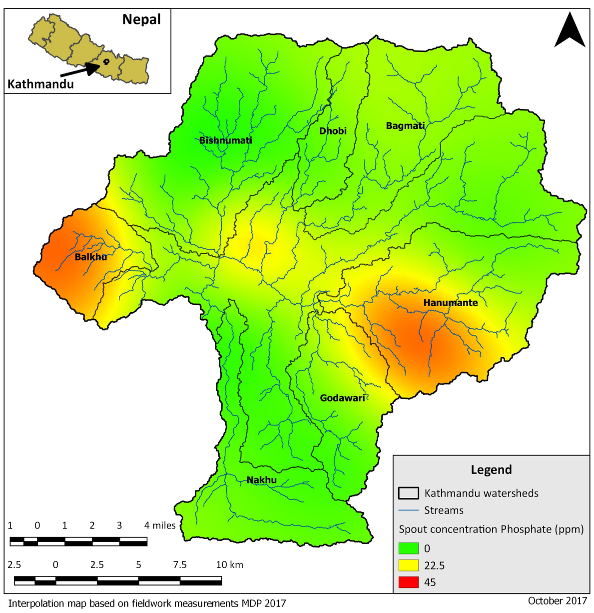


Figure 14.21: Spatial distribution of phosphate, from 3 different sources, in the Kathmandu watershed. Note: Caution is recommended when using values near the edges of this map. The interpolation maps are based on 17 well measurement points, 17 spout measurement points and 23 river measurement points. These are mainly located around the main river branches, which makes interpolated values near the edge of the Kathmandu basin not representative of the actual values.

