An Assessment of The Monsoon Water Situation in The Kathmandu Valley

Data collection and analysis of flow, water quality, land use and demand

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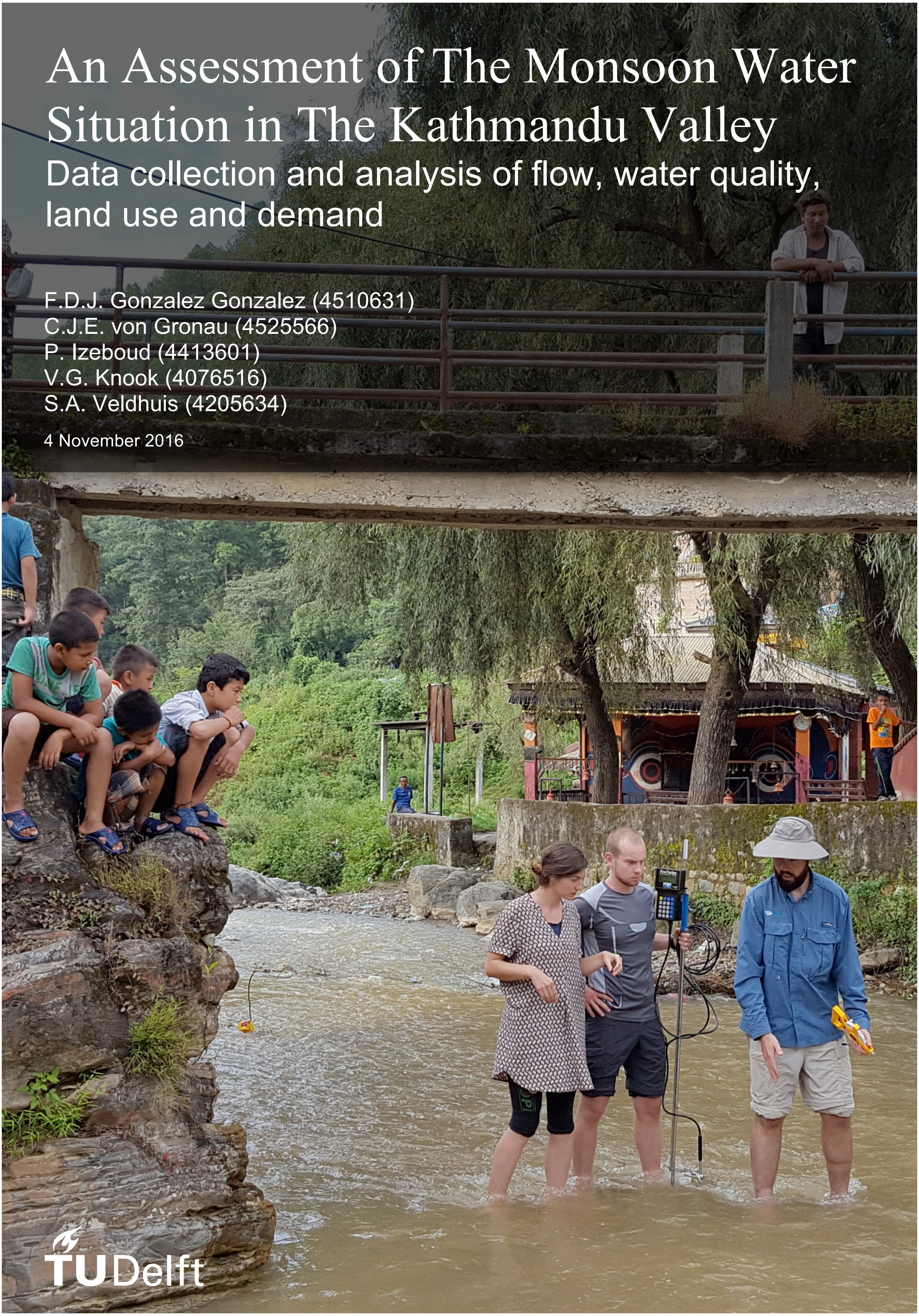


Contents

Abstract

Kathmandu, the capital of Nepal, is under increasing water stress. A rising water demand in the Kathmandu Valley is initiated by urbanisation with a rate of 4.7 % per year and amplified by a growing trend of per capita water consumption. At the same time, water availability seems to deteriorate. However, the severity of the problem is hardly known due to immense data gaps. This research aims to (1) estimate the urban water demand from literature research, (2) collect new field data about spring and stream flow, water quality, and ecological stream health, and (3) analyse remotely sensed data in order to characterize the linkages and inter-dependencies between land use, hydrology, and water quality in the Kathmandu Valley.

The field data were collected in August and September 2016 and helped to get a decent picture of the water situation. The landuse classification performed using Landsat 8 images had an accuracy of 88 % and proved to be a meaningful source of data to link to the other research topics. Automated SEBAL was attempted to be used for computing evapotranspiration estimates but cannot successfully be used in mountainous areas yet. Penman-Monteith equation was used as alternative. A simplified water balance was performed for the months of August and September 2015. The outcome showed estimates to be $2,2 \cdot 10^6\ \frac{m^3}{d}$ for ET, $5.6 \cdot 10^6\ \frac{m^3}{d}$ for precipation, $2.0 \cdot 10^6\ \frac{m^3}{d}$ for the Bagmati outflow and $1.4 \cdot 10^6\ \frac{m^3}{d}$ for groundwater infiltration. To be able to comment on long term groundwater depletion, an annual water budget needs to be performed.

The clearest influence on water quality parameters (pH, DO, EC and Rapid Stream Assessment class) was found to be the presence of developed area. With more than 20 % developed area within the considered subwatershed, the water becomes of such poor quality that it cannot be used for any purpose without extensive treatment. In the headwater areas of the Valley, a significant amount of water with a higher quality (i.e. drinking water) is found in the streams. In September 2016 the total inflow of drinkable water to the Valley floor was estimated to be at least $1.0 \cdot 10^6\ \frac{m^3}{d}$. This value cannot be considered as fully available for anthropogenic purposes, as water needs to remain in the streams in order to not jeopardize ecosystem services and other functions.

Introduction

The Multidisciplinary Project

The Multidisciplinary Project is a project executed by four to six students within the TU Delft Master curriculum. The students must come from at least two different Master tracks. During the project students are expected to work together and independently from the university. The assignment can be done abroad and should motivate students to work together with people from different educational and cultural backgrounds as well as people external of TU Delft. Further, the students have the chance to pursue a project according to their interests and are responsible for the development of the research question, the approach, the execution of the project as well as its output. One of the results of this Multidisciplinary Project is this document. The report is written by students for their master programme of TU Delft and is not a consultancy report.

The Team

For this project a team was formed out of Master students in Civil Engineering from the TU Delft. Figure 1 shows the whole team together with supervisor Jeff Davids. On page 7 the team members are introduced.

The choice of project

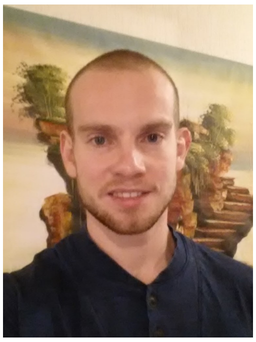
This multidisciplinary project is a great opportunity to get involved in a project in a complete different context than the well-organised Western world. We wanted to grab this opportunity to learn about a different culture, while contributing to an ever-growing problem, namely (drinking) water availability. Vera had been to Nepal several times and reported on the poor water quality of the Kathmandu Valley. This initiated the idea of going to Nepal, a country that very much spoke to the other team members' imagination. Different people were contacted until Martine Rutte got us in touch with Jeff Davids, a PhD student currently doing his research in the Kathmandu Valley. He was very interested in supervising a group of students that would link their research to his work. In order to exploit the specializations of the different team members, different possible research topics were discussed before we agreed on working on the water availability of the Kathmandu Valley, focusing on data generation of both hydrological as well as quality aspects.

Worldwide the application of remotely sensed data is growing rapidly and will be more and more important. The combination of the eager to learn how to use these data and the poor quality of the available data in Nepal made us integrate this within the project. Knowing that the land use has a big influence on quality and flow, we decided that we would use remotely sensed data to analyse the land use of the Valley. This to consequently find the linkages between the hydrological, water quality and land use data. With all these aspects combined, the project was of interest to all team members as well as being of potential value to the people in Nepal.

Felipe Gonzalez Gonzalez
Nationality: Mexican
Field of study: Sanitary engineering
Study experience: BSc Civil Engineering, Tec de Monterrey
MSc Civil Engineering student, TU Delft
What thrilled you most about the project: Knowing that the project can benefit the Nepalese people and that it can be an example for future initiatives.
The project in three words: Fruitful, positive impact, cultural

Petra Izeboud
Nationality: Dutch
Field of study: Water Resources Management and Hydrology
Study experience: Bsc Mathematics, UvA
MSc Civil Engineering student, TU Delft
What thrilled you most about the project: Combining spatial tools with ground data to obtain a useful picture of the current water situation in Kathmandu.
The project in three words: Exciting, data processing, teamwork

Clemens von Gronau
Nationality: German
Field of study: Hydraulic Engineering
Study experience: BSc Civil Engineering, ETH Zurich
MSc Civil Engineering student, TU Delft and NUS
What thrilled you most about the project: Delivering outputs that can be used by Nepalese organizations to further develop the drinking water supply in the Valley.
The project in three words: Nepalese working adventure



Sven Veldhuis
Nationality: Dutch
Field of study: Water Resource Management and Hydrology
Study experience: BSc Civil Engineering, TU Delft,
MSc Civil Engineering student, TU Delft and UNIBO
What thrilled you most about the project: Doing fieldwork and being able to have a small contribution in the path to finding more sustainability of water resources for the people of the Kathmandu Valley.
The project in three words: Challenging, educational, gratifying

Vera Knook
Nationality: Dutch
Field of study: Water Management and Engineering
Study experience: BSc Civil Engineering, TU Delft
MSc Civil Engineering student, TU Delft and ETH Zürich
What thrilled you most about the project: I have visited the country a lot and am excited to have a chance to contribute to its development with the knowledge I've gained over the last years.
The project in three words: Learning, involvement, culture

Figure 1: The team, left to right: Felipe Gonzalez, Vera Knook, Sven Veldhuis, Jeff Davids (supervisor), Clemens von Gronau and Petra Izeboud

Acknowledgements

Hereby we would like to mention and show our appreciation to third parties who helped and advised us during the course of our project.

First and foremost we want to thank our local supervisor Ir. J.C. Davids and his family. Jeff acted as a host, mentor and a fellow team-member and his ideas and professional expertise were of great value and provided us with much useful input. We are extremely thankful for his time, effort and hospitality. In addition we want to thank Jeff's assistant E. Moktan for his help during the fieldwork and his logistical assistance throughout the project.

Secondly we want to thank some members of Nayaa Aayaam Multidisciplinary Institute (NAMI), Dr. D.N. Shah and Dr. R.T. Shah for providing us with the SonTek ADV Flowtracker, and their Environmental Science students A. Pandey and N. Devkota. As interns for J.C. Davids they were also part of the team and their Rapid Streamflow Assessments (RSA's) were a very welcome and significant contribution to our water quality assessment.

Another sign of appreciation goes out to Ir. S. Shrestha of the Groundwater Resources Development Board (GWRDB) of Nepal's Department of Irrigation. We are very thankful to him for sharing his insights and documentation on the groundwater situation of the Kathmandu Valley and taking us to visit some of the water-spouts in the city.

We want to thank Ir. T. Hessels of UNESCO IHE for his help in trying to make the automated SEBAL program work successfully in computing ET-values for the Kathmandu Values.

We would like to show our appreciation towards Dr. N.M. Shakya and Mr. A. Nishikori of Tribhuvan University's Water Resources Engineering Department for meeting with us to talk about the on-going research and projects concerning water resources in the Kathmandu Valley, and to Mr. T.M. Bhandari from Kathmandu Upatyaka Khanepani Limited (KUKL) for providing us with the helpful documentation on recent work of KUKL and water supply and wastewater system improvement in the Kathmandu Valley.

Last but not least we would like to thank Dr. Ir. M. Rutten and Dr. Ir. D. van Halem, our supervisors from Delft University of Technology for their input in getting our project started and judging our results.

Chapter 1

Background information about the situation in Nepal

1.1 Socio-economic background

The National Population and Housing Census indicates that the total population of Nepal is 26.5 million people, of which 83 % live in rural areas [8]. The overall life expectancy at birth is 70 years, whereas the life expectancy at birth in The Netherlands is 81 years [67]. The infant mortality rate is 40.5 deaths within 1,000 live births according to the Nepalese government [72], but The World Bank determined Nepal's infant mortality rate to be 29 deaths per 1,000 live births. In comparison to that the rate for The Netherlands is 3 [68].

Rank	Country	Adult literacy rate (15+ years)
1	Democratic People's Republic of Korea	99.999
59	Suriname	95.539
83	Myanmar	93.090
101	Syrian Arab Republic	86.304
111	Iraq	79.722
125	India	72.225
128	Angola	71.164
129	Yemen	69.962
130	Togo	66.538
131	Malawi	65.964
132	Nepal	64.664
133	Madagascar	64.656
134	Timor-Leste	64.066
135	Bhutan	63.907
136	Papua New Guinea	63.434
137	Bangladesh	61.494
138	Haiti	60.689
139	Guinea-Bissau	59.773
147	Ethiopia	49.032
153	Afghanistan	38.168
158	Guinea	30.473
159	Niger	19.103

Table 1.1: Literacy rate as analyzed by the UN (%)

The UN analysed 159 countries (not including industrialized countries of the western world) to determine their literacy rate. Nepal is with an adult literacy rate of less than 65 % within the 30 countries with the lowest literacy rate. A list of other countries for comparison is given in Table 1.1. UNICEF further provides data that about 95 % of the children enrol for primary school and about 70 % of this also finish primary school [80]. But The World Bank notices that especially amongst the poorest families, children do not continue to post-basic education and additionally, the quality of education at all levels remains a problem [65].

The economic situation of Nepal improved remarkably from 2003 to 2011. The percentage of people living on less than 1.25 USD a day was more than halved during that time but still accounted for 25 % of the population in 2011 [65].

Interesting to mention is the low official unemployment rate of 0.8 % of the economically active population [43], although dependent on the source this varies up to 3.0 % [73]. It is to mention though that only 54 % of the population count as economically active [43]. A reason for the low unemployment rate could be the migration of unemployed people to other countries for employment opportunities as well as engagement in self-employment [13].

Figure 1.1 shows the percentage share of GDP by the three economic sectors Services, Industry and the Primary Sector, which includes agriculture, fishery, forestry and mining between 1971 and 2011.

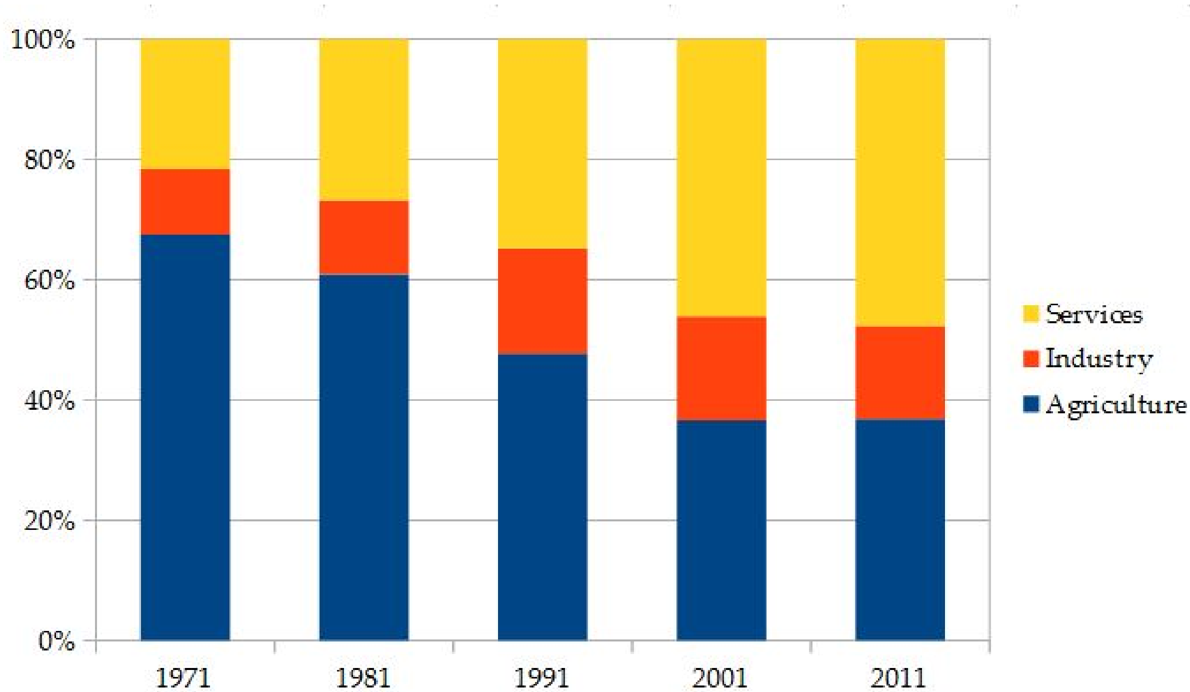


Figure 1.1: Structural transformation of nominal GDP (%) [43]

The Figure 1.1 was created to visualize the structural transformation which is described in a table of the Population Monograph of Nepal [43]. It has to be mentioned that the data only gives a snapshot on the situation every ten years. Statements about the development are therefore difficult to make, even though major trends can be seen. The figure clearly indicates that the division of agriculture, fishery and forestry decreased by about 30 percent whereas the service sector increased by 26 percent. Only a small change (in total 5 % growth) can be seen in the industrial sector. The situation in 2011 is composed of 37 % Agriculture, 15 % Industry and about 46 % Services. One of the most important contributions to the Nepalese economy are remittances. According to The World Bank, private remittances contribute to 32.2 % of the

GDP which is the highest value in the world [69]. Agriculture is another main contributor to the GDP of Nepal as can be seen in Figure 1.3a. Even though agriculture contributes with only 37 % to the GDP, 64 % of the economically active population works in that sector. Only 9 % of the population works in the industrial sector and 24 % in the field of services. The missing percentage to the 100 % is due to the category 'not stated' in the data of [43]. This relation is also shown in Figure 1.2.

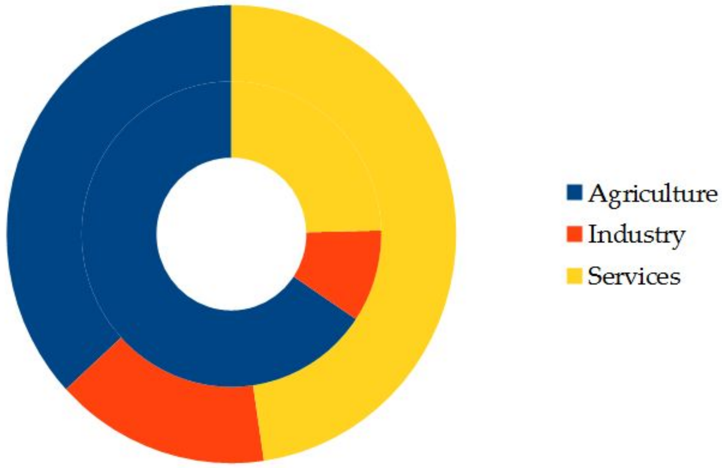


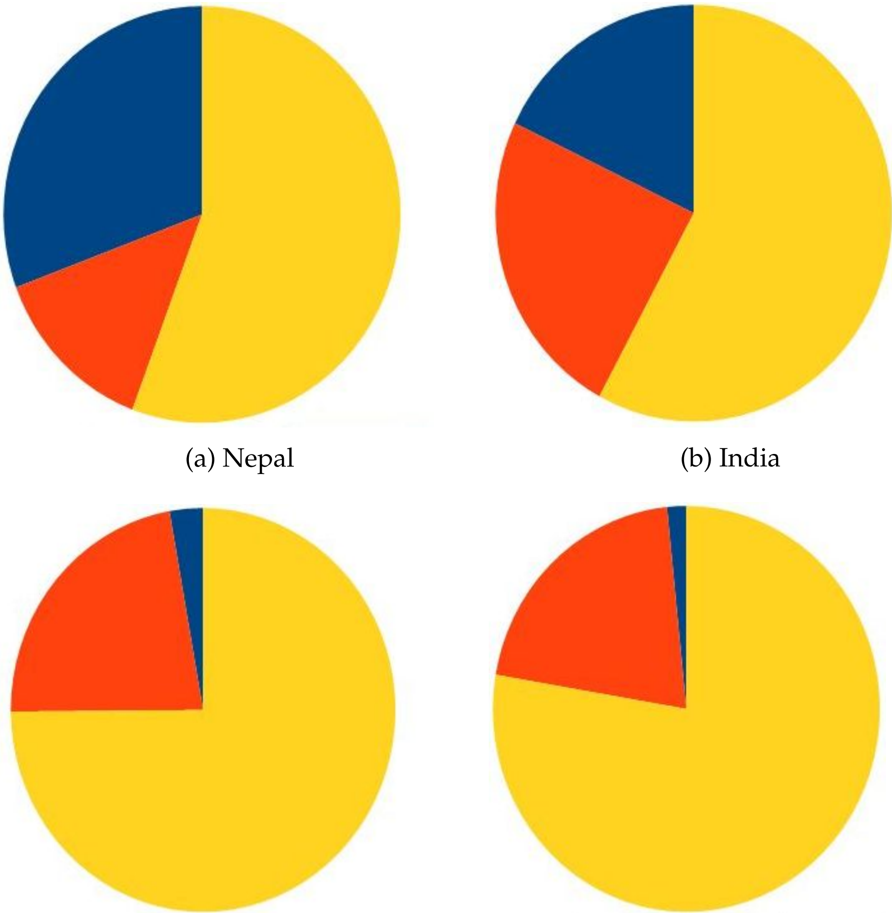
Figure 1.2: Composition of the Economic Sectors in Nepal. **Inner Circle:** Percentage of economically active population working in the different economic sectors. **Outer Circle:** Percentage of sector contribution to the national GDP. [43]

It has further been observed that a large group of economically active people moved from the agricultural sector to the industrial and service sector. The transformation rate to the service sector is high. A reason why economically active population is diverting from agriculture to non-agriculture sector may be found in the higher productivity in industrial and service sectors [43]. The higher productivity can also be concluded from the Figure 1.2 above. Therefore the economically attractive centres of Nepal like Kathmandu will continue to grow in the near future [4]. Conflicts additionally accelerating a rural to urban migration within Nepal. The population of Kathmandu increased by incredible 61.25% during the last decade [54]. The valley contributes already today to 23.4 percent of the national economy and is therefore the main economic hub of Nepal [18].

To compare the situation in Nepal with the ratio of the different sectors in other countries Figure 1.3 has been created based on the statistical data of the Statistic Times [59]. One can see that Nepal is more dependent on the agricultural sector compared to the other displayed countries. Especially compared to the United States of America but also to The Netherlands. The industrial sector in Nepal is the smallest of the four countries in Figure 1.3.

The world bank determines the following current challenges for the further growth of the country (a selection) [65]:

- Unreliable electrical power and low-quality transportation networks are the country's most important economic bottlenecks and hinder job creation and the delivery of services.
- A difficult regulatory environment constrains the private sector as businesses are required to comply with 130 processes from over 41 ministries and government agencies. A high degree of informality [...] also prevails and diminishes the quality of goods and services.
- Nepal is heavily vulnerable to climate change and natural disasters. Recent records show an increasing number of droughts, floods, hailstorms, landslides and crop diseases, mostly



(a) Nepal (b) India (c) The Netherlands (d) United States of America

Figure 1.3: Sector Contribution to the GDP (%). Primary Sector (Agriculture) in blue, Secondary Sector (Industry) in orange and the Teriary Sector (Services) in yellow. [59]

affecting the livelihoods of the poor. Nepal is located on the edge of a tectonic plate and is subject to high earthquake risks, particularly in the Kathmandu Valley.

- Nepal still ranks low on international governance indicators such as Transparency Internationals Corruption Perception Index 2014 (126 out of 175 countries) and the World Governance Indicators (declining trend over the last decade).

1.2 The recent political situation

This abstract tries to give an overview of the current situation in Nepal explaining the events of the previous ten years. The development during that time is very complex and coverage is not always clear nor objective. It was tried to catch different views on the development of Nepal's politics. The recent development shows that Nepal has an internal crisis while internationally Nepal seems to be a plaything between the two world powers China and India. This background is meant to raise understanding why Nepal could not focus on internal issues like for example the water supply and water management. It was simply of lower priority during the last decades which explains the alarming state of the water supply system.

In 2006, the House of Representatives unanimously voted to curtail the power of the king of the Hindu Kingdom Nepal, thereby abolishing the monarchy. The bill declaring Nepal a federal republic came into force on 28 May 2008 [78]. Additionally, the Comprehensive Peace Agreement

(CPA) between the Government of Nepal and the Communist Party of Nepal (Maoist) was signed in November 2006 which comprises a ceasefire between the two rivaling parties. The CPA ended a decade-long armed conflict between the Government and the Maoist [78]. It furthermore called for political, economic and social change in the country and adherence to humanitarian law and human rights principles.

In April 2008, elections to the Constituent Assembly (CA) were held. A second CA finally delivered a constitution of the Federal Democratic Republic of Nepal in September 2015 [78]. Reactions on the constitution have been diverse [29]. The Madhesi, an ethnic group in the southern part of Nepal, called the Terai, had the impression that the new constitution could lead to their political marginalisation and strengthens the Nepalese elites based in Kathmandu and the hills in the north[47]. As a consequence of that, India interfered in Kathmandu because it was concerned that the violence could spill over to its bordering provinces with Nepal [39]. While India expressed disappointment about Nepal's approach in implementing the constitution and proposed a violent-free dialog, China noted with pleasure that Nepal finally endorsed its constitution [47] [39].

As a consequence of the unrest in the Terai, in 2015, it came to a blockade of more than four months at the border between India and Nepal just four days after the new constitution was announced leading to a shortage of fuel and goods. Nepal relies heavily on imports, especially food, medicines and fuel, from India, which is its largest trade partner [49]. Nepal suspects India imposing the blockade and interfering in Nepal's internal affairs whereas India argues that truck drivers are concerned about their safety due to the violences in the Terai region ([44], [26], [25]).

India's interest in the blockade is described by Stratfor.com as follows: 'Some in Nepal believe India had a hand in the blockade as well, and not without reason. [...] If the pro-Indian Madhesi can gain greater representation in Nepal's parliament, India will have more influence over its northern neighbor. India must maximize its influence across the Indian subcontinent and hamper China's penetration into Nepal and South Asia' [60]. The situation is further intensified by consequences of the severe earthquake in April 2015 which killed thousands of people [49] [25].

To overcome the fuel crisis the new Prime Minister Oli has turned to China and signed a deal with Beijing to import as much as a third of its fuel needs, breaking a decades-long Indian monopoly in the sector [25]. In February 2016 the blockade was ended after the Nepali parliament approved the first amendment of the constitution in order to address some of the activists' demands [60]. The Madhesi however called it inadequate and announced to continue with their protest.

In August 2016 the new Prime Minister Dahal got elected. Some say that Oli was urged to resign due to Indian influence as a response on Oli's China-friendly political orientation. Coverage in the Indian media has mostly sought to place the elections as a victory of the Indian establishment and a recalibration of Nepal away from Beijing's sphere of influence and back to New Delhi's orbit [29].

Chapter 2

Analysis of the conditions in the Kathmandu Valley

The focus area of this project is the Kathmandu Valley. This chapter describes the boundaries as well as the hydrological seasonality, topographical and geological conditions of the research area. It describes the hydrological seasonality, topography and geology. These are all important factors that influence the research project.

2.1 Research Area

Kathmandu, the capital of Nepal, is the focus area of this project. In many ways this is a special area in Nepal, not only because its high population density, but also because of it's topographical location. Although one would think of Nepal as a water rich country with its Himalayas and ever flowing rivers, water is not as abundant in the Kathmandu valley. This is further explained in section 2.3.

As hydrological analyses are a big part of the project, it is chosen to set the project boundaries by delineating the watershed. All of Kathmandu's rivers flow into the Bagmati before entering a gorge at Chovar. The project boundary is therefore defined by all the area that of which water flows into this point and can be seen in Figure 2.1

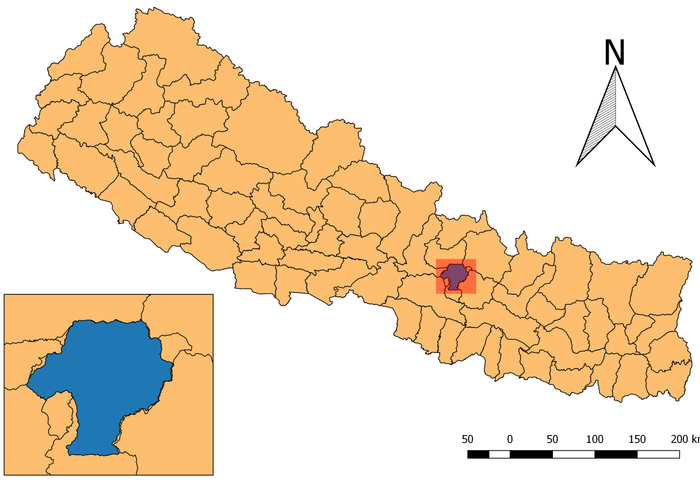
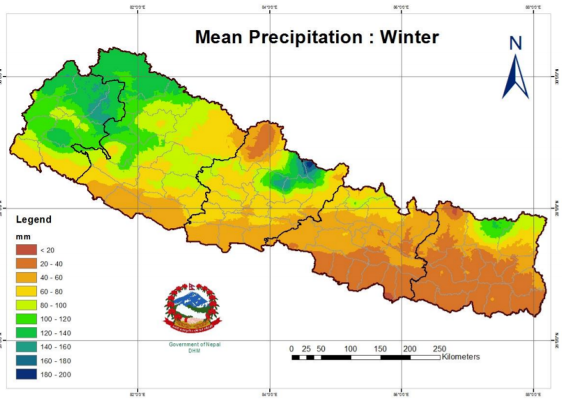


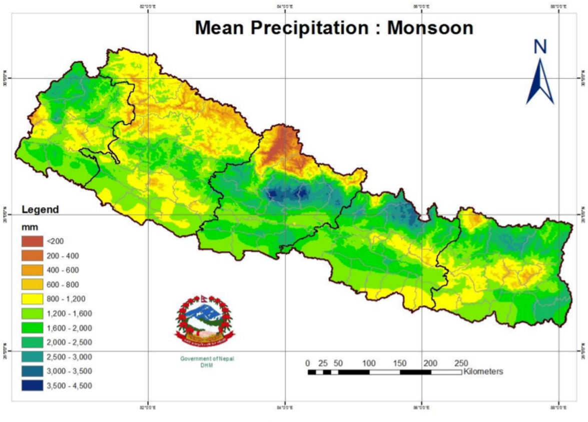
Figure 2.1: The Kathmandu valley watershed is set as the project boundary

2.2 Hydrological seasonality

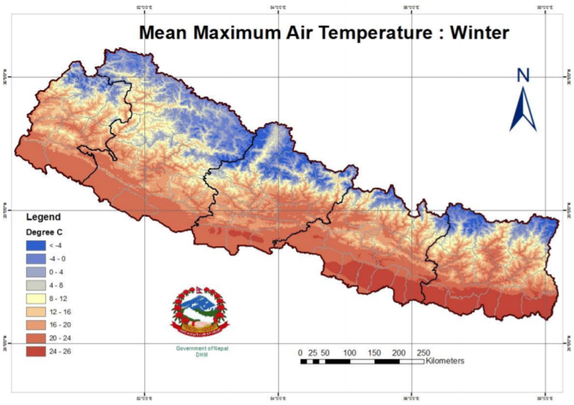
The weather system of Nepal is influenced by continental and maritime factors and is characterized by four distinct seasons [85]:



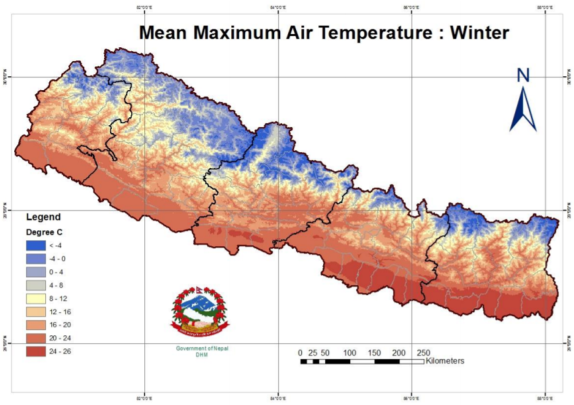
(a) Winter season



(b) Summer (monsoon) season



(c) Winter season



(d) Summer (monsoon) season

Figure 2.2: Top figures: average precipitation, Bottom figures: maximum temperatures

- Spring lasts from March to May, and is warm with rain showers and temperatures around 22°C.
- Summer, from June to August, is the monsoon season when the hills turn lush and green. Temperatures can get quite warm, up to 30°C and more during heat waves.
- Autumn, from September to November, is cool with clear skies. Temperatures are not too warm, with daily maximum around 25°C and cool nights with minimum temperatures around 10°C, it usually does not rain for more than one or two days during the entire autumn and the winter season.
- In winter, from December to February, it is cold at night with temperatures sometimes below zero. However, the maximum temperatures can still reach up to 20°C. Then the mountains are covered with snow including some high hills.

Figure 2.2 shows the big difference between the rainfall and maximum temperatures from the winter to the summer season.

This seasonality also effects the hydrology of the Kathmandu valley. An obvious influence is the change of precipitation, but also the temperature influences the hydrology directly through evaporation. The higher the temperatures, the higher the potential evaporation which causes that the losses to the atmosphere are higher in the summer months. Figure 2.3 shows the seasonality of the Kathmandu valley.

Even though the total water supply might be sufficient, the huge difference between rain and dry season (About 80.5 % of the precipitations falls in the monsoon months June to September [11]) makes it impossible to draw a conclusion on potential periodical deficits. The latitude and longitude of Kathmandu is 27.7°N and 85.3°E [36]. Compared to the latitude of for instance Amsterdam, being 52.3°N, Kathmandu lies rather close to the equator. This combined with the maritime and continental influences, makes that snow fall is very rare in the Valley, even at altitudes of more than 2,000 masl. Therefore melting snow is not a significant part of the hydrology of the Valley.

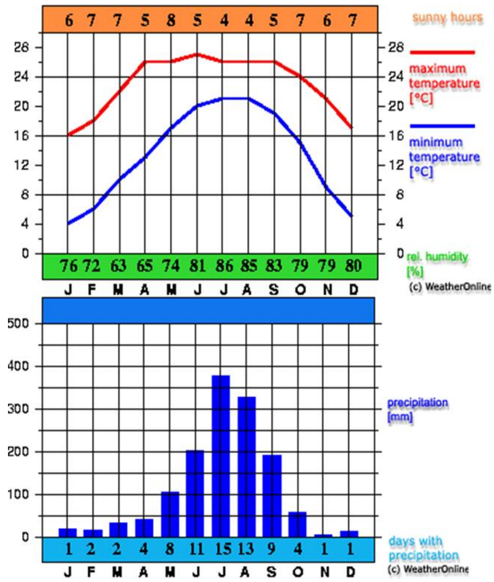


Figure 2.3: Seasonality of the Kathmandu Valley [11]

2.3 Topography

The Kathmandu valley lies in the middle hills of Nepal that are also known as the Mahabharata range. The elevation of the Valley ranges from 800 to 2,700 masl. The middle hills of Nepal are the first great barrier to the monsoon winds that produces heavy precipitations on its southern slope due to orographic effects.[20]

The valley has a bowl shape with it's high areas on the northern side. Four major mountains surround Kathmandu, namely Shivapuri, Phulchowki, Nagarjun and Chandragiri. [11]. Because of the bowl shape, the Kathmandu watershed is a water system on it's own, having no inflow from other Nepalese regions like the Himalayas.

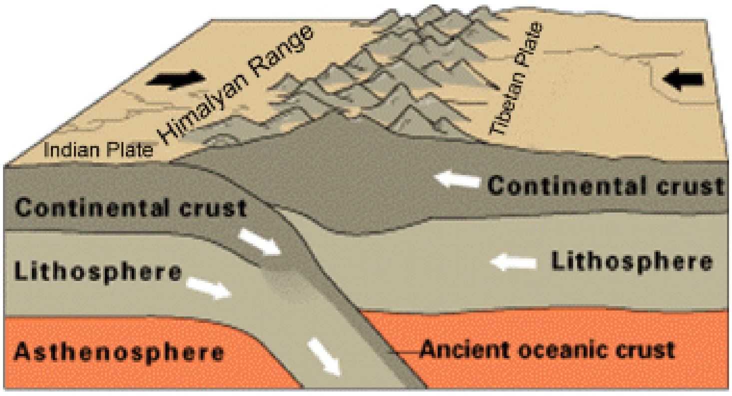
2.4 Geology

Nepal is situated at the base of the Himalayas, occupying the central 800 km extension along this formation. This well known mountainous system was formed in stages by the collision of the Indian plate and the Tibetan plate around 30 to 55 million years ago. The Himalayas are in fact still forming, since the Indian plate is moving approximately 5 cm per year against the Tibetan plate [52].

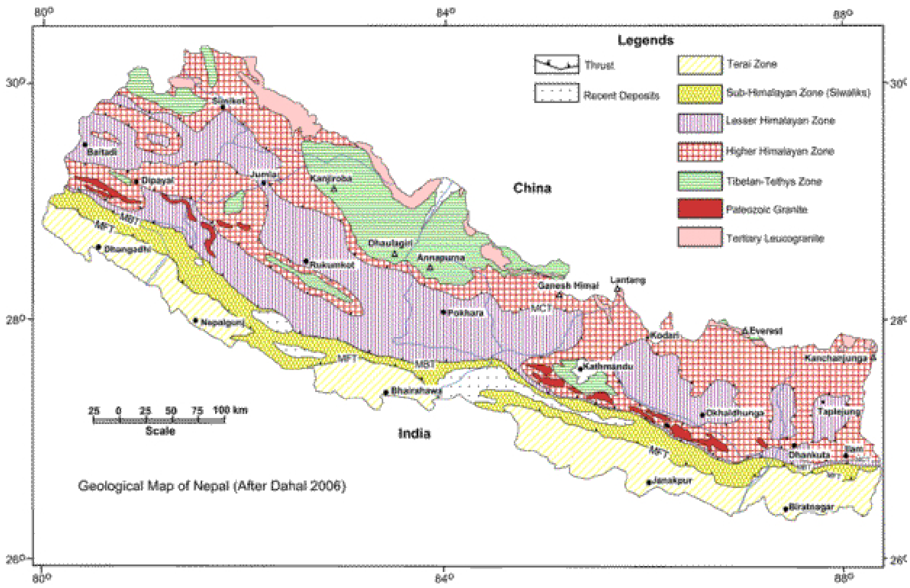
Within this mountainous formation, also called the Himalayan range and extending 2,400 km long and 200-300 km wide, a geological variety can be found, and even Nepal is subdivided into five major tectonic zones [52]:

- Gangetic Plain
- Sub-Himalayan (Siwalik) Zone
- Lesser Himalayan Zone
- Higher Himalayan Zone
- Tibetan-Tethys Himalayan Zone

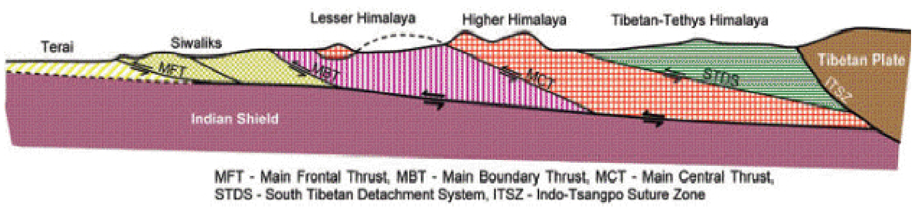
Each of these tectonic zones is separated by thrust faults, which can be seen in figure 2.4c. From left to right the thrust faults are named: MFT Main Frontal Thrust, MBT Main Boundary



(a) Indian and Tibetan plates [52]



(b) Each tectonic zone has its own geology [52]



(c) Thrust faults in the Himalayan range[52]

Figure 2.4: General geological information about Nepal

Thrust, MCT Main Central Thrust, STDS South Tibetan Detachment System and on the far right side separating the Tibetan plate is the ITSZ Indo-Tsangpo Suture Zone [52].

Focusing on the area of the Kathmandu Valley, the north part is surrounded by the Higher Himalayan zone, the south of the Valley by the Tibetan-Tethys Himalayan zone, and exactly on the big urban spot recent geological deposits are found.

Considering these two previous zones that are of importance to this project, further geological information can be described [52]:

- **Higher Himalayan zone:** consists of a very thick layer of strongly metamorphosed coarsed grained rocks, such as gneiss, schist and marble.

- **Tibetan-Tethys Himalayan zone:** composed of sedimentary rocks, such as limestone, shale and sandstone.

It is important to notice that the different types of rocks that are present in the Kathmandu Valley, can affect the quality of the water from upstream to downstream. Further details on these effects will be explained in section 6.2.

Chapter 3

Problem definition and project scope

3.1 Water Supply in the Kathmandu Valley

3.1.1 Sources of water

There are two sources of water in the Kathmandu Valley: Surface water (rivers and ponds) and groundwater. These two sources are mainly fed by rainfall [51]. Overall there are 31 surface water resources (rivers, springs, infiltration galleries, etc.) and 73 tube wells to tap the groundwater in the Valley [4]. The surface sources of water are shown in Figure 3.1. The numbers in the figure correspond to the different sources which are named below the figure.

Due to the seasonal variability of rainfall in the Valley, the amount of surface water reduces during dry season. In the majority of the rivers the flow reduces by 30 - 40 % whereas some rivers carry up to 70 % less water during dry season [4].

Out of the 73 tube-wells 54 are estimated to be functional [4].The Groundwater Development Board documented 379 tube wells in the Valley but some estimates go up to 700 tube wells [28]. A problem in determining the amount of tube wells is that only 49 tube wells belong to KUKL. KUKL is the organization which is nowadays responsible for the water supply and partly as well the wastewater handling in the Kathmandu Valley urban areas. The rest is privately operated and therefore extraction is not documented. Furthermore, an increasing amount of private households, hotels, industries and private water vendors use their own tube wells to guarantee water supply for their needs because public supply sometime fails to appear for several days in a row [38] [76].

Table 3.1 shows the surface water sources and the groundwater sources used by KUKL for the water supply of the Kathmandu Valley.

Source	Wet season	Dry season
Existing surface sources	136.8	70.25
Tube wells controlled	4.6	42.3

Table 3.1: Number of water sources used by KUKL. Numbers are given in million litres per day (MLD).[4]

Besides these two sources, there is another traditional way of accessing water in the Kathmandu Valley. The so called dunghe dharas (stone spouts or water tabs) are the primary alternative to the municipal, piped water supply [83]. These stone spouts are fed by shallow groundwater (1 - 5 meters below the ground surface) or by so called state canals which met irrigation needs [51] [83]. But these stone spouts dry up due to the depleting groundwater level in the Valley (this is described in chapter 10) and represent less and less a reliable source of

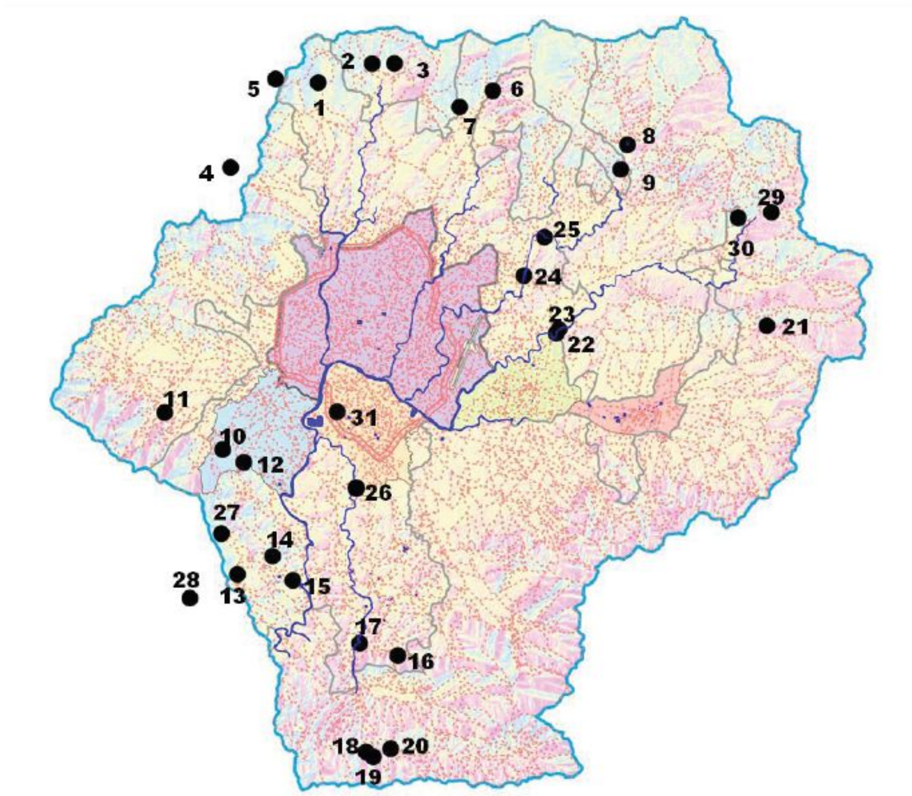


Figure 3.1: Surface water sources in the Kathmandu Valley. **Tri Bhim Dhara System:** 1 Alley, 2 Boude, 3 Bhandare, 4 Chhahare, 5 Panchmane; **Bir Dhara System:** 6 Shivapuri, 7 Bishnumati; **Sundarijal System:** 8 Nagmati and Syalmati, 9 Bagmati; **Kirtipur System:** 10 Doodhpokhari, 11 Lohnkot, 12 Simjhwa Hiti; **Pharping System:** 13 Seshnarayan, 14 Satmul, 15 Kutorimul; **Chapagaun System:** 16 Muldol, 17 Charghare, 18 Basuku-1, 19 Basuku-2, 20 Naldu; **Bhaktapur System:** 21 Mahadev Khola; **Manohara System:** 22 Manohara Infiltration Gallery 1, 23 Manohara Infiltration Gallery 2; **Bagmati System:** 24 Bagmati sump well, 25 Gokarna sump well; **Nakhu System:** 26 Nakhu Khola; **Local Pharping System:** 27 Dallu, 28 Hitidol; **Sankhu System:** 29 Lapsiphedi, 30 Old Sankhu source; **Dhungedhara System:** 31 Iku Hiti [4]

drinking water [51] [83] [28]. Figure 3.2 shows a traditional stone spout as well as a tube well.

Additionally to the surface water and the groundwater extraction, people use the service of private companies which supply water by tankers. The tanker brings a load of water directly to the people's homes at which they have to store it locally. This situation offers business opportunities to some and probably brings good money but the situation cannot be solved by this approach. It is just a measure to cope with the mismatch between supply and demand on a short term basis. But for exactly the short-term this business will grow:

'According to Matatirtha VDC [Village Development Committee] profile 2010, around 170 trips of water supply by water tanker that approximates to 1.2 million litres of water, is supplied to different places of the Kathmandu metropolis as well as to other parts of Kathmandu Valley on a daily basis. The public service centers such as bus parks, hotels in the city where there is huge demand of water, the residential areas in Balaju, Thamel, New Road, Baneshwor and Kalanki are considered as the major consumers by the water entrepreneurs based in Matatirtha' [54].

The most important supply of drinking water in Kathmandu is done by several private organizations in the way that they sell bottled drinking water. This industry is the only supplier

(a) Stone Spout (b) Tube well

Figure 3.2: Shallow water accessing methods present in the Kathmandu Valley. [Own photographs]

of drinking water that can directly be consumed. All other sources of water require treatment before use. The bottled water industry is an enormous industry in which global companies like Nestlé and CocaCola make huge profits and aggressively expand their business to gain a good market position [55]. The market in Kathmandu counts already 57 suppliers [45] and the poor water quality of the available water supports the ongoing growth of this industry. The desire to obtain more money brings vendors on the market that not necessarily have the greater good in mind:

'The Matatirtha Spring Mineral Water and Beverage Pvt Ltd and the Spring Mineral Water of Matatirtha Pvt Ltd were sealed after the authorities found out that they were operating illegally and in a very poor condition. The industries were operating with dirty water processing plants, according to the monitoring team. Likewise, the bottles lacked plastic seals necessary for proper packaging' [61].

The bottled water industry is similar to the tanker industry. It helps to cope with the current situation but does not offer a solution to the problem. It supplies the people in the Kathmandu Valley with the necessary water which otherwise would just not be available. But this business also bears the risk of abuse of confidence when companies sell dirty water. This is possible because there is no independent monitoring of the drinking water quality. The success of these businesses shows that the people have lost their faith in a functional water supply system provided by the government and are happy with the supply of the private companies. Additionally it indicates that there is a need for clean drinking water, otherwise the population would not pay for the comparatively expensive bottled water or the tankers. At least in short term people have to take care of their own water supply. During the research it was found that also government people working in the field of water make use of the private water supply services.

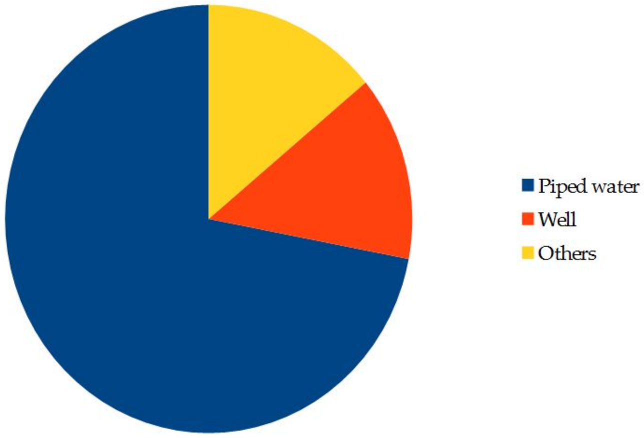


Figure 3.3: Sources of drinking water in the Kathmandu Valley [data from 2011] [2]

Figure 3.3 shows an overview of the contribution of the different sources to the total water supply in the Kathmandu Valley. Even though more and more other sources of drinking water supply appear, the piped water provided by the government has by far the largest contribution to the total water supply.