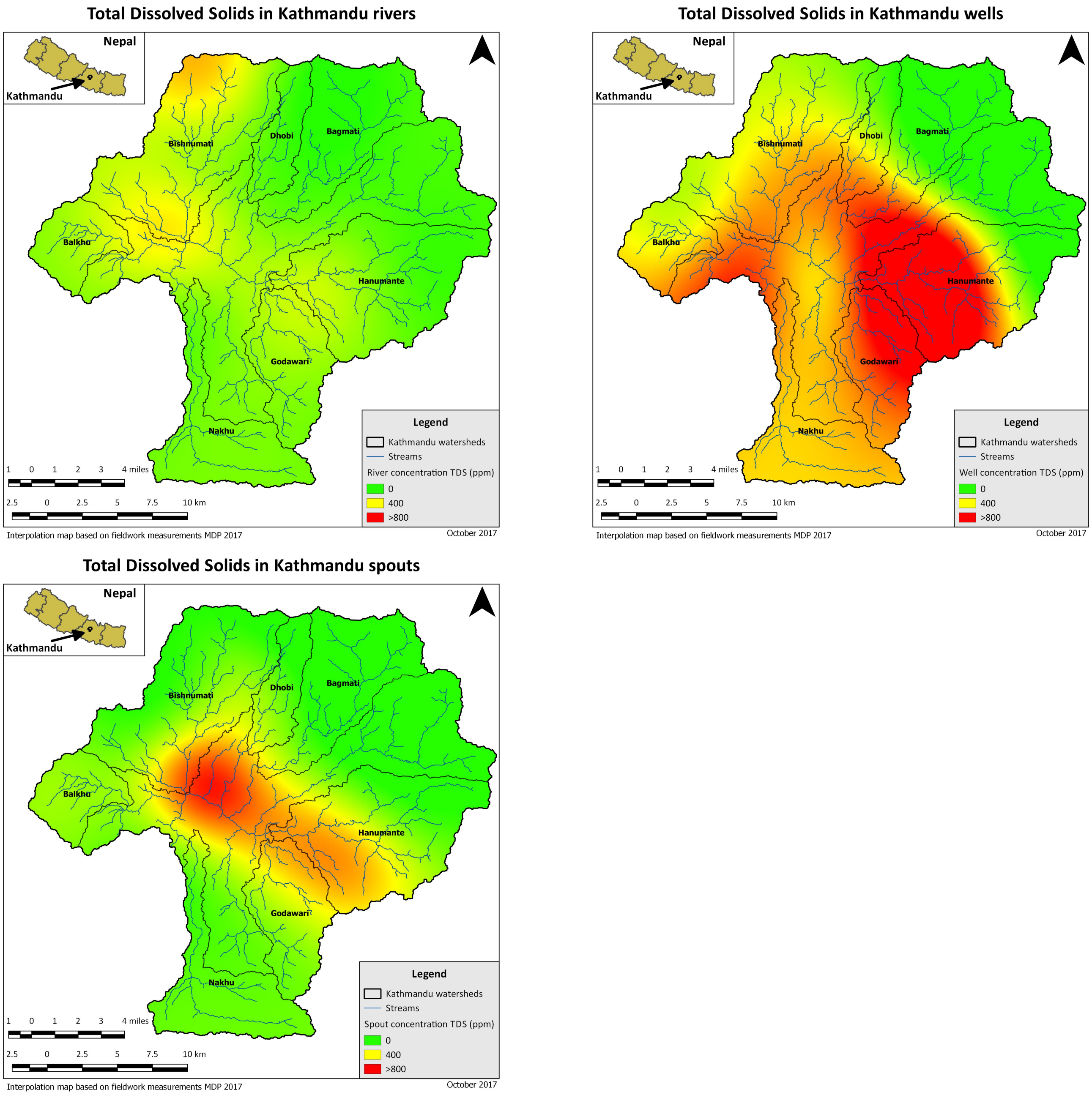


Figure 14.22: Spatial distribution of TDS, from 3 different sources, in the Kathmandu watershed. Note: Caution is recommended when using values near the edges of this map. The interpolation maps are based on 17 well measurement points, 17 spout measurement points and 23 river measurement points. These are mainly located around the main river branches, which makes interpolated values near the edge of the Kathmandu basin not representative of the actual values.

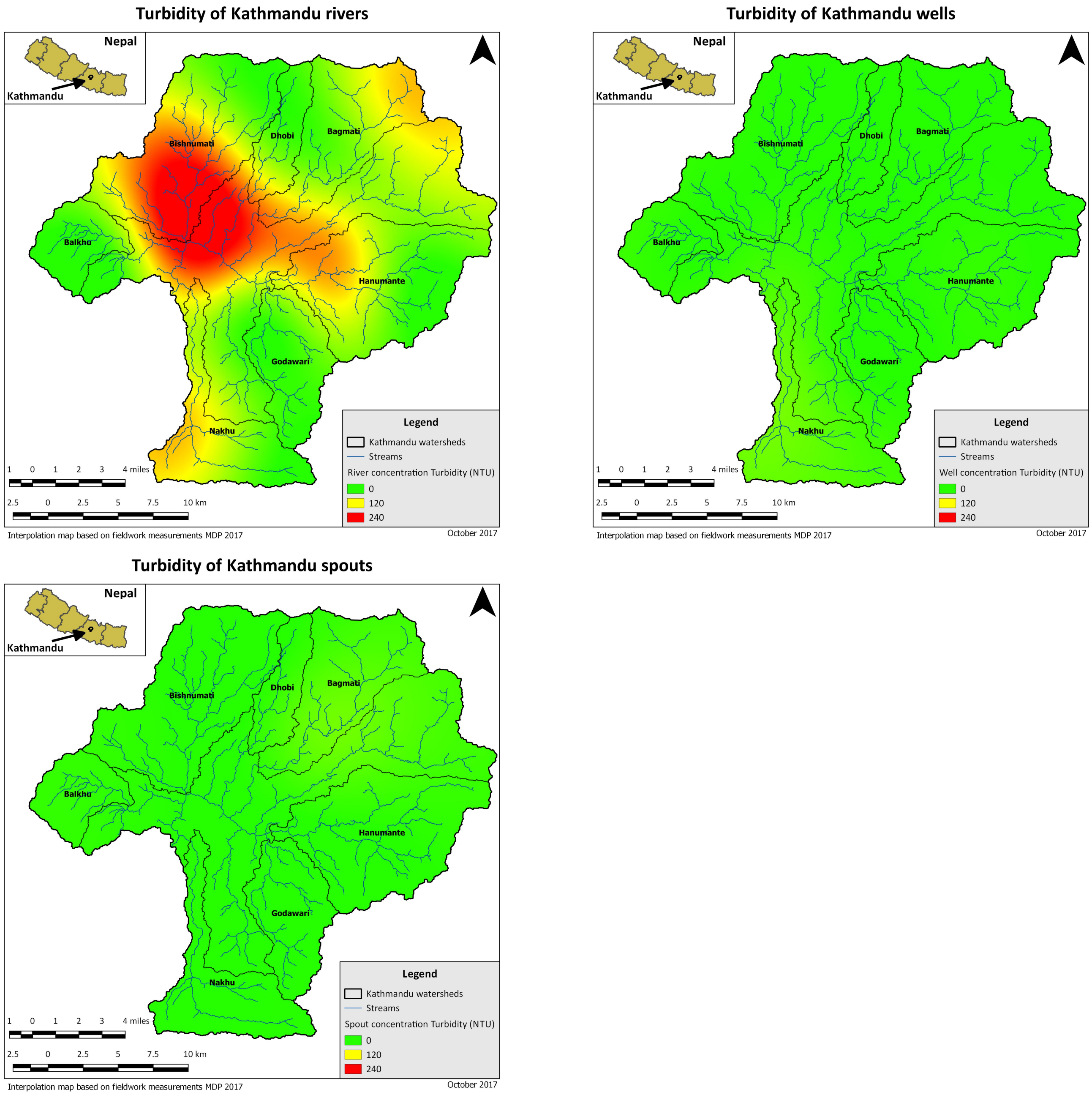


Figure 14.23: Spatial distribution of turbidity, from 3 different sources, in the Kathmandu watershed.
Note: Caution is recommended when using values near the edges of this map. The interpolation maps are based on 17 well measurement points, 17 spout measurement points and 23 river measurement points. These are mainly located around the main river branches, which makes interpolated values near the edge of the Kathmandu basin not representative of the actual values.

14.4 Appendix IV: Scripts

14.4.1 Grass

GRASS commands - Parameter interpolation

```
v.buffer input = # distance = 1000 output = #_buffer --overwrite
v.select ainput = KTM_Measurements_"source" atype = point binput = #_buffer btype = area
output = #_"source" --overwrite
r.mask vector = # --overwrite
v.surf.rst input = #_"source" zcolumn = "parameter" elevation = #_"source"_"parameter" --overwrite
r.mask -r

r.patch input = #_"source"_"parameter", #_"source"_"parameter", #_"source"_"parameter",
#_"source"_"parameter", #_"source"_"parameter", #_"source"_"parameter", #_"source"_"parameter"
out = "source"_"parameter"_patch --overwrite
r.colors map = "source"_"parameter"_patch color = gyr

g.remove type = vector name = #_buffer -f
g.remove type = vector name = #_"source" -f
g.remove type = raster name = #_"source"_"parameter" -f
```

14.4.2 VBA

VBA commands - Generation of 3-hour ground data time series

```
Sub engineprecip_aug()
Dim i, j, nr As Integer
Dim sum, timdif As Double
Dim hourbig As Boolean

Dim starttime, startdate As String
Dim MyRange As Range

Worksheets("Name").Activate
Set MyRange = Range("K3")
nr = Cells(Rows.Count, "A").End(xlUp).Row - 2

i = 0
j = 0

Do While j < nr + 1
n = 0
Do While MyRange.Offset(j + 1, -8) = Empty
j = j + 1
n = n + 1
If n > 100 Then
MyRange.Offset(i, 2) = sum
Exit Sub
End If

Loop
sum = 0
sum = MyRange.Offset(j, -5)
startdate = MyRange.Offset(j, -8).Text
starttime = Right(startdate, 5)
startdate = Left(startdate, Len(startdate) - 5)
MyRange.Offset(i, 0) = startdate
MyRange.Offset(i, 1) = starttime
j = j + 1
hourbig = False
Do While hourbig = False
n = 0
Do While MyRange.Offset(j + 1, -8) = Empty
j + 1
n = n + 1
If n > 100 Then
MyRange.Offset(i, 2) = sum
Exit Sub
End If

Loop
sum = sum + MyRange.Offset(j, -5)
If ((TimeValue(Right(MyRange.Offset(j + 1, -8).Text, 5)) - TimeValue(starttime)) >= 0.125)
Or ((TimeValue(Right(MyRange.Offset(j + 1, -8).Text, 5)) - TimeValue(starttime)) <= -0.875) Then
hourbig = True
End If

j = j + 1
Loop
MyRange.Offset(i, 2) = sum
i = i + 1
Loop
```

14.5 Appendix V: Old Correlation Matrices

14.5.1 Introduction

blbalbalalba

14.5.2 Land-use correlation

Overview tables per water-source

Wells											
	pH	DO [mg/l]	Nitrite [ppm]	Nitrate [ppm]	Phosphate [ppm]	Hardness [ppm]	Iron [mg/l]	E. Coli [$CFU/100ml$]	$EC_{25\,°C}$ [$\mu S/cm$]	TDS [mg/l]	Turbidity [NTU]
Build (low density)	0.06	-0.08	0.08	0.12	0.18	0.35	0.13	0.35	0.30	0.30	-0.05
Build (high density)	0.03	-0.06	-0.02	0.00	-0.07	0.33	0.21	0.32	0.27	0.27	-0.11
Forest	-0.26	0.12	-0.29	-0.28	-0.30	-0.36	-0.27	-0.37	-0.41	-0.41	-0.19
Shrublands	0.06	0.27	-0.02	0.02	-0.10	-0.31	-0.05	-0.07	-0.26	-0.26	0.28
Rice	0.35	-0.17	0.39	0.30	0.43	0.32	0.32	0.34	0.41	0.41	0.29
Ag. (non-rice)	0.13	-0.30	0.27	0.30	0.27	0.50	0.18	0.21	0.55	0.55	-0.06
Build (low density)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Build (high density)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Forest	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Shrublands	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Rice	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Ag. (non-rice)	NC	NC	NC	NC	NC	LC	NC	NC	LC	LC	NC