3.1.2 Responsibilities

According to the Ministry of Water Supply and Sanitation, the population in the Kathmandu Valley was initially very small. During these times it was possible to obtain the water for daily needs from natural resources in the Valley which were easily accessible. Due to a growing population in this area, the natural resources got polluted and were determined to be not sufficient in order to provide drinking water for everyone. Therefore, the government established a systematic development of water supply called the Pani Adda in 1973. The organization was restructured from time to time to meet the demands. In 1990 the Nepal Water Supply Corporation (NWSC) took over office. The NWSC is an autonomous government body which provides services to the 20 cities within the country [41]. This system of a monopoly in the water supply operation caused severe external influences and interventions which affected operational efficiency [30]. To improve the management of the water supply, different entities were formed which are shown in Table 3.2. Until today an organization called 'Department of Water Supply and Sewerage' (DWSS), established in 1972 to manage drinking water for urban, semi urban and rural areas throughout the country is responsible for the rural water supply in Nepal including the rural areas of the Kathmandu Valley. Figure 6.23 shows the service area of KUKL, the rest is supplied by DWSS.

Organization	Role	Established (Date)
Kathmandu Valley Water Supply Management Board (KVWSMB)	Owner	2005/04/14
Kathmandu Upatyaka Khanepani Limited (KUKL)	Operator	2008/02/13
Tariff Fixation Commission (TFC)	Tariff Fixation	2008

Table 3.2: Organisations responsible for the water supply in the Kathmandu Valley, founded after the decision was made to improve the management of the water supply in the Kathmandu Valley [30].

On the 13th of February 2008 all assets and liabilities were handed over to the Kathmandu Valley Water Supply Management Board (KVWSMB) and at the same day further to KUKL

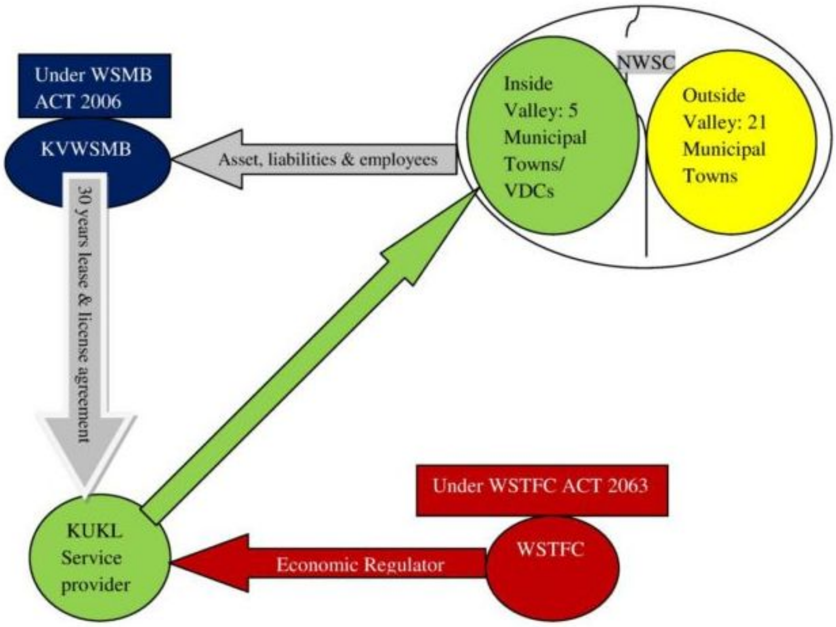


Figure 3.4: Current institutional arrangements in the Kathmandu Valley [30]

for operation on a 30 years lease and license [30]. The Tariff Fixation Commission (WTFC) is responsible for the pricing. On the website of KUKL one can find the following information about the company:

[KUKL] operates under the Public Private Partnership (PPP) modality. [...] [The] company has the objective to undertake and manage the water supply and sanitation system of the Kathmandu Valley previously operated by NWSC and to provide a quantitative, qualitative and reliable service to its customers at an affordable price.
[...]
The shareholders of the company, with relative initial shareholdings, are: the Government of Nepal (30 %), Municipalities in the Valley (50 %), Private Sector Organisations (15 %) [...], and an employee trust to be paid by the government (5 %). [35]

The strategy of introducing the PPP model in the urban drinking water supply was to achieve a number of objectives. Mainly to materialize the long awaited Melamchi Water Supply Project (see section 10.1) and run the urban drinking water supply on a commercial basis [9].

Besides KUKL there are Alternative Service Providers (ASP) which serve urban areas under-served or un-served by KUKL. The ASP rely on KUKL sources or their own sources of water. These ASP are not regulated in terms of pricing and water quality but serve 15 % of the urban and peri-urban population [9]. Figure 3.4 shows the current institutional arrangements in the Kathmandu Valley.

As one can see from Figure 3.4 above, as well as the description of the institutions involved in the water supply within the Valley, the situation is very complex. There is a lack of stakeholders' accountability for the common goal and there is a total lack of interest, collaborating among the actors and institutions [9]. Chapagain also found during interviews that there is a lack of political will to improve water related institutions and water service. Furthermore water sector guidelines are not being followed [9]. Others ascribe the government weak management capabilities [32].

Additionally, Chapagain determines the following factors as a cause of the poor water supply [9]:

- Weak institutional structure in terms of inadequate organizational resources.
- Lack of regulation and monitoring from regulatory bodies.
- Deteriorating and non-scientific infrastructure.
- Unclear supply standard and norms.
- Unsustainable water resources.
- Lack of effective human resource management.
- Conflicts over water resources.

On the other hand KUKL expresses the following complaints [4]:

- Lack of financial support to undertake projects - especially to augment potential surface sources, to improve water treatment plants, service reservoirs and distribution pipelines
- Autonomy in taking actions - Regulations to prevent consumers to illegally make connections and pumping water from distribution pipelines exist but due to political interference KUKL has not taken any action
- Lack of tools and equipment - There is simply not the right equipment available and spare parts are missing. Maintenance and construction is therefore difficult
- KUKL cannot raise service tariffs - Another organization is responsible for that
- Lack of skilled manpower

One can get a feeling of the difficulty of the situation. On the one hand it was tried to make the progress of improvement of the water supply network and its management more effective by rearranging the organizational structure, on the other hand blame the different parties each other for the bad situation. The idea of cooperation and a team spirit to solve the drinking water problem does not seem to be in sight. As a huge problem is the lacking will to improve the situation assessed. Maybe another problem is existing power structures that survived from pre-democracy days.

3.2 Water related problems

3.2.1 Water supply issues

In KUKL's first annual report the company describes the situation they found when taking over office in 2008. Following a selection of points mentioned in this report are listed to give an impression of the state of the water supply system [34].

- Almost all water production figures are from historical data or are estimated. Only a few production plants have metering equipment.
- About 130,000 (out of a total of about 160,000) customer connection are metered. 40% of the customer meters are estimated to be not functional.
- Water is distributed directly to the customer without treatment from tube wells from which some waters have high content of ammonium, iron and some, arsenic.
- The use of chemicals used to be done according to its availability in stock rather than on the need for water treatment and disinfection. Properly trained and qualified operators to conduct disinfection were not available.
- About 48% of the network is older than 25 years.

- Branches had not updated drawings of the networks.
- Illegal service connections [4]

One gets the impression that one of the major issues is actually the state of the distribution network. It seems that the system has been expanded in an uncontrolled and unsupervised manner. The same is valid for urban development which is described as unplanned and uncontrolled [51]. This uncontrolled urbanization exists on a massive scale and strangulates efforts to supply drinking water [9].

Additionally only 160,000 customers have a piped connection to the drinking water system of overall 2.5 million customers. The Asian Development Bank states in its report of 2010 about the situation in Nepal that two million consumers are connected to the piped system but mostly water is supplied only for one hour every fourth day [4]. It is very doubtful that the KUKL managed to connect about 1.8 million consumers to the piped network within such a short period of time. Especially considering the progress of other building projects in Nepal as well as the previously mentioned problems within the organizational structure of water supply organisations. Furthermore, this time was the beginning of KUKL and such a progress in this time is not plausible.

Due to the fact that not even half of the households and just a few plants are metered, the actual water supply is hard to estimate. Furthermore the old and amateurishly build / fixed pipe network produces a remarkable amount of leakage. Leakage is accounted for 40 % of the total water supply [71]. The outdated piped water system does not work efficiently and is characterized by low water pressure and frequent breakdowns [9]. It is obvious that this system does not meet the demand. Therefore people depend on trucks which supply water. In 2008 there were 17 tankers in operation which distribute the water on demand. Due to the fact that almost all tankers are beyond their economical service life, KUKL rents tankers from other companies in order to provide enough water [34]. Additionally the population has to extract water from stone spouts, dug-wells and springs [77].

Ground aquifers are the major source for these local water sources. But these local sources are affected by the groundwater depletion in the Valley [77] [4]. About 50 % of the water supply during wet season and 60 - 70 % during dry season is extracted from groundwater sources [51]. Annual extraction is exceeding recharge which causes a remarkable depletion of the groundwater level. Due to inadequate institutional responsibility in monitoring groundwater resources, the exact figures of how much water is extracted and its effect on the water quality is unknown [48]. The pressure on the groundwater resources is increasing due to increasing population and development activities [51]. Researchers found in 1994 that a sustainable withdrawal of groundwater is about 26.3 mld (million litres per day). In 2000 the actual withdrawal was estimated to be 58.6 mld which shows that the groundwater in the Valley is over exploited [51].

KUKL further describes in its report from 2008 that many of the wells contain extremely high amounts of sand and silt which causes very frequent breakdown of the pumping equipment. Repair and maintenance work is heavily affected by the unavailability of spare parts, tools and qualified personnel [34]. A study which was conducted by the Environment and Public Health Organization (ENPHO) monitored the drinking water quality in the Kathmandu Valley along the supply chain, namely at the source, at reservoirs and at the tap. The results are shown in Figure 3.5.

Figure 3.5 shows the location at which the sample was taken on the y-axis. The x-axis represents the percentage of samples taken which values exceed the National Drinking Water Quality Standards (NDWQS). One can clearly see that it is not safe to drink the tap water. Household water treatment systems are therefore very essential before consumption [56].

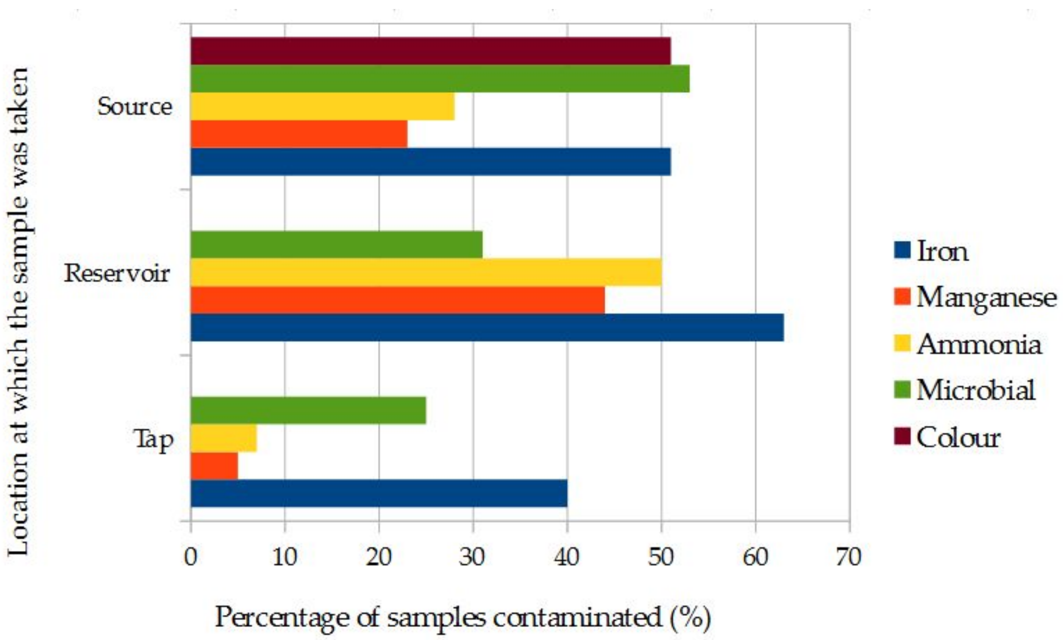


Figure 3.5: Contamination Parameters of the drinking water within the Kathmandu Valley [56]

Even though piped connections are existent, the supply is still not guaranteed continuously. Figure 3.6 shows the distribution of water supply frequency within the urban Kathmandu Valley. One can see that only a minority of the city is supplied by water 'more or less every day'. And from own experience it can be said that the water supply even if it falls under this category is not available the whole day but only for a few hours a day.

The main issues related to the water supply can be summarized in the following topics:

- Massive over exploitation of the groundwater resources leading to a depletion of the groundwater level and the resulting dry-up of the traditional stone spouts and dug wells.
- Unknown distribution network due to uncontrolled expansions. The network is not maintained and therefore in a bad shape. Losses due to leakages are up to 40% of the supply.
- Quality of the supplied water is not suitable for drinking water purposes.
- A majority of the people is not connected to the piped water supply network.

3.2.2 Wastewater Handling

Regarding the Waste Water Department, the following issues are mentioned in KUKL's annual report from 2008:

- The department has four treatment plants only one of which was functioning/working but was in a bad state of operation [34].
- There is no data available on the performance of the plant condition. The last Biological Oxygen Demand (BOD) sampling and test were conducted some 4 years ago [34].
- The sewer department did not have drawings about the networks and the connection[34].
- About 93,000 customers are connected to the wastewater system.

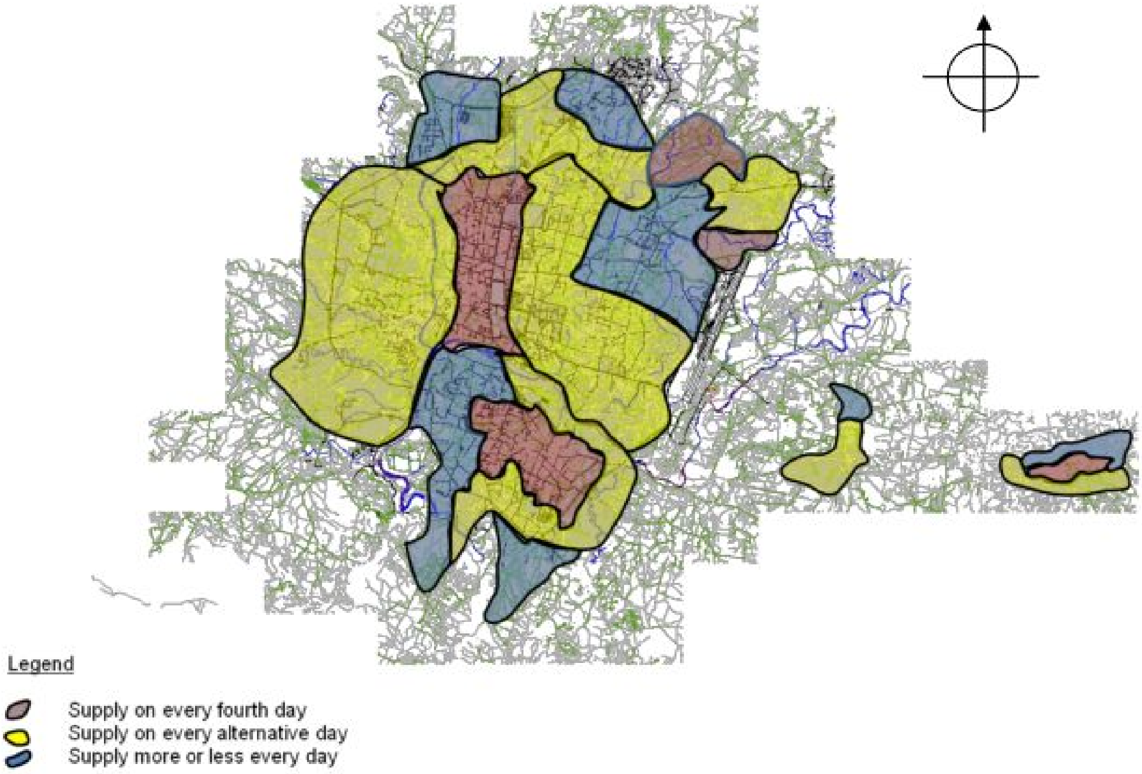


Figure 3.6: Map of the frequency of the water supply within the Kathmandu Valley [4]

- No agency is maintaining the constructed sewers in a planned manner. They react only on public request. The actual condition of existing sewers is not known as even manhole covers are hard to locate in many locations [4].

The topics mentioned above are self-explaining. One can get an impression of the situation of the wastewater conditions in 2008. A big problem regarding pollution is that the untreated sewage is directly discharged into the rivers [71]. Furthermore also solid waste and industrial effluents are disposed in the streams [51]. Much domestic wastewater seeps into the groundwater and people often defecate and urinate on open ground [51]. Figure 3.7 shows the BOD and Cl- trend at two sites of the Bagmati river in the Kathmandu Valley. One site is called Sundarijal and is located at the headwater in the north of the city. The other site is called Sundarighat and is located on the city outskirts in the south-west where the river has been flowing through Kathmandu.

The water quality is very poor at Sundarighat as indicated by the higher BOD and chloride ion values. The trends of the parameters show that the Sundarighat site is more affected by anthropogenic factors than the Sundarijal site [71].

The main issues regarding the wastewater handling can be summarized in the following bullet points:

- Treatment of contaminated water is almost not performed due to not functioning treatment plants.
- The untreated sewage affects the water quality of the rivers and the groundwater in the Valley and therefore the sources.
- Maintenance is not done regularly and errors are not detected.

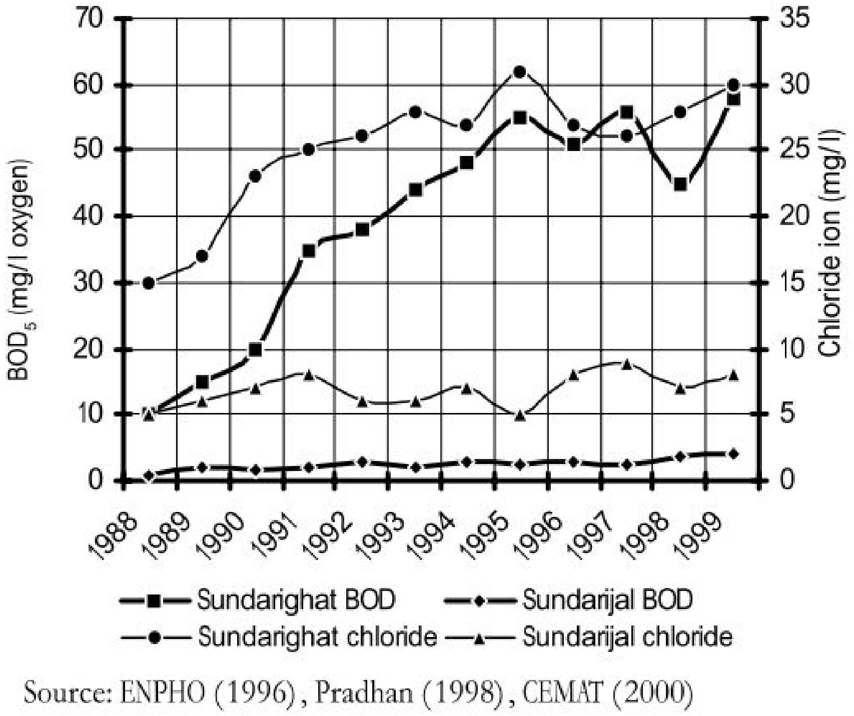


Figure 3.7: BOD and Chloride trend at two sites of the Bagmati river [71]

- The huge amount of the households that is not connected to the sewage system (30%) [4].

3.3 Outlook of the problem development

The section tries to give an idea of the further development of the existing water situation in the Kathmandu Valley.

Increasing population. The development of the population in the Kathmandu Valley will continue to grow in the near future like the population of entire Nepal as can be seen in figure 3.8 from the Central Bureau of Statistics Nepal (CBS).

The latest number about the population in the Kathmandu Valley was published in 2011. According to the CBS, 2,517,023 people were living in the Kathmandu Valley of which 1,426,641 people lived in the urban area [43] which is about 55 %. The growth rate is expected to be 4.7 % [37] [51]. Kathmandu is the economical hub of Nepal and will therefore stay attractive for a lot of people [18]. More information about the development of the population in the Kathmandu Valley can be found in chapter 6.3.3.1. But the overall development is clear: The more people in the Valley, the higher the absolute water demand for the region.

Increasing per capita water demand. Additionally to the increase in population, it is expected that also the per capita water consumption in the Kathmandu Valley will continue to grow. Technological progress will in a first phase increase the water demand. The beginning of the use of showers, dishwashers or washing machines contributes to that development. The water supply organization KUKL expects that increasing of per capita water demand as well (see chapter 6.3.3.2).

Poor water supply. The previous chapter (chapter 3.2) gives an impression of the poor state of the water supply. The piped network as well as the treatment plants are in a bad shape and not able to deal with the amounts of water necessary. All treatment plants in the Kathmandu Valley combined (assuming all are functioning) can treat at maximum 85 million litres per day (MLD) [4]. The demand is probably in the range of 200 - 400 MLD and therefore many times higher than the possible clean water supply.
As described in chapter 3.1.1 there is a growing private business that supplies water to the population. This clearly indicates that the demand is higher than the water supplied. People are willing to spend that extra money on the additional supply by tankers and bottled water industries.

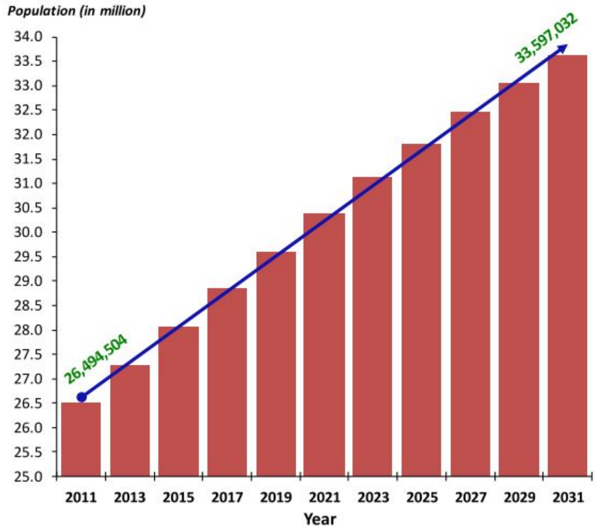


Figure 3.8: Increasing population in Nepal according to the Central Bureau of Statistics Nepal. [8]

Groundwater extraction. It was already described in chapter 3.1.1 that due to the mismatch between water demand and water supply, people are forced to look for alternative water sources than the supply by the government. This led to a massive use of tube wells and stone spouts. These are traditional water sources that are fed by deep and shallow ground water respectively. The poor water quality of these sources (after being used excessively) affects more and more of these sources and more and more water therefore requires treatment before consumption. This treatment is mostly done by the people themselves or in local community arrangements.

'Due to the short-supply, in addition to individual households, large volume water consumers like housing complexes, hotels and industries have been increasingly mining groundwater simultaneously' [48].

Figure 3.9 summarizes the above mentioned topics: An increase in water demand and an estimated groundwater extraction. The recharge level for the groundwater stays at the same level of about ten million cubic meters per year which complies with 27 MLD. As a result the water level decreases over time. Groundwater depletion causes that more and more tube wells and traditional stone spouts run dry. The quality of the remaining groundwater is very likely to decrease as well. Overall it is not a good condition for the Kathmandu Valley having in mind that the population will continue to grow. It is hard to imagine what happens if the ground water possibly dries up completely. This scenario should be avoided by all means.
While assessing information about the groundwater level, another big issue was found: A lack of data regarding all kinds of water management makes it hard to assess the current situation with certainty. But in order to develop any effective solutions to prevent that the depletion is ongoing, exactly this accurate assessment is what is necessary.

'Even though nearly half of the total water supply during wet season and 60-70 percent during dry season comes from groundwater [51], groundwater is being developed without due consideration to resource distribution over space and time. As a result, annual extraction is exceeding recharge; leading to tremendous depletion in groundwater levels. However, no one knows for sure, the current exact figures of how much water is being extracted, how quickly the groundwater level is falling, or how the groundwater

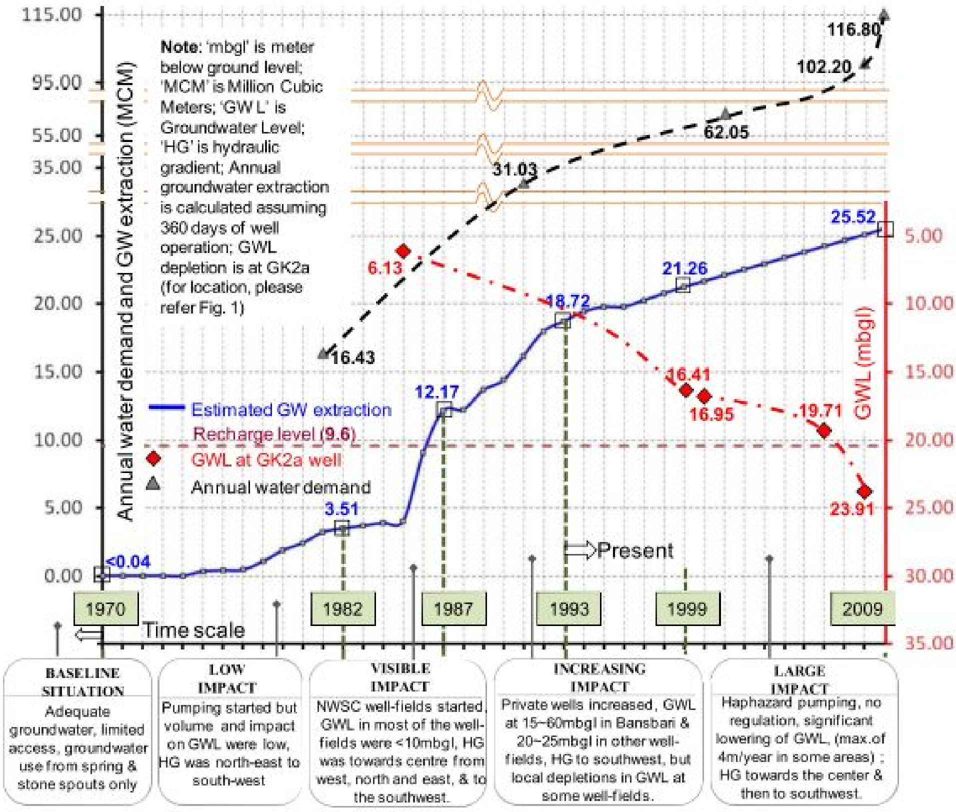


Figure 3.9: Groundwater development dynamics and its impact on groundwater level. [48]

quality is being affected because of inadequate institutional responsibility in monitoring groundwater resources and its impact' [48].

Poor water quality. Under the section *poor water supply* in this chapter it was already mentioned that the treatment plants in the Kathmandu Valley all together can treat at maximum 85 MLD. But treatment of water is necessary due to the bad quality of the available sources. In figure 3.10 one can see that the local population depends on the water, even though it is obviously not clean enough to clean the dishes in it. The state of the piped distribution network is so bad that it pollutes clean water as soon as it runs in the network [76] [4]. Additionally, no working sewage system exists that could prevent that waste water is discharged into the rivers of the Valley. It has been seen that the tendency develops in the direction that people treat their water locally in small communities [4]. This also reduces the urgency for the government to provide clean distribution pipes.

Recently the Bagmati Action Plan was agreed upon. This strategic plan 'focuses on reviving the conventional sewerage system' [4]. Actions include the reviving of two treatment plants, the extension of treatment capacity of another treatment plant, the development of several new treatment plants and the 'promotion of on-site sanitation with household and community level septic tank with implementation of faecal sludge management' [4]. It remains to be seen whether these measures actually happen and if so what the improvement of the situation will be.

The influence of climate change. *The 'assessment report mentioned that the poor are the most adversely affected by climate change due to their exposure and the impact of climate change on their livelihood assets' [12].*

Figure 3.10: A Nepalese girl is cleaning the kitchen pot in the river [24].

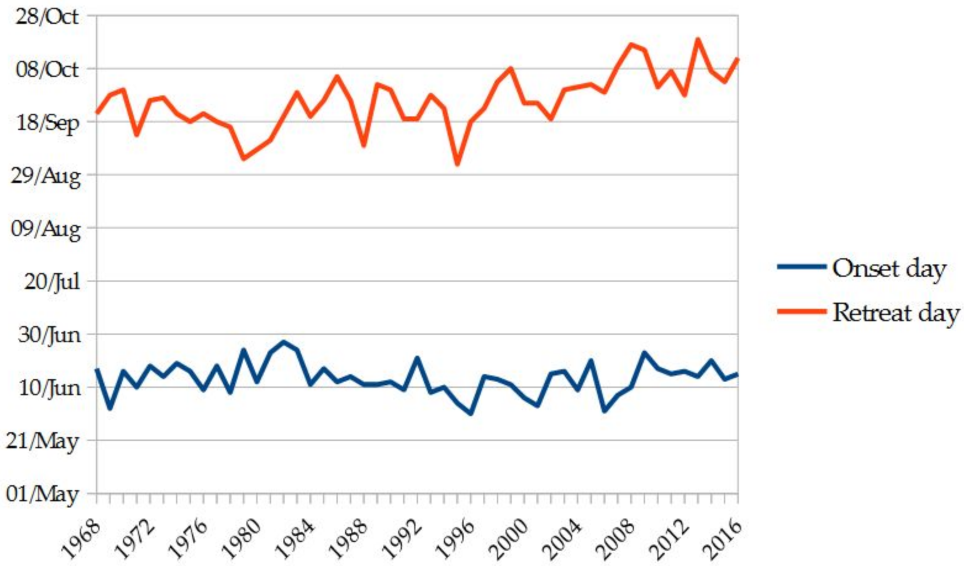


Figure 3.11: Starting and end date of the monsoon in the time of 1968 to 2016. Normal onset date for the monsoon is the 10th of June each year. [21]

The study mentioned above was conducted in Dhare Khola Basin of Dhading district which is located in the west of the Kathmandu Valley. The outcomes of this study will be explained in the following as an example for the impact of climate change on the water resources in the Kathmandu Valley. People observed that the volume of water in the Dhare Khola reduced by 50 % in the last 15 years [12]. The number of irrigation channels (kulo) using water from the stream decreased from 21 to only 9 irrigation channels. The amount of land that could be irrigated was reduced by 40 % [12]. The lack in water supply poses a big challenge to the local population with regard to their agricultural and domestic water needs.

Figure 3.11 shows the onset and retreat date of the monsoon. The figure shows that especially the retreat of the monsoon has the tendency to get more and more delayed in the last 30 years. Additionally the start of the monsoon season was never on the "normal" date since 2008 again. A slight delay can also be recognized in the past years for the starting date even though it is not possible to speak of a major trend. The Ministry of Science, Technology and Environment published that the precipitation during the monsoon season decreased by 0 - 10 % in the Kathmandu Valley, dependent on the location in the Valley. The only exception is the Shivapuri National Park in the northern region of the Kathmandu Valley. This area receives annually up to 5 % more precipitation [20]. The Dhare Khola Basin lies in the area of 5 to 10 % precipitaion decrease per year. Additionally the annual temperature increase is in the range of 0.02 and 0.06 °C [20].

The people therefore have to find adaptation methods to deal with the change of the situation that seems to become more severe:

'The focus of the communities has shifted to subsistence vegetable farming instead of cultivating cereal crops and intensive farming. Communities were found slowly shifting from three season irrigated production to seasonal production and irrigated land (khet) as unirrigated land (bari) for maize and millet cultivation' [12].

Other measures used to tackle the problem was the construction of water tanks in order to store water, the use of dripping technique for irrigation purposes or the transportation of irrigation water in pipes instead of in the open *kulos* in order to prevent loss of water by evapotranspiration or leakage [12]. Besides these measures taken, the habit of the people changes over time in order to save water:

'Less use of water in kitchen, washing utensils and other daily needs is common practices in most of the houses. Almost 70 % of the households in the watershed area use this measure to cope with drying up water resource. Some of (5 %) the households started lessening livestock in dry seasons (February to May) who are totally engaged in domesticating livestock all round year before. The community's people (almost 10 %) started going to nearby rivers for bathing, washing clothes during dry season and also 9 % of the households have been found starting to take livestock to the nearby stream daily' [12].

Even tough a variety of measures were taken by the local population in order to deal with the lesser water supply, the coping strategies were evaluated to be 'very poor and insufficient' [12]. In chapter 1.1 it was mentioned that Nepal's economy heavily relies on agriculture and 64 % of the population work in that sector [43]. Additionally the water supply system is in a really bad shape. This makes regions like the Dhare Khole Basin area highly vulnerable to impacts of climate change on water resources [12]. To approach the problem, the authors propose the so called 'Adaptation Planning Bottom up' process. This process requires a good relationship to the local people and also their involvement and commitment to the topic of climate change. The difficulty will probably be to connect the government level with the local population. Especially gaining trust and confidence in reaching an aim together can be challenging after the government bodies were not able to significantly improve the water supply situation in the Kathmandu Valley yet. Furthermore, corruption and nepotism are difficult to overcome. But it is probably worth it for the population of the Kathmandu Valley and its environment.

'Coping and adaptation is an essential strategy for reducing the severity and the cost of climate change impacts. [...] Adaptation Planning Bottom up processes are significant to come to a common understanding with the community on what are the most major climate risk and hazards, which among them are urgent and of urgent precedence, and what could be done at local level given the rich local knowledge and perceptions' [12].

3.4 The project goal

From the above sections it is clear that there are many issues considering the water situation in the Kathmandu Valley. Not only the demand seems to be increasingly exceeding the supply, also the quality is decreasing and the groundwater is depleting. These issues will have increased consequences in the future if nothing is done to improve the situation.

Some plans exist to improve this situation, but their effectiveness is doubtful. An important reason for this is that data is barely available and finding solutions for a problem that is actually not clear is an impossible mission. We therefore believe that this is the first step towards effective solutions that can benefit the people in the Kathmandu Valley. A big effort in this is the collection of representative data.

To better describe the water situation, two aspects need to be considered. At first, it is essential to know the amount of water that is available. Secondly, the quality needs to be assessed in order to know for what purposes the available water can be used. These two aspects are influenced by different factors, of which a few are:

- Water treatment
- Human behaviour (Waste dumping, washing, etc.)
- The influence of land use on the water situation
- Sources of water and their amount (precipitation, groundwater, springs, etc.)
- The (change in) water demand for the urban area as well as agriculture
- The use of water (how much water is used for which purpose)
- Characteristics of the water supply system
- Climate change

We see a chance to improve the data availability, especially with new technologies like remote sensing in order to gain more insight in the different topics mentioned above. Especially the influence of land use on the water situation and the water demand in urban areas and for agriculture use are of our interest. These are also the areas for which we see the greatest possibility to improve the understanding according to our educational backgrounds and the different skills and expertise we bring in the project.

The goal of the project therefore is to: *Characterize the linkages and inter-dependencies between land use, hydrology, and water quality in the Kathmandu Valley by (1) estimating the urban water demand from literature research, (2) collecting new field data about spring and stream flow, water quality, and ecological stream health, and (3) analysing remotely sensed data. The desired outcome is an increased understanding of the water budget in the Kathmandu Valley.*

3.5 Research Questions

To further specify the research goal, several research questions have been defined:

1. What are the post monsoon flow rates, water quality signatures, and ecological stream healths of the headwater springs of the Bagmati River watershed?
2. How can these measurement data be used to estimate the water supply of the Valley and the quality of the streams?
3. How can the land use within the Kathmandu Valley be characterized?
4. How does land use impact water availability in the Kathmandu Valley, mainly focusing on the quality?

5. What is the current water demand of the Kathmandu Valley?
6. To what extent can available literature describe the urban water demand of Kathmandu metropolitan area?
7. What is the evapotranspiration rate of the Valley and to what extent does it describe the rural water demand?

Chapter 4

General approach

This chapter gives an overview over the tools that were used to collect and analyze data in order to answer the previously stated research questions. Furthermore the approach of the fieldwork is described and a schedule for the research project is presented.

4.1 Tools

In order to accomplish the project goal, certain tools were needed of which some are measuring devices used during fieldwork and some are software and applications that support collecting and analyzing data. First the main measuring tools are explained:

- **Flow measuring device:** A *FlowTracker handheld Acoustic Doppler Velocimeter* from SonTek was used to measure the flow. The device is able to measure the total flow of a river's cross section. The device is therefore placed at several locations in the river in a way that between to measurement stations the flow difference is less than 10 % of the total flow. At a specific location the velocity is measured by using the acoustic Doppler effect (measuring the suspended particles). Depending on the depth of the water, the velocity is measured at a depth of either 0.6 of the total water depth or 0.2, 0.6 and 0.8 of the total water depth. From the known vertical distribution of the velocity, the total flow of the cross section is calculated. [57]

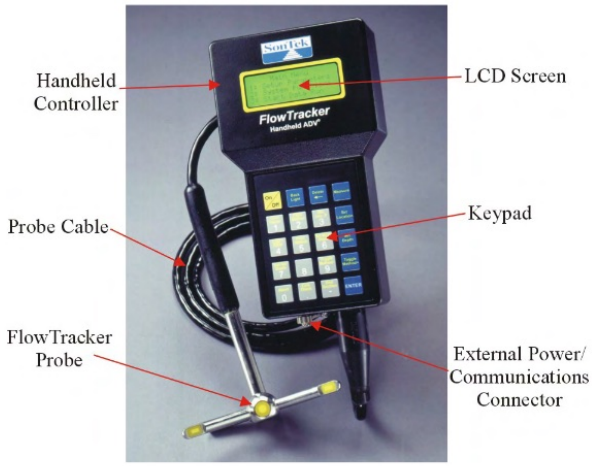


Figure 4.1: FlowTracker Handheld ADV [57]

- **Water quality multiparameter meter:** This device was supplied by the water laboratory at the Civil Engineering faculty, TU Delft. It is a *Multi-parameter portable meter MultiLine* that can determine different water quality parameters. The four parameters measured during the fieldwork with the corresponding probes were dissolved oxygen (DO), electric conductivity (EC), pH and temperature.

Figure 4.2: Multi-parameter portable meter MultiLine [31]

- **Rapid Stream Assessment (RSA):** The RSA is a way that allows a quick assessment of the stream health that is being studied by analyzing mainly micro invertebrates that live in the different microhabitats in the stream. Scores under a certain criteria are used for assessing microinvertebrates and other relevant parameters. This scoring process that determines the stream class requires quite some experience. The classes range from 1 (best) to 5 (worse). A more detailed description of the RSA can be found in chapter 6.2.7.

The following list contains some software and applications that were used:

- **ODK android app and online free database:** ODK stands for Open Data Kit, it is a free open-source tool used for collecting data for future management, visualization and analysis in convenient formats. The data can be either manually inserted online or via an android mobile app, which is then sent to the server [19]. ODK was used in this project for capturing information from the field measurements. Two applications were used, ODK and GeoODK. The first one was used to record flow measurements, water quality measurements and RSA classes; the GeoODK application was used for collecting land uses because this app also allows to record GPS tracks and poloygons. A huge benefit was found in using these applications as it automatically stores all data in a convenient way, including a link to a map that shows all measuring locations as a GPS coordinate must be recorded on site. Furthermore the handling is very intuitive which makes it an easy tool to use for citizen science (see chapter 9.2.3).
- **Quantum Geographic Information System (QGIS):** QGIS is an open source tool for Geographical Information System (GIS) information [50]. In order to analyse the spatial data it was chosen to use QGIS. The version used is QGIS 2.14.6 with Grass 7.0. Grass is a plugin for QGIS that is used for its extensive options of raster and vector manipulations. The benefit of using this program is not only its many options for watershed analysis,

but also the powerful functionality of visualising the data. This enabled us to create clear figures that helped us to analyze and further understand the data collected.

- **Surface Energy Balance Algorithm for Land (SEBAL):** Based on the surface energy balance, SEBAL is a method developed for computation of hydrological aspects such as evapotranspiration, water deficit and soil moisture. Satellite images and basic meteorological data are required as input. Initially developed for flat areas, UNESCO-IHE is developing an automated version which will be capable of also dealing with hilly terrain. This (still under development) automated version of SEBAL will be (unofficially) trialed for computation of ET-estimates.

4.2 Fieldwork

After knowing the tools and equipment needed for realizing the project and obtaining results, the fieldwork took place.

In order to do the field measurements, the working plan was done according to the following steps:

1. **Initial set-up of the field work:** To get the necessary data for our ideas of the project, flow, water quality and RSA measurements had to be done within the Kathmandu Valley. We selected the tributaries of the Bagmati river and appointed different sites for different days, usually a river per day. Even though we could determine the area of the springs roughly, the exact location was still unclear, because available maps are not detailed enough. It was therefore expected that the finding of the spring locations could include longer hikes. For the time of the field work we rented a jeep that could bring is to even remote areas within the Valley.
2. **The measuring procedure:** We started by searching for the springs of each river on the outer parts of the Valley. With support of the local population we could identify the perennial streams. The idea was to start with a stream in the headwaters in the morning. After it was confirmed that the stream found was flowing perennially, the measurements were performed from the source to the downstream parts before the river flows into the Bagmati. This procedure was chosen to have similar conditions along the river. Due to the fact that it was still raining from time to time, the conditions varied significantly from day to day. Even tough we tried to follow a river in one day it was not always possible due to weather conditions or simply the time.
3. **At the measurement sites:** Once we found the springs, we would proceed with splitting into teams and measuring the water quality parameters, doing the RSA, capturing the different land uses nearby and taking a flow measurement. After obtaining and capturing all the results with the ODK and GeoODK applications, we would decide how far downstream we would go to do the next set of measurements.
4. **After getting used to measuring on site:** At one point of the fieldwork, the presence of every team member was not needed, so we would take turns and go in couples or by three teammates.

On the last days of the fieldwork, some measurement sites hadn't been done or had missing data by mistake (very few of them), so we rescheduled them and took turns again to finish them.

4.3 Timeline and schedule of the project

Finally, in order to follow our tasks and finishing them on time and in an efficient way, a schedule was made, which is shown below and illustrated on a timeline on Figure 4.3:

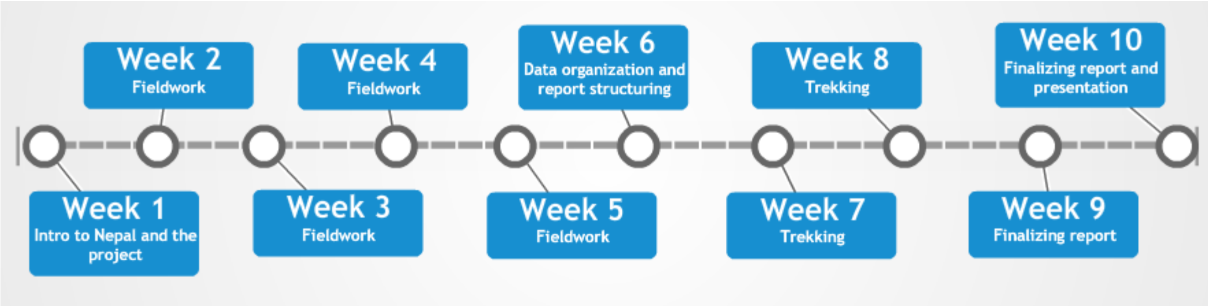


Figure 4.3: General timeline of the project

- **Week 1 (29 Aug-4 Sept):** Initial meeting for an introduction of the project, defining and shaping goals into concise activites. Nepali language lessons
- **Week 2 (5-11 Sept):** First week of fieldwork, after logistics were done in order to know which places to visit strategically in the Kathmandu Valley. First field measurements. Beginning in turns with first literature research and compilation
- **Week 3 (12-18 Sept):** Continuation of fieldwork and writing initial parts of the report. Selecting, analyzing and emptying literature in the report
- **Week 4 (19-25 Sept):** Continuation of fieldwork and more initial preparations on the report
- **Week 5 (26 Sept-2 Oct):** Last week of fieldwork
- **Week 6 (3-9 Oct):** Data analysis and report structuring
- **Week 7 (10-16 Oct):** Trekking week on the Anapurna circuit. Isotopes samples were taking when possible while going upstrem
- **Week 8 (17-23 Oct):** Second trekking week
- **Week 9 (24-30 Oct):** Analysis of the data and discussion of results
- **Week 10 (31 Oct-4 Nov):** Finalizing report and PPT presentation for meeting with TU Delft supervisors

Sticking to the schedule was the key for realizing every task well and on time. Even though timings in Nepal are more flexible and sometimes counter-productive due to the local culture, we were able to follow the proposed schedule.

Chapter 5

Quality of the data collected

After the data was collected during the field work, it is important to analyze the data and check its reliability. Only if the accuracy of the data is in an acceptable range a further analysis of the measurements is reasonable. Therefore the flow measurement device and the water quality device are checked for their accuracy. Human influence on the measurements is also discussed for both measurement types.

5.1 Flow measurements

In this abstract issues regarding the quality of the data are discussed. Most of the quality issues are also covered in the FlowTracker Manual from 2007 [57]. This manual was used as a basis for the data information and assessment and is therefore not mentioned for all citations individually.

As already described a FlowTracker Handheld ADV from SonTek/YSI Inc. was used to do the flow measurements related to this project. First the quality control parameters and their influence are discussed. Second, the focus will be on the influence that the person performing the measurement can have on the accuracy of the measurement.

5.1.1 Description of the Quality Control (QC) parameters

Signal-to-noise ratio (SNR)

The signal-to-noise ratio (SNR) is a measure of the strength of the reflected acoustic signal relative to the ambient noise level of the FlowTracker. SNR is the most important quality control data provided by the FlowTracker.

The manual suggests that the SNR value should be higher than 10 dB to reach the best operating conditions. But the device is able to work reliable with SNR as low as 4 dB. For a 2D system a low SNR of either beam means that all velocity data is affected even if the other beam shows a higher SNR value. Therefore the FlowTracker gives an alert at the end of a measurement if the SNR of any beam is below 4.0 dB. The SNR value is directly related to the amount of suspended material in the water. Low values are shown in water with little suspended material. According to the manual most field applications have sufficient natural scattering material. This is also what could be observed within the measurements taken during the multidisciplinary project.

Standard Error of Velocity (σV)

The standard error of velocity is a direct measure of the accuracy of the mean velocity data.

The standard error is calculated as follows:

$$\sigma V = \frac{\text{standard deviation of the one-second samples}}{\sqrt{\text{number of samples}}} \tag{5.1}$$

The standard error is normally dominated by real variations in the flow and will vary depending on the measurement environment. During the measurement the standard error of the velocity at that particular point (x) is shown (σVx). When this σVx is greater than the standard error threshold for that measurement, this may indicate that there is interference from an underwater obstacle, a highly turbulent environment, or highly aerated water. If there are any obstacles influencing the flow one should remove them in order to obtain higher accuracy measurements. In case the flow is just turbulent at that position, one can also continue and take that into account.

Boundary adjustment (Boundary QC)

The FlowTracker has a potential for acoustic interference from underwater objects. The system tries to avoid this interference, but you must be aware of system limitations.

Reflections can occur from the bottom, the water surface, or submerged objects (e.g., rocks). The FlowTracker records any changes required to avoid acoustic interference. It reports this as Boundary QC. This value describes the effect (if any) of the boundary adjustments on performance. To some extend the FLowTracker gives still accurate results even though an obstacle is close to the sampling volume. In case the influence of that obstacle gets too big, the FlowTracker notifies the user before the measurement is started in order to make eventual modifications before starting the measurement.

Spike filtering

Spikes in velocity data occur with any acoustic Doppler velocity sensor such as the FlowTracker. Spikes may have a variety of causes - large particles, air bubbles, or acoustic anomalies.

Spikes are filtered based on all velocity components. If values fall outside the above limits, these samples are not used to determine the mean velocity. The number of spikes is recorded and displayed at the end of each measurement.

Velocity angle

The velocity angle is defined as the direction of flow relative to the X direction. For an ideal measurement site, flow should be perpendicular to the tag line used to define the cross section.

The FlowTracker's x-axis is always held perpendicular to the tag line. The ability of the FlowTracker to measure the 2D flow eliminates the need to estimate the flow direction with each measurement which reduces a potential source for error in velocity measurements. The manual states that a good measurement site typically contains flow variations with angles up to $20 - 30°$

Maximum section discharge

Most agencies monitoring discharge expect that no individual station should contain more than a certain percentage of total discharge. The Maximum Section Discharge criterion (default 10%) alerts you if this standard is exceeded.

The maximum section discharge is checked when the End Section key is pressed and gives a notification in case any station exceeds the predefined percentage of discharge. If desired one can go back in the measurement and add more stations.

Maximum depth change

The Max Depth Change criterion is intended to avoid data entry errors.

It is assumed that the depth changes between stations will be gradual. If the entered depth is different from a reference by more than a pre-set maximum, an alert occurs to be sure that the depth was entered correctly.

Maximum location change

The Max Location Change criterion is intended to avoid data entry errors.

It is assumed that the spacing of adjacent stations is nearly constant across the river. Therefore the FlowTracker gives a warning in case the spacing between two stations has changed more than a pre-set maximum. Per default this maximum is 100% which means that the new station spacing must be more than two time the previous station spacing in order to trigger the alarm.

Furthermore, any time a station location is changed, the location is compared to the starting edge location in order to check whether the new location is outside the starting edge.

5.1.2 Uncertainty analysis

The FlowTracker is provided with a software package that performs some data analysis. In this case the 'Statistical' uncertainty calculation is used. According to the Manual it 'provides the most reliable indicator of measurement quality'.

The Statistical calculation includes the uncertainty in the depth measurement and the effect of changes in depth between stations. For the velocity also the uncertainty in the measurement and the effect of changes between locations is taken into account.

The average uncertainty in the measurements that were taken during this multidisciplinary project, is 4.9% according to the Statistical uncertainty calculation. The maximum uncertainty is 15.3% the minimum only 1.9%.

Overall 13 % of the stations show a change of the flow to the previous station of more than 10%. But the general impression of the data and its analysis is a good one. An average uncertainty of the data of about 5 % is in an acceptable range.

5.1.3 External influence

The influence of not holding the measuring pole upright is negligibly small. Assuming that the measuring tape is about 50 cm above the river bed and a maximum angle of 10° is assumed in case the person performing the measurement wants to keep the pole vertically. The resulting maximum deviation from the actual location is therefore 9 cm. If the measuring tape is higher than 0.5 meters, the river is most likely to be wider as well which makes the influence relative to the river width not more severe.

Other influences that more severely affect the measurement are the time of the measurement. In Nepal, especially in the monsoon season, the flow is higher shortly or during a rain event, than after a longer dry period. These differences can be even visible without a measuring device. It sometimes happened that during the measurement the flow increased or decreased remarkably due to human water use a bit upstream of the measurement location. These influences seem to affect the data more than the actually measured flow. Even tough we paid a lot attention in scheduling the measurements to avoid exactly these effects but the time was simply to short to wait for the monsoon to be over completely. But we managed to keep these influences as low as possible during the month of fieldwork.