Table 14.2: Correlation between land-use and parameters within the wells

Rivers												
	RSA	pH	DO [mg/l]	Nitrite [ppm]	Nitrate [ppm]	Phosphate [ppm]	Hardness [ppm]	Iron [mg/l]	E. Coli [$CFU/100ml$]	$EC_{25\,°C}$ [$\mu S/cm$]	TDS [mg/l]	Turbidity [NTU]
Build (low density)	0.90	-0.24	-0.64	0.31	0.33	0.09	0.36	0.56	0.63	0.40	0.30	0.63
Build (high density)	0.60	-0.07	-0.48	0.01	0.14	-0.10	0.17	0.51	0.32	0.42	0.36	0.70
Forest	-0.83	0.11	0.56	-0.21	-0.25	-0.25	-0.47	-0.35	-0.72	-0.32	-0.19	-0.43
Shrublands	-0.40	-0.11	0.45	-0.21	-0.15	-0.14	-0.28	-0.10	0.06	-0.50	-0.52	-0.18
Rice	0.73	0.12	-0.50	0.25	0.24	0.39	0.56	0.07	0.57	0.40	0.29	0.15
Ag. (non-rice)	0.84	-0.21	-0.69	0.23	0.22	0.31	0.52	0.41	0.63	0.31	0.21	0.40
Build (low density)	HC	NC	LC	NC	NC	NC	NC	LC	LC	NC	NC	LC
Build (high density)	LC	NC	NC	NC	NC	NC	NC	LC	NC	NC	NC	LC
Forest	MC	NC	LC	NC	NC	NC	NC	NC	MC	NC	NC	NC
Shrublands	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	LC	NC
Rice	MC	NC	LC	NC	NC	NC	LC	NC	LC	NC	NC	NC
Ag. (non-rice)	MC	NC	LC	NC	NC	NC	LC	NC	LC	NC	NC	NC

Table 14.3: Correlation between land-use and parameters within the rivers

Spouts											
	pH	DO [mg/l]	Nitrite [ppm]	Nitrate [ppm]	Phosphate [ppm]	Hardness [ppm]	Iron [mg/l]	E. Coli [$CFU/100ml$]	$EC_{25\,°C}$ [$\mu S/cm$]	TDS [mg/l]	Turbidity [NTU]
Build (low density)	-0.46	-0.69	0.44	0.64	0.38	0.62	0.09	0.17	0.71	0.71	0.04
Build (high density)	-0.40	-0.49	0.54	0.87	0.36	0.40	-0.16	0.00	0.71	0.71	0.03
Forest	0.54	0.58	-0.47	-0.44	-0.45	-0.46	-0.40	-0.23	-0.66	-0.66	0.39
Shrublands	-0.28	0.09	-0.25	-0.20	-0.27	-0.24	0.30	0.08	-0.26	-0.26	-0.42
Rice	-0.36	-0.41	0.41	0.15	0.44	0.27	0.48	0.30	0.45	0.46	-0.44
Ag. (non-rice)	-0.20	-0.36	0.39	0.26	0.49	0.53	0.24	0.02	0.61	0.61	-0.15
Build (low density)	NC	LC	NC	LC	NC	LC	NC	NC	MC	MC	NC
Build (high density)	NC	NC	LC	HC	NC	NC	NC	NC	MC	MC	NC
Forest	LC	LC	NC	NC	NC	NC	NC	NC	LC	LC	NC
Shrublands	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Rice	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Ag. (non-rice)	NC	NC	NC	NC	NC	LC	NC	NC	LC	LC	NC

Table 14.4: Correlation between land-use and parameters within the spouts

Detailed figures of parameter with a high or medium correlation with land-use parameters

ggg

14.5.3 Indication Parameters correlation

All data

Rivers, Wells and Spouts												
	Temperature °C	EC [uS/cm]	pH	DO [mg/l]	Turbidity [cm]	Nitrite [ppm]	Nitrate [mg/l]	Phosphate [ppm]	Hardness [ppm]	Iron [mg/l]	E.Coli [CFU/100ml]	Discharge [m3/s]
Temperature °C	1.00	0.23	-0.17	-0.45	-0.12	0.07	-0.03	0.10	0.28	0.26	0.15	-0.14
EC [uS/cm]		1.00	0.06	-0.06	0.30	0.24	0.52	0.26	0.57	-0.13	-0.06	-0.06
pH			1.00	0.46	-0.08	0.08	-0.21	-0.01	-0.05	-0.30	0.00	-0.18
DO [mg/l]				1.00	0.09	-0.15	-0.07	-0.23	-0.33	-0.35	-0.24	0.25
Turbidity [cm]					1.00	-0.03	0.28	0.03	0.31	-0.54	-0.50	0.00
Nitrite [ppm]						1.00	0.35	0.45	0.09	0.02	0.14	-0.14
Nitrate [mg/l]							1.00	0.25	0.22	-0.21	0.02	-0.11
Phosphate [ppm]								1.00	0.02	0.10	0.15	-0.16
Hardness [ppm]									1.00	-0.11	-0.05	0.04
Iron [mg/l]										1.00	0.28	0.15
E.Coli [CFU/100ml]											1.00	-0.17
Discharge [m3/s]												1.00
Temperature °C	HC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
EC [uS/cm]		HC	NC	NC	NC	NC	NC	LC	NC	LC	NC	NC
pH			HC	NC	NC	NC	NC	NC	NC	NC	NC	NC
DO [mg/l]				HC	NC	NC	NC	NC	NC	NC	NC	NC
Turbidity [cm]					HC	NC	NC	NC	NC	LC	LC	NC
Nitrite [ppm]						HC	NC	NC	NC	NC	NC	NC
Nitrate [mg/l]							HC	NC	NC	NC	NC	NC
Phosphate [ppm]								HC	NC	NC	NC	NC
Hardness [ppm]									HC	NC	NC	NC
Iron [mg/l]										HC	NC	NC
E.Coli [CFU/100ml]											HC	NC
Discharge [m3/s]												HC

Table 14.5: Correlations between all parameters without consideration of the water-source

Rivers

Rivers												
	Temperature °C	EC [uS/cm]	pH	DO [mg/l]	Turbidity [cm]	Nitrite [ppm]	Nitrate [mg/l]	Phosphate [ppm]	Hardness [ppm]	Iron [mg/l]	E.Coli [CFU/100ml]	Discharge [m3/s]
Temperature °C	1.00	0.50	-0.26	-0.73	-0.41	0.28	0.28	0.32	0.34	0.45	0.56	0.05
EC [uS/cm]		1.00	0.19	-0.65	-0.21	0.33	0.22	0.53	0.63	0.19	0.41	-0.17
pH			1.00	0.25	0.31	0.01	-0.23	0.00	0.25	-0.70	-0.29	-0.50
DO [mg/l]				1.00	0.16	-0.29	-0.36	-0.44	-0.42	-0.49	-0.39	0.02
Turbidity [cm]					1.00	0.01	0.22	0.05	0.16	-0.50	-0.58	-0.48
Nitrite [ppm]						1.00	0.45	0.38	0.31	0.06	0.20	-0.22
Nitrate [mg/l]							1.00	0.16	0.31	0.19	0.34	0.08
Phosphate [ppm]								1.00	0.26	0.07	0.16	-0.15
Hardness [ppm]									1.00	0.01	0.13	-0.39
Iron [mg/l]										1.00	0.32	0.62
E.Coli [CFU/100ml]											1.00	0.21
Discharge [m3/s]												1.00
Temperature °C	HC	LC	NC	NC	NC	NC	NC	NC	NC	NC	LC	NC
EC [uS/cm]		HC	NC	LC	NC	NC	NC	LC	LC	NC	NC	NC
pH			HC	NC	NC	NC	NC	NC	NC	NC	NC	LC
DO [mg/l]				HC	NC	NC	NC	NC	NC	NC	NC	NC
Turbidity [cm]					HC	NC	NC	NC	NC	LC	LC	NC
Nitrite [ppm]						HC	NC	NC	NC	NC	NC	NC
Nitrate [mg/l]							HC	NC	NC	NC	NC	NC
Phosphate [ppm]								HC	NC	NC	NC	NC
Hardness [ppm]									HC	NC	NC	NC
Iron [mg/l]										HC	NC	LC
E.Coli [CFU/100ml]											HC	NC
Discharge [m3/s]												HC

Table 14.6: Correlations between all parameters without consideration of the water-source