Finally an important influence of the measuring person is the choice of the river stretch in which the measurement is performed. It is wise to choose a spot in which the water flows parallel to the river banks over the whole cross section. Additionally turbulent flow should be avoided as it will influence the quality of the measurement due to highly variable velocities.

5.2 Water Quality measurement

5.2.1 Influence of the measuring location on the accuracy of the data

To perform the water quality measurements, water from a stream has been collected with a bucket in which the measurement probes were placed. The following Figure 5.1 shows the differences between the measurement in the bucket itself and the measurement directly in the river. Additionally the influence of the position of the measurement device within the bucket was analyzed. Therefore the device was placed once in the middle of the bucket, in order to have as little influence of the walls as possible. The other extreme is a measuring position at the bottom edge of the bucket with as much influence of the walls as possible.

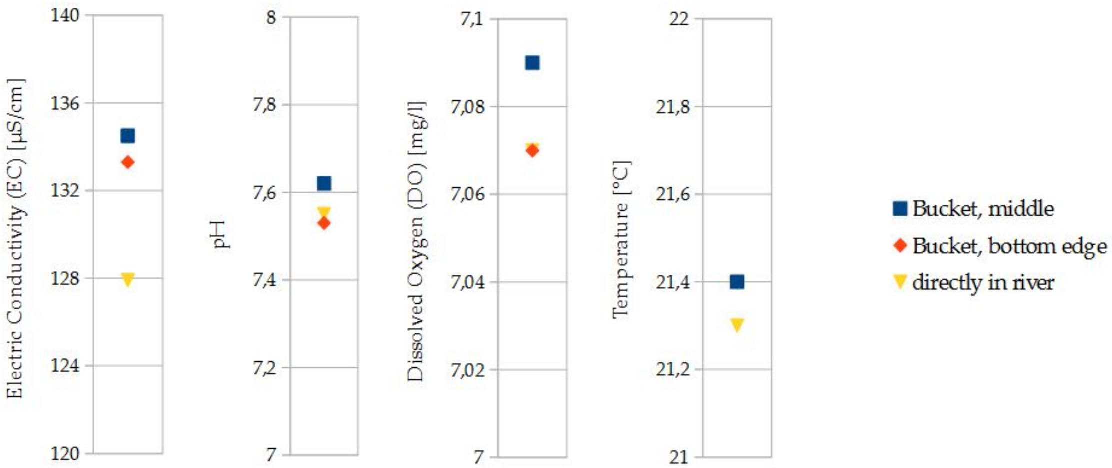
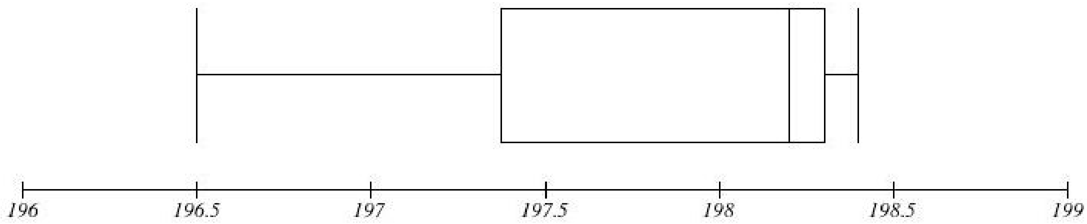


Figure 5.1: Measurements of the same water at three different locations: In the river itself, in the middle of a bucket (filled with water from the river) and on the most possible edge of the same bucket. (The orange point in the temperature figure is at the exact same location as the blue one and therefore not visible)

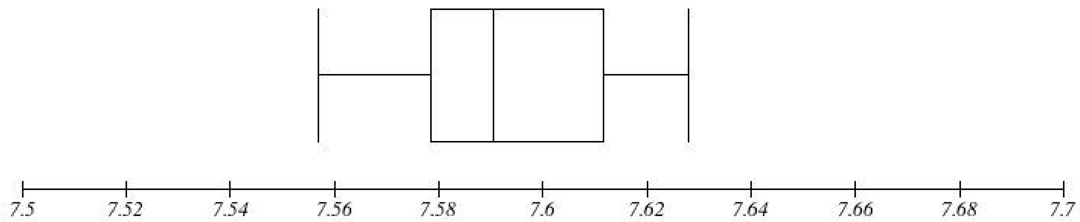
The analysis shows (Figure 5.1) that the differences of the different measurement locations do not really matter for the temperature, Dissolved Oxygen and the pH measurement. The only obvious difference can be seen in the electric conductivity (EC) measurement: The value measured directly in the river is lower than the values measured in the bucket. This is due to the characteristic of the measurement. The moving water has an influence on the measurement of the EC. Because of disruptive effects in the moving water, the conductivity will always be determined lower than in still water where the conductivity rate is more constant during the measurement.

5.2.2 Analysis of the accuracy of the water quality measuring device

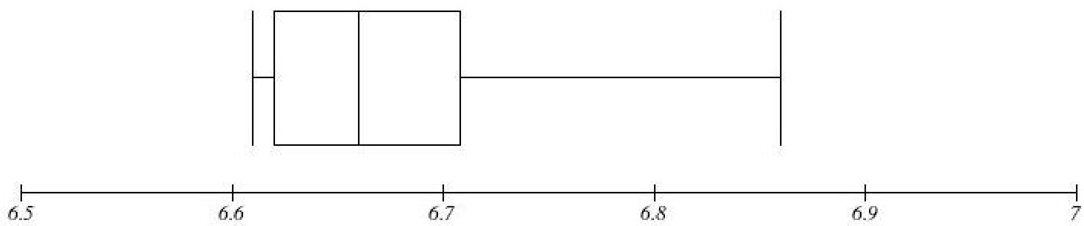
Additionally to the influence of a measuring location on the results, the accuracy of the measurement device is tested. Therefore a number of ten samples was taken from the same water. The resulting box-plots are shown in Figure 5.2.



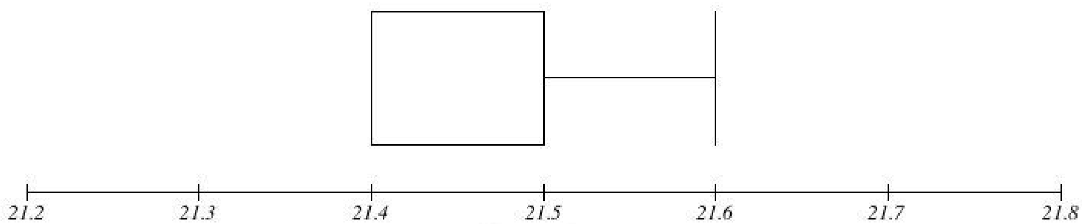
(a) Electric Conductivity (EC) [μS/cm]



(b) pH [-]



(c) Dissolved Oxygen (DO) [mg/l]



(d) Temperature [°C]

Figure 5.2: Box-plots for the water quality parameter

One should look carefully at the scale of the box-plots. Because the distance between the whiskers is little, the scale was adjusted that the data can be analyzed properly. For the EC (Figure 5.2a) the scattering of the data is large between the median and the lower whisker. The upper 50 % of the data is relatively close. The difference between the minimum and the maximum is only 1.9 μS/cm and the standard deviation is with 0.7 negligibly small.

The pH shows almost a normal distribution of the values (see Figure 5.2b) with a median at 7.59. The standard deviation is with 0.02 very little. The measuring device seem to display the reality quite accurately.

The box-plot of the DO (Figure 5.2c) shows a relatively wide scatter in the upper whisker. But also for this measurement, the difference between highest and lowest value is only 0.25 mg/l. The standard deviation is with 0.08 also relatively small.

Finally the temperature measurements (Figure 5.2d) show that the median is at the line of the 75 % quartile. The distribution is therefore very little. Only one value with 21.6 °C was measured. The standard deviation of 0.08 proves that.

In overall it can be concluded that the measurement device works properly and does not give any reason to question the accuracy of the data measured by the device.

Chapter 6

Focus areas of the project

The project looks at the interlinkages between land use and the water quality and quantity of the streams. The focus areas are determining water quality in the Valley, determining flow along the course of the rivers in the Kathmandu valley, and making a landuse map of the Valley. The methods used and the results from each of these focus areas will be discussed in this chapter.

6.1 Land use analysis

The aim of this focus area is to make a recent, detailed land-use image of the Kathmandu valley so that it can be evaluated and complemented by the field research done in the first month (September) of our project. Using watershed delineation, this map will be used to generate statistics of the upstream landuse of the different measuring points. These can be combined with the results obtained from the water quality measurements and flow measurements from the same time period.

6.1.1 Methododlogy of Landuse classification

For the classification of different land-uses, remotely sensed data are used. The available images were Landsat 8 images from the last 3.5 years. These were analysed and processed in QGIS. Different land use classes were selected from the standardized classes as proposed by the USGS [81] and is a refinement of the classes proposed by Anderson et al (1976). The selection, and sometimes aggregation, of these classes is based on additional criteria further explained in section 6.1.1.4.

This section will give detailed information about the data used, the landuse classes selected, the approach to connect the chosen landuse classes to pixels on the Landsat images, the iterative approach of making the classified maps and the validation method.

6.1.1.1 Remotely sensed data used for classification

In this project, the remotely sensed data that was used includes Landsat 8 images, a preprocessed Normalized Difference Vegetation Index (NDVI) product and Google Earth visual map. The NDVI map dates from 7 October of 2015, and both this and the Landsat images were obtained from the USGS [81]. The Google Earth images are freely available and the map used dates from 30th of April, 2016. Landsat 8 images from of the 7th of Okotber, 2015 were used. Landsat 8 has eleven bands, representing different ranges of the electromagnetic spectrum. The bands 2-4 are in the ranges that show colours visible for humans and are called the red green and blue sensors (4, 3 and 2 respectively) and combining them gives a real-colour image. An explanation of the the different bands and how they were used to determine land use classes looking at the remotely sensed data is given in section 6.1.1.5. The Landsat 8 satellite has a spatial resolution of 30 square meters, with one band having an even finer resolution of 15 square meters. The radiometric resolution, which describes the range and number of brightness values the satellite can distinguish of Landsat 8 is 12-bit [82]. This means there are potentially 4096 distinct grey levels, important for the precision with which it can identify spectral features for the identification of the land use classes.

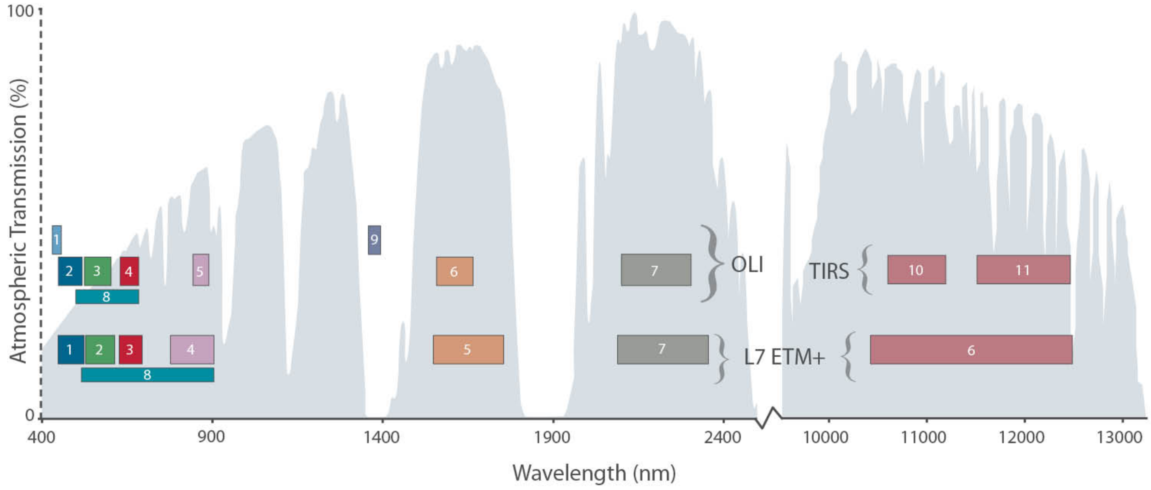
The corresponding wavelengths and resolutions are shown in figure 6.1a. Figure 6.1b compares the functioning of the OLI spectral bands of Landsat 8 (OLI is the sensor that collects the data for the visible, short wave infrared and and near infrared spectral bands [27]) with the ETM+bands of Landsat 7 (Where ETM+ is the Enhanced Thematic Mapper consisting of the 8 bands that Landsat 7 produces). It shows the atmospheric transmission at different wavelengths and gives an impression what is captured by the different bands.

It can be seen that Landsat 8 provides two very precise new bands. The first is the coastal band, which can collect specific blue light. This is very hard to capture because blue light is easily scattered by the dust and water in the air (this is why the sky looks blue). The other special band we see is band 9, the cirrus bands, which is reflected by cirrus clouds which are undetectable by other bands but can alter the observation easily up to ten percent [42]. The functionality of the different bands are briefly explained below, since this is of importance to understand which false colour maps were created for the identification of landuses via visual inspection of the Landsat 8 data.

- **Band 1: coastal/aerosol band** senses deep blues and violets. The band is mainly used for detecting shallow waters or very small particles. In this project, Band 1 contrasted against Band 2 is used to determine the location of shallow streams and ponds. However, later on water was discarded as land-use class and the band was used to make the signature file, but not to identify the training polygons as explained in section 6.1.1.2 and 6.1.1.4.
- **Band 2, 3, 4: visible blue, green and red.** The true-colour map obtained by combining these three bands is used in this project to make a rough estimate of the land-uses present. This map is then refined by the process of pansharpening, making it into a map with a resolution of 15 square meters.
- **Band 5: near infrared band** reflects green plants because the leaves scatter the wavelength. This band can be compared with other bands to obtain for example the NDVI. In this project, the band is combined with bands 4 and 3 to create a false colour map emphasizing build up area.
- **Band 6 and 7: shortwave infrared bands (SWIR).** These bands can differentiate between wet and dry soil and between different kinds of rocks, which in other bands are often hard to distinguish.
- **Band 8: panchromatic band.** This band has a bigger wave length as seen in Figure 6.1b and because it 'sees' more light at once it can produce the very nice, finer resolution of only 15 meters. Combined with the bands for visible light (a process called pan sharpening), true-colour images with very small resolution are obtained to investigate further details of the land use in this project (see Section 6.1.1.5).
- **Band 9: cirrus band.** This band has a very small range of wavelengths which almost all gets absorbed in the atmospheres as can be seen in Figure 6.1b. The only reflection comes from some particular clouds. These clouds are called cirrus clouds and are high with really soft edges. It is these characteristics that makes it hard to see them on the images of the other bands. However, measurements through these clouds are disturbed and can easily

Band Number	µm	Resolution
1	0.433–0.453	30 m
2	0.450–0.515	30 m
3	0.525–0.600	30 m
4	0.630–0.680	30 m
5	0.845–0.885	30 m
6	1.560–1.660	30 m
7	2.100–2.300	30 m
8	0.500–0.680	15 m
9	1.360–1.390	30 m
10	10.6-11.2	100 m
11	11.5-12.5	100 m

(a) Wavelengths of the Landsat 8 bands



(b) Comparing bands of Landsat 8 (upper) and Landsat 7 (lower)[27]

Figure 6.1

be a couple percent off. This band is therefore used to ensure that the training maps (as explained in 6.1.1.2) made to automate the landscape classification are not 'trained' on areas covered by these clouds.

- **Bands 10 and 11: thermal infrared bands (TIR).** These bands show the temperature of the ground, and will not be used for the land-use classification.

The Landsat images used for the classification were selected with the criteria of low cloud cover, recent in time and in the period closest to September. The period of the year was chosen so that the areal images would, as closely as possible, match the groundtruthing data and so that it would be possible to distinguish between two main agricultural uses of mais and rice.

Since September was still very close to rain-season in Nepal, it appeared to be very difficult to find any Landsat images from August or September with less than 10% cloud cover. In fact, there are not any from June to September dating at least as far back as 2012. When one goes back too far in time, the ground-truthing will be unreliable. This is why was chosen for the option of 7 Oktober 2015, with 0 % cloud cover, and relatively close to the ground period, to make the detailed land-use map used for comparison with the water quality and demand.

6.1.1.2 Supervised classification in QGIS

The landuse map was made using a semi automated approach in QGIS. This approach combines the knowledge and interpretation of the analyzer with the quantitative analysing power of the computer [53]. This has as advantage that the spatial information can be used in a qualitative sense by the interpreter; prior knowledge, visual interpretation and ground observations can be taken into account. For example, the human mind can use its knowledge of characteristics of landuses such as shape, location and contiguity.

The quantitative analysis by the computer can complement these advantages. Firstly, it has as advantage that the computer can work on pixel size for the whole valley, while for the human analyzer this would only be possible if the area under research would consist of just a few pixels. Secondly, it allows to use the full range of information supplied by the Landsat 8 images. Humans can distinguish only a limited number (approximately 16) of brightness values of a pixel, whereas a computer can distinguish all 4096 given by Landsat 8. Not only can it use all brightness values, also all the multi-spectral bands can be used, while this is limited for human interpretation [53].

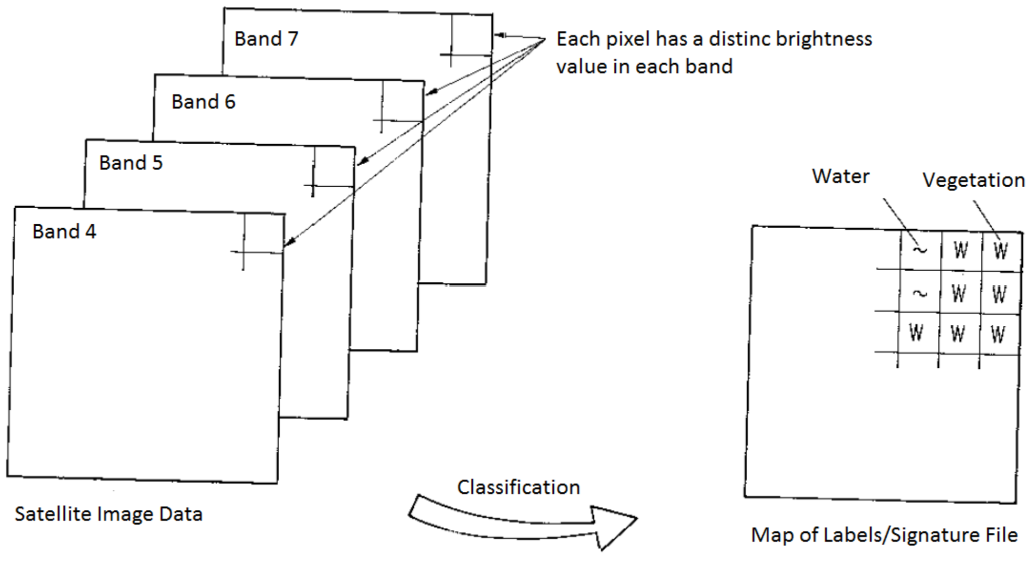


Figure 6.2: The process of supervised classification

The semi automated approach that was used is called supervised classification. The framework of the approach works by assigning a probability distribution to each spectral (landuse) class in the multi-spectral space [53]. The method works by following the next practical steps:

1. Decide on the land use classes in which the Valley should be segmented.
2. Choose pixels that represent the different classes, these form the training data.

3. Use the training data to estimate parameters (often called signatures of the class) that represent the classes.
4. The signatures are used in a probability model to classify every pixel of the area under research.
5. Summaries in tables and thematic (class) maps are made that show the results of the classification.

This process is described in more detailed below. A visual description of the process of assigning signatures is given in Figure 6.2 and of the making of a probability model in 6.3.

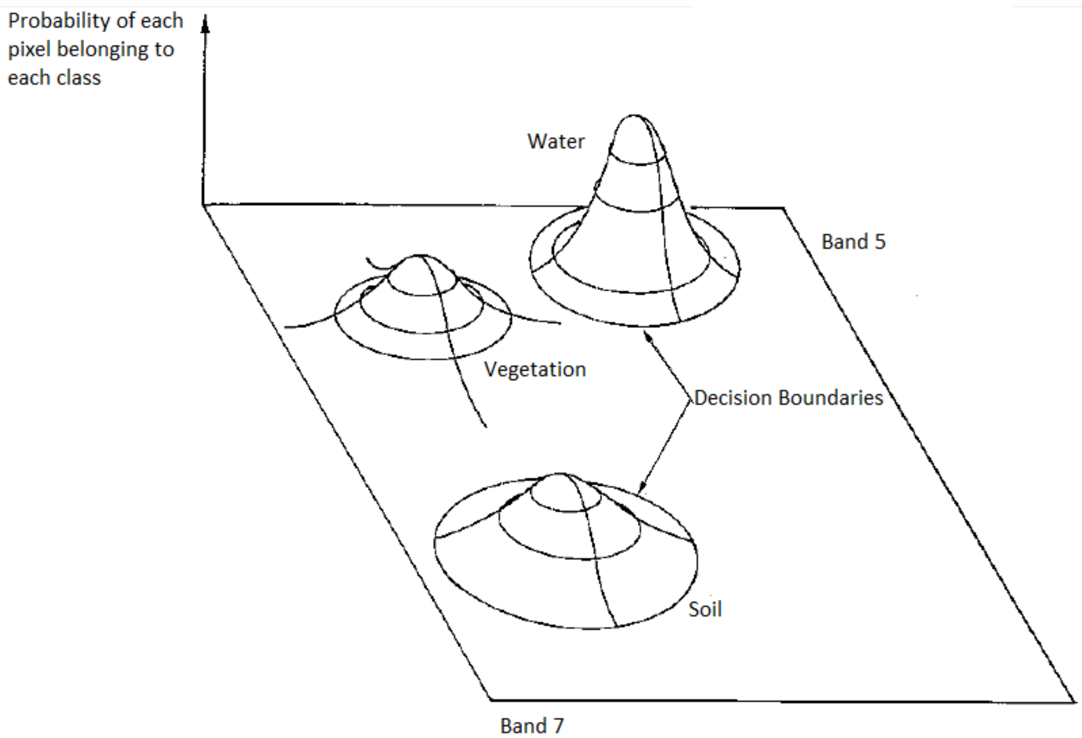


Figure 6.3: Two dimensional multi-spectral space with three spectral classes and probability distribution

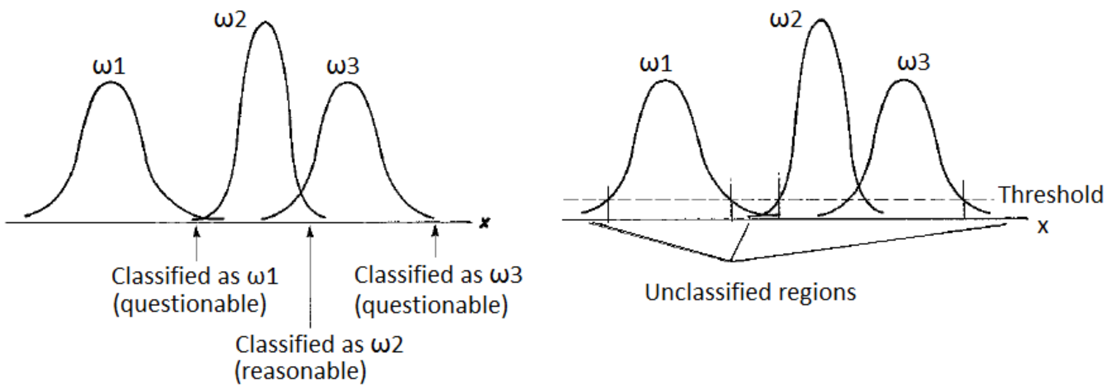
Determining spectral signatures for the classes is done by analyzing the vectors containing the brightness values of the pixels that are pre-assigned to a certain class. The multi-spectral space is formed by the different bands of the Landsat 8 satellite. This means that the probability distribution will be a multi-variable distribution (mostly the Gaussian distribution [53]), with the number of dimensions coinciding with the number of Landsat bands. An example of this process for a two dimensional multi-spectral space (in this case formed by bands 5 and 7) with three spectral classes (water, soil and vegetation) is given in Figure 6.3. The combination of the brightness information of the different bands assigns the probability to belong to a certain class. After this, the determination of all pixels to classes is done using a normal distribution given by the mean vector of these brightness values of all eleven Landsat 8 bands and the covariance matrix [53]. Mathematically, this gives

$$p(x) = \frac{1}{(2\pi)^{N/2}|\Sigma|^{1/2}} e^{-\frac{1}{2}(x-m)\Sigma^{-1}(x-m)}, \tag{6.1}$$

in which x is the vector of brightness values in the N dimensional space of the pixel and m is the mean position of the landuse class (i.e the different brightness values of each band the respective landuse class is most likely to have). The covariance matrix Σ describes the spread of the classes in the pixel space of the (Gaussian) distribution.

Assigning classes to pixels is done by using the spectral signatures for the landuse classes. Once the mean vectors and covariance matrices are calculated for all the different landuse classes, relative likelihoods that a pixel belongs to a certain class can be calculated. The pixel is then assigned to the class in which it has the highest probability. This means that as soon as m and Σ are known for all the spectral classes, the automated classification of any image with any resolution can be done automatically.

The decision boundaries that are shown in Figure 6.3 represent the points at which a pixel has equal chances for both classes. In that sense, these boundaries divide the space into (in the case of this project 11 dimensional) regions that can be linked to the different selected landuse classes. Within these boundaries, it is clear to which class a pixel should be classified. Outside these boundaries, or when the pixel values give a low likelihood to all classes, the classification is uncertain. This method of classification however, assigns an available class to the pixel, irrespective of how small the likelihood of the pixel belonging to that class is. This will give uncertainties in the final results when there are many regions within the multi-spectral space that do not belong to one of the spectral classes. A two dimensional example (when only two bands would be used for determining the spectral classes) of this problem is shown in Figure 6.4a.



(a) Process of assigning class

(b) Threshold for classification

Figure 6.4: The problem when classifying with low probabilities

To minimize this problem, two options are discussed here. The first is using an iterative approach of validation and training to minimize the number of pixels forced to be assigned to a class in which their liklihood is very low. The second option (which could be combined with the first) is to add a threshold to the process. This would discard all the pixels that have a low probability for every class and leave them un-classified, as shown in Figure 6.4b. The combination would of course give the most reliable results. To combine this with the rest of our measurements on flow and watershed analysis it is however not ideal of the surface areas of the watersheds and the landuse in that watershed do not add up. This is why it was chosen here to use extensive training and careful validation to minimize this problem.

Making a trainingsmap In order to find the mean brightness values m and the covariance matrix Σ, some pixels must be assigned beforehand to the desired landuse classes. The pixels that are linked by the interpreter to the landuse classes are called the training set because they 'train' the computer to recognize the spectral characteristics of the different landuse classes. The assigning of the pixels by the analyser is called the supervised learning [53].

To allow for proper training, the minimal number of samples for an N dimensional multi-spectral space is $N + 1$ to allow the calculation of the inverse matrix [53]. Besides technical necessities, it is clear that more training samples will give a better distribution. A practical minimum of $10N$ samples per spectral class is recommended as minimum and a number of $100N$ as highly desirable if possible. When selecting 6 land use classes in combination with the eleven Landsat 8 bands, this gives a number of 660 training polygons as absolute minimum, and number of at least 6600 (pixels) as desired. It is also a great improvement if many different sample sites are used. These all need to be determined and manually drawn by the analyser. The approach to select the trainings set and the number of trainings-polygons made is discussed in Section 6.1.1.5.

6.1.1.3 Iterative approach for classifying and validating

In order to obtain good results, the process described above was repeated five times. After classification, the results were evaluated. First, visual errors were very clear; too much water classified, problems in distinguishing between subclasses due to either too little training data/presence in the Kathmandu valley, or because of doubtful visual assigning of the classes in the training polygons. After the first three classified maps, the landuses were finalised and more training polygons were drawn for the critical classes and validation was done by looking into detail at the map. Comparing it to the validation points and google earth images. The final landuse map of the Valley and the validation of this map are found in sections 6.1.3 and 6.1.4 respectively.

6.1.1.4 Landuse classes selected

The Landuse classes are selected and grouped based on the classification system called NLCD 92 system, introduced by The USGS Land Cover Institute [81]. It is important to use standardized classification systems in order to compare land use maps to other areas, other existing land use maps of the same area, and to be able to aggregate available data. It also makes the produced maps easier to be used for different researches.

Criteria the final selected classes needed to fulfil were;

- Presence and importance in the Kathmandu Valley.
- The final classified map should be able to identify the landuse classes within a 85% accuracy interval. Furthermore, the accuracy of the different land use classes should be approximately equal for the different classes.
- It has to be possible to use the same classification system in previous and future years in the Kathmandu Valley.
- The classes should be chosen in such a way that they are as detailed as possible, and such that they can represent activity in the Valley.
- The classes should be flexible when first defined, such that subclasses can be used for ground-truthing and the option to aggregate different classes remains possible until the final automated classification made after the iterative process of validation and classification.

In order to fulfil the criteria, subclasses were introduced to allow for a wide range of options for the ground-truthing. After a month of fieldwork, a feeling for the dominant landuses was


(a) Developed Low
(b) Developed High
(c) Forest
(d) Shrubland
(e) Rice
(f) Mixed Planted

Figure 6.5: Ground photos of different landuse classes, taken during fieldwork

developed and some of the subclasses were merged together. The classes used for landuse identification during the ground-truthing are shown is shown in Table 6.1. The final selected classes used for the landuse image are shown in Table 6.2. To give an impression of the classes on the ground, for each class a representative photo of the fieldwork measurements is included in Figure 6.5.

Reasons for aggregation and elimination of landuse classes. The main reason for elimination of landuse classes was simply that their presence in the Kathmandu Valley was very limited. This holds for wetland, evergreen forest and mixed forest. Fallow planted and barren land deserve a separate mention here. Their presence was basically non-existent in the (post) monsoon months of September and October, making it impossible to make enough training polygons for the signature map to classify them. However, if one would want to make a landuse map for the period between December and May, this class should be added again.

For the elimination of the water landuse class, the reason was different. Water was the class of which most ground-truthing was done, since most measurements sites were near rivers. Furthermore, water was easy to identify using the many ground data and Google Earth for the location of the water. The problem was in the size of the water bodies. Since the water bodies in Kathmandu are very small except the lower part of the Bagmati river, most pixels of the Landsat 8 contain water as well as land. This gives a signatures for that class with a very large standard

Main classes for ground truthing	Subclasses for ground truthing	Description	Number of field data
Water		Open water or permanent ice/snow cover of at least 75%	36
Developed	Low Density	30%-80% constructed	16
	High Density	80% - 100%	9
	Infrastructure	>30% constructed, without many people residing there, e.g. commercial buildings, roads, factory, etc.	4
Barren		>75% barren soil, e.g natural rocks, brick factories, recently cleared land	5
Forested	Decideous forest	>25% of the land covered by trees, where >75% of the trees is decideous, e.g. loses its leaves during a season.	14
	Evergreen forest	>25% of the land covered by trees, where >75% of the trees is evergreen, e.g. keep there leaves all year round. Typically fine needles.	1
	Mixed Forest	Both evergreen and decideous trees, with a tree cover of >25%	0
Shrubland		Natural vegetation less than 6 meters tall. Shrubs cover >25%	6
Natural Grassland		Grasses cover >75%	6
Planted	Rice	Rice covers up >75%	23
	Corn	>75% is corn agriculture	5
	Grain	>75% is grain agriculture	3
	Fallow	>75% is normally farmed but currently barren	0
	Orchard	>75% orchard vegetation, like apple trees etc.	2
	Recreational grass	>75% covered by planted vegetation, e.g. Parks, golf courses, etc.	2
	Mixed, other	>75% agriculture, but of a mixed type or that does not fit the other catagories, e.g. greenhouses, cabbage, small mixed patches.	7
Wetland		>25% vegetation with periodic water present	2
Total			141

Table 6.1: First selection of classes and subclasses

Class	Description	Ground measurements	Measurements used for validation
Developed Low	30%-80%build up area	17	3
Developed High	80%-100% build up area	13	4
(Deciduous) forest	>25% covered by trees, of which >75% is deciduous	15	5
Shrublands	>75% natural vegetation, with hights of less than 6 m.	14	4
Rice fields	>75% rice fields	23	4
Mixed Planted	>75% is planted agriculture or recreation, with <75% rice fields, e.g. orchards, parks, corn fields and mixed agricultural patches.	19	4
Total		101	24

Table 6.2: Final selection of landuses for classification

deviation because the pixels include part water, but also part of all the other classes since water is present near all these classes. As a result, many pixels containing some combination of the bands are classified as water, which resulted in a heavy overestimation of the amount of water present in the Valley. On the other hand, if only the lower section of the Bagmati was used for training, hardly any water pixels could be used for the training which could lead to a decrease in accuracy of the classified map. Hence, it was chosen to discard the class for water. Water will likely not take up more than a percent of the land use in the Valley, so this was considered to be a reasonable alteration.

The reason for aggregation of the separate subclasses had two main reasons. In the first case they were too hard to distinguish on the aerial information by the interpreter when no ground measurements were there to allow for a definite classification. In the second case the visual classification was possible but the resulting signatures were too similar to ensure a proper distinction during the automated process. For example, it proved impossible to recognize the difference between corn and grains from the aerial images. On the other hand, the difference between natural grass and parks was possible using Google earth, but were mixed up during the automated classification. In the end it was decided to split the planted classification up in rice and mixed planted, resulting in the the six final landuse classes shown in Table 6.2.

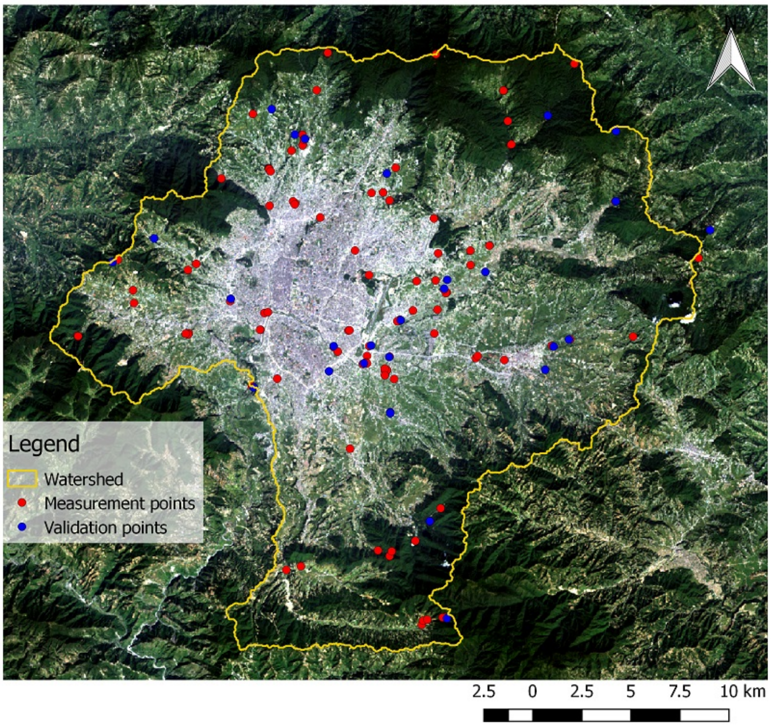


Figure 6.6: Location points of ground measurement points during fieldwork, September 2016

6.1.1.5 Visual inspection of landuse classes

The biggest uncertainty of making a landuse map is in defining the training set. Since all quantitative calculation is based on the selected training pixels, the accuracy of the classification depends strongly on the ability of the analyser to make true and representative trainings polygons [23]. This can be a most difficult task, especially for untrained image interpreters [53]. In order to minimise this uncertainty as best as possible, a 'learning' base for the analyst was set up by making field observations. During the fieldwork, a 141 landuse measurements were taken of the different selected classes. After further inspection and aggregation of some subclasses, 101 usable ground measurements remained. Of these, 77 are used for the training, the other 28 for validation. This includes four groundpoints of subclasses that were eliminated and added for the validation points to see how they are classified after the elimination of their classes.The final selected subclasses and the number groundmeasurements and validation points per class are shown in Table 6.2. The location of the measurement points and the ones used for validation are shown in Figure 6.6.

The ground observations used for the training were not merely used as training polygons. Their main importance was in training the interpreter to recognize the different classes on the different aerial data, since for every class many more trainings polygons needed to be drawn. This training was done by comparing the aerial footage with the found classes of the ground data to be able to recognize their signatures on the aerial images. This was especially useful for learning to recognize the differences between the classes that are rather similar; shrubland and forest, high and low developed urban area and mixed planted and rice. The aerial data used for determining the landclasses was obtained from Google Earth and different combinations of the Landsat 8 bands in the form of true and false colour maps, as can be seen in Table 6.3.

The false colour maps are made because they have the ability to emphasize different characteristics that do not show up on a true-color image by the use of different landsat bands like the thermal band or the near infrared band (used to detect vegetation). Using the visual inspection,

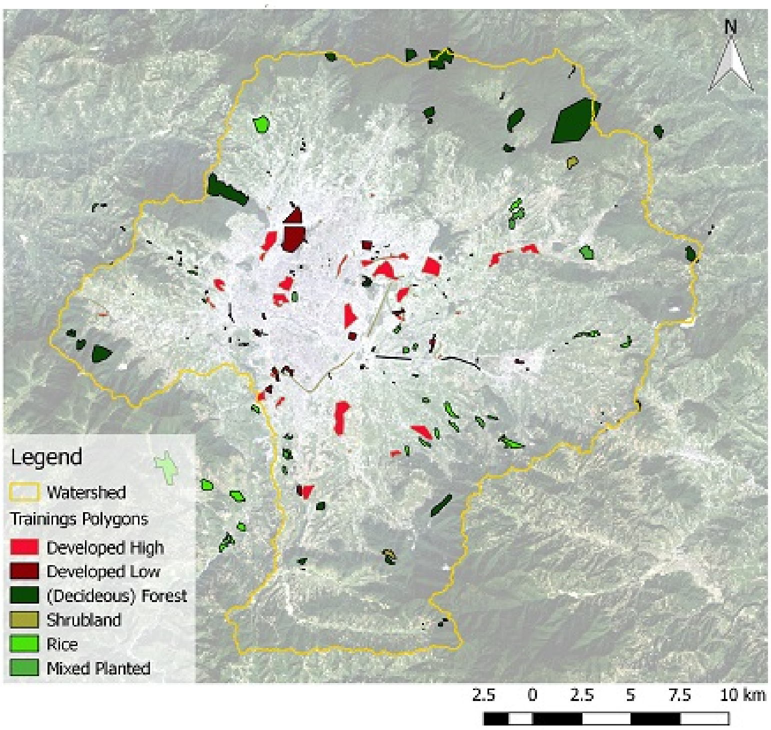


Figure 6.7: Training polygons based on the fieldwork measurments and aerial images

a total number of 305 locations were assigned to a class and used as a training polygon. The locations of these polygons are shown in Figure 6.7. Per class, the number of polygons, average pixel size, standard deviation and total trained area are given in Table 6.4. The area per landuse class is calculated by multiplying the number of pixels per class by the size of the pixel, which for the Landsat 8 is 900 m^2. Note that there are no unclassified pixels since no threshold was

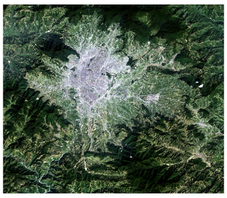
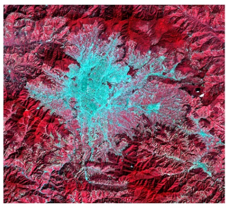
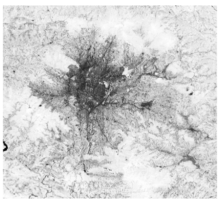
Map visual	Map name	Date	Discription
	Google Earth	30/04/2016	Google earth is a very detailed virtual globe map. The map is a combination of satellite imagery and aerial photography. Many 'ground' photos are available in the map, which are also used to improve the estimations.
	True Color Map	07/10/2015	Combination of the visual bands of Landsat 8 gives a true colour image, giving an intuitive impression
	False Color Map RGB543	07/10/2015	A False colour map emphasizing healthy vegetation, most commonly used to see changes in vegetation. The plants reflect much more near infra-red light (band 5) while absorbing the green, making the vegetation seem red is this picture. The darker red the vegetation, the denser the plant growth. Cities and bare ground show up as grey or blueish and clear water is black. However if the water is muddy or contains other solids, it will show up as blue. Brighter blue will indicate less clear water.
	False Color Map RGB1073	09/10/2015	A false colour map emphasizing differences in vegetation. In the true colour image, all vegetation has a similar olive colour. In this image, the thermal bands helps showing the shrubland as peach coloured, while woodland gives a redder color. Urban area appears as pink.
	Flase Color Map RGB764	10/10/2015	A false color map emphasizing differences in build up area. The denser the build up area, the more of the short wave bands is absorbed, hence the more blue (band 4) it appears in this image.
	NDVI	11/10/2015	A combination of the near-infrared band and the red visual band, emphasizing vegetation growth. This image was readily available for day 280 of 2015, and was left black and white because it appeared easier to recognize different features that way. Build-up area and the difference between agriculture and forestry vegetation can be clearly distinguished here.

Table 6.3: Images assisting the visual classification

used, as explained in 6.1.1.2. The size and variation in the trainingspolygons illustrates the difference per class; forest is rather easy to classify and is bulked into big areas of the same landuse, with an average size of 352 pixels per trainings-polygon. The ground measurements would often indicate a GPS coordinate, with an indicated buffer of the extend of the forest, making it easy to draw big polygons with high certainty. For the agriculture, especially the mixed planted was a very different story. These mixed planted lands usually contain very small patches and are often near light densely populated areas, making it often impossible to draw big

	Polygons	Total Pixels	Average Pixel per Polygon	Stand Dev	Total Area classified (km^2)
Developed Low	93	8713	94	189	7.8
Developed High	58	3251	56	180	2.9
Forest	29	10236	352	735	9.2
Shrubland	10	438	43	78	0.39
Rice	51	3224	63	49	2.90
Mixed Agriculture	64	1646	26	59	1.48
Total	305	28517	93	285	25.67

Table 6.4: Statistics of the trainings polygons

areas containing the same landuse. The total assigned area per class exceeds the desired number of trainingareas imposed by Richards et al. as explained in 6.1.1.2 for all classes and fulfils it for the shrubland classification.

6.1.2 Methodology of Watershed Delineation

During the fieldwork 60 water quality measurements and 83 flow measurements have been performed. In order to link these to the classified landuse map, area statistics of the delineated watersheds of those measuring points are generated. This section explains the methodology for the watershed delineation.

The program used to generate the delineated watersheds is QGIS 2.14.6 with Grass 7.0. QGIS is an open source tool for Geographical Information System (GIS) information. [50] Grass is a plugin for QGIS that is used for its extensive options of raster and vector manipulations.

A grass location is set up in the same coordinate system as the landsat images. This coordinate system is the WGS 84 UTM 45N system. The grass region is bound between the coordinates 3080000°N, 3045000°S, 358000°E and 319000°W. This includes the whole Kathmandu Valley watershed in which we are interested. The base map for the watershed analysis is a Digital Elevation Model (DEM) map. An Shuttle Radar Topography Mission (SRTM) map is used from USGS. The resolution is 30 meters and it is converted to the right coordinate system by saving it within QGIS in the project's system, see Figure 6.8.

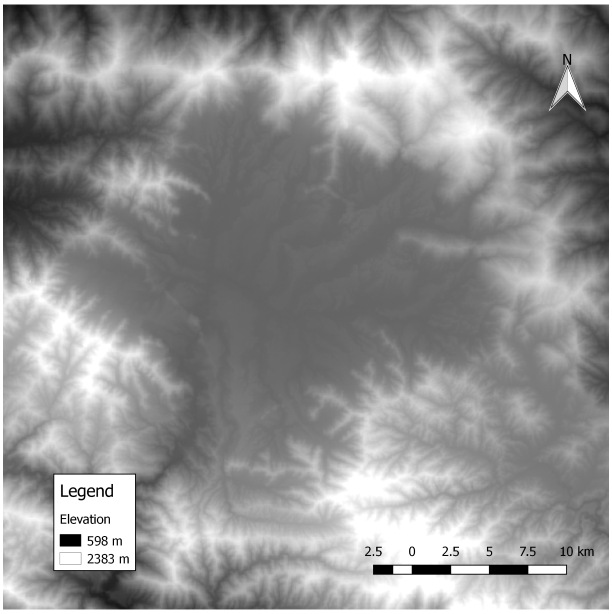
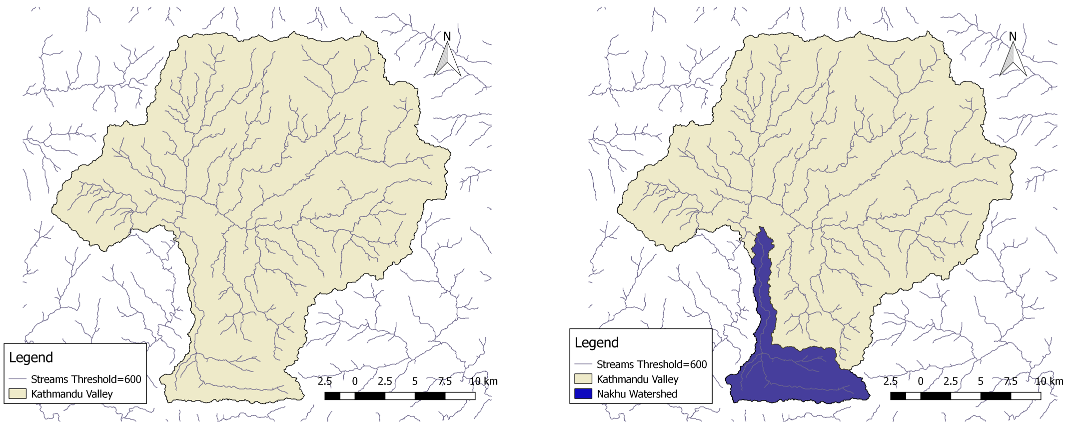


Figure 6.8: DEM from SRTM used for watershed analysis. Resolution is 30 meters

Using the Grass module r.watershed, a Drainage Direction Map is generated. For every rasterpoint this module chooses the rasterpoints with the lowest elevation out of the eight neighbouring rasterpoints and gives it a number accordingly. This allows the same module to create a drainage accumulation map, which, for all rasterpoints, counts the number of points that flow into it. This information is used to generate streams by setting a certain threshold, giving a value of 1 only to the rasterpoints that pass this threshold. By vectorizing this layer (r.to.vect module), a continuous line can be created, representing the streams that are expected from the DEM. The streams with threshold 600 are shown in Figure 6.9a. This threshold is used for in the figures throughout the report as it visually has the right amount of detail. The only further use for the stream vector file is to determine the coordinates in order to find the watersheds as described in the next section.



(a) Streams generated from the DEM (b) Watershed of the Nakhu River

Figure 6.9: Delineation of watersheds. The boundary shows the Kathmandu Valley watershed

The Grass module r.water.outlet uses the drainage direction map to determine all the points that flow into a given coordinate. It creates a new rastermap with value 1 for all these rasterpoints. This rastermap can consequently be vectorized using module r.to.vect which creates a vectormap of the watershed. The watershed of the Nakhu river until it flows into the Bagmati river is given as an example in Figure 6.9

Using the Grass module r.stats with the option 'area', a csv file with statistics from the given rasterfile is created. This module is used to derive the total areas of the different landuse categories from the landuse map. In order to get the statistics from a specific watershed only, a mask is created from the watershed rasterfile, which then masks the raster compilation of the r.stats and gives the landuse statistics only of this watershed.

The above procedure is performed for all the GPS coordinates of the RSA measurements done. As these points lie not exactly on rivers, let alone on the streams generated by Grass, the points are manually moved onto these streams. This in order to include the whole subwatershed instead of only a small side area. For this step, a stream map with threshold 100 is used, as this has a lot more detail than the map with threshold 600 that is used for the illustrations. Writing a python script allows to loop through all the 60 coordinates and consequently store them in one csv file which can later be used for the analysis. This script can be found in 11 and after arranging the data loops through the following Grass commands:

- r.water.outlet; Input=Drainage Direction Map, Output=Watershed Rasterfile.
- r.to.vect; Input=Watershed Rasterfile, Output=Watershed Vectorfile, type=area.
- r.mapcalc; MASK for Watershed Rasterfile=1.
- r.stats; input=Landuse Map, Output=stats csv file, options=area
- r.mask; options=remove

The results generated are sorted using script 11.2 in appendix 11 and will be used for further analysis.

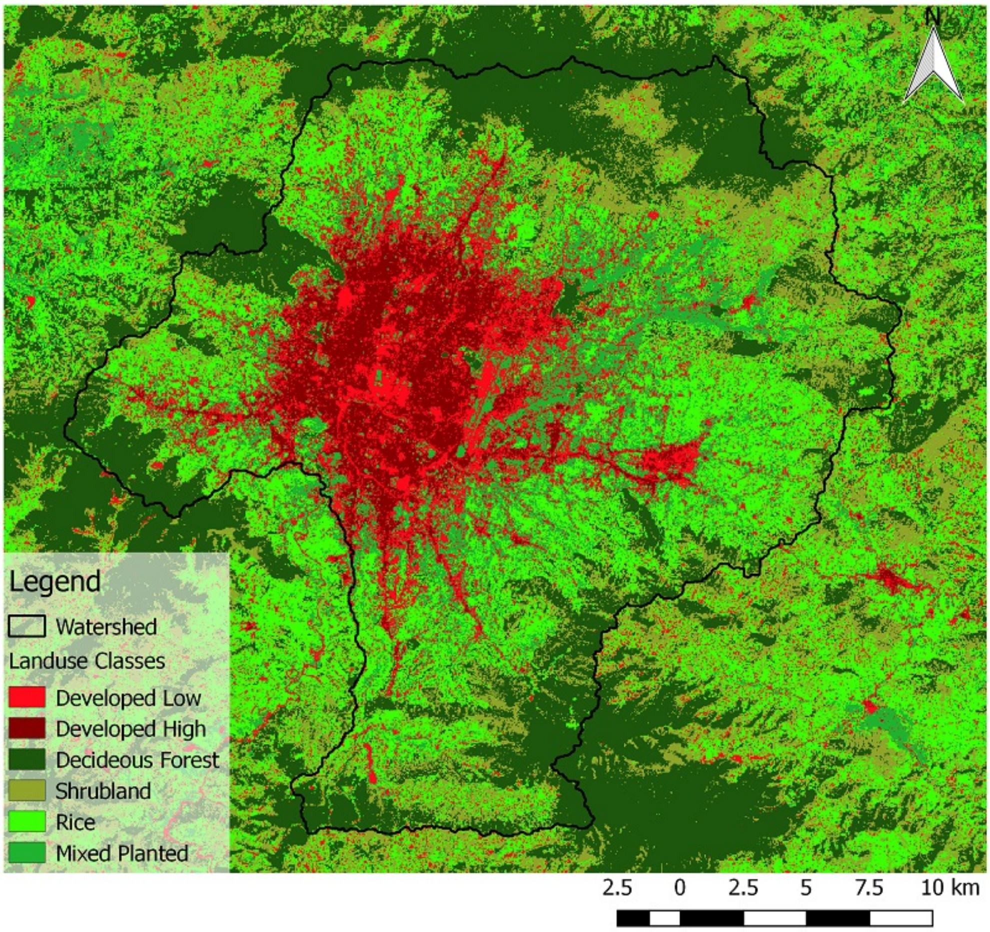


Figure 6.10: Landuse Map classified by the use of remotely sensed data

6.1.3 Results

This section describes the results of the Landuse classification and the statistical analysis of the delinearized subwatersheds.