14.6 Appendix VI: Watershed land use development vs water quality parameters

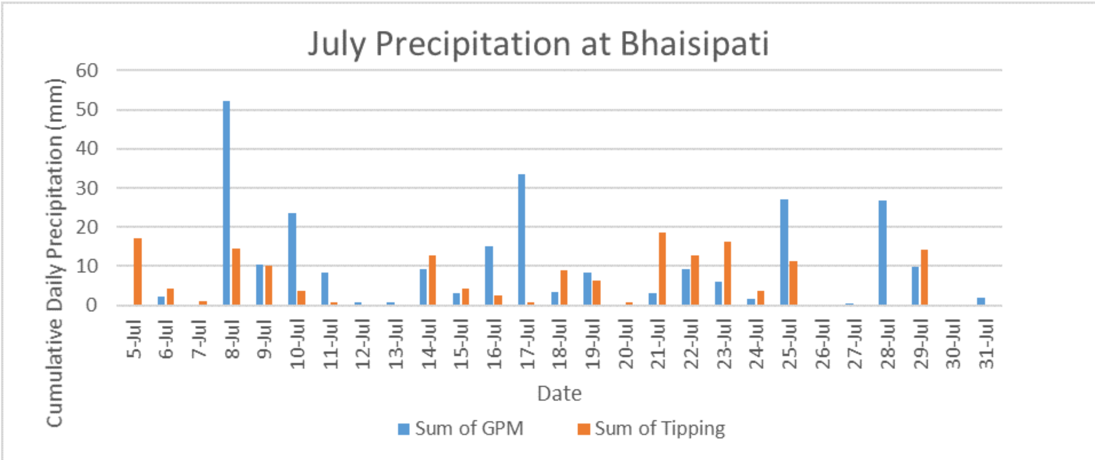


Figure 14.24: July Precipitation at Bhaisipati

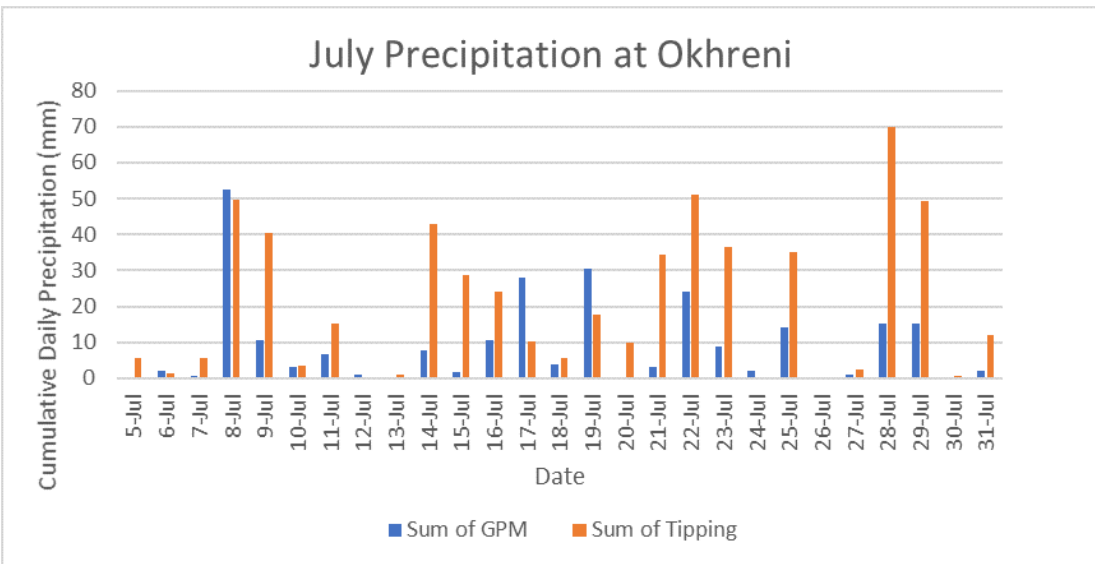


Figure 14.25: July Precipitation at Okhreni

14.7 Appendix VII: Uncertainty analysis

This chapter will show the uncertainties in the gathered data and its analysis with the help of a qualitative uncertainty analysis. The qualitative uncertainty analysis will show the confidence levels given by the IPCC standards Table 14.7.

Every parameter will start with a confidence level of 10. Every uncertainty can decrease the confidence level with a certain amount of points. The errors are subdivided in human errors, errors of the device, location, weather, lab, time scale and calculations. Depending on the parameter, the error can be of higher importance or have no influence at all. An overview of all the errors and how they decrease the confidence level are shown in section 14.9.

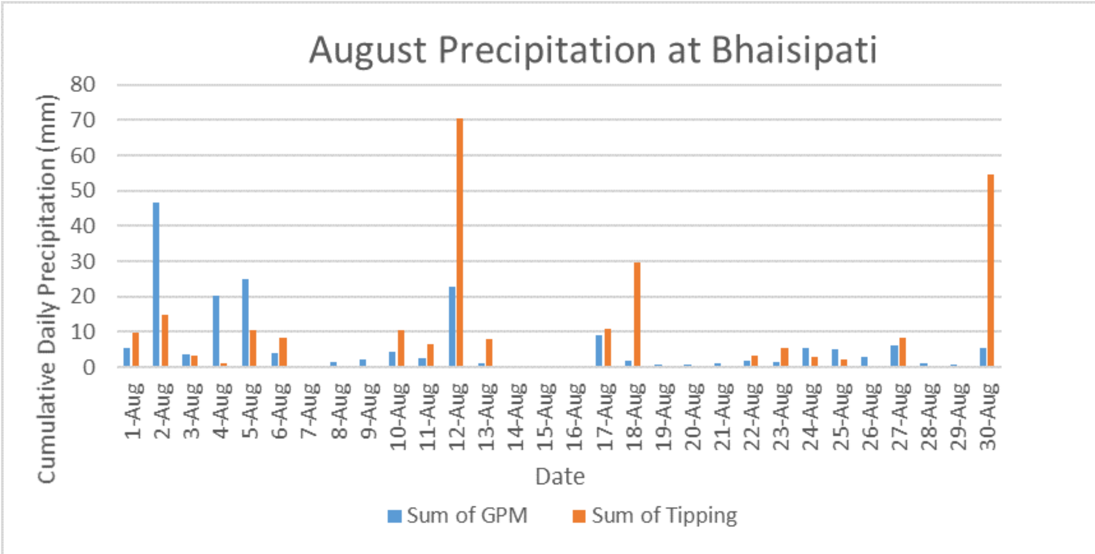


Figure 14.26: August Precipitation at Bhaisipati

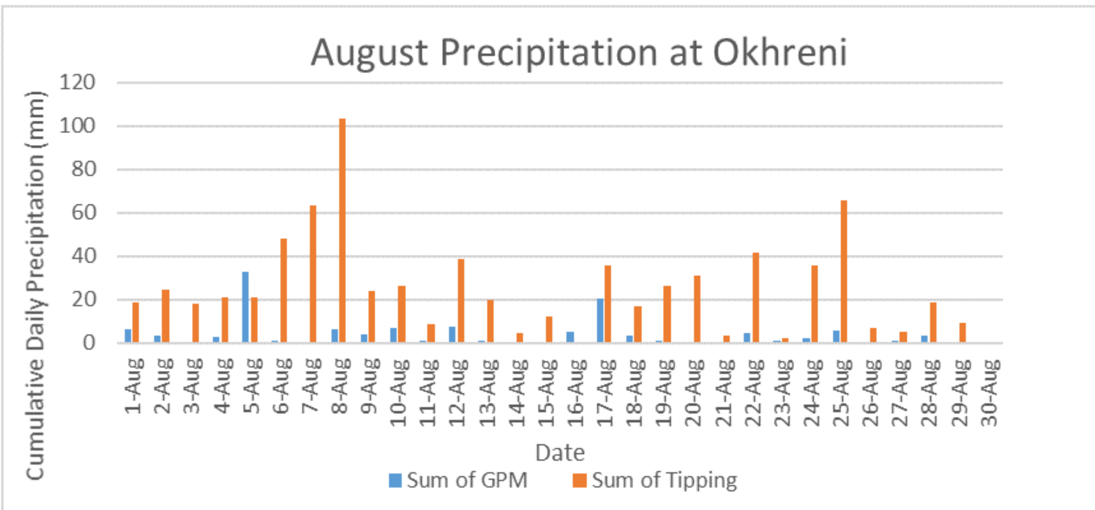


Figure 14.27: August Precipitation at Okhreni

	Human errors				Device		Location		Weather	lab	Time	Calculations	Confidence level
	Eyesight	Stopwatch	Counting	Interpretation	Stabilization	Equipment	Limited access	GPS					
pH					-1	-1			-1		-1		6
DO					-3	-2			-1		-1		3
Nitrate	-1		-1						-1				7
Nitrite	-1		-1						-1				7
Phosphate	-1		-1						-1				7
Hardness	-1		-1						-1				7
Iron									-1	-1	-1		7
E. coli									-1	-1	-1		7
EC					-1				-1				8
TDS												-3	4
Turbidity	-3		-1						-2				4
Discharge, flow tracker							-2		-2				6
Discharge, salt dilution		-1					-2		-2				5
Discharge, bucket	-1	-1				-1							7
- divers					-1		-1		-1		-1		6
groundwater level	-1					-3							6
Land Use classification	-1			-1		-1		-1					6

Table 14.8: Uncertainty analysis of the parameters measured

Level of confidence	Degree of confidence in being correct
Very high	At least 9 out of 10
High	About 8 out of 10
Medium	About 5 out of 10
Low	About 2 out of 10
Very low	Less than 1 out of 10

Table 14.7: The IPCC level of confidence scale (IEHIAS, n.d.)

14.8 Overview

In Figure 14.28 an overview of the confidence levels is given. The highest confidence is placed in the EC values while parameters like DO, Turbidity, TDS, salt dilution are more prone to errors.