6.1.3.1 Results of Landuse classification

In figure 6.10 the final Landuse map is shown. As can be seen, the city area is mostly situated in the centre of the Valley, which is in line with what is expected, as this is the flatter part of the Valley. Different areas with deciduous forest can be distinguished in the outer areas of the watershed. Between the developed area and this forest, a clear presence of rice cultivation is found. Having Figure 6.9a in mind, it is clear that the built-up area is developed along the rivers showing the preference of people to live close to a water source.

6.1.3.2 Statistical analysis of the landuse within the subwatersheds.

The distribution of the landuse classes for the whole Kathmandu valley watershed is illustrated in figure 6.11. Of the total area only 26 % is built area, while 33 % is natural vegetation and 41 % is planted area. Almost 60 % of this planted area is rice. All delineated watersheds are illustrated in Figure 6.12. The areas are accumulated meaning that a downstream watershed includes all upstream watersheds. Table 6.5 sums up the total areas of the landuse categories per subwatershed. That the developed area increases towards the centre of the Valley, can be read from table 6.5 as well, as the percentage of developed area increases for the watersheds more downstream. Furthermore it can be seen that in the most upstream watersheds, the landuse consists mainly of deciduous forest.

A particular subwatershed that shows some interesting results is the watershed of the Nakhu river. This river is formed in between two close ridges, which makes that the watershed is very narrow for a long stretch. This makes that the percentage of the developed area stays relatively low.

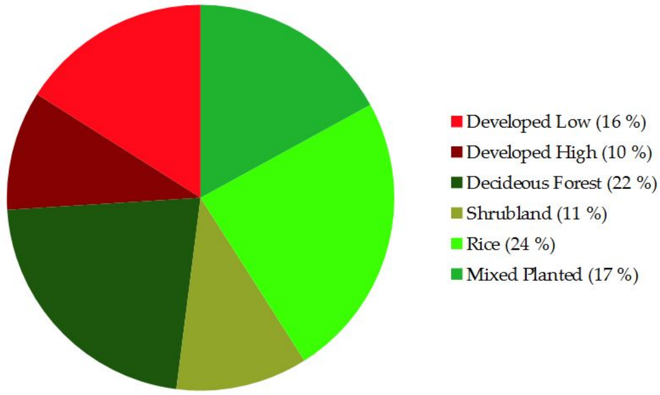
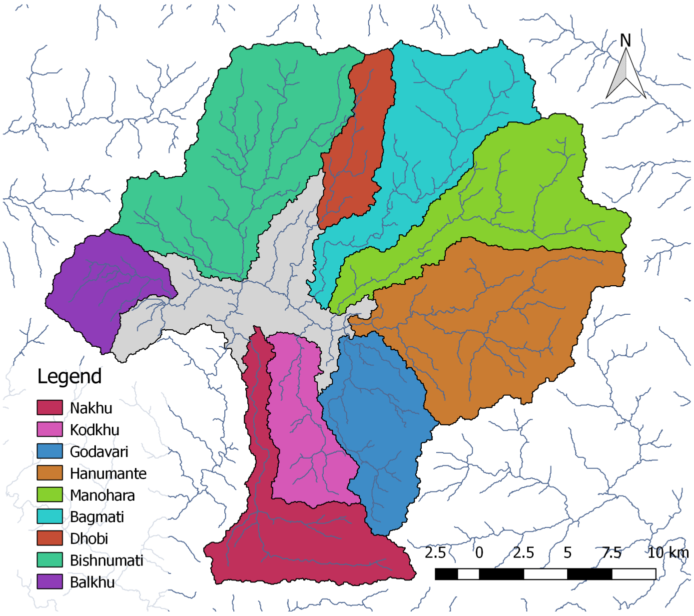


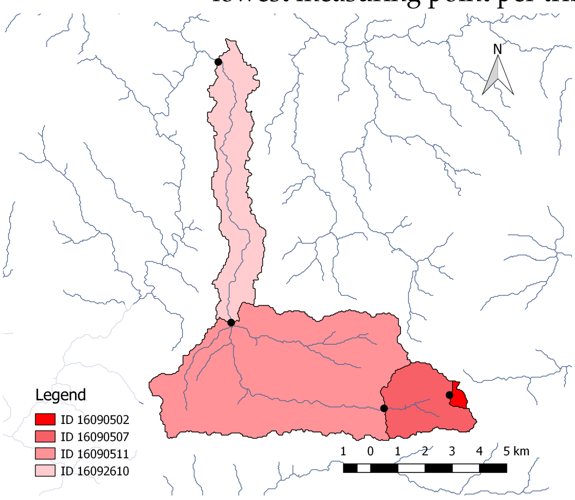
Figure 6.11: Distribution of the different landuse classes over the complete Kathmandu Valley

Watershed	siteID	DevLow		DevHigh		(Dec)Forest		Shrubland		Rice		MixPlanted		Total
Nakhu	16090502	0	(0%)	0	(0%)	408	(98%)	6	(1%)	3	(1%)	0	(0%)	417
	16090507	310	(5%)	0	(0%)	3610	(53%)	1202	(18%)	1388	(21%)	250	(4%)	6760
	16090511	2827	(7%)	3	(0%)	16068	(43%)	9162	(21%)	11208	(24%)	2706	(5%)	27120
	16092610	5446	(10%)	1803	(3%)	16826	(31%)	9540	(17%)	15386	(28%)	5882	(11%)	54883
	16090512	5446	(10%)	1803	(3%)	16826	(31%)	9540	(17%)	15386	(28%)	5882	(11%)	54883
Kodkhu	16091406	82	(3%)	0	(0%)	986	(34%)	982	(34%)	724	(25%)	129	(4%)	2903
	16082702	2776	(13%)	155	(1%)	3597	(17%)	2617	(13%)	7705	(37%)	3909	(19%)	20760
	16082703	4167	(17%)	492	(2%)	3670	(15%)	2627	(11%)	8044	(33%)	5417	(22%)	24416
	16093001	7962	(24%)	2235	(7%)	3681	(11%)	2628	(8%)	8639	(26%)	7647	(23%)	32792
Hanumante	16091619	145	(2%)	0	(0%)	3453	(52%)	2190	(33%)	802	(12%)	99	(1%)	6688
	16091614	4118	(17%)	823	(3%)	4851	(20%)	1858	(8%)	8685	(36%)	3471	(15%)	23806
	16091610	5489	(10%)	1120	(2%)	9312	(17%)	6881	(13%)	22120	(41%)	9036	(17%)	53958
	16091603	12366	(13%)	2872	(3%)	12232	(13%)	8888	(9%)	37870	(40%)	20455	(22%)	94683
Godavari	16091502	0	(0%)	8	(0%)	3809	(91%)	280	(7%)	102	(2%)	2	(0%)	4200
	16091503	8	(0%)	0	(0%)	1298	(82%)	251	(16%)	20	(1%)	0	(0%)	1577
	16082701	8	(0%)	0	(0%)	1748	(79%)	397	(18%)	46	(2%)	26	(1%)	2225
	16091505	724	(4%)	53	(0%)	11743	(58%)	2798	(14%)	3480	(17%)	1412	(7%)	20212
	16091506	2196	(6%)	175	(0%)	15785	(44%)	4450	(12%)	8717	(24%)	4711	(13%)	36033
	16091605	3523	(8%)	260	(1%)	16302	(35%)	4707	(10%)	12956	(28%)	8497	(18%)	46246
Manohara	16091706	422	(4%)	0	(0%)	2642	(25%)	4618	(44%)	2479	(24%)	237	(2%)	10398
	16091709	4538	(8%)	88	(0%)	10261	(18%)	16012	(28%)	14775	(26%)	11465	(20%)	57138
	16092704	6025	(10%)	126	(0%)	10409	(16%)	16175	(26%)	15622	(25%)	14983	(24%)	63339
	16092716	7802	(11%)	569	(1%)	10515	(15%)	16191	(24%)	15852	(23%)	17444	(26%)	68373
	16091601	9963	(14%)	1178	(2%)	10524	(14%)	16191	(22%)	15920	(22%)	19077	(26%)	72853
Bagmati	16090905	3	(2%)	0	(0%)	198	(98%)	2	(1%)	0	(0%)	0	(0%)	202
	16091002	0	(0%)	0	(0%)	243	(78%)	67	(21%)	3	(1%)	0	(0%)	313
	16091004	0	(0%)	0	(0%)	8631	(94%)	504	(5%)	27	(0%)	6	(0%)	9168
	16091005	29	(0%)	0	(0%)	11762	(92%)	1030	(8%)	157	(0%)	9	(0%)	12987
	16090901	67	(3%)	0	(0%)	1627	(62%)	819	(31%)	85	(3%)	6	(0%)	2604
	16091101	291	(2%)	0	(0%)	8398	(60%)	4387	(31%)	931	(7%)	24	(0%)	14032
	16090801	330	(2%)	0	(0%)	8951	(56%)	5341	(34%)	1193	(8%)	44	(0%)	15860
	16093004	627	(2%)	0	(0%)	24470	(69%)	8255	(23%)	1878	(5%)	268	(1%)	35498
	16092905	3483	(6%)	61	(0%)	26755	(48%)	12395	(22%)	6795	(12%)	6233	(11%)	55722
	16092903	8820	(13%)	2471	(4%)	27816	(42%)	12506	(19%)	7102	(11%)	8245	(12%)	66960
	160924	10839	(15%)	4979	(7%)	28072	(39%)	12509	(17%)	7161	(10%)	8713	(12%)	72273
	16091302	221	(11%)	0	(0%)	440	(21%)	476	(23%)	886	(42%)	68	(3%)	2091
	16091303	65	(17%)	0	(0%)	5	(1%)	21	(6%)	250	(66%)	38	(10%)	379
	16091304	1041	(10%)	0	(0%)	3327	(33%)	1397	(14%)	3559	(36%)	628	(6%)	9952
	16092604	2188	(16%)	638	(5%)	3470	(25%)	1514	(11%)	4307	(31%)	1710	(12%)	13827
Dhobi	16092103	0	(0%)	0	(0%)	3610	(99%)	30	(1%)	9	(0%)	6	(0%)	3655
	16092401	831	(8%)	79	(1%)	6577	(62%)	994	(9%)	1321	(13%)	744	(7%)	10546
	16092504	1870	(12%)	102	(1%)	7154	(45%)	1656	(11%)	3183	(20%)	1799	(11%)	15764
	16092508	5255	(21%)	3234	(13%)	7219	(29%)	1721	(7%)	3870	(16%)	3502	(14%)	24800
Bishnumati	16091904	0	(0%)	0	(0%)	164	(96%)	8	(4%)	0	(0%)	0	(0%)	172
	16091903	304	(4%)	0	(0%)	4217	(58%)	1090	(15%)	1566	(21%)	125	(2%)	7301
	16092804	785	(7%)	3	(0%)	5131	(43%)	1505	(13%)	3873	(32%)	677	(6%)	11975
	16092811	5700	(17%)	1838	(5%)	10570	(31%)	2928	(8%)	8812	(26%)	4620	(13%)	34469
	16092606	18453	(18%)	16089	(16%)	24036	(24%)	6994	(7%)	23378	(23%)	11853	(12%)	100803
	16091901	50	(4%)	0	(0%)	519	(44%)	341	(29%)	256	(22%)	12	(1%)	1178
	16091902	1328	(24%)	43	(1%)	377	(7%)	373	(7%)	2232	(41%)	1123	(21%)	5477
	16092406	1041	(11%)	8	(0%)	2450	(26%)	1304	(14%)	3981	(42%)	781	(8%)	9564
	16092413	4118	(17%)	823	(3%)	4851	(20%)	1858	(8%)	8685	(36%)	3471	(15%)	23806
	16091614	4118	(17%)	823	(3%)	4851	(20%)	1858	(8%)	8685	(36%)	3471	(15%)	23806
	16092606	18453	(18%)	16089	(16%)	24036	(24%)	6994	(7%)	23378	(23%)	11853	(12%)	100803
Balkhu	16090708	484	(10%)	33	(1%)	1293	(26%)	835	(17%)	1787	(36%)	566	(11%)	4999
	16090706	1414	(12%)	195	(2%)	4719	(39%)	1188	(10%)	3220	(26%)	1424	(12%)	12160
	16092601	4080	(15%)	733	(3%)	9277	(33%)	2328	(8%)	7698	(28%)	3864	(14%)	27980
Complete	16092901	96084	(16%)	56425	(10%)	130877	(22%)	65911	(11%)	138609	(24%)	99074	(17%)	586980

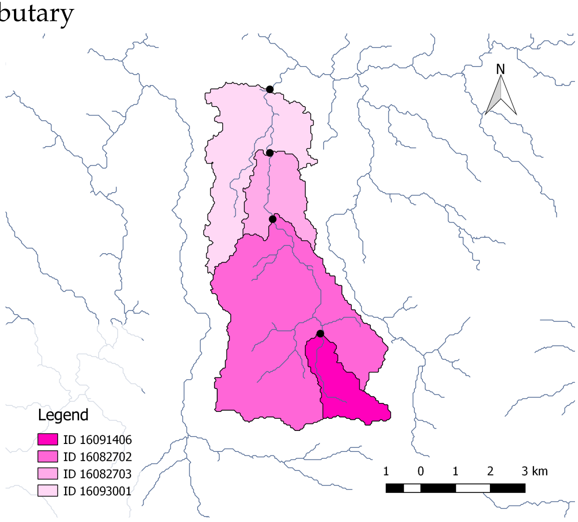
Table 6.5: Total area's of the different landuse categories per subwatershed in $10^3\ m^2$



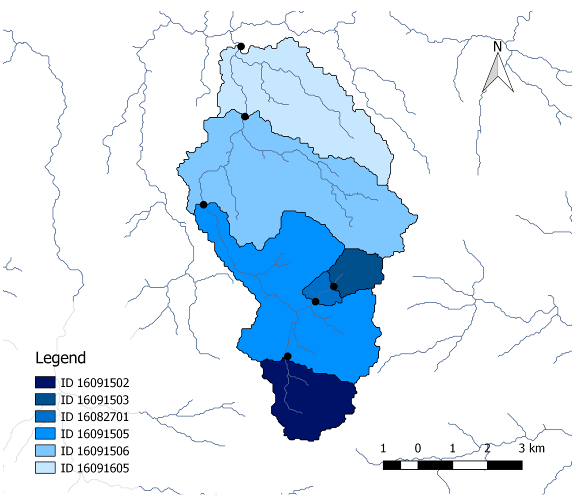
(a) The subwatersheds as determined by delineation of the lowest measuring point per tributary



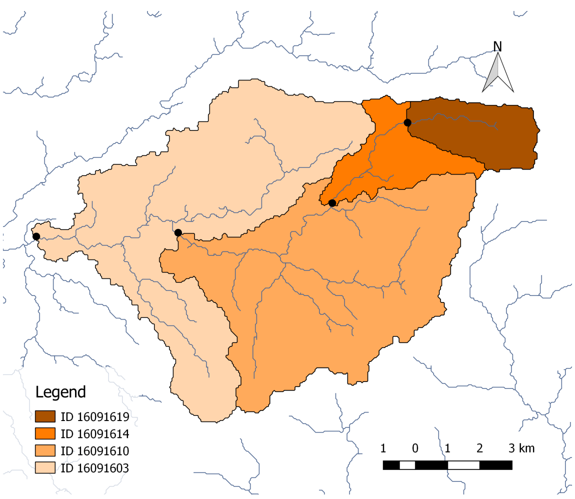
(b) Nakhu



(c) Kodkhu

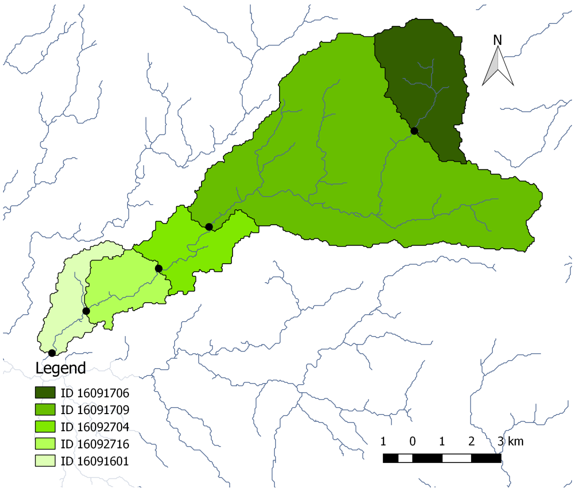


(d) Godavari

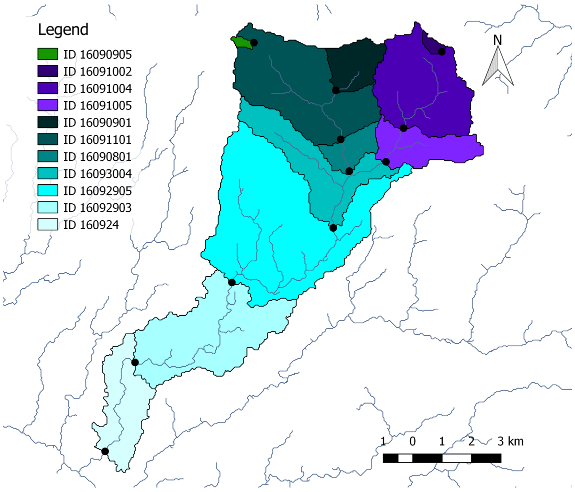


(e) Hanumante

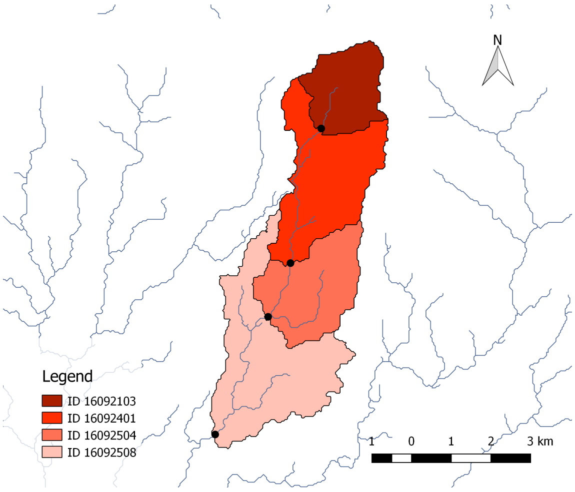
Figure 6.12: The different subwatersheds in which the measuring points are illustrated by the black dots



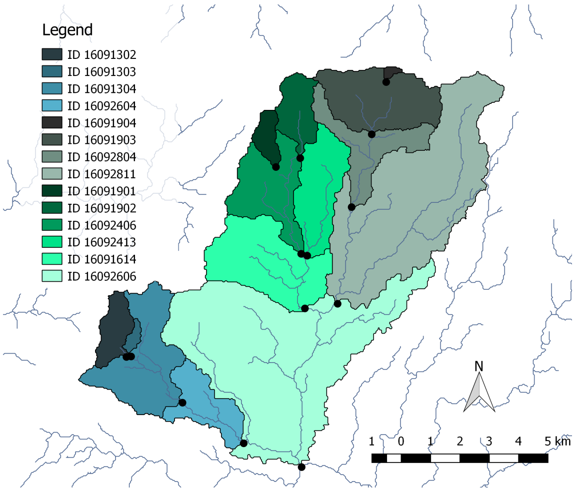
(f) Manuhara



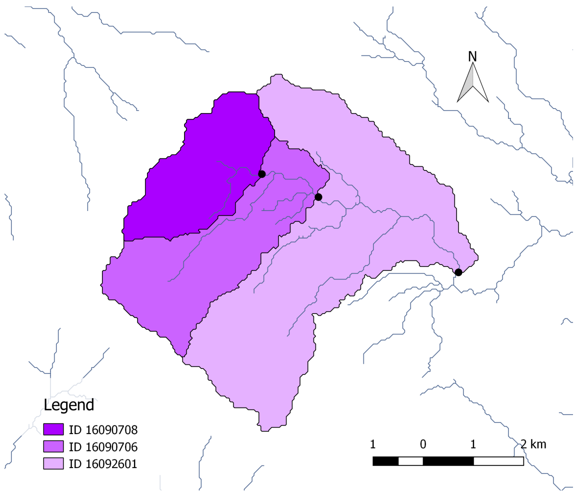
(g) Bagmati



(h) Dhobi



(i) Bishnumati



(j) Balkhu

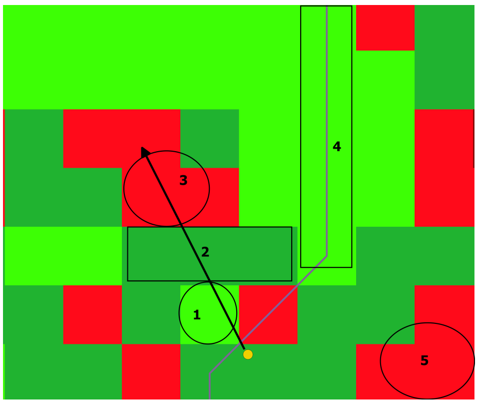
Figure 6.12: The different subwatersheds in which the measuring points are illustrated by the black dots

6.1.4 Validation

Validation of the classified landuse map is done in three ways. Firstly, 28 validation points from the fieldwork were compared to the classified map. Secondly, detailed parts of the landuse map are compared to google earth. Thirdly, the map is compared to landuse results from other sources.

6.1.4.1 Validation using groundtruthing

The ground data obtained by the fieldwork include for every measurement a GPS location, photos and a description of the landuse and the surroundings that can be seen. When possible, a buffer is indicated giving an impression of the extend of the observed landuse. An example of such a measurement is given in Figure 6.13b and Table 6.6. In order to compare the validation points to the classified map, snapshots of the landuse map were made and analyzed. This was not a simple True or False validation, looking merely at the class given by the ground measurement and comparing it to the pixel class at that GPS location. The image was interpreted with and compared to the photos and comments of the landuse measurement. Quite some times, the classes at the corresponding pixel did not match while the 'wider' classified image showed that the classification actually was done right. A reason for this phenomenon is that the GPS recording is often done at the edge of the landuse. For example in the case of a rice field measurement: instead of walking into the rice field, the location point is taken from the edge, often a road and hence classified as low developed. Having the locationpoint at the edge of the landuse mainly happened for the landuse classes consisting of smaller areas; Rice, Mixed Planted and Shrubland. Forest is a class that is often very homogeneous and has this problem very little. Another reason not compare only the one-pixel at the measurment location, is that the GPS measurements are too inaccurate. The precision of the point measurements using smart phones ranges between the 3 and 20 meters, which could cause the actual landuse to be in a different pixel even though the measurement was taken at the right point. All together, if a 1 pixel analysis would be applied the validated accuracy of the landuse map would give an unfair (low) impression.



(a) Validation point on the Classified map

(b) Ground image at validation point

Figure 6.13: Comparing validation point 16091507 with the classified map. The arrow indicates the direction in which the photo was taken. The numbered polygons are used to compare the images in the text.

To illustrate the validation, the validation of a random ground measurement point is explained. The randomly chosen validation point is shown in Figure 6.13a and is classified (at pixel-

Classified as Rice. Exact pixel value: Mix Planted. Comments written with the measurement are:
'We can see rice but also other plants. In the back as far as can be seen tomato plats with a roofstructure (greenhouse-like).'
'Boundary is the river on the right hand side (looking downstream), the road on the left. The rest of the boundary is houses. '
'Closest village: Lubhu. Buffer: Along the river rice fields continue for at least 500 meter.'

Table 6.6: Comments during fieldwork at ID 16091507

level) as Mixed Agriculture by the automated classification and as Rice by the groundtruthing. When we look at the comments and the photo of the landuse measurement (Figure 6.13b and Table 6.6), we read that the measurement was taken from the road right next to a stream. This resulted in a measurement location on the edge between Low developed, Rice and Mixed Planted. When the line of sight from the photo (given by the arrow) is followed, we see that the classification corresponds to the photo: Location 1 (indicated by the cirlce with a 1 in Figure 6.13a) shows the rice field as shown in the photo. Location 2 shows Mixed Planted, a class that also includes greenhouses, corresponding to the photo as well. Behind the greenhouses we see houses, corresponding to the Low Developed shown in 6.13a. The rest of the comments of the ground measurement can also be found within the classified map: One can see that the ricefields indeed extend along the river at location 4 and that houses indeed form a boundary at location 5. This method of validation for every point is summarized in Table 6.7.

Of the 28 validation points, only three were classified wrongly and one unknown. This is of course too small a test group to draw any statistics on, but the general outlook is very good with a percentage of good classified landuse of 88 %.

The three wronly classified validation points could not distinguish between Shrubland and Mixed Planted, Rice and Mixed Planted and Developed High and Developed Low. Little can be concluded from this number of mistakes. However, since Mixed Planted is a very broad class it seems logical pixels witch does not show the perfect signature of the rice or shrubland class will be classified as Mixed Planted. This might increase the area of this class significantly. The problem appears to be be small enough to obtain the desired accuracy of 85 % as explained in 6.1.1.4 so the distinction between the classes should be kept.

The difference between High Developed and Low Developed is hard to validate using ground data. By the method of classification used, the class is solely determined on the signatures of that pixel. This causes that there is no homogenous classified area of High Developed; as soon as there is a grass field next to a house, or a small agricultural land that is found throughout the city, the pixel is classified as Low Developed. This is not necessarily a problem but can raise some questions when looking at the landuse map or when comparing the classified map to the ground data. Note here that Developed Low is defined as built up area taking up 30-80 % of the landuse. This is therefore still easily found in the city center of Kathmandu. Most roads are also classified as Developed Low. When doing ground validation, the groundtruthing is made based on the general view of the city or the village; Not the fact that you are standing next to a river, or a small unpaved area. Looking at Google Earth images, the general distinction between Developed High and Developed Low seems to be good. Even though distinction between these two classes can be difficult, it seems unnecessary to aggregate the two classes.

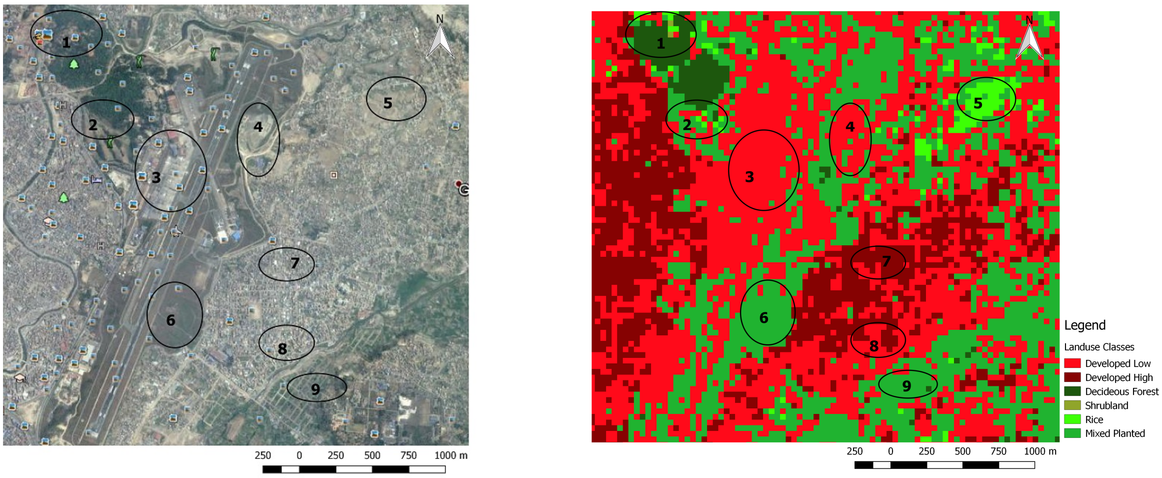
6.1.4.2 Comparing the Landusemap with Google Earth

A second source used for validation was comparing a detailed area of the Valley in Google Earth to the classified map. Google Earth uses a combination of many satellite images in

Measurement ID	Class assigned at Fieldwork	Classified by Landuse map	Right?	Right after consideration	Comments during validation
16092404	Dev High	Dev Low	No	Yes	Using Google Earth, it does seem Low Developed because there are many gardens behind the houses. This can be hard to estimate standing on the road at the front of the houses.
16091507	Rice	Rice	Yes	Yes	Fieldwork comments of surrounding are also perfectly visible
16090501	Forest	Forest	Yes	Yes	
16092703	Rice	Mix Planted	No	No	Some Rice, but mainly classified as Mixed Planted.
16092706	Mix Planted	Mix Planted	Yes	Yes	
16091603	Water	Dev High	Impossible	Yes	According to fieldwork comments and photos, the river is surrounded by garbadge and 3 to 4 story buildings and an asfalt road. Since water is not an option for classification, Dev High is the proper classification
16091302	Dev Low	Dev Low	Yes	Yes	
16092715	Shrubland	Dev Low	No	Yes	The fieldwork comments say this was a 'small patch of grass in the village of 30 by 30 m'. This can easily be classified as LowDeveloped when the pixels contain part of the surrounding houses. This is considered correct.
16091613	Rice	Rice	Yes	Yes	
16092719	Barren	Planted Mix	Impossible	Yes	The fielwork comments said that it is a 'not natural barren/grassy field for sports'. Since Barren is a non existend class, this should indeed be classified as Mixed Planted, which includes planted fields.
16090709	Forest	Forest	Yes	Yes	The comments say 'Light coniferous forest/Shrubs'. In the landuse map we see that the GPS location indeed lies at the edge between forest and shrubs.
16091618	Water	Rice	Impossible	Unknown	Comments and photos are too unclear to determine the dominant surroundings of the water.
16092605	Dev High	Dev High	Yes	Yes	
16091701	Shrubland	Shrubland	Yes	Yes	
16091703	Forest	Forest	Yes	Yes	Big buffer given in the fieldwork comments can be seen in the landuse map
16092902	Shrubland	Mix Planted	No	Yes	The location on the Landuse map is classified as Planted Mix instead of shrubs. In the landuse map, the pixel is close to shrubs, some Forest and some Dev Low. The landuse picture also indicates a similar variability in the classes, so the classification is correct
16091005	Forest	Forest	Yes	Yes	Big buffer of 500 meters given in the fieldwork comments. The GPSpoint is indeed widely surrounded by forest in the Landusemap
16091709	Water	Mix Planted	Impossible	Yes	The fieldwork comments say the following: 'Beautiful unknown white plants at River bed. Some mais and grass as well'. This implies Mixed Planted would indeed be the best possible classification for the 'Water' ground measurement.
16092503	Shrubland	Mix Planted	No	No	Comments of thefieldwork state: 'Mostly shrubland, single trees in between' , which should indicate real shrubland and not Mix Planted.
16092802	Mix Planted	Mix Planted	Yes	Yes	
16091202	Dev Low	Dev Low	Yes	Yes	
16091902	Dev Low	Dev Low	Yes	Yes	Very clear classification, corresponding with the allround buffer of 60 meter given in the ground data.
16093003	Dev High	Dev Low	No	Yes	The Low Developed classiefied at the GPS is surrounded by High Developed land. Google earth shows a patch of grass near the location point, making the classification Dev Low, but the landuse map shows the right general visual of Dev High. Therfore the classification is considered correct.
16091506	Dev Low	Dev Low	Yes	Yes	
16092805	Mix Planted	Mix Planted	Yes	Yes	
16091708	Rice	Rice	Yes	Yes	
16091617	Mix Planted	Mix Planted	Yes	Yes	Very clear, only Mixed Planted surrounding the GPS-point, as indicated by the fieldwork comments.
16091602	Dev High	Dev Low	No	No	Showing on the photos and comments of the fieldwork, this was a slum-like village. Densly populated, but streets of soil and no concrete present, probably the cause for the classificaiton of Low Developed.

Table 6.7: Results of validation using the fieldwork measurements

combination with aerial photographs and is considered a very accurate source. When comparing a recognizable part of the Kathmandu valley, the good accuracy also found in the validation with the ground data was confirmed again. As example, the area surrounding the airport was chosen because this has many recognizable features. The google earth image and landuse map are zoomed in on the same part are displayed in Figure 6.14. At first sight, the main features are clear; the runway is visible and rightly classified as Developed Low. A forest appears in the left upper corner, even the road intersecting it can be found in the picture. The green areas around the runway and at the lower right corner also follow the same outline. The water that is visible in the Google Earth image is mainly classified as its surroundings; Low Developed in the city and Mixed Agriculture when the surroundings are non-urban. Roads are mainly classified as Developed Low.



(a) Google Earth

(b) Landuse map

Figure 6.14: Comparing Google Earth and the Landuse map of the area around the Kathmandu Airport

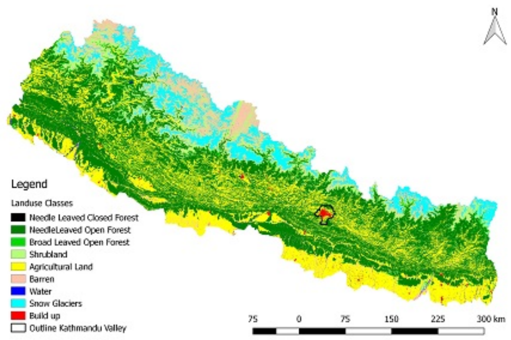
In order to really visualize what is classified, some locations are marked and discussed in more detail in Table6.8. The location 1 to 9 are selected because they display the most interesting/surprising features. Even though the comparisson was done critically, the results were very convincing and the general conclusion is that the classification shows the true signatures of the image. The same holds for other visually compared parts of the Kathmandu Valley compared to Google Earth.

Detailed Aerial photo	Number	Succesful Classification?	Comparisson with the Landuse map
	1	Yes	The classified map shows a mixture with mainly forest, some urban area and some general planted and a very small part of rice. This coincides with the picture for the largest part. The small houses within the forest are nicely shown, as well as the urban area around the edges. The Mixed Planted is present, the small rice that is classified is actually park ground and should have been Mixed Planted.
	2	Yes	The classified map shows a mixture of urban, forest, rice and mixed agricultue. Urban in the lower left corner and some in the middle. Forest in the right corner. The mixed agriculture that is seen indeed corresponds with the Golf course that is situated there.
	3	Yes	The main landuse class given by the classified map is low developed urban area. As can be seen, this corresponds with the stationing of the airplanes and the airport itself.
	4	Yes	The little area of low developed shown in the Landuse map at 4 corresponds to another depot of the airport. This little houses and paved surfaces are indeed surrounded by grassland, as also shown in the Landuse map.
	5	Yes	The bright green corner given at 5 corresponds to a mixture of some houses and mainly ricefields as can be seen in the picture. As can be seen by the colour change in the agriculture in the right of the pixture, there is some mixed agriculture. This is also classified in the Landuse map
	6	Yes	The park surrounding the runway at 6 is clearly visible in the Landuse map as well, starting the developed area at the same point.
	7	Yes	The difference in High and Low Developed area is hard to recognize from the google earth photo with the scale of Figure 6.14a and it seems as if everything should be high developed. However, the detailed photos show that there is indeed a difference between the development in 7 and 8, and that it is classified correctly.
	8	Yes	Looking more in detail, we indeed that in the lower left corner of 7 is Low Developed, corresponding to some agriculture and more green in between the houses in the picture. For 8 holds the same, the left upper corner has some High Developed, corresponding to the more densely packed housing in the picture.
	9	Yes	The Planted Mixed that is classified hier is very clearly reflected in the picture. One pixel is classified as forest, which could have to do with the trees that are sparsely present in the picture.

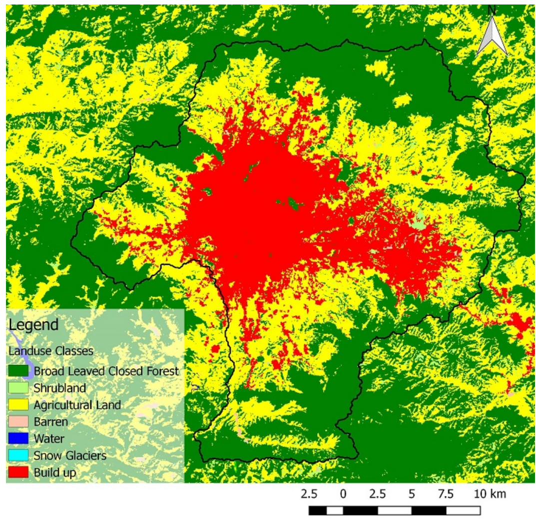
Table 6.8: Comparing the classified map in detail with the Google Earth image.

6.1.4.3 Validation using historical landuse classification results

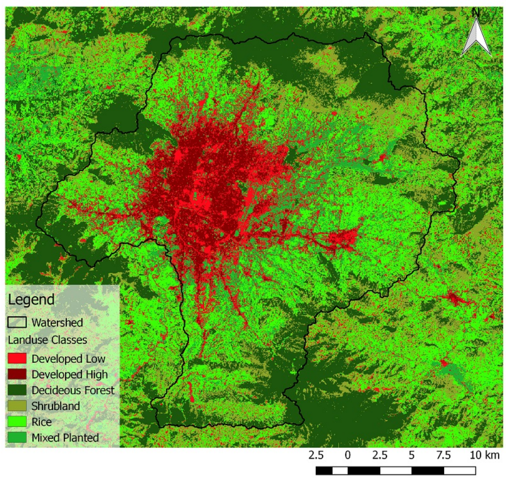
Another way the classified map was validated was by comparing it to historical landuse maps of the Valley. The research of Uddin [75] was used for the comparison. The complete and a detailed image of the produced map of the landuse are shown in Figure 6.15 together with the produced landuse map of this project for comparisson. This landuse analysis was done for the whole country of Nepal, instead of the Kathamandu Valley and more clases were used. Unfortunatly, no statsitics of the Kathmandu Valley itself are available from this map since the focus of the research was only of Nepal. Visual inspection does give a similar image as the one created in this project. A first thing to notice is that the assumptions of eliminating the classes of water and barren land are in agreement with this map, since they are difficult to find at all in the detail of Kathmandu Valley showed in Figure 6.15b. Of the 9 classes used in the research by Uddin at all. only three are dominantly present in the Kathmandu Valley: forest, agricultural land and rice; corresponding to the findings in this project.



(a) Complete map



(b) Detail of the Kathmandu Valley



(c) Landuse map created in this project

Figure 6.15: Land use map of 2010 [75]

The forested areas are smaller in the landuse map made by this project, mostly replaced with agricultural land. The forest does follow the same outline and a decrease in forest can be explained by deforestation that is likely to have occured in the last six years.The agricultural landuse in both maps is very similar and gives an encouraging notion of the correctness of the landuse maps.

The build up area also follows the same outline, but extends further to the east in Figure 6.15b. This difference is not likely because the city will have not decreased in size over the last six years. For the image of Uddin et al. Landsat TM satellite images with a resulutoin of 30 meters were used, coinciding with the resolution of this projects map. This indicates that it is not the lack in spatial resolutoin causing the additional build up area. The difference is most likely caused by the methodology used for classification. Uddin et al. use a GEOBIA classification technique, which is based on machine-interpretation by spectral, spatial, contextual and hierarchical properties [75]. This method is not pixel-based but uses segmentation of satellite images instead. The landuse map produced in this project determines the classes really per pixel, while the GEOBIA method groups the classificaiton in broader parts. This gives a possible explanation for the difference in classificaiton since the developed area is also present in this corner in this projects' map, but only more mixed with agricultural lan. Overall, the comparison with the landuse map of Uddin et al. shows good results.

6.1.5 Discussion

A general discussion about possible uncertainties or options that could have been implemented to obtain better landuse results is given here.

The chosen landuses The landuses were aggregated in such a way that it is known that some available classes in the Valley are not represented. This includes water and barren land, whose percentage of the area is very small and therefore will not have an big influence on the classification. Barren land is not much present in the Kathmandu Valley but should definitely be added to the classification if done for a different season. The aggregation of the other subclasses into a bigger class was necessary since not enough validation data or training data were available for a preciser classification. However, this would be possible for some of the classes if there is more time to do groundtruthing and validation. The classes that could still be implemented as subclasses are the classes that are present enough. These include corn, greenhouses and fallow for the planted class. Natural grassland could be combined with parks as a new class. Furthermore, an additional subclass for Developed could be added, in order to distinguish between medium developed and low developed. The classified map shows a big percentage of low developed, but since this class is defined from 30% to 80% build up area, this consists of most of the build up area, where the low developed area changes from really villages, to buildup areas in the center of Kathmandu with relatively many gardens. When looking at trends between water quality and developed land, or when trying to estimate an urban water demand, it would be better to have these classes more precise.

Chosen method for classification Another part for discussion is the method used for the classification. The supervised classification is the method used here. There are many methods available, some complementing to this method, others following a complete different approach. Some methods exclude the use of parameters and distributions, called non-parametric methods, and have their own set of advantages. These methods are discussed in [46]. Some methods do not use pixel based classification but let the computer segment the data into landuse classes. This was done in the landuse map made by Uddin et al.[75], and gives a different kind of map as result where the landuses are grouped together more. The reason the supervised classification method was chosen was because it is most common for supervised classification in remote sensing analysis [53] and it allows to use the knowledge the interpreter has of the area under investigaton.

Options for unsupervised classification also exist, in these there is no foreknowledge about the classes and they are assigned without names. This is for example useful when one wants to determine the number and location of the (yet unknown) spectral classes. The analyst's task comes then after the automated classification, using the knowledge to assign the classes *a posteriori* [53]. This method is often applied in remote sensing analysis as a first impression of the composition of the landscape, before proceeding to the more detailed process of supervised classification. From literature research and a month of fieldwork, there was already a reasonable idea of the outlook of the landscape classes in the Valley. Taking the time limit of the project into account, it was chosen to limit the approach to just the process of supervised classification. However, if the landuse map should be refined or if more time is available to make a landuse map, this would be interesting to include. When more time for analysis is available, it would be interesting to use the same data with the different methods to do the classification in order to truly compare the results.

Uncertainties within automated the classification The method of supervised classification forces every pixel to be classified within one of the six classes that were chosen. This means that even when the liklihood of a pixel belonging to any of the classes is very low, it will still be classified as one. With the approach used now, there is no way of knowing what the liklihood is that a pixel actually belongs to its assigned class. This increases the uncertainty of the classification. An option to reduce this uncertainty would be to include a threshold for the classification, as explained in section 6.1.1.2. This would allow to investigate the uncertainties of the different classes. By using different thresholds and comparing the size of the unclassified area, one can determine which classes show the biggest uncertainties.

Uncertainties in the validation and results Using the grounddata for validation gave the very good impression of a certainty of 88%. However, this number was derrived from only 28 validation points. With only 101 usable fieldwork measurements taken, there was not much room for more validation points, reducing the meaning of the number 88% for accuarcy estimation.

6.2 Water Quality

Water availability is not only important in quantitative terms, but also in qualitative ones. The goal of this section is to give an overview of what was achieved regarding water quality, explaining the different measurements that were done during fieldwork and giving an insight of what they are about, among other important topics that are related to this section.

6.2.1 Methodology

By using the *Multi-parameter portable meter MultiLine* that measures four different basic water quality parameters (pH, DO, EC and Temp), we were able to obtain a series of results from the different measuring points around the Kathmandu Valley. These results are compared to the water quality assessment obtained by the RSA (Rapid Stream Assessment) method in order to find a relation. Furthermore, the results obtained are also analysed together with the land-use and the water flow at the measuring points in order to find any trends and relations which are shown in chapter 7.

The following subsections explain in detail what each water quality parameter can potentially say about the measured water source, the RSA methodology used, and a geological justification on some water quality results obtained from the field work.

6.2.2 Dissolved Oxygen (DO)

Dissolved oxygen is one of the most important parameters when assessing the quality of a water body. Even though a chemical oxygen demand (COD) measurement was not carried out in this project, DO could be used to initially assume that organic loads were present in the different rivers; however, some crucial factors had to be taken into account to better understand this assumption.

The following factors are important to consider when analyzing the DO in a certain water body:

- **Aeration process:** Along the river due to natural or artificial means (wind, waterfalls, rocks, weirs, water velocity and turbulence, etc.) aeration takes place. This factor can speed up the process of oxygen dissolving into the water from the air [14].
- **Temperature:** The warmer the water, the less dissolved oxygen is required to reach 100% air saturation (this saturation means that the water is holding enough dissolved oxygen molecules as the atmosphere at that altitude does, being both water and air at balance), and vice versa, the colder the water, the more dissolved oxygen required to reach 100% air saturation. So this is also affected by the water depth, since shallow waters can be affected by solar radiation more rapidly than deeper waters, which are normally colder [14].
- **Aquatic plants photosynthesis by-product:** Due to this natural process, O_2 is produced as a 'waste' by plants, meaning that plants that are submerged in water and can obtain sunlight can contribute to an increase in dissolved oxygen in water [14].
- **Salinity:** The more saline the water, the less dissolved oxygen it can contain because of the higher particle density due to the salts [14].
- **Pressure:** Both atmospheric and hydrostatic pressure are factors. Water at lower altitudes can hold more dissolved oxygen than water at high altitudes, and also deeper water compared to shallow water behaves in the same way [14].

6.2.3 Electric Conductivity (EC)

This parameter measures the capability of water to pass electrical flow, which is directly related to the concentration of ions in water, such as dissolved salts and inorganic materials, like alkalis, chlorides, sulfides and carbonic compounds. The higher the EC, the higher the concentration of anions and cations (negatively and positively charged respectively) [16].

It is important to consider the temperature of the water where the EC is measured in order to be able to compare different EC values from different water sources, and 25°C is the standard temperature at which this comparisons are made since the conductivity ratios change with temperature. The specific conductance is made at or corrected to 25°C [16].

Electrical conductivity can be translated as the presence of dissolved solids, meaning that the less the Total Dissolved Solids (TDS) in a water body, the less the conductivity [16].

Agricultural run-off and sewage inflow into a body of water are common ways of polluting and increasing the EC of the measured water source because of the addition of nutrients and salts, such as nitrates, phosphates and chloride; whereas the addition to a water body of oils and organic compounds would pollute and decrease the EC, since this pollutants cannot dissolve and break down into ions [16].

Naturally, EC comes from dissolved minerals (ions) from the surrounding geology. For instance, superficial and underground water flow through clay and limestone soils will dissolve these contributing minerals, whereas through granite bedrocks they won't. Groundwater flow can then contribute to the EC of a stream flow if the geology allows it [16]. Table 6.9 shows the

average EC values for different water sources [16]:

Source	**uS/cm**
Distilled water	0.5 - 3
Melted snow	2 - 42
Tap water	50 - 800
Potable water in the U.S.	30 - 1500
Freshwater streams	100 - 2000
Industrial wastewater	10000
Seawater	55000

Table 6.9: Average EC values for the different water sources in the Kathmandu Valley

As expected, freshwater has a wide range of EC values due to the influence of various geological formations.

6.2.4 pH

pH is used to measure how acidic or base a body of water is by using a scale from 0 to 14. pH expresses the concentration of hydrogen ions (H^+) and hydroxide ions (OH^-). The lower the value, the more acidic the water body, taking 7 as a neutral value, and above 7 as basic, the higher the more basic [15].

pH is calculated with the molar concentration of the hydrogen ions. By calculating the negative logarithm of the hydrogen ions we obtain the pH value on a scale from 0 to 14. In other words, the higher the concentration of hydrogen ions with respect to hydroxide ions, the lower the value of pH, making the body of water more acidic. Therefore, neutral water with a pH value of 7 has the same molar concentration of hydrogen ions and hydroxide ions, that is 10^{-7}. Regardless of the pH value, the sum of both concentration of ions will always give 10^{-14} [15].

A base then would dissolve into water and release a OH^+ ion, and an acid would dissolve and release an H^- ion, but also a hydrogen ion can be released by an acid compound and accepted by a basic compound, meaning that both can cancel each other [15].

Furthermore, alkalinity is a term used to describe the capacity of a body of water to resist pH changes due to the presence of an acid, or in other words, the capacity to buffer an acid. This capacity is increased naturally by soils rich in carbon and limestone, and decreased by sewage inflow and aerobic respiration. Natural water bodies that have an almost neutral pH and have an already high alkalinity due to the presence of carbonic materials, can stand acidic or basic intrusions and can keep the actual pH; however, some water bodies can still increase their pH a little due to further carbonate material addition, creating a slightly basic water body [15].

Figure 6.16: Example of sedimentary rocks at a spring measurement site in the Nakhu watershed, southeast of the Kathmandu Valley

pH is important in water bodies because if it goes too high or too low it can seriously affect the aquatic organisms living in them. Furthermore, changes in pH can improve the solubility of toxic compounds and their mobility in water, being able to be absorbed more easily by aquatic species. The preferable pH for aquatic species survival is between 6.5 and 9, however, there are some species that can tolerate outer range values for pH [15].

Also, big changes in pH can increase the solubility of nutrients that trigger eutrophication. These changes can attributed to man activity, for instance, agricultural and industrial run-off, as well as sewage discharges, which all contain chemicals [15].

In conclusion, alkalinity in a water body is an important factor to be considered if pH changes want to be avoided. This alkalinity can help aquatic species remain on healthy conditions and keep an ecological balance [15].

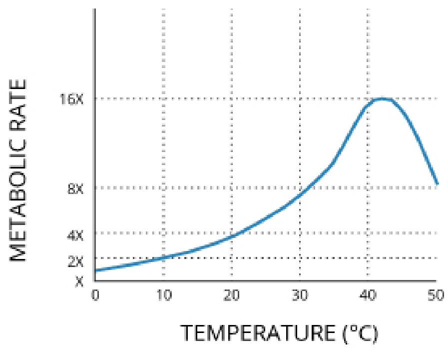
6.2.5 Temperature

In simple words, temperature is a physical parameter that expresses how cold or warm the water is with the use of three different numbered scales: Kelvin, degrees Fahrenheit and degrees Celsius [17]. Previously mentioned, temperature alters water quality, and in this case, dissolved oxygen, electric conductivity and pH can be affected by variations in water temperature.