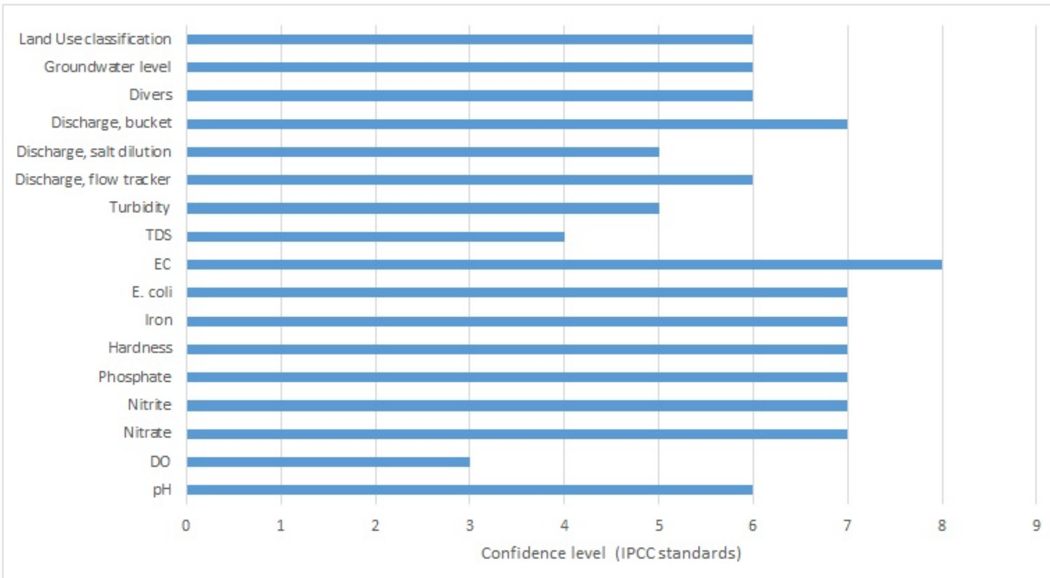


Figure 14.28: Overview of confidence levels

14.9 Appendix VIII: Uncertainty analysis qualitative tables

Type of error	Human errors			Device		Location		Weather	Extern laboratory	Time	Errors due to indirect measurement
	Eyesight	Stopwatch/Counting	Interpretation	Stabilization	Equipment	Limited access	GPS				
-1	Different people measured	Interval between signal and start	Land use description interpretation can differ	Small fluctuations at stable level	Equipment is not working optimal	Water to deep	Inaccurate GPS	Indirect impact	Other standards	Time difference between sample time and measurement time	Errors direct parameter
-1	Unclear boundaries	Different counting speeds		Doesn't stabilize well	Different types of equipment	No mixing		Direct impact			Errors calculations
-1	Shadow and sunlight influence			Stabilization influenced by how you use it	Different way to use the same equipment	Measurement sometimes done at different cross-section interval					Errors multiplier chosen

14.10 Appendix IX

Well nr	mei(of juni)-jul	δh jul-aug	δ h aug-sept	sep-sep (of jul-sep)	LAT	LONG	ALT	Accuracy	Dates
1		1	-0.099999952		27.69994441	85.21514512	1384	5	"15/7, 16/8 en 14/9"
2		null	0		27.696646	85.23218558	1325	5	17/8 en 14/9
4		3.116	-0.354		27.66816	85.3081759	1269	5	"23/7, 15/8 en 18/9"
5		-0.03	-0.36	-2.01	27.61235084	85.32004812	1402	5	"22/7, 20/8, 17/9, 18/9"
6		0.2	-1.033		27.63409266	85.34732776	1285	5	"20/7, 15/8 en 12/9"
7		0.57	-0.1		27.70113487	85.30802712	1277	5	"31/7, 13/8, 15/9"
8		1.772	-1.372	-0.68	27.6792778	85.34139961	1250	5	"23/7, 14/8, 16/9, 19/9"
9	0.224			-0.29	27.66400554	85.3647685	1298	10	"9/5, 17/7, 12/9"
11	1.3	0.4	-0.038		27.69523165	85.35006913	1229	5	"29/5, 15/7, 15/8 en 12/9"
12		0.71	-0.17		27.73409777	85.34748965	1265	4	"20/7, 20/8 en 17/9"
13		0	-0.42		27.76013687	85.32976921	1310	5	"20/7, 15/8 en 15/9"
14		-1.05	-0.65		27.79875952	85.32987184	1425	5	"24/7, 15/8 en 15/9"
16		-1.8	-0.65		27.72979561	85.37402645	1333	3	"31/7, 16/8 en 19/9"
17	-0.9	2.2	-0.19		27.74130559	85.40544168	1303	5	"21/6, 15/7, 15/8 en 19/9"
19	-0.048	-0.002	0.412		27.67393254	85.43733836	1275	5	"11/5, 15/7, 16/8 en 11/9"
20	0.5219998	1.3180001	-0.286		27.67616957	85.44788807	1275.944229	8	"15/5, 15/7, 15/8, 18/9"
21		0.4	-0.06	0.09	27.66373599	85.46525573	1308.542168	4	"15/7, 15/8, 15/9, 20/9"
22	1.34	5.35	-3.04	1.79	27.65428009	85.45889806	1337.5536	4	"24/6, 15/7, 15/8, 15/9, 20/9"
23		0.008	-0.016		27.68201396	85.48598549	1397	5	"19/7, 16/8 en 18/9"

Table 14.9: Overview of recharge of groundwater during and post monsoon

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