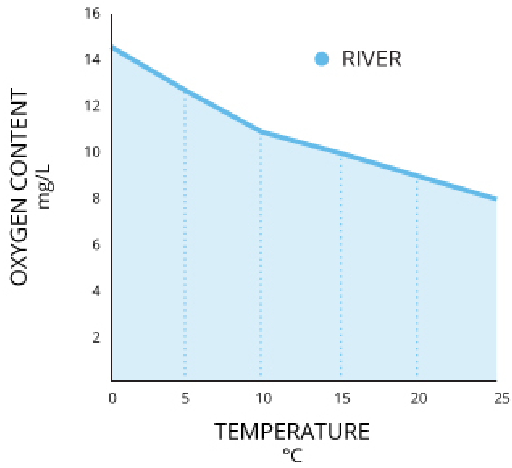
Other parameters that affect water quality and aquatic species is metabolic rates and photosynthesis production, compound toxicity, among others [17]. For instance, some aquatic species increase their metabolic rate by two times with a 10°C increase in water temperature, whereas other species are more tolerant to this changes. Some toxic compounds can increase their solubility at higher water temperatures [17].

Dissolved oxygen is important for the aquatic species. The warmer the water, the less dissolved oxygen in can retain [17], thus affecting and even killing the species, as just showed in Figure 6.17b.

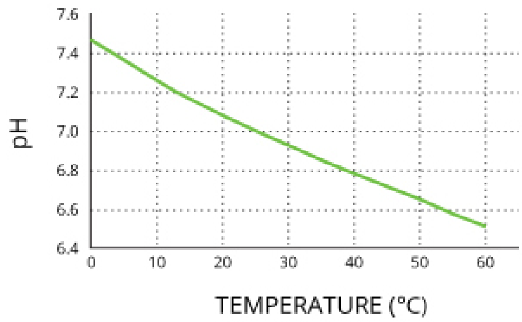
Electric conductivity can be affected by temperature in two ways: first by making water less viscous and allowing ions to move more; and second by making some salts more soluble and increasing the ionic concentration. Conductivity increases 2-3% per each degree Celsius that increases [17]. Regarding pH variances, when water increases its temperature, the H^+ and OH^- ions decrease in concentration, thus increasing the pH, and vice versa, the colder the water the more of these ions present in water and the lower the pH [17]. However, this doesn't mean that a solution is more or less acidic or basic, in only means that the neutral pH shifts up or down, since the ratio of both kinds of ions remains the same [17]. For instance, water at 25°C has a neutral pH value as shown in Figure 6.17c



(a) Temperature vs. Metabolic rate [17]



(b) Temperature vs. Oxygen Content [17]



(c) Neutral pH at different temperatures [17]

Figure 6.17: Temperature in relation to other water quality parameters.

6.2.6 Geology

As introduced in the geology section 2.4, the Kathmandu Valley consists of mainly 2 types of tectonic zones: the Higher Himalayan zone, which consists of metamorphosed coarsed grained rocks like gneiss, schist and marble; and the Tibetan-Tethys Himalayan zone, composed of sedimentary rocks, such as limestone, shale and sandstone [52]. These types of rocks are important to mention because some field measurements on water quality done on the springs in the outer parts of the Kathmandu Valley presented electric conductivity results with higher values than the average values we obtained on other measuring points.

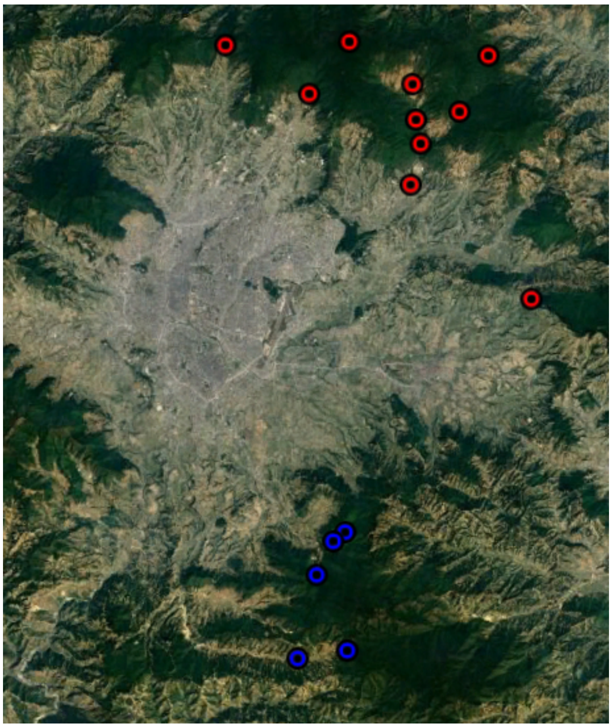


Figure 6.18: Location of the high and low EC values in the Kathmandu Valley for the RSA Class 1

In principle the electric conductivity is a way of measuring an electric flow in a solution through anions and cations: the more the ionic concentration, the more the electric conductivity [16]. The previously mentioned kinds of sedimentary rocks are know for releasing salts when water flows through them (e.g. underground water flow), which dissolve in the water and increase the concentration of ions, thus, increasing the electric conductivity, and just the opposite happens with the metamorphic rocks, they do not contribute to and increase in the EC (electric conductivity) [16]. The following table 6.10 contains the measured values for EC in all the measuring points throughout the Valley of Kathmandu that were assessed with an RSA class 1, in other words, mainly all the springs measured right where they begin to flow out of the ground or close enough to this point.

ID	EC
16090502	331
16091503	228
16090507	213
16082701	210
16091502	193
16090801	59.3
16091004	50.7
16091619	49
16091101	34.3
16092103	32.3
16091904	27.8
16093004	25.3
16090901	22.1
16091002	17.7
16090905	16.2

Table 6.10: High and low EC values for RSA Class 1 measurement sites

The higher values (193-331 uS/cm) correspond to the southern part of the Kathmandu Valley, where sedimentary rocks can be found, whereas the lower values (16.2-59.3 uS/cm) correspond to the northern part of the Valley, where metamorphic rocks are found as already explained in section 2.4.

6.2.7 Rapid Stream Assessment

Doing water quality measurements is not always enough to assess the quality of a certain river, especially with the only four parameters measured during this project (DO, EC, pH and Temp).

Physical/chemical parameters can tell actual conditions in a water body but might not be able to tell the overall status of the river, since some effects in the river ecosystem can last long after the physical/chemical parameters have returned to their normal values. Furthermore, there are many more chemical contaminants that are rarely or never measured because they are just not commonly found in waters, but diverse land uses can increase the possibility to find them, such as organic micropollutants and pharmaceuticals. These pollutants in high concentrations can cause adverse health effects on the aquatic species and the living species that rely on that polluted water body, including us humans. Therefore, in the last years there has been a change in methods for assessing the health status of a water body, and that is a biological assessment [22]. However, the physical/chemical measurements done in this project are of great help to support the information obtained from the Rapid Stream Assessments (RSA) and vice versa: they help pre-classify the river segments and have a rough calibration of the biological results [22]. The Rapid Stream Assessment is a method used in this project that evaluates the health of a segment of a river by analysing its biological status. The principle behind this assessment is studying the biota in the water bodies, that is the animal and plant life in a certain stream segment, so that a class can be assigned to that part of the river studied and a general water use can be concluded when necessary [22]. There are 5 different classes used in the RSA for this project, and they've been described by the University of Natural Resources and Applied Life Sciences in Vienna [22] as follows:

Class 1 - None to very slight organic pollution:

- Clean and clear water with low concentration of organics and nutrients.
- High and healthy concentrations of oxygen for the biota, around 8 mg/L O_2 or more.
- No ferro-sulphide reduction phenomena occurs, fine sediments are of light or brownish colour.
- Not many filamentous algae, more common algae, mainly diatoms.

Class 2 - Moderate organic pollution:

- Moderate concentration of organics and nutrients
- Still clear water with the exception of natural turbidity.
- O_2 concentrations above 6 mg/L
- Little reduction phenomena occurs, top sediment layers of light/brownish colour, whereas deeper layer are grayish or blackish because of oxygen depleting organic matter.
- Filamentous algae is more abundant, common algae present as well.

Class 3 - Critical organic pollution

- Visible organic and nutrient loads
- Water sometimes slightly turbid due to the organics in it.
- O_2 concentrations around 4 mg/L, but can fluctuate due to localized water aeration.
- Upper fine sediment layers still light/brownish colour, deeper layers sometimes dark colour, stones might have black spots beneath them.
- Diversity of microorganisms is sometimes reduced.
- More abundant green algae and high abundance of filamentous algae and macrophytes due to the nutrient increase in the water.
- Sewage bacteria can be recognized.

Class 4 - Heavy organic pollution

- High organic and nutrient loads
- Turbidity noticeable locally, and streams might have different colours due to industries, smell could be detected.
- Putrefactic conditions on fine sediment layers on places with no flow (stagnant), muddy dark brownish layer soils where water flows, deeper layers are blackish, and stones have larger black spots beneath them.
- O_2 concentrations from 2 to 4 mg/L or even lower, but may vary due to localized water aeration.
- High abundances of filamentous algae and macrophytes, specially on calm water areas (stagnant). Sewage bacteria (fungi) totally visible.
- Poor fauna of high abundance, tubificid worms and bloodworms can be found on calm water areas.

Class 5 - Very heavy to extreme organic pollution

- Very heavy loads of organics, oxygen-depleting substances appear and the O_2 concentrations can go below 1 mg/L and close to zero, as a general rule it's almost always a few mg/L.
- Anoxic conditions can exist, water is very turbid due to sewage income. Deeper substrate layers are black coloured, and can release bad odours due to hydrogen sulphide. Upper side of stones in calm water areas can even be black from ferro-sulphide reduction.
- Abundant filamentous sewage bacteria in water flowing areas, algal covers is reduced in both quantities and quality, and abundance of tubificid worms and bloodworms.
- Presence of fish is not possible in this class.

In order to assess a water body according to the 5 previously described RSA classes, the standardized procedure for the Hindu Kush Himalayan region was used. At the measurement sites, the following assessments [22] were done and put in a table with numerical values that add up for each class so that the highest number of each sum stands for the final RSA class of that measuring (Detailed explanation on the criteria needed for assessments and the scoring on each one of them will not be described since is not in the scope of this report):

1. **Sensory features:** Turbidity, colour, foam, odour and wastes.
2. **Ferro-sulphide reduction** for three different flow velocities: $<$0.25 m/s, 0.25-0.75 m/s and $>$0.75 m/s
3. **Bacteria, fungi and periphyton:** Bacteria and sewage fungi are mainly for class 4 and 5; periphyton and filamentous green algae for class 3; and lower concentrations of green algae for class 1 and 2.
4. **Benthic macro-invertebrates:** focusing on the species richness, abundance, number of sensitive species and number of tolerant species. Due to the physical/chemical requirements for freshwater macro-invertebrates and their specific microhabitats needed for their survival and reproduction, these species are an excellent way of reflecting the general conditions of a certain site.

After classifying the streams in the Kathmandu Valley at different measuring sites, recommendations of uses for the five different classes can be done, nevertheless, they are only intended to be included in the report for practical purposes and not to be considered as official guidelines. It's important to mention that other important water quality parameters were not measured, which are crucial for assigning water uses more precisely. These parameters include biological presence (bacteria, viruses and protozoa), toxic compounds (e.g. arsenic), hardness, etc. The recommended water uses for each RSA class are explained below.

- **Class 1:** Drinking water purposes: the organic and nutrient loads are very low, no discharges from industries or households, therefore barely any organic micropollutatns. Waterborne pathogenic microorganisms could be found due to animal faeces around the water source area. A simple sand filtration followed by chlorination can be used to ensure a biological reliability.
- **Class 2:** Drinking water purposes: organic and nutrient loads are still not very high. Waterborne pathogens are more probable to be present, the more downstream the measurement, the more probable the cattle presence and small sewage discharges. Again, a simple sand filtration followed by chlorination can be used.
- **Class 3:** Agricultural purposes (irrigation, feeding animals): Since higher organic loads are present, sandfiltration followed by a biological treatment (i.e. activated sludge treatment) would be needed, therefore the water can be directly used for the mentioned purposes. It's important to mention that the nutrient loads serve as fertilizers for the irrigated crops. Sand filtration is recommended in order to remove bacteria and protozoa, but not viruses.
- **Class 4:** Agricultural purposes, however, a biological pre-treatment is recommended in order to decrease the organic concentrations. Activated sludge treatment can conserve the nutrients which are good for irrigating crops. Already organic micropollutants can be found in higher concentrations, a post-filtering step could be recommended such as activated carbon.
- **Class 5:** No direct use before a proper treatment is recommended. These waters can be highly concentrated with organic micropollutants, pharmaceuticals, pathogens, organics, inorganics, etc.

6.2.8 Conclusion on results

From the fieldwork, a set of water quality measurements was done and organized in Excel in order to be analyzed. Trends could be found and conclusions were drawn.

It is clear from Figure 6.19 that as the RSA Class increases, all the water quality parameters worsen due to organic pollution and other factors mainly coming from sewage discharges. Nevertheless, the second picture in Figure 6.19 does not really follow a trend, but what can be concluded from it is that the value ranges get more narrow when the RSA class increases.

On the other hand, dissolved oxygen, electric conductivity and temperature worsen in general along the river stretch.

The amount of measuring points was good enough to show understandable behaviors for each water quality parameter except pH. This parameter seems to fluctuate a lot within a very small range, so it is difficult to conclude on this parameter.

Further trends and conclusions are done in chapter 7, where detailed explanations are described.

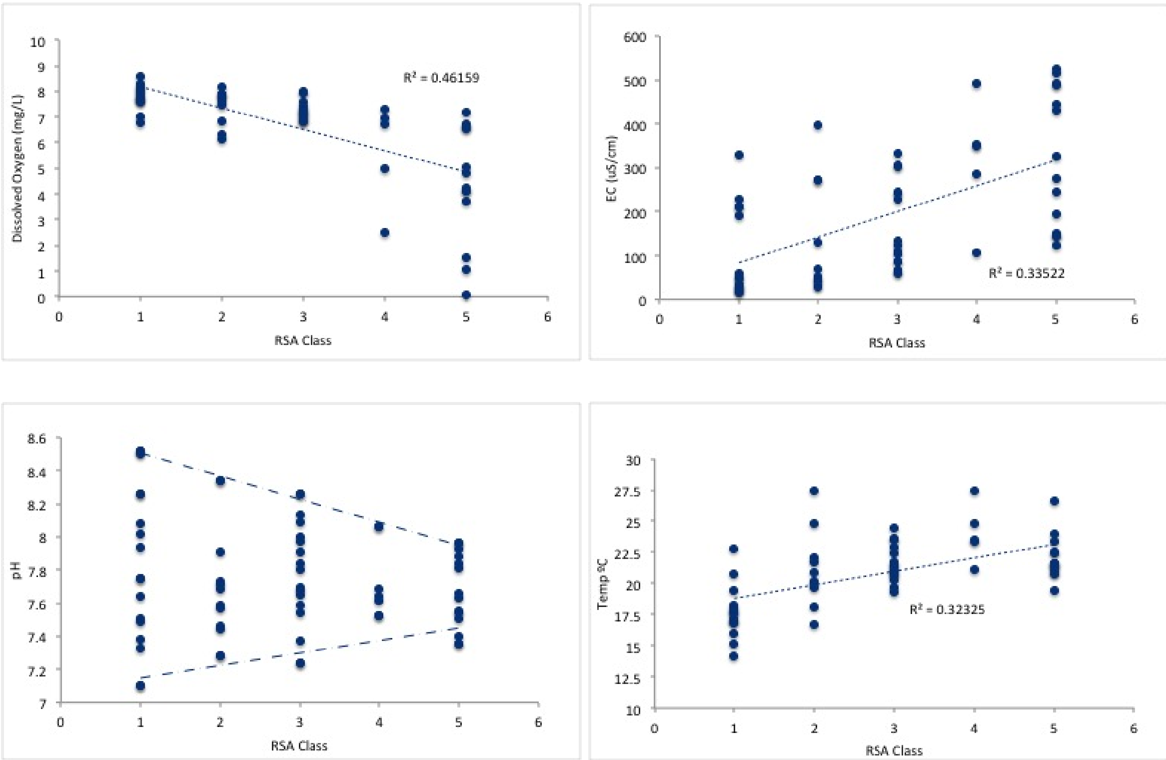


Figure 6.19: Relations between the change in RSA class and the changes in the four main water quality parameters measured

6.3 Availability and demand

6.3.1 Availability of surface water

As described under the problem definition, data on the water situation of the Kathmandu Valley are very rare. The availability of water is no exception. This section aims to give an estimate of the water availability within the Valley.

Before being able to give an estimate of the water availability, it is essential to define this term. Several questions have to be asked:

- Which water sources are considered to be available?
- For which purpose do we want to know the availability?
- Of which quality should the water be?
- Can all water be used or is an outflow of water necessary?
- Can water be reused and therefore be available multiple times?

For the few data sets available, the answers to those questions seem to differ immensely, making it very hard to give an answer to the question: *How much water is available in the Kathmandu Valley?* In this section Water Availability is defined as the total flow through the riversystem with a certain quality class. In this definition any other sources like groundwater are ignored, as well as the necessity to not completely exploit the rivers.

6.3.1.1 Methodology

With the data generated, the answer on the availability question will only be a rough estimate. Despite the fact that a lot of the water used within the Valley comes from other sources like tubewells, see section 3.1.1, this chapter will only focus on the surface water. It is simplified by only considering the river flows.

Water is available in different quality ranges. During the field work the quality was assessed by RSA measurements, which give a link to the possible usage of the water, see section 6.2.7.

For all subwatersheds as found in section 6.1.3 the most downstream point for every RSA class is found. This divides the area of the Kathmandu Valley in different classes as seen in 6.20. A certain area is defined by its best downstream RSA class. Note that if an upstream area is expected to have a good class, but no measurement has been done, it will be classified as the poorer downstream classification. Therefore, this division generally underestimates the water quality and can be read as the minimum class of the area.

For all these lowest points, the values of the flow measurements performed during the fieldwork are added per class within each watershed. Adding up these values gives the estimate of available surface (river) water for the Kathmandu Valley. The values are accumulative, meaning that this water is available at the measured locations in the specified class, but water of higher class might still be available higher up.

6.3.1.2 Results

In Table 6.11 the flow values per class within each watershed are shown. Note that if there is no measurement available in a certain class, the value stays the same as that of the higher class. This can be justified by the idea that if water is available as class II, it is available as class III as well. The total of available class V is the sum of the lowest measuring points on the headwaters before flowing into the Bagmati and is therefore smaller than the total Bagmati outflow.

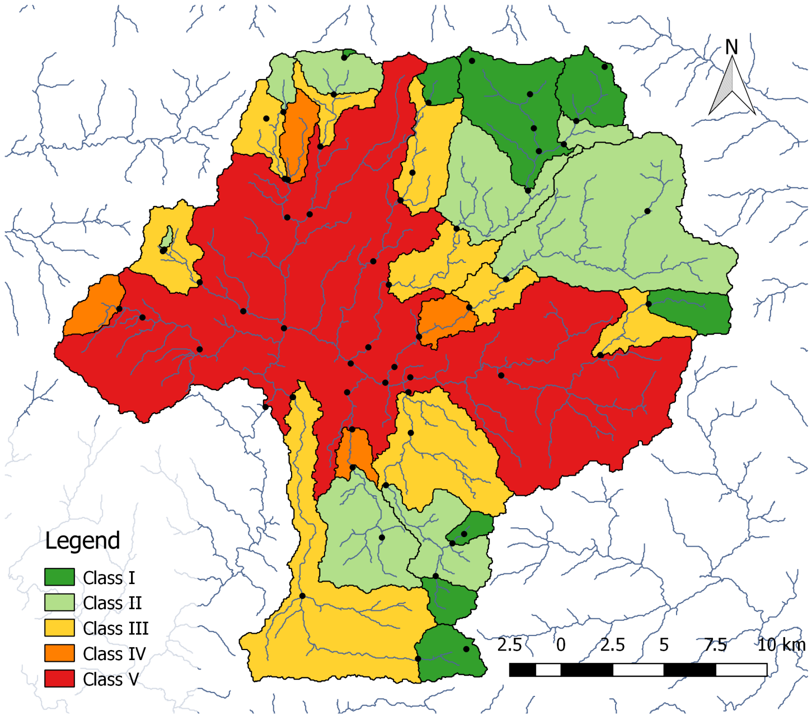


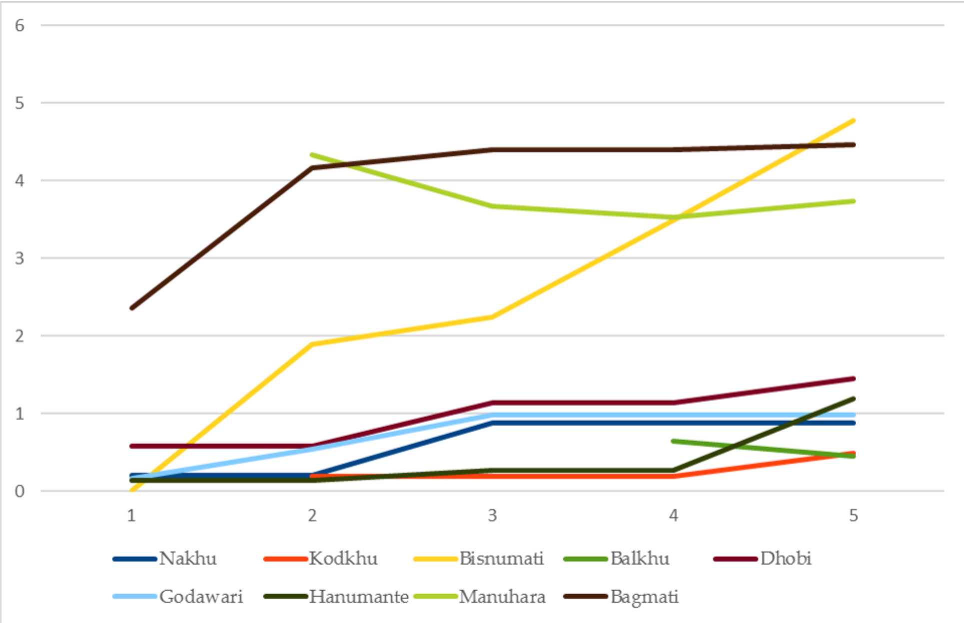
Figure 6.20: The subwatersheds defined by their best downstream RSA class. The measuring locations are indicated as black dots.

Class	I	II	III	IV	V
Nakhu	0.204	0.204	0.88	0.88	0.88
Kodkhu	-	0.189	0.189	0.189	0.497
Bisnumati	0.008	1.888	2.247	3.493	4.78
Balkhu	-	-	-	0.6496	0.4503
Dhobi	0.583	0.583	1.144	1.144	1.458
Godawari	0.167	0.543	0.98	0.98	0.98
Hanumante	0.14	0.14	0.265	0.265	1.199
Manuhara	-	4.33	3.670	3.527	3.740
Bagmati	2.367	4.169	4.402	4.402	4.463
Total	3.469	12.046	13.777	15.529	18.446
Bagmati Outflow					22.68

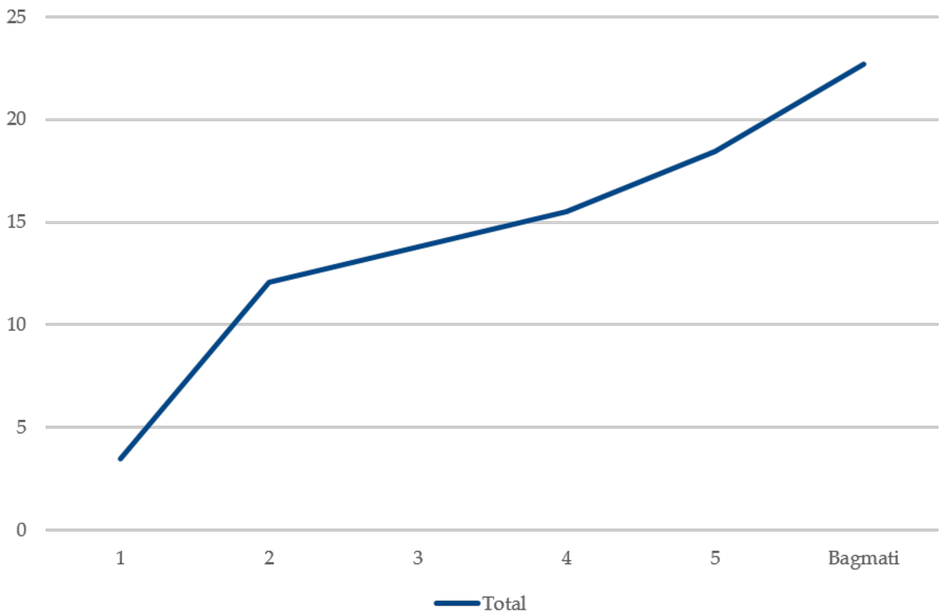
Table 6.11: Available water per class for the subwatersheds m^3/s

The total flow per class is shown in Figure 6.21. It can be seen that generally the flow increases where the quality is decreasing, being in line with the idea that the quality decreases downstream while the flow increases as the size of the watershed gets bigger. An exception is the Manuhara, which has a decreasing flow over the classes. A good explanation for this is that the flow is of such a quality that a lot of the flow is extracted for e.g. agriculture.

According to section 6.2.7, class I and II are good for drinking water, class III can still be used for agriculture, class IV can be used for agriculture after processing and class V is nothing more than wastewater. Assuming the values of Table 6.11 to be averages over the month September, the total volume of available water per use can be found in Table 6.12. For the drinking water, this would mean an available amount of 1,040 Million Liters per day in September 2016. Please refer to section 6.3.1.3 for a discussion on these numbers.



(a) per subwatershed



(b) Total before and after flowing into the Bagmati

Figure 6.21: The measured flow per RSA class in m^3/s

Available for	September 2016
Drinking Water (Class I + II)	31,223,232 m^3
Agriculture (Class III)	35,709,206 m^3
Agriculture after pre-treatment (Class IV)	40,251,230 m^3
Wastewater (Class V)	47,811,513 m^3

Table 6.12: Rough indication of total available river water in September 2016 for different purposes.

6.3.1.3 Discussion

As mentioned before, the numbers described in Section 6.3.1.2 are very rough estimates of the water availability. It is important to consider them as nothing more than a first indication because of the following reasons:

- The flow measurements are performed between 27 August 2016 and 30 September 2016. During this month the amount of rainfall was highly variable, making that some flows are much higher, while some are lower than a characteristic flow for this time of the year. Even though the presence of this variability, the values are simply summed up which makes that they don't indicate more than an order of magnitude.
- The total values as shown in Table 6.11 are taken as averages over the month September. This is a big simplification, caused by the impossibility to measure the flows every day.
- The flow measurements themselves are rather accurate, but are also influenced by human errors. This will be further discussed in section 5.
- The term availability is used, while other sources like groundwater are ignored. In that sense it would be an underestimation of the available water. At the same time however, also a certain part of the river flow is not considered. As the rivers have more functions than only water supply, the values cannot be used as supply values. First, the following river functions (amongst others) should be taken into account:
    - o Transport of sediments as well as sewage
    - o Dillution: if taking away all upstream water, the quality of the downstream water will drop rapidly, decreasing the availability of class II, III and IV water
    - o Being a habitat for different ecological species requires a minimum environmental flow
    - o etc...
- The values given per class are totals values with a quality that have the specified class at minimum. Even though it is not measured, upstream sections might be of higher quality. Therefore the availability of the higher classes will be underestimated. Figure 6.20 shows a clear indication of the distribution of the classes and shows how some areas are considered as class V even though they are situated higher up in the hills.
- All measurements are performed in September 2016. This month is part of the monsoon period. This year September seemed to be particularly wet. From October onwards, the precipitation values will decrease till almost zero. The dry season will therefore have much lower stream flow values as well. September 2016 is therefore NOT representative for the whole year, or even for other months of September in different years.
- No further validation of the results was performed

6.3.2 Agricultural Demand

When a significant amount of crop lands is present, the amount of water needed for agricultural purposes usually accounts for the biggest part on the demand side. Through the process of transpiration, plants use water for photosynthesis, which makes them grow. Especially in a country like Nepal, where the fast majority of the rain falls only during the monsoon-months, this means that there is a big water need for artificial irrigation practices. When looking at an agricultural area, evapotranspiration (ET) combines the amount of water that is used in transpiration by the crops and the water that is lost by evaporation from the soil. ET therefore gives a good quantitative measure of the amount of water that is needed for agricultural purposes. However, uncertainties in ET calculations combined with water losses due to infiltration and surface runoff, gives rise to the need to for an uncertainty-factor for computation of the total demand. Subtracting the amount of expected rainfall provides the water needed for non-rainfed irrigation.

For the purpose of this project, ET estimates will be used for a simplified water budget of the Kathmandu Valley (see chapter 6.4). Unavailability of recent meteorological and hydrological data prohibited us to do this for September 2016. In stead it was chosen to compute the water budget for the months of August and September of 2015. This with the purpose of going through the process and determine where problems and possibilities lie for future work on water budget computation.

As such, the methodology of computing ET estimates, together with the results, will be discussed in chapter 6.4.

6.3.3 Urban demand

In the beginning of the project it was thought to actually calculate, verify and analyse the water demand in the Kathmandu Valley. It became clear quite quickly that there is not a lot of information on the water demand. It was found that connections are not metered and that the piped network is in a terrible state. Further it is not even known how many people live in the Kathmandu Valley. The challenge became to get an idea of the water demand in the Valley. Various data sources were analyzed and compared in order to make the most promising estimate. This chapter shows a selection of data analyzed to point out the difficulty of finding reliable data and come up with an idea of the water demand in the Valley. Finally the mismatch between supply and demand is shown.

'Water demand varies with the socioeconomic status of households, the setting (rural or urban), and existing infrastructure, etc., but in most cases, relevant data is not available to local administrative divisions in developing countries (including the Kathmandu Valley)' [76]

Figure 6.22 shows the water demand within the entire Kathmandu Valley with its municipalities. The darker the blue colour, the higher is the water demand. Even though the method used (Bureau of Indian Standards (BIS)) to determine the water demand is maybe not appropriate for the Kathmandu Valley, it still gives a good impression of the spatial distribution of the water demand within the Valley. The demand corresponds well with the population density in the Valley. It can be seen that the water demand in most of the municipalities is very low (0.13 - 4.00 million litres per day (MLD)). The regions coloured in the darkest blue need remarkably more water than the other regions (up to 63 MLD).

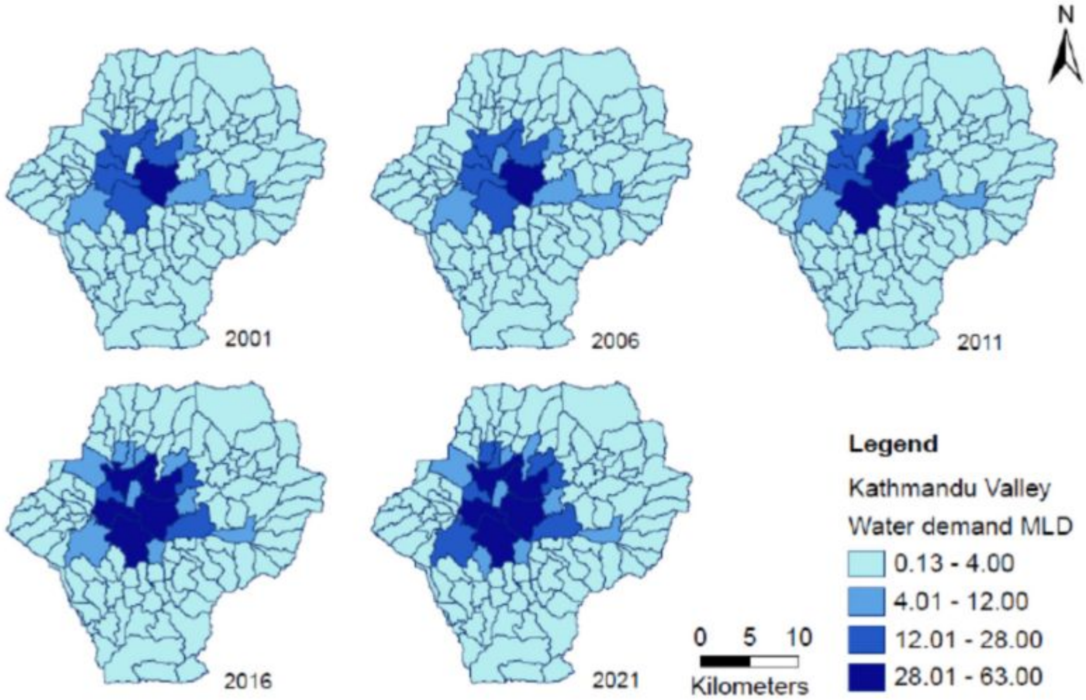


Figure 6.22: Village Development Committee (VDC) water demand using Bureau of Indian Standards (BIS) guidelines. [76]

6.3.3.1 Population and population growth

An estimate for the population is hard to make because even today the percentage of not registered births is far above 50 [79]. However, the Central Bureau of Statistics tried to estimate the population within the Kathmandu Valley in 2011. Its conclusion is that there are 2,517,023 people living in the Kathmandu Valley of which 1,426,641 people live in the urban area [43] which is about 55 %. This is the official statement about the population. Almost all of the people that have been met during the research believe that the real number of inhabitants is higher than that. KUKL assumes that in 2010 the number of inhabitants just in its service area was already 2.1 million [4]. Even though KUKL covers with its service area the most densely populated areas of the Valley (see Figure 6.23), it is by far not the whole area of the Valley.

The population of Kathmandu is estimated to grow with a rate of 4.7 % [37] [51]. This would result in a population of about 1.8 million people for the urban area of Kathmandu in 2015. KUKL on the other hand expects a population of 3.6 million in their service area by then [4]. This corresponds to a growth rate of 20 % which seems to be quite unrealistic. It is however obvious that an increase in population also causes a higher demand for water:

In the recent past, water demand of the Valley has raised abruptly by increasing population and industrial activities. [48]

The world wide growth rate for urban areas is 1.84 % according to the World Health Organization (WHO) [86]. The Guangzhou region, one of the fastest growing urban areas in the world, recently reached a maximum growth rate of 7 % [10]. Values of The World Bank show an urban population growth rate in Nepal of 4.5 % in 2010 but a reduced growth rate of 3.2 % in 2014 [74]. Also the trend of the WHO shows a decreasing growth rate for the upcoming years [86]. It is therefore very unlikely that the KUKL population estimate is realistic. Nevertheless can the KUKL data be used to estimate a per capita water demand.

Type of toilet	Urban		Rural		**Total**	
	2001	**2011**	**2001**	**2011**	**2001**	**2011**
Flush toilet	67.4	93.4	66.4	80.3	67.1	88.1
Ordinary toilet	31.1	6.3	10.8	15.3	23.6	9.9
No toilet	1.5	0.3	22.7	4.4	9.3	1.9
Not stated	1.903	2.985	1.268	2.013	3.171	4.998
Total Percentage	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Total Households	**218.322**	**366.255**	**127.240**	**247.351**	**345.562**	**613.606**

Table 6.13: Percentage of household by type of toilet used for urban/rural Kathmandu Valley, 2001 - 2011. [43]

6.3.3.2 Per capita water consumption

As described previously the access to data is very difficult in Nepal. There are no numbers on the urban water demand in the Kathmandu Valley that state how they are determined. A variety of estimates exits as will be shown later in this chapter. The idea was to verify one of the demand numbers due to information on typical water use. In relation to this research some indications from which one could start collecting information on the water consumption were found. One of these indications is the situation on toilets in the Kathmandu Valley. For the reason of the hygienic situation in the Kathmandu Valley, the toilet situation is analyzed in detail. Table 6.13 shows that the total number of flush toilets increased by 21 % within ten years. The total amount of households in the Kathmandu Valley not having a toilet at all decreased by 7.4 % during the same time. Remarkable differences still exist between rural and urban areas.

With regard to the water demand in the Kathmandu Valley, one can see that technological development causes higher water demand (a flushing toilet needs more water than an ordinary one). On the other hand, the technological development can improve water consumption like for example a two button flush toilet that either flushes a full load or just a half load of water according to the needs. But to use this information to calculate the total water demand in the Kathmandu Valley more time and more insight is needed. A lot of assumptions have to be made in order to determine the water demand of a flush toilet per day. Furthermore, flush water is only one part in the whole picture of domestic water consumption.

Figure 6.23 shows the supply zones within the KUKL service area. But, the arrangement in different supply sections seems to be fairly useless:

'The present distribution system, with the exception of local supplies from both the surface and ground water sources and supply from an individual tube well to specific location, is so cross-linked that it is not possible to exactly predict the supply area supplied by a specific system' [4]

The water demand is estimated according to the distribution system (Figure 6.23). Table 6.14 shows the assumed water demand in the KUKL service area in the Kathmandu Valley in 2015. In comparison to that table 6.15 shows the estimated water demand for the same areas in 2025.

This is the most precise data that could be found on the analysis of the water demand. It comes from a final report from the Asian Development Bank (ADB) on a Capital Investment and Asset Management Program but is closely related to KUKL. This program is part of the Kathmandu Valley Water Supply and Wastewater System Improvement. Unfortunately there is no information on how the data for the year 2010, the initial situation of KUKL's data, is collected. For the other years 2015, 2020 and 2025, the water demand is of course estimated. After gaining experience in the data situation in Nepal during the research, the impression arose

2015							
District	**Population total**	**Population served**	**Total water demand domestic (MLD)**	**Total water demand not domestic (MLD)**	**Leakage (MLD)**	**Total water demand (MLD)**	**Per capita water demand (LD)**
(A) Kathmandu Metro	256′1074	177′7408	143.91	14.39	85.24	243.54	89.1
(B) Kathmandu North-East	324′870	201′960	10.86	1.3	6.55	18.71	60.2
(C) Kathmandu North	222′218	147′917	10.77	0.97	6.32	18.06	79.4
(D) Kirtipur	52′556	31′699	2.16	0.19	1.27	3.62	74.1
(E) Patan South	167′869	112′418	8.17	0.73	4.79	13.69	79.2
(F) Bhaktapur	193′369	127′723	8.64	0.78	5.07	14.49	73.7
(G) Pharping	27′685	16′611	1.04	0.09	0.61	1.75	68.0
(H) Sankhu	11′451	6′870	0.43	0.04	0.25	0.72	68.4
KUKL service area	**3′561′092**	**2′422′606**	**185.98**	**18.49**	**110.1**	**314.58**	**84.4**

Table 6.14: Water demand in the KUKL service area in 2015. Sorted by service area. Data for the table from [4]

2025							
District	**Population total**	**Population served**	**Total water demand domestic (MLD)**	**Total water demand not domestic (MLD)**	**Leakage (MLD)**	**Total water demand (MLD)**	**Per capita water demand (LD)**
(A) Kathmandu Metro	3′484′039	3′114′312	326.15	48.92	125.02	500.1	120.4
(B) Kathmandu North-East	536′009	447′746	37.66	5.65	14.44	57.75	96.7
(C) Kathmandu North	319′777	277′400	27.77	2.78	10.18	40.72	110.1
(D) Kirtipur	66′700	53′098	4.73	0.47	1.74	6.94	97.9
(E) Patan South	399′395	333′709	31.95	3.19	11.71	46.86	105.3
(F) Bhaktapur	266′573	217′921	20.36	2.04	7.47	29.87	102.8
(G) Pharping	34′192	27′354	2.33	0.23	0.86	3.42	93.6
(H) Sankhu	11′929	9′544	0.81	0.08	0.3	1.19	93.2
KUKL service area	**5′118′614**	**4′481′084**	**451.76**	**63.36**	**171.72**	**686.85**	**115.0**

Table 6.15: Water demand in the KUKL service area in 2025. Sorted by service area. Data for the table from [4]

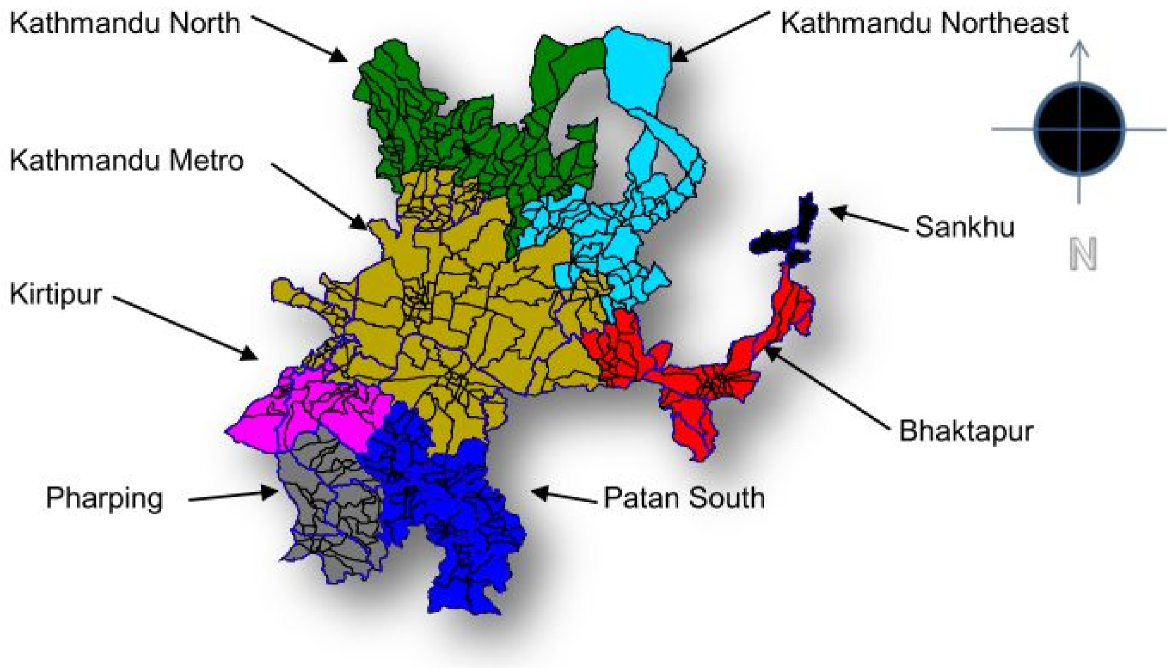


Figure 6.23: Supply zones of KUKL within the Kathmandu Valley [4]

that also the data for 2010 is an assumption. Which means that mistakes in estimates are even greater for the following years.

Interesting about this data is as well that urban non-domestic water consumption is taken into account even though this is a comparably small contribution to the total demand. Most other sources do not analyze the demand in such detail. Having the misleading facts presented with regard to the leakage (see following section), one has however the impression that the detail of the analysis is only simulated.

Leakage The total water demand (in Table 6.14 and 6.15 includes leakage because leakage is 35 % in 2015 and 25% in 2025 (according to the ADB) and therefore makes up a non-negligible amount of water. The per capita water demand in Tables 6.14 and 6.15 on the other hand does not include leakage. The per capita water demand including the leakage would sum up to 130 litres per day.

Assumptions are made for the leakage that it could be reduced from 40 % in 2010 by 1 % every year. Hidden in the data provided from the ADB one can find that the leakage is actually on average 67 % in the 2010 situation. In case the data is an estimate, one would assume that the amount of leakage correlates with the indicated percentage. This is true for the years 2015 and 2025. In the year 2020 leakage is given with 30 % but the data reveals that the ADB actually estimates leakage to be 42 %. It seems that the ADB made a right estimate for the water demand and leakage for the period of 2010 - 2020 and then forgot to change the data in order to make a consistent forecast. For the year 2010 the ADB seems to conceal how high the amount of leakage actually is. Therefore it becomes even more ridiculous to reduce the loss of water due to leakage to 35 % in 2015. Table 6.16 clarifies these mismatches, recognizing this makes it doubtful that the data is at all reliable.

Increase in customer connections Another ambitious assumption is that the amount of people served can be significantly improved (almost 10 %) every five years. These estimates do not

	2010	2015	2020	2025
Leakage, given (%)	40	35	30	25
Leakage, from data (%)	67	35	42	25

Table 6.16: KUKL's mismatch information about leakage in the distribution system. [4]

seem very reasonable when taking the progress of the last eight years of KUKL's operation as well as its complaints about a lack in project financing, proper material and qualified staff into account.

The total population in 2015 is estimated to be about 3.5 million (ADB). This is more than one million people more than determined in the population census in 2011 by the government. For 2025 it is predicted that the population increases by 44 % to more than five million people. The increase in the percentage of served people from 68 % to 88 % from 2015 to 2025 is already remarkable, but the fact that the population increases drastically during the same period, makes it almost unbelievable that KUKL can actually provide that service. In the following this will be described in more detail:

In 2010, according to KUKL's information, the number of customers connected to the system was 1,427,789. That means that KUKL has to increase the amount of connections by one million within five years to reach the desired value of 2015. Calculating that down on a daily basis, about 640 consumers have to be connected to the network every single day, assuming 52 working weeks with each 6 working days. This seems to be absolutely unrealistic in a country like Nepal.

In the ten years following 2015, KUKL wants to provide more than two million additional customers to the network. Again in the calculation with 52 working weeks a year and 6 working days a week, KUKL has to connect even 660 new customers every day. It is obvious that this goal cannot be reached. Even if large investments, the know-how and the manpower are available, this is still considered as an over-ambitious aim.

Comparison of the ADB values from table 6.14 with data of The World Bank Figure 6.24 compares the data of The World Bank with the information of the ADB. It reveals that the water demand estimated by the ADB is 4.5 times as high in 2010 and even more than six times as high in 2025 as the values presented by The World Bank. But one should have in mind that the service area of KUKL covers the areas of darkest blue and therefore highest water consumption according to Figure 6.22. According to that figure it is true that the water demand in these areas is many times higher than in the rural areas of the Kathmandu Valley. And as it was already mentioned in chapter 1.1, 83 % of the population in Nepal lives in rural areas.

Having the excessive leakage rates of about 70 % in mind, one could also get the impression that the ADB wants to conceal that the state of the piped water distribution system is horrific. To cover that fact, ADB simply increases the water demand per person. If the water demand of 2010 given by ADB is calculated in that way that 70 % of leakage is already included, one gets a water demand of 40 litres per day and person. This corresponds better with the value of The World Bank. However it is not clear how The World Bank determined the value for the water demand but the values seem to correspond with the values of other sources for industrialized countries. It is worth mentioning that the value of The World Bank in figure 6.24 does not show the water demand, but the actual water consumption from freshwater sources. The values provided by KUKL represent an estimate of the water demand. Nevertheless, a daily water demand of only 40 litres per person seems to be relatively low. Especially when taking the increasing number of flushing toilets into account (table 6.13). On the other hand, the majority of the people does not have dishwashers, washing machines nor do they drink the water from the tap.

Comparison of the water demand with other countries In comparison to other selected countries in the world, the per capita water consumption seems incredibly low. Figure 6.25 shows the daily water demand per person in Nepal, Bangladesh, India, The Netherlands and the United States of America according to The World Bank. Bangladesh was chosen to compare Nepal with a country of a similar state of development in the region. One can clearly see that Bangladesh's water consumption is already three times as high as the value of Nepal. India as the direct neighbour and has a similar development situation in rural areas as Nepal, but overall it is more developed and shows tendencies of an emerging market (see also Figure 1.3). The Netherlands and the U.S. are displayed to give an impression of the situation in countries that the reader is familiar with.

Figure 6.25 does not display the water demand, it only shows the water consumption. It could therefore be that Nepal's water supply is simply remarkably less than in the other countries. Another influence could be that water for the daily use in Nepal is not procured from freshwater sources. Surprisingly is then though that the situation of freshwater supply in Bangladesh seems to be remarkably better than in Nepal. An interesting question that should be mentioned in this context is: How does the availability of water influences the demand? Another factor regarding the accuracy of the data is the source of information that The World Bank uses to determine its value of water consumption. It is doubtful that the information situation for The World Bank is remarkably better than for a student team researching for two months. Due to the fact that even the government has no data to determine the actual water consumption it is unlikely that The World Bank is able to determine the water consumption precisely. However this shows again that information in Nepal is not easy to get, that data is missing to an enormous extent and that values are often based on guesses and estimates which reveal a whole range of possible scenarios.

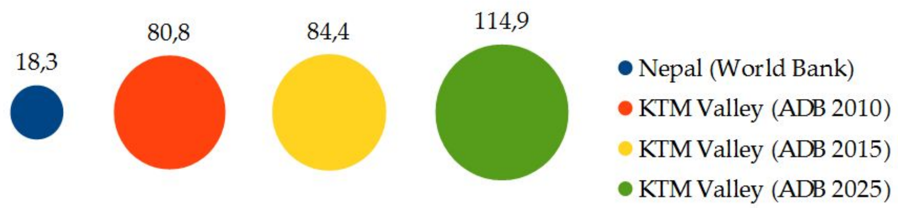


Figure 6.24: Per capita water demand in litres per day. The value from The World Bank is an average value over all Nepal and displays the water consumption. The other values are provided by the ADB and cover the water demand in the Kathmandu Valley. All ADB values are presumably estimates and do not base on any measured data. [4] [70] [64] [66]

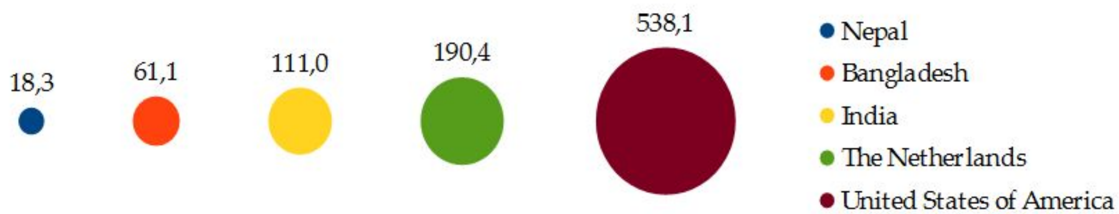


Figure 6.25: Per capita water consumption in litres per day for a selection of countries according to The Word Bank. [70] [64] [66]

Increasing water demand The water demand will increase according to the estimated data from KUKL up to 115 litres per day per person in 2025 (see Figure 6.24). Compared to that the water demand in 2015 was estimated to be 84 litres per day per person. It is also obvious that the water demand did not increase a lot from 2010 to 2015. This is mainly due to the fact that the amount of leakage is reduced from 67 % to only 35 % during that time. Even tough the data does not contain the leakage this is relevant because the ADB did not indicate such a descend in its data. Therefore, 30 % of losses are saved in the water demand data. In other words: An increase of 30 % of real water demand is not displayed here. When clearing the data from this leakage issue, the water demand in 2010 results in 40 litres per person per day. This means that the water demand doubles within five years (2010 - 2015).

Having in mind how the ADB manipulates the data, one gets the impression that the actual water demand in 2015 will be below 84.4 litres per person per day. The demand is probably estimated to be as high in order to conceal that the leakage in the piped water distribution network will be way above 35 %.

From Table 6.13 one can see that the technological development in this case regarding the increasing use of flush toilets contributes to an increase in water demand. However the increase of water demand proposed by the ADB seems to be a bit unrealistic.

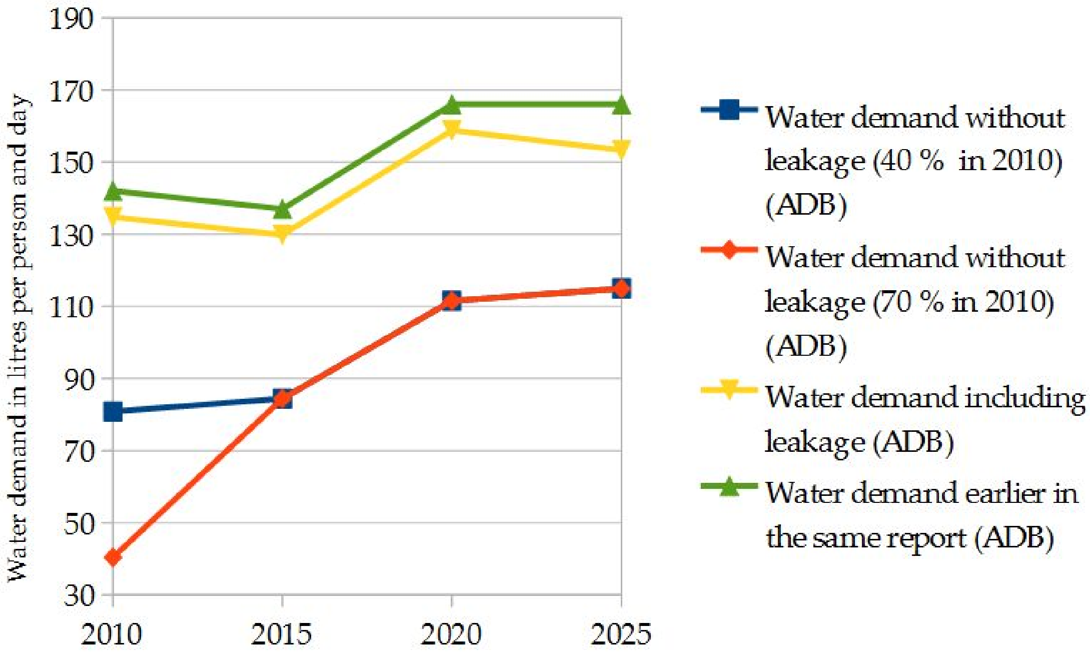


Figure 6.26: Values of the ADB's water demand estimate in comparison to values of the KUKL and the Asian Development Bank (ADB) from the same published report. [4]

One can see in Figure 6.26 that the water demand per person decreases from 2010 to 2015 and from 2020 to 2025 which is against all information available and also contradicts KUKL's as well as ADB's scenario of a drastically increasing water demand. That the values decrease is due to the fact that the 70 % and 42 % leakage are most likely hidden in the data. To cover these problems the per capita numbers are not published and can only be seen if the data sheets are analyzed. The overall trend seems to be an increasing water demand and fits therefore in the picture that KUKL and the Asian Development Bank seem to be wanting to create: A massive water shortage in the Kathmandu Valley due to an increasing water demand.
The numbers of the actual water demand (without leakage) that are also provided in the data

sheets and displayed in 6.26 show that the water demand will increase in the coming years but the absolute value in 2025 will still be lower than the assumed value of today's water demand. The increase of the per person water demand from 40 respectively 80 litres per person and day to 115 litres seems to be more reasonable. Even though it is a dramatic increase over a relatively short time.

Interesting is as well that the Asian Development Bank finds the following (in the same report that contains the data which is discussed above):

'Allowing for 25 % UFW [unaccounted-for water] and 15 % commercial / institutional allowances, the resultant water demand projections for the entire service area, by 2010, 2015, 2020 and 2025 would be 203 MLD, 332 MLD, 466 MLD and 724 MLD respectively' [4].

Recalculating that to a daily per capita demand, one gets 142 litres (2010), 137 litres (2015), 166 litres (2020) and 166 litres (2025). Just for comparison these values are also shown in Figure 6.26. It is obvious that these values are even higher than the values previously discussed.

The fact that the ADB is not even able to present a coherent picture of the water demand in one single report gives a bad impression of the quality of the data. There are simply too many mistakes in the report and mismatches can even be revealed when dealing with this information for a couple of weeks. The partnership between the Asian Development Bank and KUKL seems to work, because the ADB constantly funds new projects of KUKL. The fact that Nepal is within the 50 most corrupt countries leaves room for speculations [65].

ADB data on water demand in comparison with data of other sources After the ADB disproved its water demand estimate in its own report, it is interesting to see how the ADB estimate performs in relation to other approaches. The other approaches are not necessarily based on more information. For example the following approach uses a guessed uniform value and Indian standards to calculate the water demand in the Kathmandu Valley:

'Assuming a uniform demand in the Valley of 135 litres per person and day, we obtain a value of 415.5 MLD. If we use the Bureau of Indian Standards (BIS) guidelines water demand is calculated to 366 MLD' (2016). [76]

To reach the value of total water demand, a population of around three million must have been assumed. According to the BIS calculation, the per capita daily water demand results in 117 litres. Researchers from Japan and Thailand found a water demand of 276 litres per person and day [48].

The VDC, which created figure 6.22 in the beginning of this chapter, states a water demand in 2016 in the range of 18 - 43 litres per person and day [76].
Another research that analyzed a region in the Kathmandu Valley in the transition from urban to rural area concluded the following:

The average water demand for domestic purpose was 145 liters per day per household in poor families whereas 350 liters per day in well off family for this purpose. The reason behind this was that the average household number of family member in poor was 5 whereas in well off families it was found to be 7. Similarly, the average number of animals that are domesticated in poor families was 1, but in case of well off families it was found 4. [12]

This results in an average water demand of 29 litres per day and person in poor families and an average water demand of 50 litres per day and person in well off families.

In conversations with people from the Kathmandu Valley during the research, it could be found that most of the people have a per person water demand between 80 and 90 litres per person per day. People connected to the piped network with 24 / 7 water supply in the Godawari region of the Kathmandu Valley use on average 110 litres per person and day according to the person who collects the money for the water used.

6.3.3.3 Conclusion remarks on the urban water demand

First it can be concluded that due to the miserable data situation an estimate of the urban water demand is difficult to make. Additionally there are enormous losses of water due to leakage. This distorts the comparability of the data. It is often unknown whether leakage is included or not in the per capita water demand.

The information presented by the organization Asian Development Bank is very ambiguous and many things are suspicious about the data provided. Furthermore the organization seems to work closely with KUKL which has an interest to gain money to improve its service (we hope that at least). Additionally funding for the huge Melamchi project (see chapter 10.1) is needed. Other sources provide a whole range of estimates for the per capita water demand in urban areas. After performing this intensive research on the water demand a final validated number for the total water demand in the urban areas of the Kathmandu Valley could not be found. Most realistic seems to be the assumption of an water demand of around a 100 litres per person per day. Additionally an urban population of about two million people seems reasonable. This would result in a total water demand of 200 MLD. It is important to mention though that this number is not based on any data (as probably most of the other estimates as well) and is just an idea of the project team taking the not representative conversations with local people into account as well as the official population estimate extended by the population growth rate of Kathmandu to reach a value for 2016. Another 20 % of population is added to take into account that most people have the impression the population of Kathmandu is underestimated.
The biggest issue in the Kathmandu Valley which has to be tackled as soon as possible is the excessive amount of lost water due to leakage. If that can be solved, the water demand can be reduced by incredible an 67 %.

6.3.4 Matching the availability and demand

When we simply compare the estimated urban water demand with the water available which is qualitatively good for drinking water, we can see that the availability is about 5 times higher than the demand. This is calculated by multiplying $12.046m^3/s$ (table 6.11) by 86400 s/d, and taking 200000 m^3/d as an estime for urban water demand. However, as discussed in detail in the sections above, there are too many uncertainties and simplifications to come to a representative conclusion.

In order to be able to do make a reasonable comparison between supply and demand in the Kathmandu Valley, a water budget is computed for the months of August and September of 2015. Details can be read in the corresponding chapter 6.4.

6.4 Water Budget August & September 2015

6.4.1 Methodology

This section will describe how the data for the water budget, the evapotranspiration and the precipitation were obtained.

6.4.1.1 Water Budget

A simplified water budget is computed for the 2-monthly monsoon period of August and September 2015 in the Kathmandu Valley. As the main focus of this project lies in the month of September 2016, this water budget lies somewhat out of the scope if this project. A lack of available ET- and precipitation data was the reason for not being able to compute the balance for September 2016. The reason for making a water budget for 2015, is to go through the process of doing so, and conclude where restrictions and opportunities lie for future water budget computation. The reason both August and September were chosen is because in 2016 the monsoon-rains went on through late September, as opposed to the end of August in 2015.

An overview of the considered in and outflows of water are shown in Figure 6.27a. The flux of precipitation, evapotranspiration and Bagmati outflow can be determined by data acquired from Nepal's Department of Hydrology and Meteorology (DHM). Because there is no data to determine values for groundwater extraction and groundwater recharge, these two flows are combined into a net groundwater flow (see Figure 6.27b). The upwards pointing arrow reflects the suspicion of groundwater depletion. A negative NG-value will mean that groundwater recharge dominates extraction. Computation of the water budget allows for solving of the unknown NG-value. Here it is assumed that the amount of water stored in valley does not change. In the form of an equation the water budget looks like equation 6.2:

$$P + NG = ET + BO \Rightarrow NG = ET + BO - P \tag{6.2}$$

6.4.1.2 Evapotranspiration

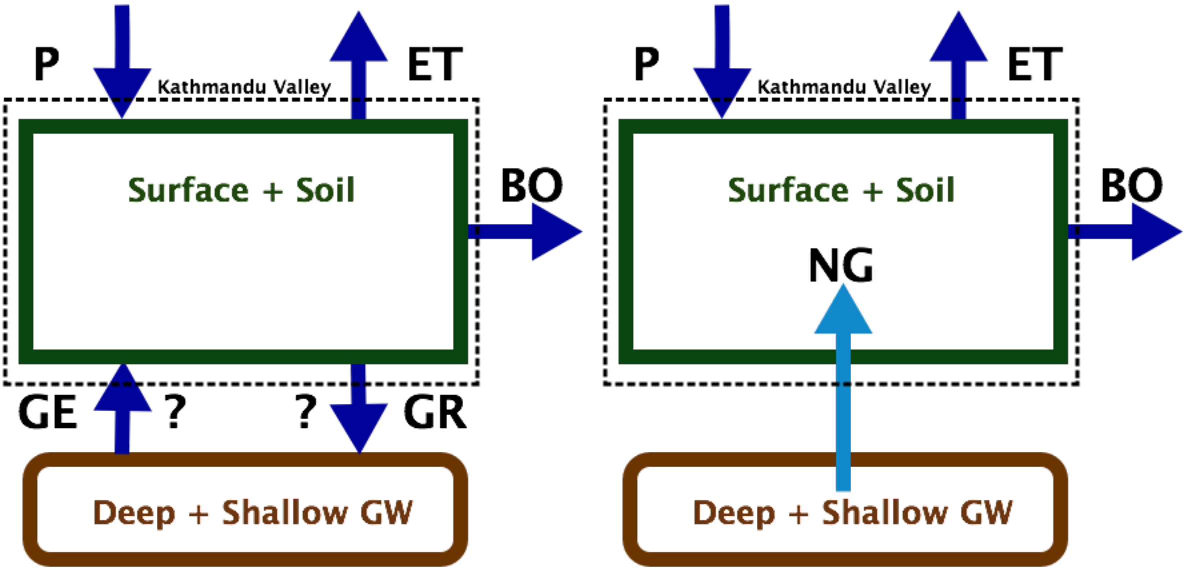
Several methods have been developed to estimate ET, for this project, the intial choise was using the SEBAL (Surface Energy Balance Algorithm for Land) [7] method. When this did not work out, Pennman Monteith was used to calculate the ET. The methodology for both is described here.

SEBAL. As the name implies, ET estimation by SEBAL is based on an energy balance which can be mathematically represented by:

$$R_{net} = G + H + \lambda E \tag{6.3}$$

Where:

- $\boldsymbol{R_{net}}$ is the nett radiation (W/m^2)
- $\boldsymbol{G}$ is the soil heat flux (W/m^2)
- $\boldsymbol{H}$ is the sensible heat flux (W/m^2)
- $\boldsymbol{\lambda E}$ is the latent heat flux (W/m^2)



(a) KTM Valley in- and outflows. (b) Simplified schematic of water budget

Figure 6.27: P=Precipitation, ET=Evapotranspiration, BO=Bagmati Outflow, GE=Groundwater Extraction, GR=Groundwater Recharge, NG=Net Groundwater Flow

The latent heat flux represents the energy needed for ET, which can then be translated into a more useful quantity like e.g. mm per day.

One of the things that make SEBAL an attractive tool, is the fact that the algorithm works solely with remotely sensed data as input, which is freely obtainable.

One of the downsides of the algorithm, especially regarding the scope of this project, is that it is originally designed for flat areas and cloud free conditions [7]. Both of which are not likely in the Nepalese rain season. However, UNESCO-IHE is currently working on an automated and improved version of the algorithm that is better suited to deal will cloud cover and altitude differences, and has recently provided us with their latest version in order to try it out. The automated SEBAL program is based on a python-script that uses an Excel spreadsheet to provide the program with the needed input data. The needed input for automated SEBAL consists of:

- A thermal and an optical satellite image, Landsat or PROBA-V and VIIRS.
- Digital Elevation Map.
- Meteorological data: temperature, radiation, humidity and wind speed.
- Soil data: soil moisture, field capacity, wilting point and depletion factor.

For the satellite images two options are available. The images can either be provided by a Landsat image, which contains both a thermal and an optical image, or by a combination of PROBA-V and VIIRS images. Landsat is probably the easier option of the two, but as Landsat images are only available every 16 days, one can choose to (also) use PROBA-V/VIIRS. Landsat-8 images have two thermal bands (10 and 11), which are used for computation of the surface temperature. The program gives the possibility to use either one (band 10) or both bands. There is no consensus on whether it is better to use one or two bands.

Automated SEBAL gives results in the form of a set of tif-files which can then be analysed easily with the help of GIS-software. Output data are categorized as follows:

- Biomass productions.

- Cloud-mask.
- Energy balance.
- Evapotranspiration.
- Meteorological.
- Radiation balance.
- Soil moisture.
- Vegetation.

As the results comes in images, they give a spatial distribution of a certain outcome-parameter over the area corresponding to that of the DEM or satellite image (whichever is smaller). There are two methods to ensure that the spatially distributed output is properly computed by the input-data. One can (1) use area-average values as input, or (2) use spatially distributed input. For all meteorological and soil input data, tif-files can be used as input.

Penman-Monteith. The fact of not being able to use the automated SEBAL program (as discussed in chapter 6.4.3.1) created the need for an alternative method to compute ET-values. An obvious solution was found in the Penman-Monteith equation 6.4 after Howard Penman and John Monteith. This equation requires only meteorological data as input and is used by the United Nation's Food and Agriculture Organisation (FAO) as the standard method for computing reference evapotranspiration [1].

The reference evapotranspiration (ET_0) represents the ET of a hypothetical grass reference surface with a fixed surface resistance of 70 s/m, a crop height of 0.12m and an albedo of 0.23. This resembles a surface of a well-watered, actively growing grass of uniform height. The computed ET_0 can then be adjusted to a real ET value by means of a crop-coefficient (K_c) which takes different crop types, growth stages, and local climatic conditions into account (equation 6.5).

The Penman-Monteith equations read:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{6.4}$$

Where:

$\boldsymbol{ET_0}$ is the reference evapotranspiration [mm/d]

$\boldsymbol{R_n}$ is the net radiation [MJ/m^2/d]

$\boldsymbol{G}$ is the soil heat flux [MJ/m^2/d]

γ is the psychometric constant [kPa/ C°]

$\boldsymbol{T}$ is the mean daily air temperature at 2 m height [C^{circ}]

$\boldsymbol{u_2}$ is the wind speed at 2 m height [m/s]

$\boldsymbol{e_s}$ is the saturation vapour pressure [kPa]

$\boldsymbol{e_a}$ is the actual vapour pressure [kPa]

$\boldsymbol{\Delta}$ is the slope of the saturation vapour pressure - temperature relationship [-]

$$ET = k_c ET_o \tag{6.5}$$

Where:

ET is the evapotranspiration [mm/d]

$\boldsymbol{k_c}$ is the crop-coefficient [-]

e_s is a function of the minimum and maximum air temperature (T_{min} and T_{max}) and e_a can be calculated by means of either the dew temperature (T_{dew}) or the minimum and maximum relative humidity (RH_{min} and RH_{max}). In case the RH_{min} data is unreliable it is possible to determine e_a with just RH_{max}, and when both RH_{min} and RH_{max} are lacking or unreliable, a mean value RH_{mean} can be used. However this is not recommended due to non-linearities in the computation.

Net radiation R_n is defined as the difference between the net incoming (shortwave) solar radiation R_{ns} and the net longwave radiation R_{nl} that is emitted by the earth. R_{ns} can be calculated with the albedo (α) and the incoming solar radiation (R_s) which can be measured. In case no measured radiation data is available, R_s can be manually calculated by means of parameters based on date, geographical location and the number of daily actual sun-hours. R_{nl} is a function of R_s and extraterrestrial radiation R_a which is also a function of geographical location and date.

The soil heat flux G is relatively small compared to R_n, especially when small time steps are used and when vegetations is covering the ground. That is why with time steps up to 10 days, G can be considered negligible [1]. In this case, ET calculations will be performed per day so G will be ignored.

Concluding, computation of ET_0 requires data on minimum and maximum air temperature, relative humidity, wind speed, and ideally incoming radiation. In case of great data scarcity, there exists an alternative version of the Penman-Monteith equation that only requires T_{min} and T_{max}, needless to say that this is far less accurate than the original equation and therefore not recommended.

Differences in ET between the grass reference surface and the actual crop(s) present are integrated in the crop-coefficient. Two variations of K_c are defined. The more simplified, single-component crop-coefficient and the more detailed dual-component crop-coefficient. For the latter, K_c is split up into two components, one accounting for crop transpiration and one accounting for soil evaporation. Based on the quality and available of data, and the required detail of the results, for this project the choice was made to use the single-component K_c.

Computation of K_c works in a similar way as the computation of ET. Standard K_c values can be found in table 12 of the FAO's Drainage and Irrigation paper [1]. These time-averaged values are based on non-stressed, well-managed crops in a semi-humid climate ($RH \approx 45\%$, $u_2 \approx 2m/s$). These standard values can than be adjusted to local climate conditions by means of available equations. Corresponding to the three main growth-stages of a crop, K_c is subdivided into $K_{c\ ini}$, $K_{c\ mid}$ and $K_{c\ end}$ (see figure 6.28). Adjustment of the standard K_c is based on equation 6.6 [1].

$$K_{c\ mid} = K_{c\ mid,tab} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3} \tag{6.6}$$

Where:

$\boldsymbol{K_{c\ mid,tab}}$ is the value for $K_{c\ mid}$ from table 12 of FAO Paper No.56

$\boldsymbol{u_2}$ is the mean value for daily wind speed at 2 m height with 1 m/s $\leq\ u2\ \leq$ 6 m/s

$\boldsymbol{RH_{min}}$ mean value for daily minimum relative humidity

$\boldsymbol{h}$ is the mean plant height

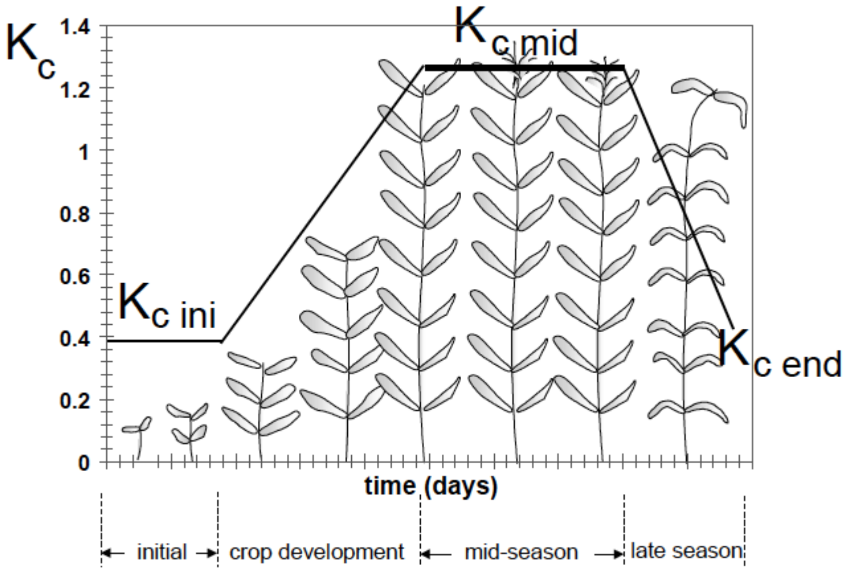


Figure 6.28: Generalized crop-coefficient curve for the single crop-coefficient.[1]

Normally, one would determine all three values, adjust them to local conditions, and then construct a K_c-curve in order to be able to determine ET in every stage of the crops growing process. However, because rice is the main cultivated crop in the Kathmandu Valley, and ET is computed for the monsoon-months of August and September when the rice is in the mid-season stage, for the purpose of this project only $K_{c\ mid}$ is determined. This assumption also excludes the need for a K_c-curve.

Because the ET is used for computation of a simplified monthly water budget of the Kathmandu Valley, the decision was made to determine one overall $K_{c\ mid}$, taking into account all the different landuses in the Valley. From now on this value will be referred to as K_c. The K_c is based on K_c-values for the six different landuse-classes which are then weighted over their corresponding area.

6.4.1.3 Precipitation

When looking at the water budget (Figure 6.27b), precipitation will represent the main inflow of water during the monsoon months. This section will discuss how the total amount of rainfall in the Kathmandu Valley has been estimated.

In the Valley, DHM has 20 weather stations capable of measuring rainfall (Figure 6.29. When looking at the figure, stations Khokana and Lele appear to be outside of the Kathmandu Valley. This is caused by the way the shape of the Valley is determined as being the watershed above the most downstream measurement station on the Bagmati river. This results in the map missing a little part in the South-West of the actual geographical valley.

For both August and September 2015, daily rainfall data was available for 18 stations, data for Budhanilkantha and Sankha was missing. Daily values were summed over the total 2-month period. For the two stations with missing data, an average value was taken of the 3 nearest stations. For Budhanilkantha these were Jethpurphedi and both Sundarijal stations. For Sankha these were Nagarkot and both Sundarijal stations. After determination of which stations lie in the 9 different subwatersheds, precipitation values of stations within the same watershed were used to compute an average precipitation value per watershed. By multiplying these average values with the corresponding watershed area, and dividing their sum by the total watershed-area, an area weighted average precipitation value for the whole valley was computed. This

Figure 6.29: Overview of DHM's weather station capable of measuring rainfall.

value can then be easily converted into the total volume of inflow originating from rainwater.

6.4.2 Results

This section will show the results of the performed calculations with Penman-Monteith as discussed in the section 6.4.1.2, and the computation of precipitation and Bagmati outflow. Next to that, the available and used data will be shortly discussed as well as its manipulation and required assumptions. Finally, the water budget will be completed.

6.4.2.1 Evapotranspiration

Reference ET. There is only one weather station in the Kathmandu Valley that is capable of measuring wind speed and radiation. This is the station at Tribhuvan International Airport, which is situated fairly centrally in the Valley. Therefore the ET calculations are solely based on data from this station and therefore it had to be assumed that the values are representative for the whole valley. Further on in the report, discussed data will refer to that of the Kathmandu airport, of the months August and September 2015.

The following data was available:

- Daily T_{min} and T_{max}.
- Two-daily RH at 3 AM and at 12 PM.
- Hourly u_2.
- Hourly R_s.

The daily T_{max} data was complete but the T_{min} data had 13 missing values. The missing values were added by means of linear interpolation. For relative humidity, where RH_{min} and RH_{max} are preferable, only values measured at 3 AM and 12 PM were available. The data did not show any consistency (see figure 6.30) and could therefore not be used as RH_{min} and RH_{max}. Instead it was chosen to take the average values and use these as RH_{mean}-values.

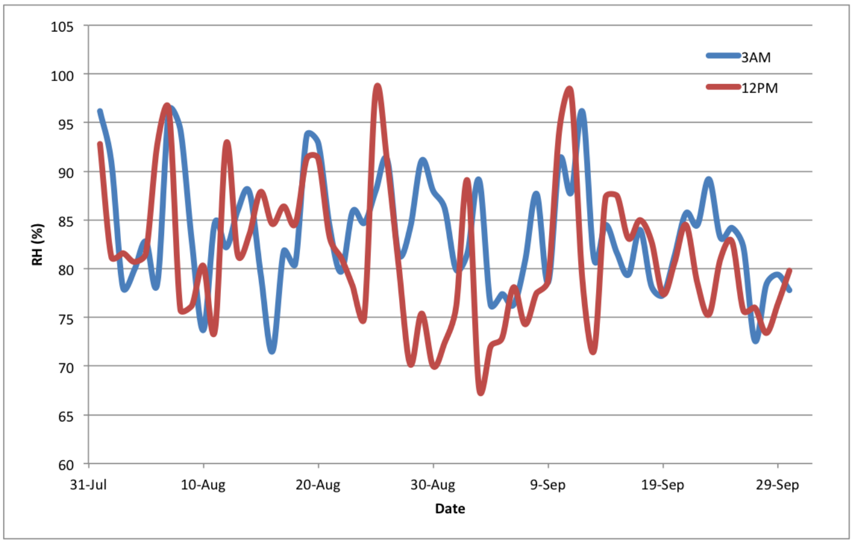


Figure 6.30: Relation RH measurements 3AM and 12PM

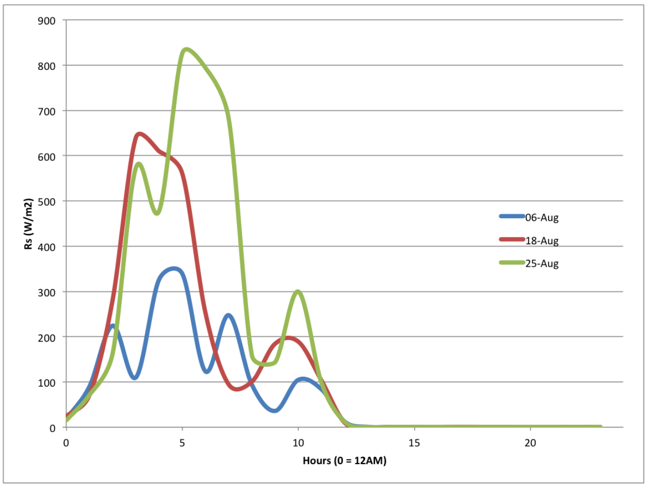
The hourly u_2 data was complete for both months. With a maximum value of 3.85 m/s and an average of 0.79 m/s, the values seem quite low, but the fact that no real wind has been noticed during the 10 week course of the project makes it plausible. Average daily values were computed for use in the ET calculations.

In the hourly radiation data, only 6 days showed complete data sets. Other days had up to 11 hours of missing measurements. The distribution of R_s over the day showed a very strange pattern Figure 6.31a). Incoming solar radiation seemed to be peeking between 3AM and 6AM and then be close to zero from about 12PM onwards. This is completely different from the normal pattern where R_s starts going up at sunrise, peak around noon, and then goes down to around zero after sunset (Figure 6.31b). This raises the expectation that the data set has a wrong distribution of hours over the day. It seems like what is said to be 12AM, should actually be around 6AM. The data also showed that all missing data was from 1PM onwards. Analysis showed that all values after 1PM where up to a factor 200 lower than values in the time frame of 12AM to 12PM. In computation of the daily sum, using all hourly values or only the values in the 12AM - 12PM range, showed a maximum difference of only 0.28%. Because an daily average is computed, it was decided to use only values in the 12AM - 12PM range, where actual solar radiation was being measured. This to prevent the average from being brought down by all (close to) zero values. Lastly, the data was converted from W/m^2 to MJ/m^2 as this is the required unit for the Penman-Monteith input values.

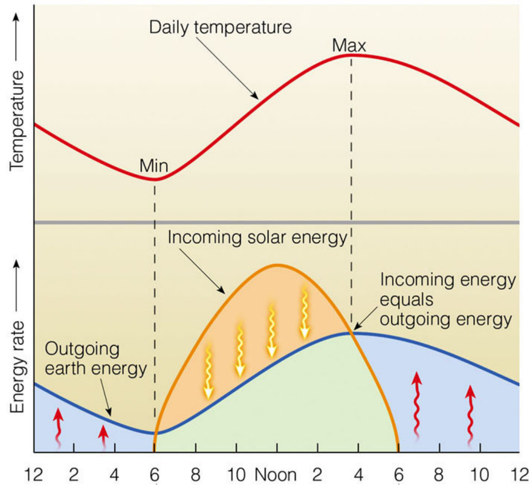
After analyses and manipulation of the data, daily ET_0 for the two months can be computed using equation 4.4. The results are visible in Figure 6.31c. Although not very convincingly, it can be seen that peaks are getting slightly lower towards the end of September. This is what is to be expected as solar radiation is getting less when moving away from the summer months.

Crop Coefficient. The result of the K_c computation can be seen in Table 6.17. As mentioned in section 6.4.1.2, a single crop-coefficient for the entire Kathmandu Valley is determined. Values are based on table 12 of FAO Paper No.56 [1]. The landuse classes are used to produce an area-weighted K_c. The following assumptions are made in computing the K_c:

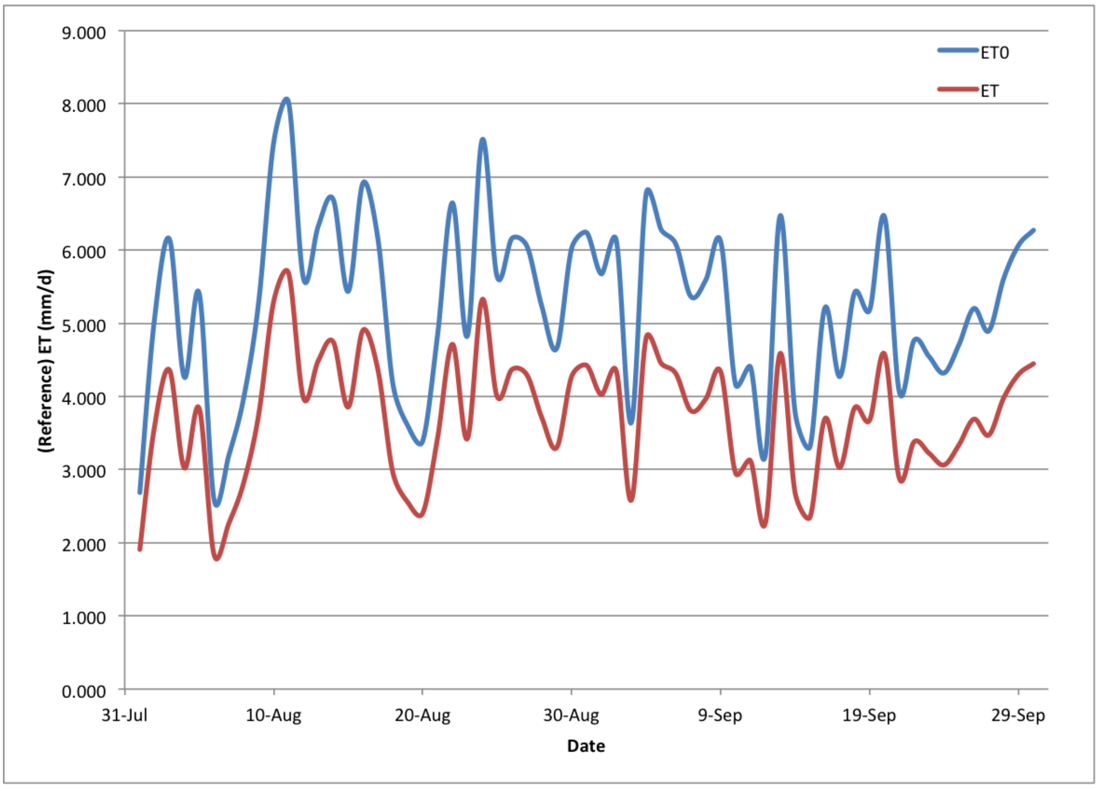
- The months of August and September lie in the mid-season growing stage of the crops.



(a) DHM radiation pattern of 3 complete daily sets



(b) Normal radiation pattern [84]



(c) Daily average ET and ET_0 of the Kathmandu Valley in August and September 2015.

Figure 6.31: Information about data sets concerning Reference ET

This is reasonable as the Valley's main crop, rice, has a mid-season growing stage of 60 to 80 days [1].

- The K_c for mixed planted is taken to be as a mix of maize, potato and turf grass.
- The K_c for deciduous forest is based on deciduous fruit-trees (stone fruit), an average between no ground cover and active ground cover was taken.
- Shrubland is a mix of deciduous forest and turf grass.
- The K_c for low developed area is 0.2.
- The K_c for high developed area is 0.05.

- The mean cropheight of rice is 1 m.
- The mean cropheight of mixed planted is 0.5 m.
- The mean cropheight of shrubland is 1.5 m.
- The mean cropheight of deciduous forest is 10 m.
- Daily average RH_{min} is assumed to be 75%, based on graph 6.30.

Adjustment of the standard K_c is based on equation 6.6[1]. As the mean value for daily wind speed is 0.793 m/s, 1 m/s was taken as this is the minimum value for the adjustment equation. The calculated adjustments are as seen in table 6.17. After multiplying the adjusted K_c-values with the corresponding areas and then dividing this by the total area of the Valley, the final area weighted crop coefficient is computed to be $K_c = 0.7148$.

Landuse Class	Kc_mid stnd	Kc_mid adjustment	Kc_mid adjusted	Area (m2)
Rice	1.2	-0.115	1.079	138609130
Mixed Planted	1	-0.093	0.902	99074348
Shrubland	0.9375	-0.130	0.801	65911087
Decideous Forest	1.025	-0.230	0.784	130877174
Low Developed	0.2	0	0.2	96084130
High Developed	0.05	0	0.05	56424565

Table 6.17: K_c determination and adjustment

After calculating the ET_0 and K_c, the ET can now be computed through equation 6.5. The course of ET over the months of August and September of 2015 can be seen in Figure 6.31c.

ET. By multiplying the determined daily ET-estimates with the total area of the Kathmandu Valley, values of daily evaporated water volumes can be computed. Summing up these daily values shows that in both months, a total amount of $133,3 \cdot 10^6\ m^3$ is estimated to have been lost by evapotranspiration. As will be discussed in section 6.4.3, this estimate is subjective to several uncertainties. That is why the value for ET will be rounded off to be $133 \cdot 10^6\ m^3$. The daily average estimate can then be computed to be $2.2 \cdot 10^6\ \frac{m^3}{d}$.

6.4.2.2 Precipitation

Results of the precipitation calculations can be seen in Table 6.18. The average area weighted precipitation in the Kathmandu Valley over the 2-months period is estimated to be 580 mm (or 9.5 mm/d). This amounts up to a total volume of $339 \cdot 10^6\ m^3$ rainwater that has fallen in the Kathmandu Valley during August and September 2015, or $5.6 \cdot 10^6\ \frac{m^3}{d}$.

6.4.2.3 Bagmati Outflow

All the streams and rivers in the Kathmandu Valley eventually end up in the Bagmati river, which is the only river flowing out of the Valley at the village of Chobar. Assuming that there is no significant outflow of groundwater and anthropogenic practices, this makes it the only outflow of water next to evapotranspiration. The most downstream flow gauge on the river is that at the village of Khokana. Because there are no big confluences downstream of Khokana, these measurements give a good representation of the amount of water that the Bagmati transports out of the Valley.

siteID	siteName	Total Precip Aug Sept 2015 (mm)	Watershed	Average Precip per Watershed (m)	Area weighted precip (m)	Total Precip Valley (m3)
1052	Bhaktapur	450.7	Hanumante	0.66	0.580	339000000
1059	Changunarayan	682.9	Hanumante			
1082	Nangkhel	704.7	Hanumante			
1043	Nagarkot	798.8	Hanumante			
1071	Budhanilkantha	772.8	Dhobi	0.79		
1039	Panipokhari	622.9	Dhobi			
1060	Chapagaun	237.3	Kodkhu	0.43		
1029	Khumaltar	276.2	Kodkhu			
1022	Godavari	503.8	Godavari	0.39		
1080	Tikathali	372	Godavari			
1081	Jetpurphedi	858.5	Bishnumati	0.62		
1079	Nagarjun	545.3	Bishnumati			
1030	Kathmandu Airport	641.4	Manohara	0.59		
1035	Sankhu	752.9	Manohara			
1073	Khokana	278.5	Nakhu	0.52		
1075	Lele	403.6	Nakhu			
1076	Naikap	446.6	Balkhu	0.43		
1015	Thankot	412.5	Balkhu			
1074	Sundarijal	834.3	Bagmati	0.62		
1077	Sundarijal	625.6	Bagmati			

Table 6.18: Calculation area weighted average precipitation of the Kathmandu Valley in August and September 2015.

As extensively discussed throughout this report, quality and reliability of data is a major issue. The same holds for acquisition of data by third parties. Historical flow data from the Khokana gauge was requesed alreday at the beginning of October, but we still had not received anything by the beginning of November. It has to be mentioned that local holidays made for October to be a difficult month to get anything done in Kathmandu that requires any kind of bureaucracy. However, during this time, people responsible had made several promises of sending us the data. Unfortunately this never happened. Reaching the deadline of finishing our report forced us to an alternative solution.

The alternative solution is to use the flow data that we collected in September 2016 as an estimate of the flow in August and September of 2015. The water budget will be completed using this estimate.

The flow rate of the Bagmati was measured to be 22.68 $\frac{m^3}{s}$ (see section 6.3.1.2). This value is assumed to be the average flow rate of the river over the 2 months. This means the total estimated volume of the Bagmati that flows out of the Kathmandu Valley is: $5,270,400\ s \cdot 22.68\ \frac{m^3}{s} = 119,532,672\ m^3$. As this is only a rough estimate, the value is rounded up to $120 \cdot 10^6\ m^3$ or $2.0 \cdot 10^6\ \frac{m^3}{d}$.

6.4.2.4 Water Budget

As can be seen in Table 6.19, the total balance of the in- and outflows show that the net groundwater flow amounts to $-86.0 \cdot 10^6\ m^3$. The fact the the value is negative implies that the direction of the flow is in the opposite direction as initially assumed. This means that there is a groundwater recharge flow of $1.4 \cdot 10^6\ \frac{m^3}{d}$.

In/outflow	Total Volume (10^6 m^3)
Precipitation	339.0
Evapotranspiration	133.0
Bagmati Outflow	120.0
Nett Groundwater Flow	***-86.0***

Table 6.19: Overview of in- and outflow values of the water budget.

6.4.3 Discussion

The Discussion will talk about the methodology for evapotranspiration, difficulties with the data and the uncertainties of the results.

6.4.3.1 ET Methodology

With the help of Tim Hessels of UNESCO-IHE, it was attempted for about two weeks to successfully compute ET values for the Kathmandu Valley. Unfortunately SEBAL proved not completely capable yet to deal with big slopes, resulting in too unreliable results.

At first, the ET was overestimated. The results displayed much too high values (up to 8 mm) in the densely urbanized centre of the Valley (Figure 6.32a). SEBAL needs a 'cold pixel' for computation of the sensible and latent heat flux. If this cold pixel is too cold, the latent heat flux will be overestimated and therefore also the ET. Ideally, SEBAL uses an open water body for the cold pixel. Despite the presence of the Bagmati and the Kulekhani-reservoir, SEBAL did not recognize this as open water, possible due to high sediment concentrations. Instead, the program selected the coldest vegetated pixel as cold pixel, which is too cold. The first attempt for a solution was to make the program use the mean-temperature vegetated pixel instead of the minimum. However, this did not help and the cold pixel turned out to still be too cold.

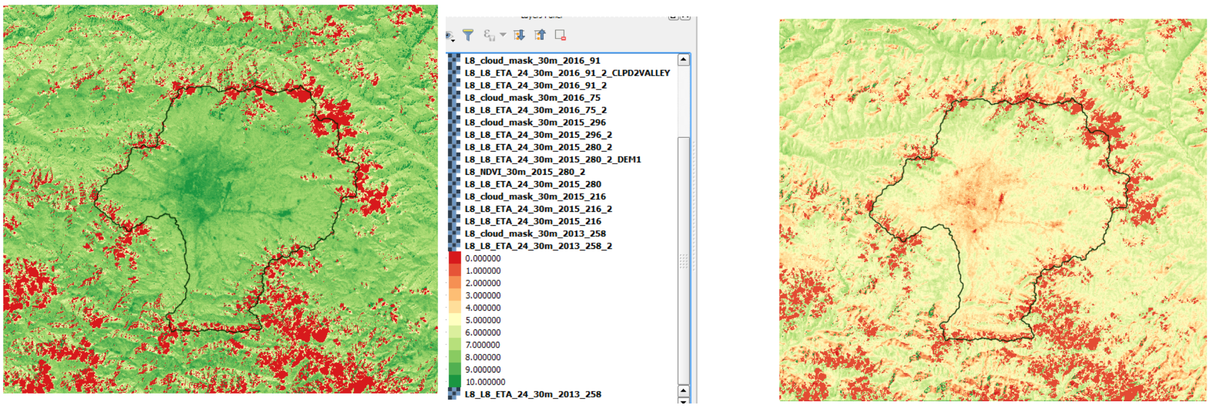
As expected, another problem appeared to be caused by some of the steep slopes around the Kathmandu Valley. The slopes caused a miscalculation in temperature, resulting in very low temperatures. An additional condition was added to the python script to account for this. The difference in results between before and after the change of the script can be seen in Figure 6.32. It can be seen that the computed ET values in the urbanized part of the Valley are way more realistic than before. However, now ET seems to be heavily underestimated in the many forest areas covering both the perimeter of the Kathmandu Valley, as well as areas outside of the Valley. It is suspected that the slope-correction is still not accurate enough.

A problem of a more general nature is the problem that is induced by cloud cover. Normally, automated SEBAL detects the clouds and the program will discard the cloud-covered areas, leading to NaN-values for those areas. Some types of cloud however are hard for SEBAL to detect (cirrus clouds for example) which can lead to wrong calculations.

At this point, it was decided that getting SEBAL to work properly for the Kathmandu Valley will take too much time. Another big limitation was the inability to acquire the needed meteo-input data for the wanted period, and the availability of low cloud-cover satellite images in the rain season. For these reasons, the choice was made to compute ET-estimates using the Penman-Monteith equation.

6.4.3.2 Data

Two main factors can be distinguished when looking at the uncertainty in the results, (1) quality of the used data and (2) the fact that calculations are based on valley-wide averages. The ET calculation are based on meteorological data from only one station (Kathmandu Airport) which



(a) Before

(b) After

Figure 6.32: ETA on 15/09/2013 as computed by automated SEBAL.

is located on the edge of the densely urbanized center of Kathmandu. Data recorded here might be quite different from data that would have been recorded in more rural areas that dominate the Valley. Besides the availability of the data, their reliability is also a point of concern. We do not have any information about the position and the condition of the measuring devices and the capability and involvement of the operators. One has to keep in mind that collecting quality data for research purposes does usually not have a high priority in developing countries.

The rest of this section will discuss the quality of the used data.

T_{min} and T_{max} : The data set for daily maximum temperature was complete. The set for daily minimum temperature had 13 missing values, which is quite a lot over a two month period. The missing values were added by linear interpolation between the available values. Although there did not appear to be anything wrong or unrealistic with the present values, the fact that 13 values were missing gives rise to some doubt about the general quality of the measurements as temperature is one of the easiest things to measure.

RH: Data on relative humidity was a big cause for uncertainty in the results. Reference ET computation by Penman-Monteith ideally requires RH_{min} and RH_{max} values calculation of the actual vapour pressure e_a, which is used for determining the net outgoing longwave radiation. A less accurate way is using only RH_{max} and an even less accurate way is using RH_{mean}. As RH_{min} and RH_{max} values where not available, RH_{mean} had to be used. Because RH was only measured at 3AM and 12PM, the mean was based on only two values. The measurement times also raise some question-marks. The normal pattern of RH over the day will have a minimum in the end of the afternoon and a maximum just before sunrise. The reason to measure at 3AM and 12PM seems quite random. Another good way of calculating e_a would be by using the dewpoint temperature T_{dew}. Unfortunately this data was also not available.

R_s: The data on incoming solar radiation also had some flaws. As also mentioned in chapter 6.4.1.2, the hourly data did not match the normal daily trend of incoming radiation. It is expected that the hours were wrongly presented in the data set. Apart from that, many days had a lot of missing values, especially after 12PM (which is expected to actually be around 6 or 7 pm). Because values between 12PM and and 12AM were decided to be discarded, these missing values did not impose a big problem in the end.

u_2: The set of hourly wind speed data did not have any missing values. It could be noticed however that the values were quite low. Although we did not feel any strong winds during our 10 week stay in Nepal, an average wind speed of 0.79 m/s is extremely low. Especially when the weather station is on the airport which implies there is a relative large amount of open space. Faulty wind speed measurements can easily be caused by poor positioning of the measurement device, and as we do not have any information on that, this is considered a fair possibility. This also means that it is not sure if the wind speed is actually measured at a height of 2 m. When asked, DHM's data-officer said that it was, but he appeared to be quite doubtful.

6.4.3.3 Results

As there is only one properly equipped meteorological station in the Valley, all values were used as if representative for the whole valley. It goes without saying that the results would be more representative if in stead of using valley-average values, it would be possible to compute e.g. ET estimates per region. This section will shortly address the plausibility of the final results of the water budget.

Apart from averaging and data-induced uncertainties, the biggest discrepancy is caused by the fact that precipitation and evapotranspiration estimates are computed for the year 2015, and the Bagmati outflow estimate is based on data from 2016. Although the period is comparable, duration and intensity of the monsoon-rains are hard to compare on a year-to-year basis. However the difference will not be an order of magnitude and it is therefore still considered to be a reliable estimate.

The results show there is a surplus of $86.0 \cdot 10^6\ m^3$ of water which flows into the ground as groundwater recharge (Table 6.19). To put this a bit in perspective, this would mean during the two monsoon-months, over the entire area of the Kathmandu Valley, 14.5 cm of water infiltrates into the ground. This result is deemed plausible.

Chapter 7

Interlinkages between water quality, flow and landuse

This chapter elaborates on relations between water quality parameters, flow and the different landuses upstream of the measurement points. These different focus areas were investigated in chapter 6. The chapter splits the analysis of the relations between water quality versus landuse and flow versus landuse in two sections.

Landuse classes which were expected to have a similar effects on change in quality and flow are grouped together in one class. This reduces the landuse classes to Developed (including high and low developed), Natural (including deciduous forest and shrubland) and agriculture (including mixed planted and rice). In order to find the most relevant trends of the data obtained, a correlation matrix (shown in Table 7.1) was made to prioritize the elaboration of statistical graphs and figures in this chapter. The number of field quality measurements taken was 58. This corresponds to a Pearson's critical value of a two tailed 0.01 confidence interval of 0.33 [58]. This implies that a significant relation between two measured parameters exists if the absolute value of the correlation coefficient between the two is larger than 0.33. Some relations with a high correlation coefficient are obviously trivial like the negative correlation between the percentage natural landuse and the percentage developed landuse and will not be discussed.

	RSA Class	%dev	%nat	%ag	lat	long	elev	temp C	ph	EC (uS/cm)	DO (mg/L)	Flow cm/s/km2
RSA Class	1											
%dev	0.85	1.00										
%nat	-0.82	-0.81	1.00									
%ag	0.71	0.62	-0.96	1.00								
lat	-0.20	-0.20	0.29	-0.30	1.00							
long	-0.57	-0.47	0.58	-0.56	0.13	1.00						
elev	-0.49	-0.32	0.53	-0.56	0.10	0.20	1.00					
temp C	0.67	0.51	-0.74	0.76	-0.15	-0.42	-0.66	1.00				
ph	-0.18	-0.13	0.17	-0.17	-0.39	-0.03	0.13	-0.21	1.00			
EC (uS/cm)	0.63	0.61	-0.67	0.62	-0.53	-0.58	-0.20	0.44	0.21	1.00		
DO (mg/L)	-0.71	-0.72	0.68	-0.57	0.19	0.24	0.32	-0.50	0.21	-0.67	1.00	
Flow cm/s/km2	-0.41	-0.38	0.47	-0.46	0.55	0.38	0.16	-0.33	-0.03	-0.49	0.35	1

Table 7.1: Correlation matrix of all the parameters obtained

7.1 Relation between water quality and land use

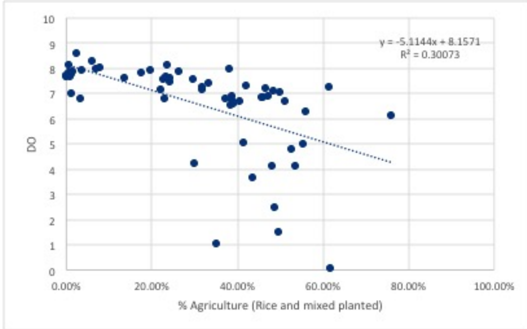
Water quality parameters that showed significant trends with landuse classes that were found using Table 7.1 include RSA, temperature, EC and DO. Furthermore correlations between water quality parameters themselves were investigated. The section will end with an intuitive visualization of the discussed changes in the quality parameters due to landuse, following the Dhobi sub-watershed.

7.1.1 DO and landuse

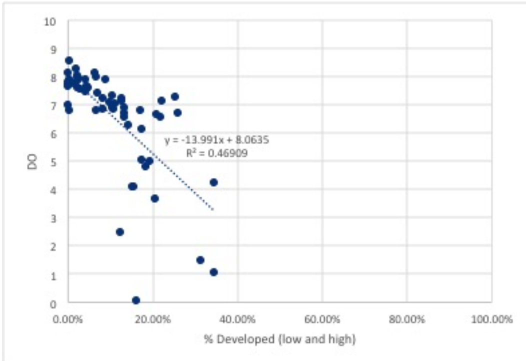
The landuse change that was expected to have the biggest impact on DO concentration was Developed land because this landuse would produce most waste (including sewage). In Figure 7.1, it can clearly be seen that the three different land uses have a direct influence on the dissolved oxygen in the water. This is as expected since agriculture and developed land pollute the water with matter that is either chemically or biochemically degradable, resulting in a higher oxygen demand in the water for the degradation processes. In natural areas, there is not much matter that reduces the DO levels, corresponding with the trend shown in Figure 7.1c. It means the organic matter at those measurement point is significantly lower.

This can be corroborated with the results of Figure 7.2c and the RSA classes descriptions. For the RSA classes with a high value, the water contains relatively more organic matter which causes an oxygen reduction. Figure 7.2b shows a similar thing: EC concentrations can only get such high values when non-natural ions are added, which can be by the inflow of sewage. This helps justifying why the DO concentrations decrease when the RSA Class increases: the dissolved ions in the increment are coming mainly from sewage discharges into the rivers. It can be seen that dissolved oxygen concentration stays above 6 mg/L until RSA Class 3. Only after this, the DO values can drop dramatically and their values are in a wide range.

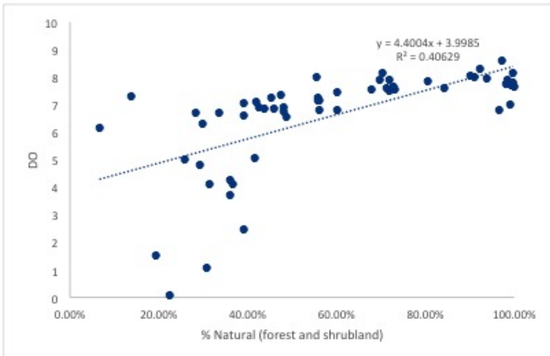
Figure 7.2c shows that in the fieldwork high temperature measurements link to low DO values. This corresponds to what was already mentioned in DO subsection 6.2.2: when the temperature of the water increases, it has a lower capacity to hold dissolved oxygen. This behavior can also relate to the RSA classes, for which at class 5 the water temperature on average is the highest and the dissolved oxygen the lowest. However, the parameter of temperature is not an independent parameter. It is codependent on altitude and percentages of forest shading the water. The more urban area, the lower the DO, but also the lower the altitude of the Valley and the less the percentage of forest.



(a) Influence of Agriculture on DO

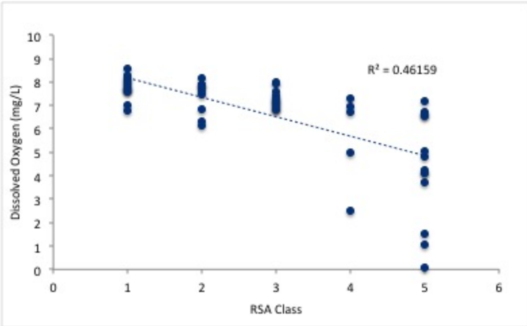


(b) Influence of Developed landuse on DO

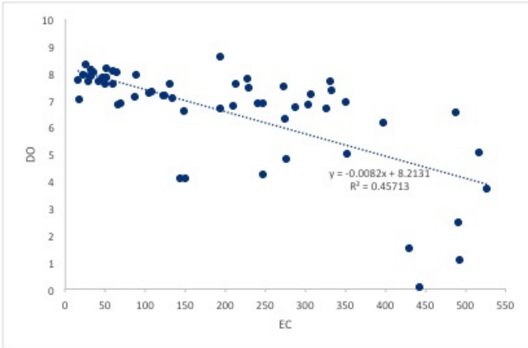


(c) Influence of Natural Landuse on DO

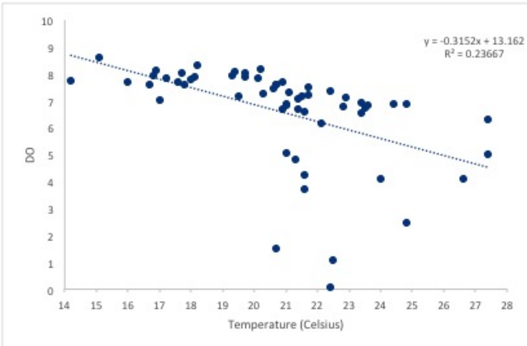
Figure 7.1: Respective concentrations of dissolved oxygen in the water set out against three percentual landuses of the watershed above the measuring location



(a) Relation between DO and RSA



(b) Relation between DO and EC



(c) Relation between DO and EC

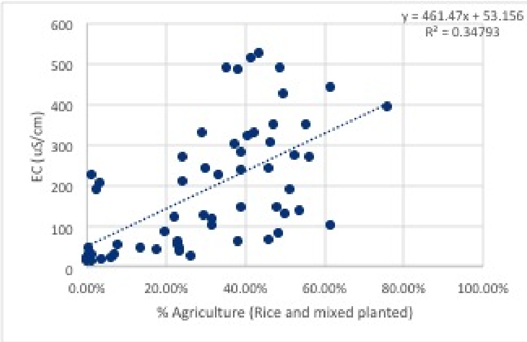
Figure 7.2: Relations between DO and other water quality parameters

7.1.2 EC and landuse

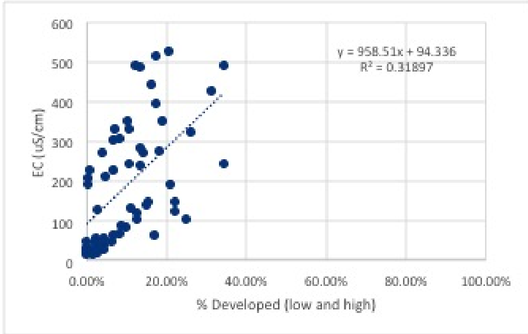
In Figure 7.3a and Figure 7.3b, a clear change in EC values can be seen according to the land use: increase in agricultural and developed land increase the EC values. Low EC values only appear when there is a low percentage of developed landuse and agriculture landuse. Relations can be discussed as follows:

- Agriculture land use land use tends to increase the EC values when it increases in area percentage, this could be explained by fertilizers and other nutrients present in the water for irrigation which increase the ionic concentration. Another explanation is that when agricultural percentages increase, so do the urban percentages including additional ions via the sewage. This relation is also confirmed in Figure 7.3b.
- When there is mainly natural landuse above the measurement point, the EC values are generally lower. For the natural land use, it has on average a bigger presence on the outer parts of the Valley, where developed land use is not significant and agricultural land use is low. This means that the previously mentioned EC-increasing contributors are less present. In case natural land use would contribute somehow to EC, this could be explained after precipitation events (which occurred during this project's field measurements). Heavy rain events would dissolve salts and infiltrate them into the ground, causing the underground flow to contribute to the rivers as the base flow. This would increase the EC since the salts cannot be filtered and retained through the soil.

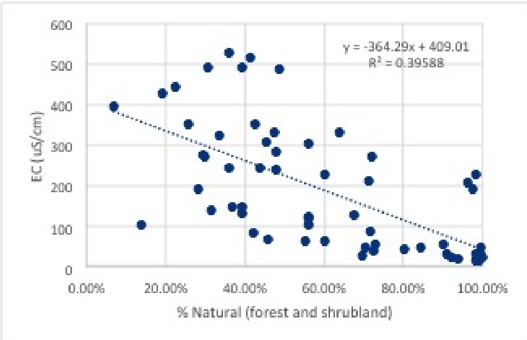
When looking at the relation between RSA and EC in Figure 7.3d, we see that EC values of higher than 400 $\mu S/\text{cm}$ only occur when the RSA class is 4 or higher. Naturally high EC concentration range up to around 300 $\mu S/\text{cm}$. An interesting correlation from the EC data is with the latitude and longitude. In Figure 7.3e it can be seen that values decrease when the



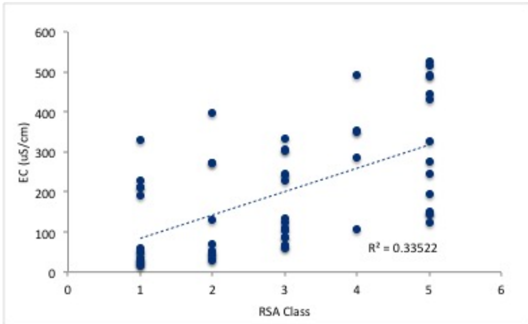
(a) Influence of Agriculture on EC



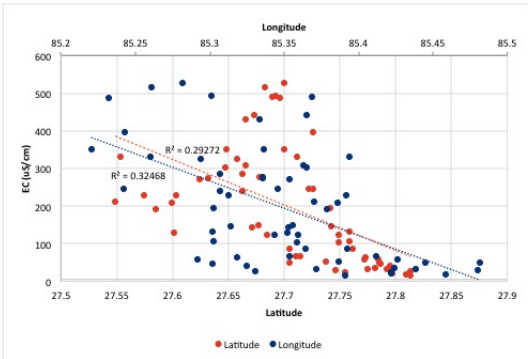
(b) Influence of Developed landuse on EC



(c) Influence of Natural landuse on EC



(d) Relation between EC and RSA



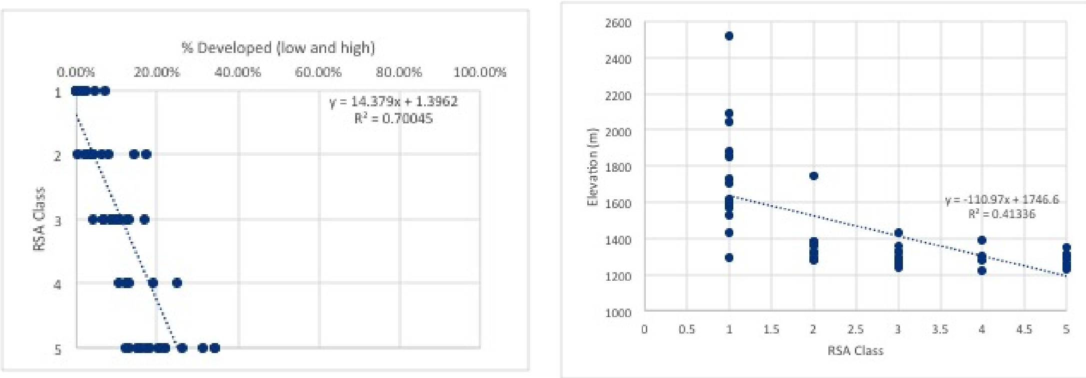
(e) EC change with respect to location in the Valley

Figure 7.3: Respective concentrations of EC in the water set out against two landuses (%)of the watershed above the measuring location (a,b,c) and the relation between EC, RSA and latitude and longitude (d,e)

measurement points shift to the east and north of the Valley. The explanation to this is can be found in the geological composition of the soils that contribute to the EC at the spring. The limestones in the south and west will increase the ions in the springs, while the marbelish geology in the north will not, which is explained in more detail in subsection 6.2.6. These explain the high values up to 300 for classes 1 and 2 that are seen in Figure 7.3d.

7.1.3 RSA and landuse

It was expected that the developed land would have the most significant impact on the RSA values in the stream due to urban waste. Figure 7.4a shows an even stronger relation then expected with a correlation coefficient of 0.85. From figure 7.4a it can be concluded that only



(a) Influence of Developed landuse on RSA

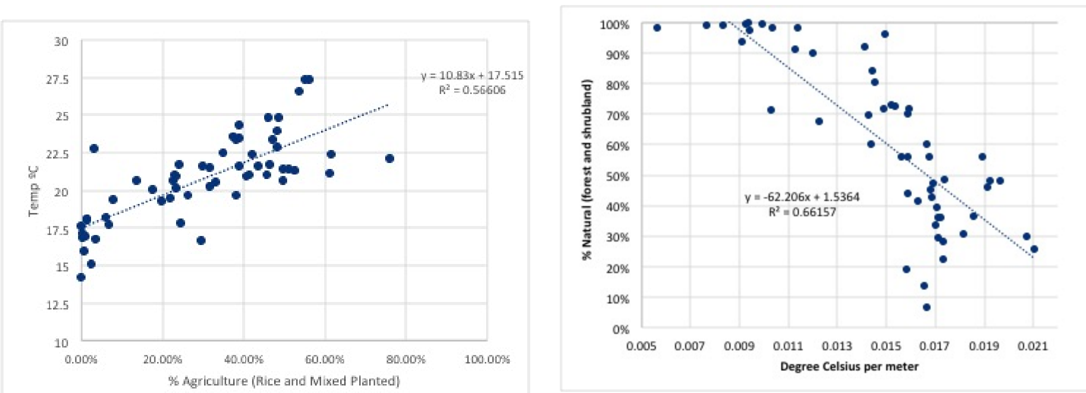
(b) Relation between elevation and RSA

Figure 7.4: Comparing developed landuse and elevation with RSA values of the measurements

with less than 10% of developed area, an RSA class 1 is possible. When the urban area of the watershed above the measuring point is less than 10%, the RSA class is still below 3. As soon as the percentage of developed area hits a 20%, the RSA classes are all a 4 or 5.

Another interesting relation that can be found is between elevation and RSA class. In figure 7.4b it is shown how the RSA class 5 measurements were all done at altitudes between 1200 and 1300 meter. This is the altitude in the center of the Valley, where most urban areas are located. The measurements with an RSA class of 1 vary in altitude, but 98 % are found above an elevation of 1400 meters, placing the measurements in the mostly 'green' hills at the edges of the Valley. This stresses again the big influence of developed areas on the water quality.

7.1.4 Temperature and landuse



(a) Influence of agricultural landuse on temperature

(b) Relation between percentage of natural landuse with the temperature normalized over the elevation.

Figure 7.5: Comparing agricultural landuse and elevation/forested areas with water temperature values of the measurements

Temperature is expected to be influenced by altitude, natural vegetation and agricultural land. Agricultural land is expected to have a positive correlation with temperature of the water because of irrigation techniques, which for rice mostly consists of flooding the fields with a thick layer of water that is exposed to the sun throughout the day. When looking at the relation of agricultural landuse and temperature in Figure 7.5a, indeed a relevant correlation is found with a correlation coefficient of 0.67. Elevation is a well known factor that directly affects temperature. The question arises whether the forest has a significant influence on the water temperature (due to shade), or whether this is just due to the fact that elevation and forest are closely linked because the hills at the edges of the Kathmandu Valley are mostly forested. In order to asses the influence of the forest, a graph with the percentage of natural landuse versus the temperature normalized over the elevation is shown in Figure 7.5b. This assumes a linear relation between temperature and elevation. The Figure shows a significant trend with an R^2 of 0.66, where indeed the temperature increases as the percentage forested land decreases.

A last observation about the temperature concerning the rising temperature as the stream distance to the spring increases: The measurements at higher elevation with the good water qualities were always done first in the day, ending up in the lower parts at later times that day. This could have an unwanted effect on the temperature analysis due to the heating of the streams during the day.

7.1.5 pH and RSA

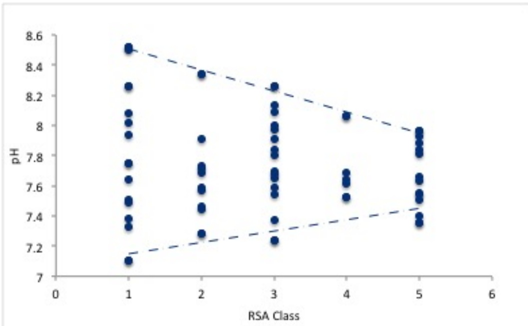
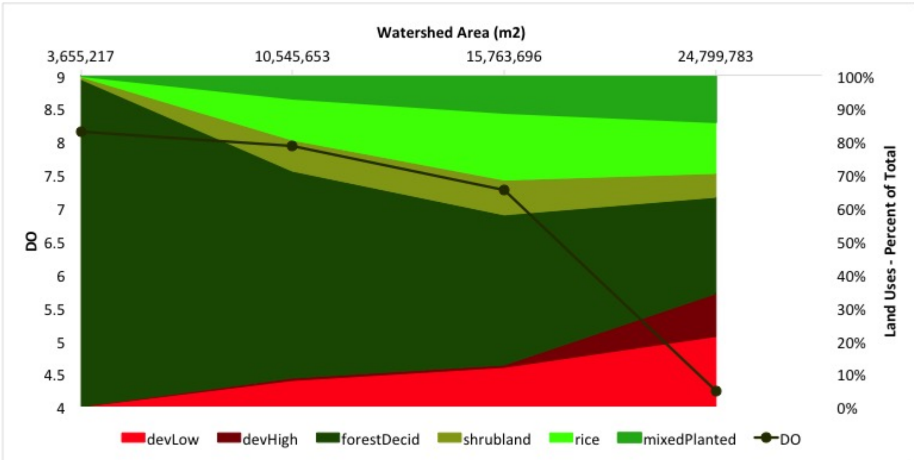


Figure 7.6: pH measurements with their respective RSA class

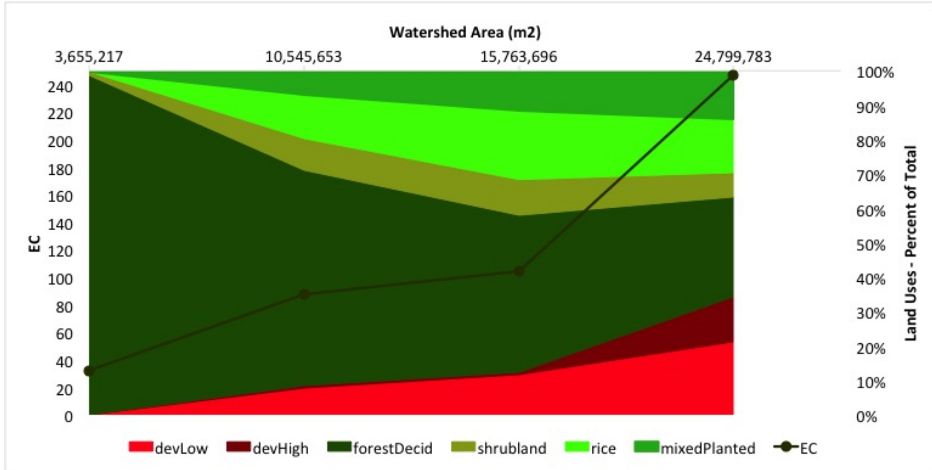
From Figure 7.6 it can be seen how each RSA class has a certain range of pH values that narrow when the RSA class decreases from 1 to 5. The correlation within the data is not good enough to base the conclusion solely on the data. However, since the results coincide with the literature review written in 6.2.4, the trend is excepted. Class 1 has a wider range, whereas class 5 has a very small range of values from approximately 7.4 to 8. This decrease in variability is attributed to an increase in the alkalinity in the RSA class 5 measurements. This alkalinity increment can be attributed to dissolved chemical compounds that can be formed by alkali metals and alkaline earth metals (sodium, magnesium, potassium and calcium are the common ones) that come from sewage discharges (e.g. detergents). In other words, these compounds create a buffer for the pH.

7.1.6 An intuitive visualization of water quality change due to landuse

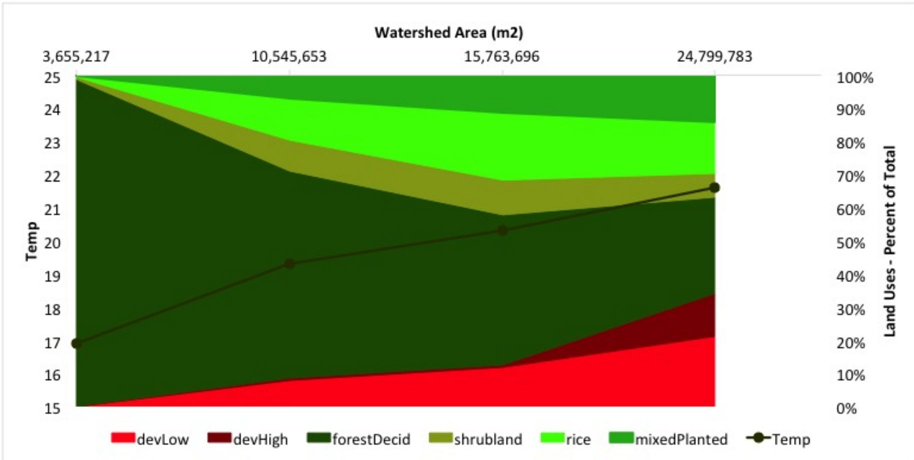
The Dhobi khola is the stream in the chosen sub-watershed which is followed from the spring to the outflow into the Bagmati river. Figure 7.7 displays intuitively the role of the different landuse classes on the parameters. It shows again the drastic impact of (high) developed area within the landuse classes on DO, RSA and EC. Temperature shows a gradual increase as expected.



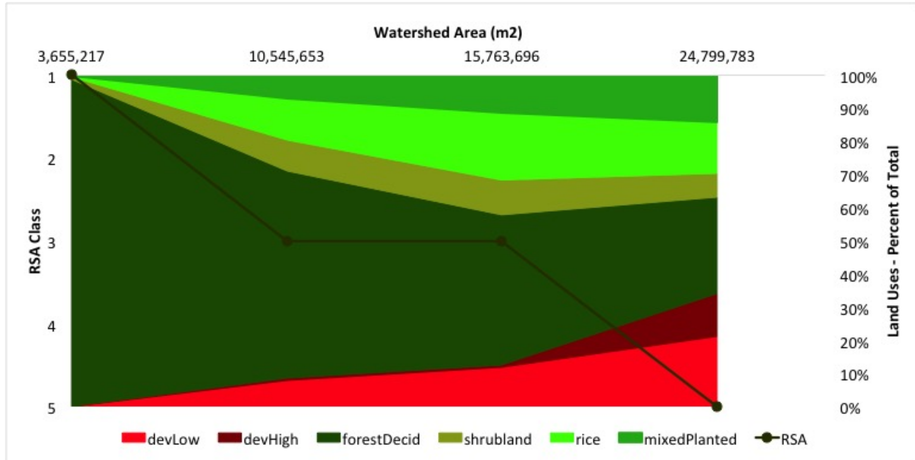
(a) DO



(b) EC



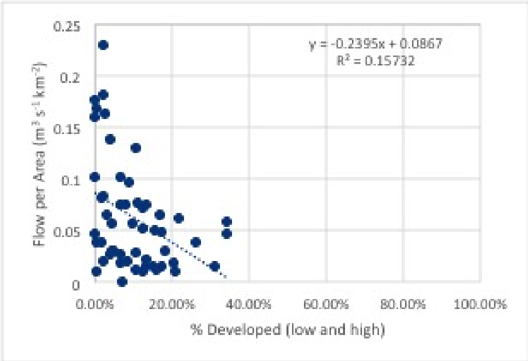
(c) Temperature



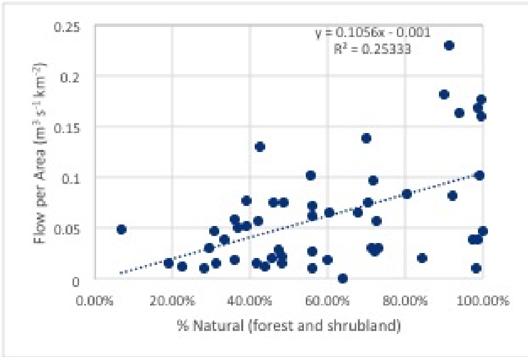
(d) RSA

Figure 7.7: Visualization of the change in water quality parameters along the stream of the Dhobi river, set out against the watershed area that supplies the measurement points. In the background are the percentages of the landuses of the upstream watershed.

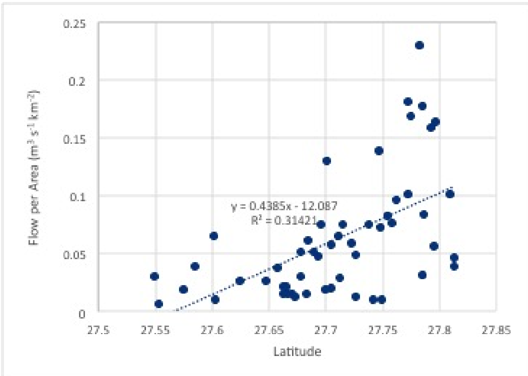
7.2 Relations between water flow and landuse



(a) Flow generation per area for percentage developed landuse



(b) Flow generation per area for percentage natural landuse



(c) Change of flow generation per area over latitude

Figure 7.8: Comparing flow generation per area over different parameters

The trends shown in figures 7.8a and 7.8b have a correlation coefficient of -0.38 and 0.47 respectively. The trend shows that relatively more flow is generated from natural (forested) areas then from developed areas. This makes sense with respect of the conceptual understanding of flow in the Valley, shown in Figure 7.9. The forested areas will allow more infiltration during rain events, creating a storage which is then released over a long(er) time period after the precipitation has stopped. Urban areas generate more runoff during rain events, but provide little flow to the stream in dryer periods. Since most of our measurements were not taken during rain events, it makes sense that the natural landuse generates more flow per square kilometer.

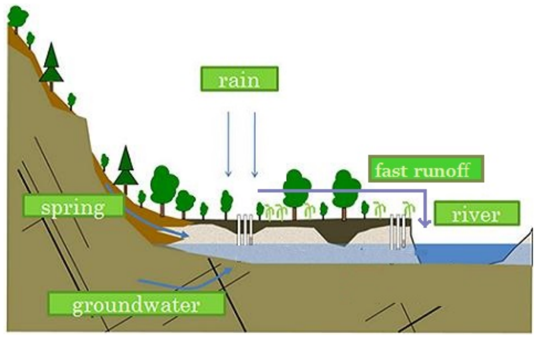


Figure 7.9: Conceptual model of runoff

Another observation is the flow generation per area that increases when the measurement points shift to the north of the Kathmandu Valley. From the collected data of the citizen scientists in the northern part of the Valley, precipitation is 3.15 times higher than precipitation collected by citizen scientists in Bhaisipati in the south of Kathmandu during the monsoon of 2016 . This precipitation change is mainly orographic, causing the forests in the mountains (which happen to be in the north) to generate more flow per square kilometer.

7.3 Conclusion

A short summary of the found relations in this chapter is given here:

- The EC values, RSA and DO are all sensitive to the presence of sewage discharges, and hence show a strong correlation with the percentage of developed land. DO drops as the RSA class worsens, while EC increases when DO and RSA worsens. The bigger the landuse coverage containing urban land, the bigger the drop. For an RSA class up to 3, the DO values stay above 6 mg/L. For RSA class 4 and 5, the DO values become spread out and can be within the range of 0 to 8 mg/L.
- EC values of higher than 400 μS/cm only occur when the RSA class is 4 or higher. Naturally high EC concentration can range up to 300 μS/cm. These high concentrations in very clean water are mostly found in the north-east of the Valley, where the geology influences the ionic concentration in the spring water.
- RSA has a very strong relation to developed areas, with a correlation coefficient of 0.85. Only with less than 10% of developed area an RSA class 1 was found. As soon as the percentage of developed area reaches 20%, all the RSA classes are 4 or 5, showing a very high sensitivity for urban development on water quality. RSA class 1's are found at higher altitudes (above 1,400 meters), indicating that they are all in the outer rims of the Valley, where little urban pollution has been added to the stream.
- Water temperature shows significant trends with elevation, percentage of natural (forested) landuse and agriculture.
- As the water quality gets worse, the variability of the pH decreases. At RSA class 5, the found pH values are all between 7.4 and 8, buffered by the alkalinity found in sewage.
- Higher flows are generated at forested areas than in the developed areas during the measurements for days without rain due to the storage capacity of natural lands.

Chapter 8

Conclusions

The water management of the Kathmandu Valley is an increasing challenge as the water demand is rising continuously while the water availability seems to deteriorate. Developing solutions requires proper understanding of the current situation, based on reliable data. However, the data gap is even bigger than expected and the data quality is far from satisfactory. This report contributes to closing this data gap on different fronts. Flow measurements as well as water quality measurements allow for a good evaluation of the surface water situation in September 2016. A very hopeful source is the use of remotely sensed data. Using satellite images, classified landuse maps were generated with an accuracy of 88%. As the landuse is an important influence on the water quality, understanding this influence can be helpful for further urban development planning.

The clearest linkage between the generated data is found between the land use and the water quality. As soon as the developed area covers more than 20 % of the watershed area, the quality of all the streams have deteriorated to a RSA class V. All the streams in central Kathmandu are therefore basically an open sewage and the water cannot be used without treatment. Even though it was expected that the developed land use would have the highest influence on the water quality, the deterioration was still surprisingly fast. The influence of developed land is also very significant on other quality parameters, increasing the alkalinity which buffers the pH, increasing the EC and minimizing the DO.

Higher up in the headwaters, a significant amount of water is available that is of better quality. A rough estimation tells that a total of $1.04 \cdot 10^6 \frac{m^3}{d}$ of water with drinking water quality flow through the streams in September 2016, which is about 5 times the estimated urban water demand. This might sound like a lot, but it needs mentioning that agricultural demand is not yet considered and streams should by no means be fully exploited, as this jeopardize other river functions.

Besides the use of satellite images for landuse classification, they have the potential to be used with SEBAL to determine evapotranspiration estimates. The initial goal was to create a simple water budget for September 2016 by deducting estimates for evapotranspiration and the Bagmati outflow from the incoming precipitation, thereby quantifying the net groundwater flow. However, The SEBAL model is not far enough developed to successfully handle ET-calculations in mountainous areas. Moreover, this analysis is hampered by the high cloud cover during the monsoon-time making this analysis still challenging. Penman-Monteith equation was used instead.

Due to data unavailability the water budget was computed for the months of August and September of 2015 instead. Evapotranspiration is estimated by computation of a valley-average reference ET and crop-coefficient. The total estimated ET in the months of August and

September of 2015 is $2.2 \cdot 10^6$ $\frac{m^3}{d}$. Precipitation was estimated at $5.6 \cdot 10^6$ $\frac{m^3}{d}$ and Bagmati outflow at $2.0 \cdot 10^6$ $\frac{m^3}{d}$. Results of the water budget showed a net groundwater flow of $1.4 \cdot 10^6$ $\frac{m^3}{d}$. This means that during these months the groundwater is recharged due to infiltration of rainwater. Before being able to comment on the expected depletion of groundwater, this analysis needs to be performed for the whole year.

All together this research is a step in the right direction to obtain an accurate overview of the water situation in the Kathmandu Valley and we believe that by continuing the measurements more and more reliable conclusions can be drawn about the water budget of the Kathmandu Valley.

Chapter 9

Discussion and Recommendations

9.1 Discussion

It is clear, even for the government, that the bad water situation is an issue that needs to be tackled. Section 10.1 describes the Melamchi project, which is generally believed to be the long awaited solution. The effectiveness is however doubtful. We are astonished that a project this big can be based on such poor data. This makes us highly suspect that the project is mostly a means of money generation for the Nepalese government, the Asian Development Bank or other parties involved. Money that doesn't necessarily benefit the people that it should benefit. This suspicion is amplified by numbers of The World Bank, showing that the level of corruption is still very high [65].

As visitors to the country, we were not directly confronted by corruption, but the lack of transparency drastically reduced the availability of data in comparison with the Western world. Cultural differences have a big role in this. On multiple occasions we have experienced that people have a big tendency to say "yes" to requests, even when they do not intend to follow up on that. Saying no seems to be considered as being too rude.

When looking at the measurements that were performed, it is important to note that this was in the monsoon period, meaning that the values can be very different in the other parts of the year. Even though all the measurements are taken at perennial streams and will therefore also flow in the dry season, their flows will be up to 70% lower. This makes that the values found in this project are not necessarily representative for the overall water budget.

The uncertainty of data is enlarged by the fact that climate change influences the Kathmandu Valley. As seen in section 3.3, the monsoon time is shifting significantly which implies increasing biases when using averages over previous years. Also rain intensities and evapotranspiration values might vary.

9.2 Recommendations

9.2.1 ET

Most added value to future ET-calculations can probably be achieved by the use of SEBAL (introduced in section 4), as this produces spatial data that is very conveniently analysed with the help of GIS-software. Therefore the main recommendation would be to stay in touch with UNESCO-IHE on the progress of the automated SEBAL development, and if possible maybe even participate in the process. Despite the fact that the program was not yet successfully applicable to mountainous areas at the time of this project, it was in a far stage of development and our contact at UNESCO-IHE was very eager to make it work. It seems very reasonable to assume that the program will have reached that stage within half a year. Especially when there are third parties (like us) who put effort into testing it.

One of the main problems however, even with using SEBAL, will be the availability of reliable and up-to-date meteorological data. As it is unlikely that Kathmandu will increase its capability in supplying qualitative data, it might be necessary to look for alternatives. The ideal alternative would be to collect the meteorological data ourselves. This would require equipment capable of measuring temperature, humidity, wind speed and radiation.

Depending on the required/wanted level of detail, having a better understanding on soil characteristics could increase accuracy of ET calculation. Therefore it can be recommended to either perform measurements on soil water content, etc., or do more literature research into soil characteristics in comparable areas.

Although this would not be a solution for computing a monsoon water budget, another recommendation would be to perform the same analysis in the dry season. Climatic factors are much more comparable on a year to year basis because there's simply no rain. This makes it easier to use data of the same period from, for instance, the year before (if available). It will also make it easier to find cloud free satellite images which are beneficial for using SEBAL.

9.2.2 Landuse

Different suggestions for further research to the landuse in the Kathmandu Valley can be made.

Firstly, it would be interesting to have a time series of landuse images, showing the landuse change over the last years. Landsat data for the Kathmandu Valley is available dating back to 1987. This is using different versions of the Landsat satellite, causing the need for different training maps and signature files, which can be a time consuming process.

Secondly it would be really interesting to investigate the influence of different classification approaches on the same remotely sensed data to compare the resulting landuse results. Proposed methods are to add a method of unsupervised classification to get a grasp of the number of different signature classes the computer could recognize in the Kathmandu Valley before using the supervised classification as used in this project to refine the results.

Another method that would be interesting to use for classification is the method of GEOBIA, which is not based on pixel-classification and is said to produce good results. Furthermore, this would allow a better comparison with the landuse map produced by [75] in 2010 because it would use the same method.

Recommendation for improving the results of the landuse map using the supervised-classification method as in the project are:

- Taking (many) more fieldwork measurements that can be used to draw really precise small trainings polygons and for a better validation. A number of 500+ ground measurements would be very useful.
- Including a threshold in the classification, which would result in having unclassified pixels as explained in section 6.1.5. This can be used to generate a landuse map with a higher certainty, or to analyse the sensitivity to errors of the different classes and improving the 'weakest' ones afterwards.
- When more fieldwork data are available, more subclasses can be reinstated again. It would be interesting to see if corn, greenhouses, fallow and wheat can be classified. Furthermore, it will be good to introduce a new subclass of medium developed area. The range of 30%-80% built up area in one class gives a very broad estimate. When analysing the landuse for dryer months, the class for barren land needs to be reintroduced as well. Classes that

can be left out at any time of the year are Evergreen Forest, Mixed Forest, Infrastructure and Wetland. Grassland and Parks can be aggregated.

- Including citizen science more in the collection of ground data.

9.2.3 Citizen science

J.C. Davids set up a database that can be filled with the help of a smart-phone application. This is used to involve citizens of the Kathmandu Valley in research. In the current set-up inhabitants of different areas within the Kathmandu Valley measure precipitation regularly. The set-up of the system, the input of the data via the application as well as the data handling is assessed to be extremely positive by the whole project team. During our fieldwork we could test the application for the collection of flow, water quality and ground truthing data.

A few recommendations can be made in order to further improve the use of Citizen Science. First it was evaluated that it is important that the local population stays motivated to collect the data. Besides a small financial compensation, the focus should be put on the intrinsic curiosity of the people and the option to improve their situation or provide them with useful data. Therefore it was thought of a small newsletter that informs the people involved about what is their data used for. The best way to reach the citizen scientists is via their smart-phone. Due to the fact that they are able to put in the data via the mobile application, they own a smart-phone with which they can receive the newsletter. A small thank you for their participation could already be enough.

Furthermore it was thought of a way how to include flow measurements in the Citizen Science idea. The measurements are fairly complex and require the use of special and expensive equipment like the FLowTracker in order to analyze the flow. The idea would be the following: The more measurements are taken with the help of proper equipment in one spot, the more precise the water level - discharge relationship gets. When these relationships are made for all the desired measurement locations, a citizen scientist only has to read out the value of the meter which measures the water level and the discharge can be determined. Of course some accuracy will be lost by that method, but it also helps a lot in gaining an overview of the water flows in the Kathmandu Valley. By the time the system is set up, the water level can be observed 'permanently'. The measurements were performed for the first time at most of the locations. The support of a citizen scientist will not be of great help at the moment. But already in a second cycle of flow measurements in the Valley, a meter to read out the water level should be affixed at all locations. The accuracy of a weir level - discharge relationship will be very little still after the second measurement, but can give at least an idea. Additionally the system can be set-up and citizen scientist can be found already. After the measurement are performed for the third time, the accuracy could already be quite decent. This could leave enough time to observe the water flows for one more year during J.C. Davids' research.

Furthermore, it should be taken care that this great set-up of involved people can be continued after the research of Mr. Davids is terminated on this field. As we have seen also in chapter 10, it is important to get contact to the population in the Valley. The bottom-up adaptation planning seems to be a promising approach to solve the water supply situation in the Valley. Moreover, the Kathmandu Institute of Applied Sciences (KIAS) set up a citizen science program to collect rainfall. A cooperation between Mr. Davids and the institute seems to be strongly recommended. Luckily during this research, contacts could already be established and the start seems to be quite fruitful.

9.2.4 Watershed Delineation

The method of watershed delineation suits its purpose and does not need further development. If it had been used earlier in the process however, it can be more beneficial. Delineating the proposed measuring location and doing the statistics on the land use can give an idea of the significance of the location.

9.2.5 Water quality

Water quality measurements is a very important part that can tell so much about water availability and its possible uses in a certain area. The four parameters measured and complemented by the RSA method gave a good and clear idea of how the water quality degrades as the rivers go downstream into the developed landuse (urban area), however the water uses assigned are not quite precise and are just recommendations for practical purposes.

In order to be able to assign more detailed an reliable water uses for the different rivers in the Kathmandu Valley, more parameters are recommended, however, it's important to mention that the technology and resources for doing this parameters are not easily found in Nepal, or are expensive compared to European countries. The proposed parameters that can help improve the water quality analysis in future projects in the Valley are the following:

- **Coliform test strips:** Coliforms themselves are not pathogenic or at least not likely to cause serious illnesses, but their presence in water indicate faecal contamination that might contain pathogenic microorganisms, like E. Coli, which can cause diarrhea and other enteric diseases. These strips only tell the presence of coliforms, but not the concentration.
- **Hardness test strips:** Hardness is an important parameter that tells the concentration of calcium and magnesium. Hardness on water is know to cause scaling when it is heated, damaging boilers, pipelines and others.
- **Nitrate and nitrite test strips:** This measurement can tell more precisely where the nutrients in the water come from, giving more data to relate to land uses.
- **Iron test strips:** Ingestion of high concentrations of iron can affect human health. The strips intends to tell wether the water could be iron-safe or would need a certain treatment for further drinking.

These are a few parameters than can be mentioned among many others that can also be done with test strips. These strips are found to be inexpensive, but some of them don't have wide ranges for mearusing and results cannot be numerically precise for finding more reliable statistical trends and correlations with other parameters.

9.2.6 Water flow

To get a better estimate of the perennial flow, the measurements need to be redone during the dry period.

9.2.7 Water budget

As computation of the water budget is based on quantification of all water flows, it goes without saying that the recommendations are linked to those of the relevant flows as well. When talking about making a water budget in the monsoon period, the main flow of water will be that of precipitation. Doing this project has proven that even something as relatively simple as qualitative rainfall data is not available for recent months. A good alternative in this case might be found in the use of citizen scientists. It does of course take time to set up a properly spatially distributed network. As mentioned in the recommendations for ET-computations, performing a water budget in the dry season would simplify things drastically. First of all there will be no rain, diminishing the inflow of precipitation. The lack of rain will also mean there will be hardly any active agricultural area, decreasing the impact of uncertainties in ET-calculations. The river flow will be more steady and can therefore be measured with less uncertainties accompanied by rainfall.

Chapter 10

Outlook

10.1 Future development: The Melamchi Project

Due to the depleting groundwater level caused by an overexploitation of the groundwater resources and all problems related to it, there are new ideas to use off-the-valley sources to satisfy the water demand in the Kathmandu Valley [48] [5] [3]. This resulted in the Melamchi Project, which plans to get water from outside the Kathmandu Valley into the city. The initial project consisted of six sub-projects of which some had to be abandoned due to economic and environmental reasons. Today's project idea contains now in the first phase a supply of 170 million litres per day (MLD) from the Melamchi River in the Sindhupalchowk district via a tunnel to the Kathmandu valley. In the second phase, an additional 170 MLD should be supplied by each the Yangri and Larke rivers, which are in proximity to the Melamchi river, via the same tunnel [5]. An overview of the situation is given in Figure 10.1. The Asian Development Bank stresses that the project comprises of (i) infrastructure development; (ii) social and environmental support; (iii) institutional reforms; and (iv) project implementation support [6].

Figure 10.1 shows the 26.6 km long tunnel from the intake point at the Melamchi river to its end at Sundarijal, with its water treatment plant (first phase). The almost horizontal red dotted line represents the intake of the two rivers Yangri and Larke (second phase). Additionally the project contains a bulk distribution network (blue line in the figure) with reservoirs (red squares in the figure).

Initially the project was supposed to be completed in September 2006 but poor construction management, a change of the main contractor, the earthquake and other issues, continuously delayed completion [62] [3]. The most recent monitoring report (from December 2015) states that 13.8 of the 26.6 km long tunnel are excavated.[5]

10.1.1 Group view of the Melamchi Project

The research about the Melamchi Project revealed a lot of fascinating facts, inconsistencies and challenges in the implementation of the project. The Asian Development Bank (ADB), the main donor of the project, seems to be concealing facts in order to make the project look more appealing. Especially the Environmental Impact Assessment (EIA), which is performed by several companies and summarized by the Asian Development Bank (ADB), gives the impression of an advertisement brochure for the Melamchi Project instead of an independent analysis of the environmental impact. In the following a selection of six major issues are presented in order to give an impression of what the above mentioned conclusions are based on.

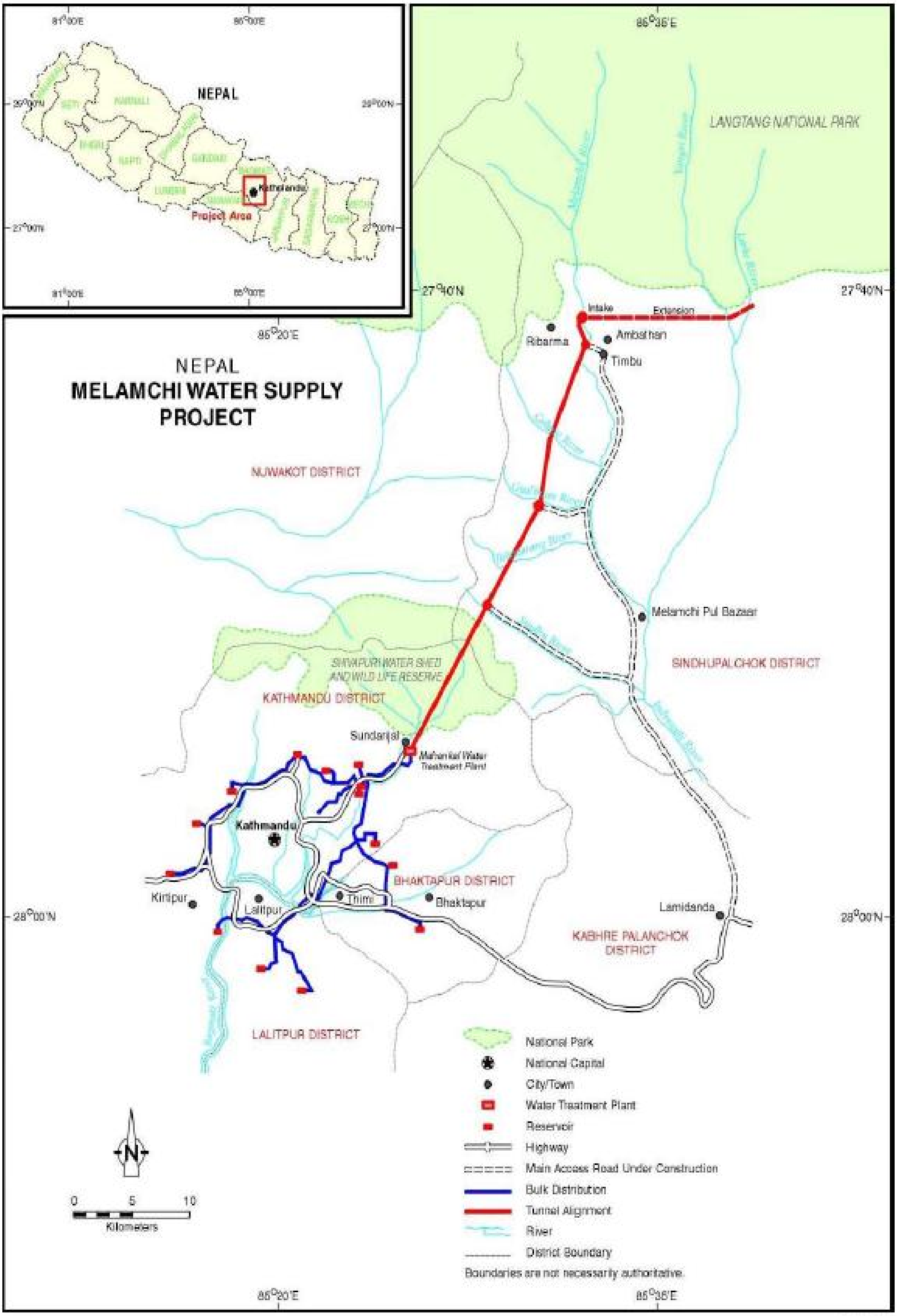


Figure 10.1: Melamchi water supply project overview

The ADB seems to conceal important information about the project. The official report of the ADB, which is a summary of EIAs performed on the Melamchi Project states that the residual flow in the Melamchi River is 45% of the original flow in case the full amount of 170 MLD is withdrawn [3].

The document of the Asian Development Bank includes a figure of The World Conservation Union of 1999 with the comment 'adjusted'. It shows that the residual flows of the Melamchi River in the month of March under full exploitation of 170 MLD (as planned) reduces from about 2'300 litres per second to just 200 litres per second. This is a residual flow of less than 10%. The original figure could not be found within the time of the project and the term 'adjusted' underneath the figure leaves unclear what was exactly adjusted. Additionally another source from 2008 can be found which states: 'the downstream release of water at a rate of 0.4 m^3 per second is not adequately justified' [33]. Taking again the full exploitation into account, the flow would reduce by more than 80%.

Finally the overall amount of environmental impacts stated by the ADB is 13, whereas one of the underlying EIAs identified and predicted more than 140 impacts [33]. This suggests again that the Asian Development Bank conceals the real content of the Environmental Impact Assessment in their summary.

The EIA cannot be taken seriously. The impact of only 45% residual flow in the Melamchi River is commented to be 'adequate to maintain habitats suitable for fish breeding' only because another river flows in the Melamchi 20 km downstream of the withdrawal point. The water level at that point is then allegedly adequate again. Regarding the 20 km stretch of the river with too little water for fish breeding, one can only find the comment 'river fisheries are already overexploited' [3], which leaves a feeling of uneasiness to us. Other environmental impacts are named but their actual effect on the environment is not described. For example, the 460'000 m^3 of rocky spoil from the tunnel have no negative influence (according to ADB) on the environment as long as they are deposited on safe ground and 'potential adverse aesthetic effects from the main trekking routes (i.e., disposal behind ridges or in local valley bottoms)' are minimized [3]. Some problems are treated in such a way that the government or the construction company have to pay compensation to private citizens, for example in case of loss of land or falling of trees [3]. However, a solution to the environmental problem is not offered.

A huge amount of real environmental issues is not taken into account at all. For example, how to prevent that fish get into the tunnel or what ecological impact has the enormous reduction of water in the remaining Melamchi river. It seems definite to us that the remarkable environmental impact is not only limited to the 20 km long stretch downstream of the withdrawal point. But even for that stretch they do not even do a prediction about the quality of the remaining water which will still be used by the local population for irrigation, households and drinking purposes. Finally, environmental impacts have simply not been analyzed in the ADB summary.

Environmental Issues of the additional phase two are not considered. Additionally to all this, the water reduction of the Yangri and Larke rivers are not at all analysed in the ADB report, even though the percentage of water withdrawal for these rivers will even be higher than from the Melamchi River (if that is even possible). This is stated as follows:

'The estimated percentage reductions in the Yangri and Larke rivers are indicated to be slightly higher [...] and hence, lower flow rates than those of the Melamchi [will result]. Additional hydrological analysis and environmental assessment including revised impacts for the Yangri and Larke schemes,

such as potential cumulative effects, are being undertaken in the revised [Melamchi Diversion Scheme] investigations.' [3]

The reason for the later time for analysis is that phase one and phase two are treated as different projects. Of course one could do so, but the problematic thing is that the Melamchi project without the additional withdrawal is not even sufficient for the water demand of the Kathmandu Valley. Furthermore, there are several dependencies between the sub-projects. For example the diameter of the tunnel of the Melamchi project is dependent on the final amount of water which should flow through it. This gives the impression that as soon as the first sub-project was agreed on, the second would follow anyway regardless of the environmental impact.

Wrong timing for the setup of management and controlling programs. Some good programs or ideas are mentioned in the EIA that could compensate for the loss of people's homes, the falling of trees and the lesser water supply for the population downstream of the withdrawal point. There was also a plan made to protect the river and the fishery, mentioned as:

'A project-assisted, river, water use, and fishery management program is planned [and] [...] will be set up during construction' [3].

The problem is that these programs 'will be set up during construction'. From our experience in the construction sector, all expenses must be defined far before the construction phase of a project. At a stage in which all contractors are set and the budget is fixed, it is very unlikely that for example a fishery management program is set up.

'Any replacement afforestation required by the Department of Forestry will be negotiated and implemented during the construction phase' [3].

Furthermore replacement for fallen trees will not be negotiated during the construction phase anymore. At that stage it is already decided which trees have to be felled. The executing party will therefore not start negotiating about the price anymore as it has no alternatives to the determined plan which puts the executing party in a very bad bargaining position. The financial situation of the project makes the situation even worse. Due to the fact that massive financial cuts in the project plan had to be accepted in order to realize the project with the money from the ADB, responsibles are not expected to pay any replacement afforestation efforts. Especially not in a country in which people obviously do not care about environmental protection. These facts give the impression that the ADB summary of the EIA tries to appease environmental organisations or opponents of the project by mentioning these programs, knowing at the same time that they will never be established.

In order to prevent miscommunication, planning and construction mistakes, and costly delays, it is indispensable to involve stakeholders and the local population as early as possible. Together with these parties one can set up realistic management and controlling programs which benefit the losers of the project. The citizens and other stakeholders have approached too late, which causes conflicts and maybe results in inadequate or incomplete compensation and protection programs.

Poor organizational structure for environmental monitoring programs. The organizational chart for the specific people, government bodies and NGOs being responsible to guarantee the implementation of the various programs mentioned, is very complex. One would not be surprised if it turns out to be like the responsibility problems regarding the water supply in the Kathmandu Valley as described in chapter 3.1.2: No progress can be recognized and the different parties hinder each other in working effectively. This point is strengthened by the fact that other donors of the Melamchi Project 'have made conditional a series of institutional reforms to be made to the government agency currently managing drinking water supply to the Valley' [9].

Water in the Kathmandu Valley - the unsolved issue. There are thousands of challenges that still have to be tackled in the Kathmandu Valley itself. For example, the treatment plant at Sundarijal which is part of the first phase, is only able to treat 85 MLD [63] of at first 170 MLD and later 510 MLD, due to crunches in the budget. It is still unclear how the rest of the supplied water is handled [76] but treatment is necessary to get potable water from the supplied raw water [63]. The other 21 treatment plants in the Kathmandu Valley can handle all together another 85 MLD [4]. Therefore, the amount of treated water will be far below the demand. But even if water treatment facilities are sufficient, the piped network within the city is in such a bad shape, that the water loses its potable water status by being pumped in the distribution network [76] [4].

Local treatment facilities could support a long-term solution [4]. But still the distribution network is in a really bad shape. Water treatment plants are not working properly and a sewage system is mostly not existent nor does it meet the requirements for a hygienic waste water handling [34]. Furthermore no information could be found on how the additional water in the Valley will be diverted to the outflow of the watershed. The imported water will be four times as much as the Bagmati river carries during rainy season at Sundarijal. Are the riverbeds of the Bagmati able to carry that much water out of the Valley?

Concluding Remark Overall the Asian Development Bank report gives the project a negative connotation. One can get the impression that certain organizations want the project so badly that they do not fully consider its consequences. However, these consequences may lead to new, serious problems. Certainly the project has a huge amount of advantages in case it can be implemented successfully. But the risks of making the situation worse are very high. Already the delay of currently ten years, the weak organizational structure and overall project management as well as the unrealistic assessment of the social and environmental impact of the project lets the reader doubt that the Melamchi project can solve the drinking water issue in the Kathmandu Valley. This might be the reason why The World Bank withdrew its financial support on the project. Unfortunately, it was not possible to get a statement of The World Bank on their withdrawal from the Melamchi project during the time of this research.

From the research that was done, one got the impression that people rely too heavily on the completion of the Melamchi project. Everyone imagines a future where the pure drinking water is supplied from the neighbouring valley, all water problems in the Kathmandu Valley are solved and 'health and well-being of the people' [3] is improved. The pride about this outstanding project may be the reason why some of the information is presented misleadingly.

'The Melamchi Water Supply Project is one of the most important projects for the Government of Nepal and has been declared a National Pride Project reflecting the high priority attached to it. The

Project is financed by the Asian Development Bank (ADB) and ADB also attaches very high priority to this project' [40].

10.2 Impact of our work

Even though time restrictions are a big limiting factor on the scope and reach of our project, we do aim to produce results that might be useful for third parties and/or will be used in further research. This section will discuss that aim and explains what we hope that the impact of our work will be.

As this project is done for, and in collaboration with Ir. J.C. Davids, who is doing a PhD research on the groundwater availability in the Kathmandu Valley, our primary aim is to produce something that he can use in his research. Although the desire of giving this project a personal twist has led to the scope of this project being slightly different from that of Davids' research, we do think that our work can complement his. The data obtained from a month of monsoon flow measurements for the perennial springs in the Valley will no doubt be useful in the computation of a water balance. The measurements of, and links between land-use and water quality will be useful in determining where and how the water quality reaches a certain threshold level. This information can be used in addressing the alarming qualitative state of open water sources in the city, which might become more important as groundwater resources are kept being used in an unsustainable manner.

As this was the first time that a project was carried out as part of TU Delft's MSc multidisciplinary project, we mostly hope that our work will be seen as a starting platform and that it will encourage new groups of TU Delft students to follow our footsteps and continue doing research on water availability in the Kathmandu Valley. Of course this implies that after the project we want to take an active role in making more students enthusiastic in doing so.

A succeeding group of students could for example aid J.C. Davids in computing a water balance in the dry season, which would give an estimate of the minimum water availability in the Kathmandu Valley. Furthermore, much more research can be done to get a more detailed picture of the Valley's water demand. Even though we have made some connections with people involved in Kathmandu's water governance, due to the lack of detail in our current research, we do not expect our work to have any impact at this stage. However, we do sincerely hope, that our work and hopefully that of groups to come, will have a small contribution to Davids' research and that this will be used for decision making by Kathmandu's government in order to achieve more sustainable water resources management, thereby improving security of qualitatively good water for the increasing population of the Valley.

Chapter 11

Group evaluation

This chapter will reflect on the group dynamics and lessons learned during our time in Nepal.

In general we are very satisfied about how the team was able to work together. Some of us did not know each other before coming to Nepal, but the atmosphere within the group developed, and we did not find it hard to reach consensus when needed.

Our first week mainly consisted of group meetings, where we sat down together with our local supervisor in order to fine tune our research goals and scope of the project, make a division of tasks, talk about our personal goals and expectations, prepare for the weeks to come, and getting to know each other better. The meetings were properly prepared for and well documented. As due to some of us being abroad during the run-up of our project we had never been able to really sit together. We found it extremely helpful to have a couple of days like this and noticed that our motivation, together with having a consensual insight in the scope of the project, quickly rose. The results of the week was a clear list of project-goals, division of tasks and corresponding deadlines. Besides the working tasks, we also had every day two hours of Nepali language course during the first week. The challenge to learn a new language and the playful approach was a great team building experience.

The following four weeks were dedicated to doing fieldwork. This was a particular exciting part of our project as non of us had any experience in doing fieldwork. The first field-week we decided to all participate on a daily bases so that we would all gain the necessary experience and get sufficiently familiar with the different measurements that had to be taken in the field. The week ended with a 4-day fieldwork trip in Shivapuri, a national park in the north of the Valley. The whole team including supervisor and Nepalese colleagues participated, allowing everyone to get familiar with the field-work team. During the following three field-weeks, we established a more efficient way of working in which we rotated the team-members going into the field. This so that we would be able to start with the theoretical work that needed to be done, and start working on other activities that did not need our field-data. Initially we participated in the field work with three people of our group while the other two started working on the theoretical parts of the project already. To make the progress even more efficient, we managed to perform the field work with only two people after some time while three could take care of the non-field work. Frequently we had a meeting to discuss our progress and possible improvements. The field-weeks were succeeded by one week of initial data-processing.

After this we had planned a two-week break in which we took some time to explore some of the beauty that Nepal has to offer and would also be able to do some bonding as a team. A trek in the Nepalese Himalaya proved to be a very good way in achieving these goals. Of course we also took advantage of the surroundings in trying to learn something about hydrology in mountainous areas.

The last two weeks of our project were completely dedicated to finishing the analysis of the obtained data, and report-writing. Again, we had some group meetings to keep each other up to date on the made progress, and discuss the conclusions to be drawn from our work.

We are also happy about how the multidisciplinary aspect of the project was incorporated. The team consisted of two students of hydraulic engineering, and three of water management, of which two follow the track of hydrology/water resource management and one follows the track of sanitary engineering. Performing and assessment of stream flow measurements to see how flow changes over the course of the rivers falls definitely within the scope of the fields of hydrology and hydraulic engineering. Assessing land use, water quality and linking this to stream flow of course involves the fields of sanitary engineering, hydrology and water resource management. It was clear that our combined knowledge in combination with the skill-set obtained over our years at TU Delft, ETH Zürich, University of Amsterdam and Tec de Monterrey, provided us with a very good basis to tackle most problems we encountered. Whenever we had doubts, the experience and knowledge of our supervisor J.C. Davids provided the needed additions.

Next to learning a lot from working as a team of students, more or less disconnected from the university, doing this project in a developing country like Nepal was also an educational experience. Differences in culture and habits force one to be flexible and resourceful. It goes without saying that occasionally we had to reopen discussion on the feasibility of reaching certain project-goals and deadlines.

All in all we really enjoyed our work in Nepal and the way the team-dynamics evolved and improved along the course of the project. We appreciate that TU Delft gives us this unique possibility to perform such a project within our master curriculum.

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Appendix A: ADB-Kathmandu Valley Water Supply and Wastewater System Improvement

Capital Investment & Asset Management Program
(CIAMP)

ANNEX E

Water Supply Demand Projections
for
KUKL Water Supply Service Zones

WATER DEMAND CALCULATION - CONSTRAINED SUPPLY ZONE A - KATHMANDU METRO					
S.No.	**Item**	**Year**			
		2010	**2015**	**2020**	**2025**
1	Total population (permanent, projected)	1,502,949	1,882,445	2,186,137	2,559,722
2	Percentage of permanent population served	70	80	90	100
3	Permanent Population served	1,052,064	1,505,956	1,967,523	2,559,722
4	Temporary population	556,539	678,629	784,064	924,317
5	Percentage of temporary population served	30	40	50	60
6	Temporary population served	166,962	271,452	392,032	554,590
7	Domestic water demand (in liter per capita per day)				
7.1	Fully plumbed households				
	Per capita water demand (l/d)	100	110	120	135
	Percentage of population served (% of item no. 3)	**50**	**60**	**65**	**70**
	Average daily demand (ml/d)	52.60	99.39	153.47	241.89
7.2	Yard connection				
	Per capita water demand (l/d)	45	55	55	70
	Percentage of population served (% of item no. 3)	**40**	**30**	**30**	**30**
	Percentage of population served (% of item no. 6)	**20**	**25**	**30**	**40**
	Average daily demand (ml/d) of permanent population	18.94	24.85	32.46	53.75
	Average daily demand (ml/d) of temporary population	1.50	3.73	6.47	15.53
	Average daily demand (ml/d)	20.44	28.58	38.93	69.28
7.3	Stand post				
	Per capita water demand (l/d)	45	45	45	45
	Percentage of population served (% of item no. 3)	**10**	**10**	**5**	**0**
	Percentage of population served (% of item no. 6)	**80**	**75**	**70**	**60**
	Average daily demand (ml/d) of permanent population	4.73	6.78	4.43	0.00
	Average daily demand (ml/d) of temporary population	6.01	9.16	12.35	14.97
	Average daily demand (ml/d)	10.74	15.94	16.78	14.97
7.4	Total domestic demand (ml/d)	83.79	143.91	209.18	326.15
8	Non-domestic demand (ml/d)				
	Percentage of domestic demand (% of 7.4)	8	10	12	15
	Average daily demand (ml/d)	6.70	14.39	25.10	48.92
9	Total water demand (ml/d)	90.49	158.30	234.28	375.07
10	Leakage and wastage (%)	40	35	30	25
	Amount of water lost due to leakage and wastage (ml/d)	60.33	85.24	100.40	125.02
11	**Total average daily demand**	**150.82**	**243.54**	**334.68**	**500.10**

WATER DEMAND CALCULATION - CONSTRAINED SUPPLY

ZONE B - KATHMANDU NORTHEAST

S.No.	Item	Year			
		2010	2015	2020	2025
1	Total population (projected)	176,583	240,041	311,730	420,469
2	Percentage of population served	60	70	80	90
3	Population served	105,950	168,029	249,384	378,422
4	Temporary population	69,567	84,829	98,008	115,540
5	Percentage of temporary population served	30	40	50	60
6	Temporary population served	20,870	33,931	49,004	69,324
7	Domestic water demand (in liter per capita per day)				
7.1	Fully plumbed households				
	Per capita water demand (l/d)	80	90	100	120
	Percentage of population served (% of item no. 3)	**40**	**50**	**60**	**70**
	Average daily demand (ml/d)	3.39	7.56	14.96	31.79
7.2	Yard connection				
	Per capita water demand (l/d)	45	50	55	70
	Percentage of population served (% of item no. 3)	**40**	**35**	**30**	**25**
	Percentage of population served (% of item no. 6)	**20**	**25**	**30**	**40**
	Average daily demand (ml/d) of permanent population	0.38	0.59	0.81	1.21
	Average daily demand (ml/d) of temporary population	0.19	0.42	0.81	1.94
	Average daily demand (ml/d)	0.56	1.02	1.62	3.15
7.3	Stand post				
	Per capita water demand (l/d)	45	45	45	45
	Percentage of population served (% of item no. 3)	**20**	**15**	**10**	**5**
	Percentage of population served (% of item no. 6)	**80**	**75**	**70**	**60**
	Average daily demand (ml/d) of permanent population	0.95	1.13	1.12	0.85
	Average daily demand (ml/d) of temporary population	0.75	1.15	1.54	1.87
	Average daily demand (ml/d)	1.70	2.28	2.67	2.72
7.4	Total domestic demand (ml/d)	5.66	10.86	19.25	37.66
8	Non-domestic demand (ml/d)				
	Percentage of domestic demand (% of 7.4)	10	12	12	15
	Average daily demand (ml/d)	0.57	1.30	2.31	5.65
9	Total water demand (ml/d)	6.22	12.16	21.56	43.31
10	Leakage and wastage (%)	40	35	30	25
	Amount of water lost due to leakage and wastage (ml/d)	4.15	6.55	9.24	14.44
11	**Total average daily demand**	**10.37**	**18.71**	**30.79**	**57.75**

WATER DEMAND CALCULATION - CONSTRAINED SUPPLY ZONE C - KATHMANDU NORTH					
S.No.	**Item**	**Year**			
		2010	**2015**	**2020**	**2025**
1	Total population (projected)	144,324	196,769	235,722	285,115
2	Percentage of population served	60	70	80	90
3	Population served	86,595	137,738	188,578	256,603
4	Temporary population	20,870	25,449	29,402	34,662
5	Percentage of temporary population served	30	40	50	60
6	Temporary population served	6,261	10,179	14,701	20,797
7	Domestic water demand (in liter per capita per day)				
7.1	Fully plumbed households				
	Per capita water demand (l/d)	90	100	110	120
	Percentage of population served (% of item no. 3)	**40**	**50**	**60**	**70**
	Average daily demand (ml/d)	3.12	6.89	12.45	21.55
7.2	Yard connection				
	Per capita water demand (l/d)	45	50	60	70
	Percentage of population served (% of item no. 3)	**50**	**45**	**35**	**25**
	Percentage of population served (% of item no. 6)	**20**	**25**	**30**	**40**
	Average daily demand (ml/d) of permanent population	1.95	3.10	3.96	4.49
	Average daily demand (ml/d) of temporary population	0.06	0.13	0.26	0.58
	Average daily demand (ml/d)	2.00	3.23	4.22	5.07
7.3	Stand post				
	Per capita water demand (l/d)	45	45	45	45
	Percentage of population served (% of item no. 3)	**10**	**5**	**5**	**5**
	Percentage of population served (% of item no. 6)	**80**	**75**	**70**	**60**
	Average daily demand (ml/d) of permanent population	0.39	0.31	0.42	0.58
	Average daily demand (ml/d) of temporary population	0.23	0.34	0.46	0.56
	Average daily demand (ml/d)	0.62	0.65	0.89	1.14
7.4	Total domestic demand (ml/d)	5.74	10.77	17.56	27.77
8	Non-domestic demand (ml/d)				
	Percentage of domestic demand (% of 7.4)	8	9	9	10
	Average daily demand (ml/d)	0.46	0.97	1.58	2.78
9	Total water demand (ml/d)	6.20	11.74	19.14	30.54
10	Leakage and wastage (%)	40	35	30	25
	Amount of water lost due to leakage and wastage (ml/d)	4.13	6.32	8.20	10.18
11	**Total average daily demand**	**10.33**	**18.06**	**27.34**	**40.72**

WATER DEMAND CALCULATION - CONSTRAINED SUPPLY
ZONE D - KIRTIPUR

S.No.	Item	Year			
		2010	**2015**	**2020**	**2025**
1	Total population (projected)	31,796	35,590	39,317	43,592
2	Percentage of population served	60	70	80	90
3	Population served	19,078	24,913	31,454	39,233
4	Temporary population	13,913	16,966	19,602	23,108
5	Percentage of temporary population served	30	40	50	60
6	Temporary population served	4,174	6,786	9,801	13,865
7	Domestic water demand (in liter per capita per day)				
7.1	Fully plumbed households				
	Per capita water demand (l/d)	90	100	110	120
	Percentage of population served (% of item no. 3)	**35**	**45**	**55**	**65**
	Average daily demand (ml/d)	0.60	1.12	1.90	3.06
7.2	Yard connection				
	Per capita water demand (l/d)	45	55	60	70
	Percentage of population served (% of item no. 3 & 6)	**45**	**40**	**35**	**30**
	Percentage of population served (% of item no. 6)	**20**	**25**	**30**	**40**
	Average daily demand (ml/d) of permanent population	0.39	0.55	0.66	0.82
	Average daily demand (ml/d) of temporary population	0.04	0.09	0.18	0.39
	Average daily demand (ml/d)	0.42	0.64	0.84	1.21
7.3	Stand post				
	Per capita water demand (l/d)	45	45	45	45
	Percentage of population served (% of item no. 3 & 6)	**20**	**15**	**10**	**5**
	Percentage of population served (% of item no. 6)	**80**	**75**	**70**	**60**
	Average daily demand (ml/d) of permanent population	0.17	0.17	0.14	0.09
	Average daily demand (ml/d) of temporary population	0.15	0.23	0.31	0.37
	Average daily demand (ml/d)	0.32	0.40	0.45	0.46
7.4	Total domestic demand (ml/d)	1.35	2.16	3.19	4.73
8	Non-domestic demand (ml/d)				
	Percentage of domestic demand (% of 7.4)	8	9	9	10
	Average daily demand (ml/d)	0.11	0.19	0.29	0.47
9	Total water demand (ml/d)	1.45	2.35	3.48	5.21
10	Leakage and wastage (%)	40	35	30	25
	Amount of water lost due to leakage and wastage (ml/d)	0.97	1.27	1.49	1.74
11	**Total average daily demand**	**2.42**	**3.62**	**4.97**	**6.94**

WATER DEMAND CALCULATION - CONSTRAINED SUPPLY
ZONE E - PATAN SOUTH

S.No.	Item	Year			
		2010	**2015**	**2020**	**2025**
1	Total population (projected)	100,484	150,903	231,720	376,287
2	Percentage of population served	60	70	80	85
3	Population served	60,290	105,632	185,376	319,844
4	Temporary population	13,913	16,966	19,602	23,108
5	Percentage of temporary population served	30	40	50	60
6	Temporary population served	4,174	6,786	9,801	13,865
7	Domestic water demand (in liter per capita per day)				
7.1	Fully plumbed households				
	Per capita water demand (l/d)	90	100	110	120
	Percentage of population served (% of item no. 3)	**40**	**45**	**50**	**60**
	Average daily demand (ml/d)	2.17	4.75	10.20	23.03
7.2	Yard connection				
	Per capita water demand (l/d)	45	55	60	70
	Percentage of population served (% of item no. 3)	**50**	**45**	**40**	**30**
	Percentage of population served (% of item no. 6)	**20**	**25**	**30**	**40**
	Average daily demand (ml/d) of permanent population	1.36	2.61	4.45	6.72
	Average daily demand (ml/d) of temporary population	0.04	0.09	0.18	0.39
	Average daily demand (ml/d)	1.39	2.71	4.63	7.10
7.3	Stand post				
	Per capita water demand (l/d)	45	45	45	45
	Percentage of population served (% of item no. 3)	**10**	**10**	**10**	**10**
	Percentage of population served (% of item no. 6)	**80**	**75**	**70**	**60**
	Average daily demand (ml/d) of permanent population	0.27	0.48	0.83	1.44
	Average daily demand (ml/d) of temporary population	0.15	0.23	0.31	0.37
	Average daily demand (ml/d)	0.42	0.70	1.14	1.81
7.4	Total domestic demand (ml/d)	3.99	8.17	15.96	31.95
8	Non-domestic demand (ml/d)				
	Percentage of domestic demand (% of 7.4)	8	9	9	10
	Average daily demand (ml/d)	0.32	0.73	1.44	3.19
9	Total water demand (ml/d)	4.31	8.90	17.40	35.14
10	Leakage and wastage (%)	40	35	25	25
	Amount of water lost due to leakage and wastage (ml/d)	2.87	4.79	5.80	11.71
11	**Total average daily demand**	**7.18**	**13.69**	**23.20**	**46.86**

WATER DEMAND CALCULATION - CONSTRAINED SUPPLY
ZONE F - BHAKTAPUR

S.No.	Item	Year			
		2010	2015	2020	2025
1	Total population (projected)	143,441	167,920	194,892	231,911
2	Percentage of population served	60	70	80	85
3	Population served	86,065	117,544	155,914	197,124
4	Temporary population	20,870	25,449	29,402	34,662
5	Percentage of temporary population served	30	40	50	60
6	Temporary population served	6,261	10,179	14,701	20,797
7	Domestic water demand (in liter per capita per day)				
7.1	Fully plumbed households				
	Per capita water demand (l/d)	90	100	110	120
	Percentage of population served (% of item no. 3)	30	40	50	60
	Average daily demand (ml/d)	2.32	4.70	8.58	14.19
7.2	Yard connection				
	Per capita water demand (l/d)	45	50	60	70
	Percentage of population served (% of item no. 3)	**50**	**50**	**40**	**30**
	Percentage of population served (% of item no. 6)	**20**	**25**	**30**	**40**
	Average daily demand (ml/d) of permanent population	1.94	2.94	3.74	4.14
	Average daily demand (ml/d) of temporary population	0.06	0.13	0.26	0.58
	Average daily demand (ml/d)	1.99	3.07	4.01	4.72
7.3	Stand post				
	Per capita water demand (l/d)	45	45	45	45
	Percentage of population served (% of item no. 3)	**20**	**10**	**10**	**10**
	Percentage of population served (% of item no. 6)	**80**	**75**	**70**	**60**
	Average daily demand (ml/d) of permanent population	0.77	0.53	0.70	0.89
	Average daily demand (ml/d) of temporary population	0.23	0.34	0.46	0.56
	Average daily demand (ml/d)	1.00	0.87	1.16	1.45
7.4	Total domestic demand (ml/d)	5.32	8.64	13.75	20.36
8	Non-domestic demand (ml/d)				
	Percentage of domestic demand (% of 7.4)	8	9	9	10
	Average daily demand (ml/d)	0.43	0.78	1.24	2.04
9	Total water demand (ml/d)	5.74	9.42	14.98	22.40
10	Leakage and wastage (%)	40	35	30	25
	Amount of water lost due to leakage and wastage (ml/d)	3.83	5.07	6.42	7.47
11	**Total average daily demand**	**9.57**	**14.49**	**21.41**	**29.87**

WATER DEMAND CALCULATION - CONSTRAINED SUPPLY

ZONE G - PHARPING

S.No.	Item	Year			
		2010	2015	2020	2025
1	Total population (projected)	24,328	27,685	30,750	34,192
2	Percentage of population served	50	60	70	80
3	Population served	12,164	16,611	21,525	27,354
4	Domestic water demand (in liter per capita per day)				
4.1	Fully plumbed households				
	Per capita water demand (l/d)	80	90	100	110
	Percentage of population served (% of item no. 3)	25	35	45	55
	Average daily demand (ml/d)	0.24	0.52	0.97	1.65
4.2	Yard connection				
	Per capita water demand (l/d)	45	50	55	60
	Percentage of population served (% of item no. 3)	45	40	35	30
	Average daily demand (ml/d)	0.25	0.33	0.41	0.49
4.3	Stand post				
	Per capita water demand (l/d)	45	45	45	45
	Percentage of population served (% of item no. 3)	30	25	20	15
	Average daily demand (ml/d)	0.16	0.19	0.19	0.18
4.4	Total domestic demand (ml/d)	0.65	1.04	1.58	2.33
5	Non-domestic demand (ml/d)				
	Percentage of domestic demand (% of 7.4)	8	9	9	10
	Average daily demand (ml/d)	0.05	0.09	0.14	0.23
6	Total water demand (ml/d)	0.71	1.14	1.72	2.57
7	Leakage and wastage (%)	40	35	30	25
	Amount of water lost due to leakage and wastage (ml/d)	0.47	0.61	0.74	0.86
8	**Total average daily demand**	**1.18**	**1.75**	**2.46**	**3.42**

WATER DEMAND CALCULATION - CONSTRAINED SUPPLY

ZONE H - SANKHU

S.No.	Item	Year			
		2010	2015	2020	2025
1	Total population (projected)	11,165	11,451	11,687	11,929
2	Percentage of population served	50	60	70	80
3	Population served	5,583	6,870	8,181	9,544
4	Domestic water demand (in liter per capita per day)				
4.1	Fully plumbed households				
	Per capita water demand (l/d)	80	90	100	110
	Percentage of population served (% of item no. 3)	25	35	45	55
	Average daily demand (ml/d)	0.11	0.22	0.37	0.58
4.2	Yard connection				
	Per capita water demand (l/d)	45	50	55	60
	Percentage of population served (% of item no. 3)	45	40	35	30
	Average daily demand (ml/d)	0.11	0.14	0.16	0.17
4.3	Stand post				
	Per capita water demand (l/d)	45	45	45	45
	Percentage of population served (% of item no. 3)	30	25	20	15
	Average daily demand (ml/d)	0.08	0.08	0.07	0.06
4.4	Total domestic demand (ml/d)	0.30	0.43	0.60	0.81
5	Non-domestic demand (ml/d)				
	Percentage of domestic demand (% of 4.4)	8	9	9	10
	Average daily demand (ml/d)	0.02	0.04	0.05	0.08
6	Total water demand (ml/d)	0.32	0.47	0.65	0.89
7	Leakage and wastage (%)	40	35	30	25
	Amount of water lost due to leakage and wastage (ml/d)	0.22	0.25	0.28	0.30

Appendix B: Python Scripts

```python
# settings
import os
import sys
import subprocess
grass7bin_win = r'C:\OSGeo4W64\bin\grass70.bat'
gisdb = r"E:\GrassData\2016MDP"
location="Loc_KathmanduValley"
mapset="Watersheds_VK"

os.environ['PATH'] += ';' + r"C:\OSGEO4W64\apps\grass\grass-7.0.4\lib"

if sys.platform.startswith('win'):
    grass7bin = grass7bin_win
    print "platform should be configured now"
else:
    raise OSError('Platform not configured.')

print grass7bin

startcmd = [grass7bin, '--config', 'path']
print startcmd

# query GRASS GIS itself for its GISBASE
startcmd = [grass7bin, '--config', 'path']
try:
    p = subprocess.Popen(startcmd, shell=False,
                         stdout=subprocess.PIPE, stderr=subprocess.PIPE)
    out, err = p.communicate()
except OSError as error:
    sys.exit("ERROR: Cannot find GRASS GIS start script"
             " {cmd}: {error}".format(cmd=startcmd[0], error=error))
if p.returncode != 0:
    sys.exit("ERROR: Issues running GRASS GIS start script"
             " {cmd}: {error}"
             .format(cmd=' '.join(startcmd), error=err))
gisbase = out.strip(os.linesep)

# set GISBASE environment variable
os.environ['GISBASE'] = gisbase

# define GRASS-Python environment
grass_pydir = os.path.join(gisbase, "etc", "python")
sys.path.append(grass_pydir)
sys.path.append(r"C:\Program Files\QGIS 2.14\bin")

# import (some) GRASS Python bindings
import grass.script as g
import grass.script.setup as gsetup
```

```python

gsetup.init(gisbase, gisdb, location, mapset)

print gisbase
sys.path.append(r"C:\OSGEO4~1\apps\grass\grass-7.0.4\bin")
sys.path.append(r"C:\OSGEO4~1\apps\grass\grass-7.0.4\scripts")
sys.path.append(r"C:\OSGEO4~1\apps\grass\grass-7.0.4\lib")
##check Path
print sys.path

##Read CSV File
#   Modify the following variables as desired
inputFilePathArray = [r"E:\Watersheds"]
inputFilePathArray.append(r"E:\Watersheds")
outputFilePath = r"E:\Watersheds\Output"
numHeaders = 0
inputNumRecPerDay = 96
subSampleInterval = 96
numIterations = 50
fNameCriteria1 = ".csv"

#   Import system modules
import os
import sys
import datetime
import random
import numpy as n

print("\nSubsampling input file(s), please wait...\n")
print("Average subSamplingInterval: " + str(subSampleInterval) + "\n")

#   Loop through the entire inputFilePathArray
for inputFilePath in inputFilePathArray:

#   Create directory list and iterate to the next fName if fNameCriteria1 and fNameCriteria2 isn't found
# I'm sure this is an 'omweg' to get the inputfile. Might as well have just named it. but yeah.. all good.
    dirList=os.listdir(inputFilePath)

    for fName in dirList:
        if fName.find(fNameCriteria1) > 0:
            inFile = open(inputFilePath + '/' + fName, 'r')
            print("Subsampling " + fName + "\n")

#   determines the total number of lines in inFile

            numLines = sum(1 for line in inFile)
            print("Input file total lines: " + str(numLines) + "\n")
            inFile.seek(0)
#   Next function makes an array of the offset in bytes that each new line in the file starts at
#   The lineOffset array can then be used to navigate to any line in the file

            lineOffset = []
            offset = 0
headings=inFile.readline()

#Create an empty matrix for the data
Riverpoints=n.zeros((numLines-1,3))
```

```

# Stores ID number and xyCoordinates in the Riverpoints matrix
for i in range(0,numLines-1):
    dataRow=inFile.readline()
    dataField=dataRow.split(";")
    Riverpoints[i,0]=float(dataField[4])
    Riverpoints[i,1]=float(dataField[5])
    Riverpoints[i,2]=float(dataField[3])
    xyCoordinates=[float(dataField[0]),float(dataField[1])]

# Loops through all riverpoints to create watershed delineation, a vectorfile and statistics
for k in range(0,numLines-1):
    # Create a string from ID number
    ID=Riverpoints[k,2]
    ID=int(ID)
    IDstring=str(ID)
    # Create Filenames
    rastoutput='delrast'+IDstring
    vectinput=rastoutput+'@Watersheds_VK'
    vectoutput='delvec1_'+IDstring
    statsinput='LandUseMap_15280@Watersheds_VK'
    statsoutput='E:\GrassData\stats'+IDstring
    # Make a string of coordinates
    x=Riverpoints[k,0]
    x=x.astype(str)
    y=Riverpoints[k,1]
    y=y.astype(str)
    coordinates=x+','+y
    # Create a string to make a mask
    Maskstring="if("+rastoutput+"@Watersheds_VK > 0 , 1, null())"
    print ID

    # Create a rasterfile of the watershed, then vectorize it.
    g.run_command('r.water.outlet', input="KV_DraiDir@Watersheds_VK", output=rastoutput, coordinates=coordinates, overwrite=True)
    g.run_command('r.to.vect', input=rastoutput, output=vectoutput, type='area', flags='s', overwrite=True)
    #Make a mask of the rastermap
    g.run_command('r.mapcalc', MASK=Maskstring, overwrite=True)
    # run stats over the masked landuse map
    g.run_command('r.stats', input=statsinput, output=statsoutput, flags='a', overwrite=True)
    #remove the mask
    g.run_command('r.mask', flags='r')

# python uitproberen
print 'hoi'
print "at least it's all working now. or well.. all"
```

Listing 11.1: Python script for determining statistics per watershed

```
#   Import system modules
import os
import datetime

print ("Merging files, please wait...\n")

#   Modify the following three variables as desired
inputFilePath = r"G:\_GIS\2016MDP\LandUseStats\Stats"
outputFilePath = r"G:\_GIS\2016MDP\LandUseStats\Merged"
```

```
outputFileName = "Merged_LandUseStats_" + datetime.datetime.strftime(datetime.
    datetime.now(), '%Y%M%d%H%M%S') + ".csv"
try:
    outFile = open(outputFilePath + '/' + outputFileName, 'w')
except OSError:
    input("Output file: '" + outputFileName + "' open. Please close the file and try
     again.")
    sys.exit()

#   Write headers to output file
outFile.write("siteID, DevLow, DevHigh, ForestDecid, Shrubland, Rice, MixedPlanted\n
    ")

dirList=os.listdir(inputFilePath)
for fName in dirList:
    if fName == outputFileName or fName.find("stats") == -1:
        continue
    inFile = open(inputFilePath + '/' + fName, 'r')
    print("Merging file " + fName + "; please wait.")

#   Create the siteID from the fName after removing stats
    siteID = fName.replace("stats","")

#   Write siteID to outFile
    outFile.write("%s," % (siteID))

#   Initialize areas to zero
    area1 = 0
    area2 = 0
    area3 = 0
    area4 = 0
    area5 = 0
    area6 = 0

#   Set iteration variables
    numIterations = 7
    i = 1

#   Read first line of data
    row = inFile.readline()

#   Check to make sure there is data in the row and limit to number of iterations
    while i <= numIterations and len(row) > 0:

#   Set classID and area and remove carriage return from area
        dataFields = row.split(" ")
        classID = dataFields[0]
        area = dataFields[1].replace("\n","")

#   Print data to user
        print("Class " + str(classID) + " had " + str(area) + " m^2 of area.")

#   Set areas depending on classID
        if classID == "1":
            area1 = area
        elif classID == "2":
            area2 = area
        elif classID == "3":
            area3 = area
        elif classID == "4":
```

```
            area4 = area
        elif classID == "5":
            area5 = area
        elif classID == "6":
            area6 = area

#   Move to next iteration
        i += 1

#   Read next line of data
        row = inFile.readline()

#   Write data to outFile
    outFile.write("%s,%s,%s,%s,%s,%s\n" % (area1,area2,area3,area4,area5,area6))

#   Clean up
    inFile.close()
outFile.close()
```

Listing 11.2: Python Script for combining the statistics per watershed in one csv file

Appendix C: Correlation Graphs

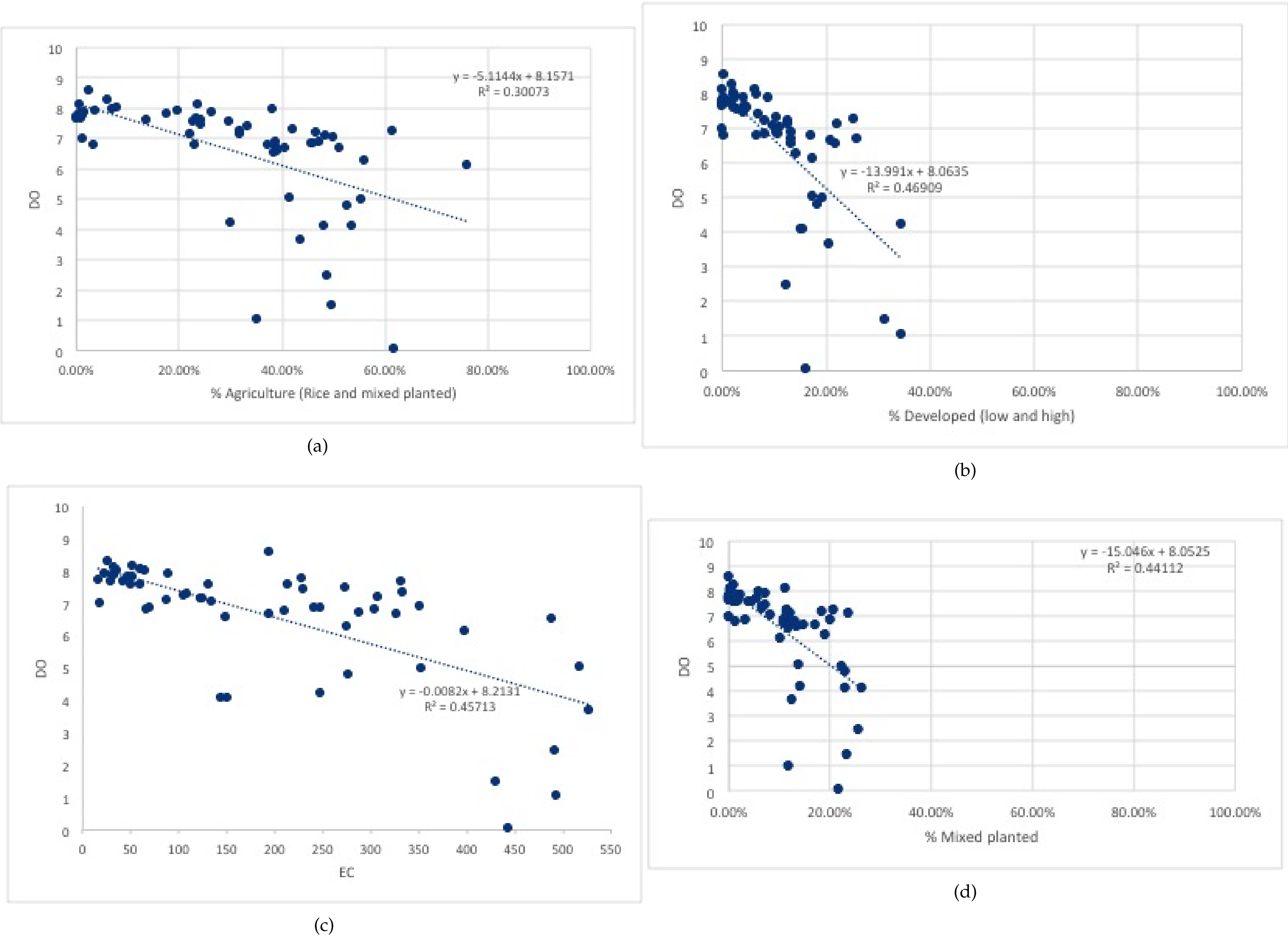
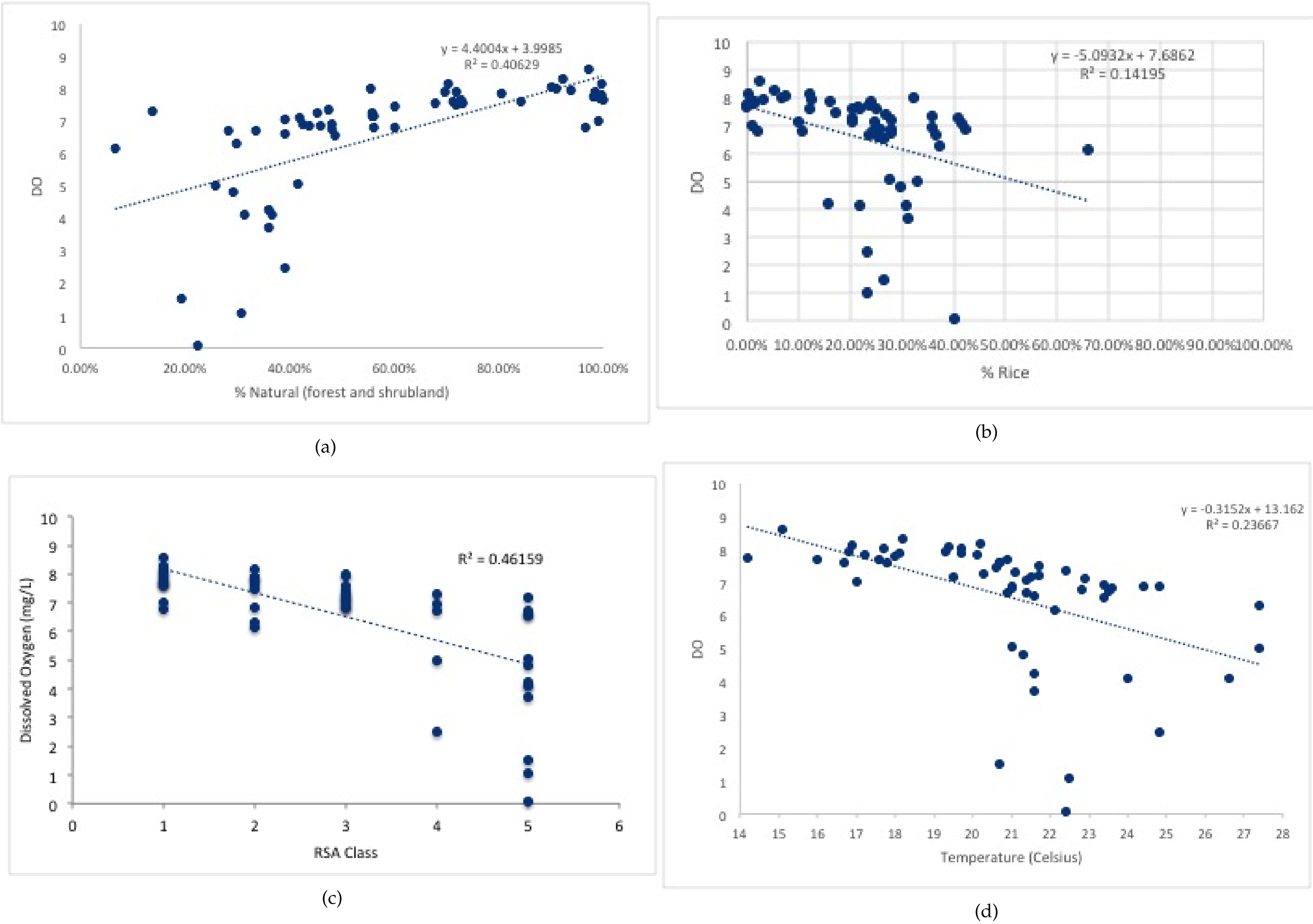

DO
% Agriculture (Rice and mixed planted)
y = -5.1144x + 8.1571
R² = 0.30073
(a)
DO
% Developed (low and high)
y = -13.991x + 8.0635
R² = 0.46909
(b)
DO
EC
y = -0.0082x + 8.2131
R² = 0.45713
(c)
DO
% Mixed planted
y = -15.046x + 8.0525
R² = 0.44112
(d)

Figure 11.1



y = 4.4004x + 3.9985
R² = 0.40629
DO
% Natural (forest and shrubland)
(a)
y = -5.0932x + 7.6862
R² = 0.14195
DO
% Rice
(b)
R² = 0.46159
Dissolved Oxygen (mg/L)
RSA Class
(c)
y = -0.3152x + 13.162
R² = 0.23667
DO
Temperature (Celsius)
(d)

Figure 11.2

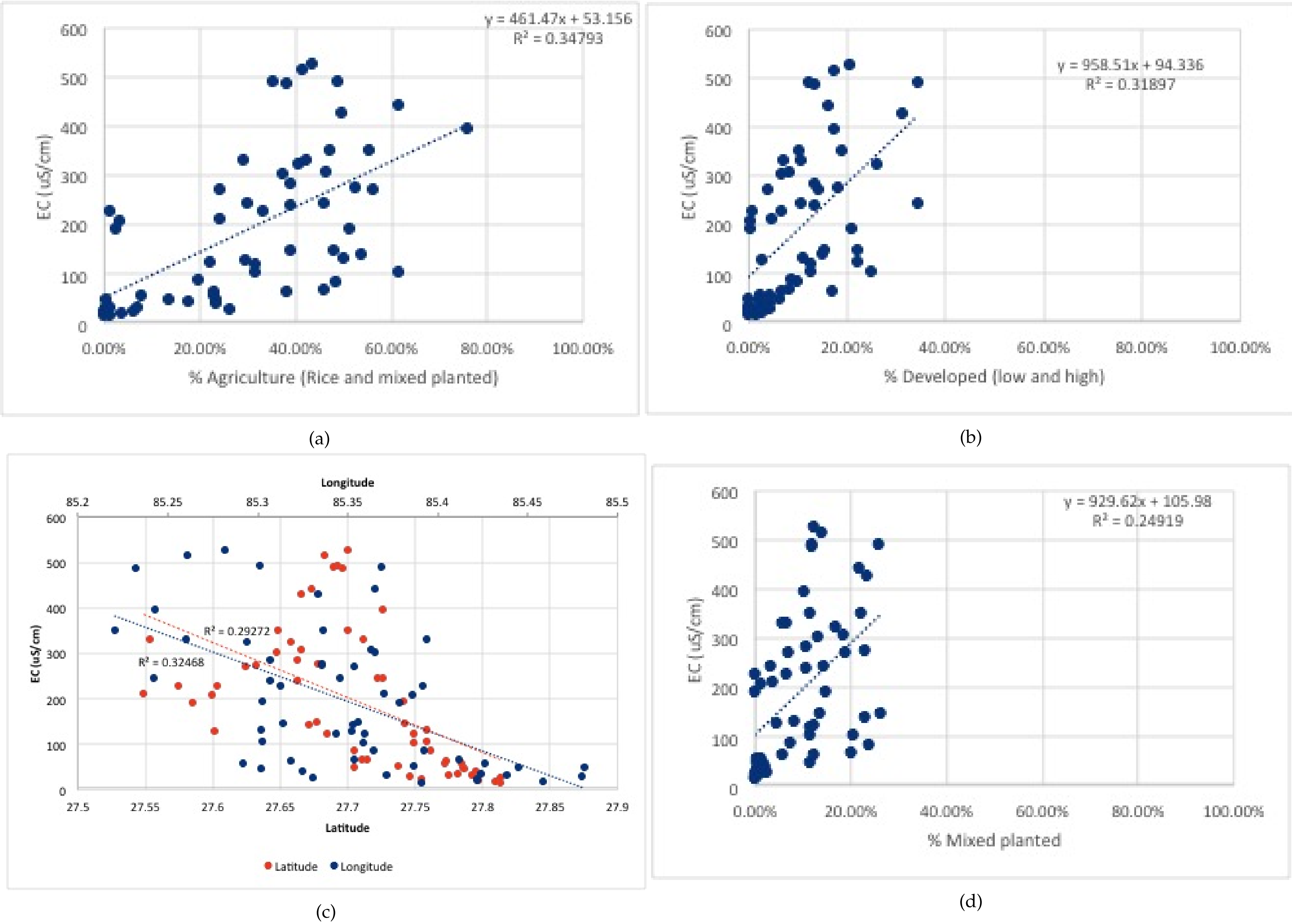
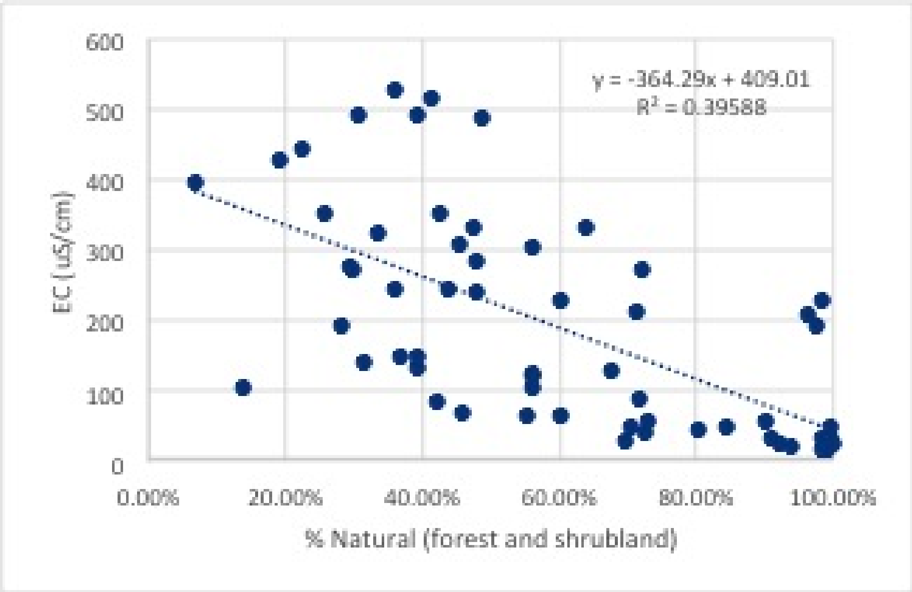
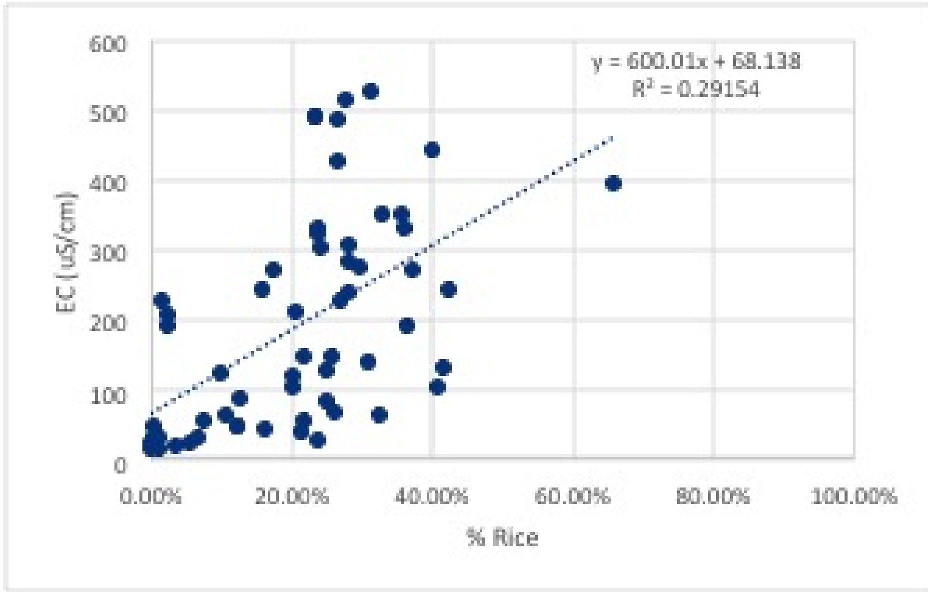

y = 461.47x + 53.156
R² = 0.34793
EC (uS/cm)
% Agriculture (Rice and mixed planted)
(a)
y = 958.51x + 94.336
R² = 0.31897
EC (uS/cm)
% Developed (low and high)
(b)
Longitude
R² = 0.29272
R² = 0.32468
EC (uS/cm)
Latitude
Latitude
Longitude
(c)
y = 929.62x + 105.98
R² = 0.24919
EC (uS/cm)
% Mixed planted
(d)

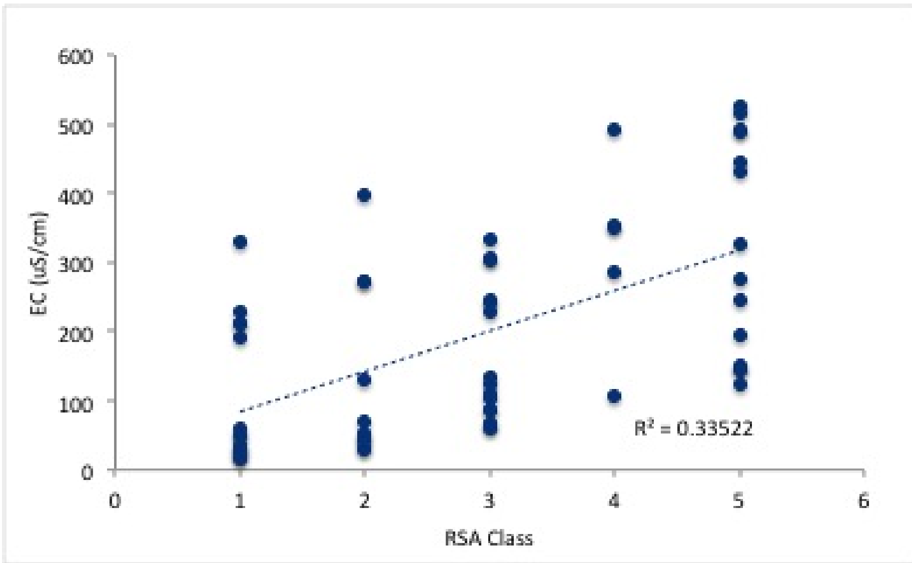
Figure 11.3



(a)



(b)



(c)

Figure 11.4

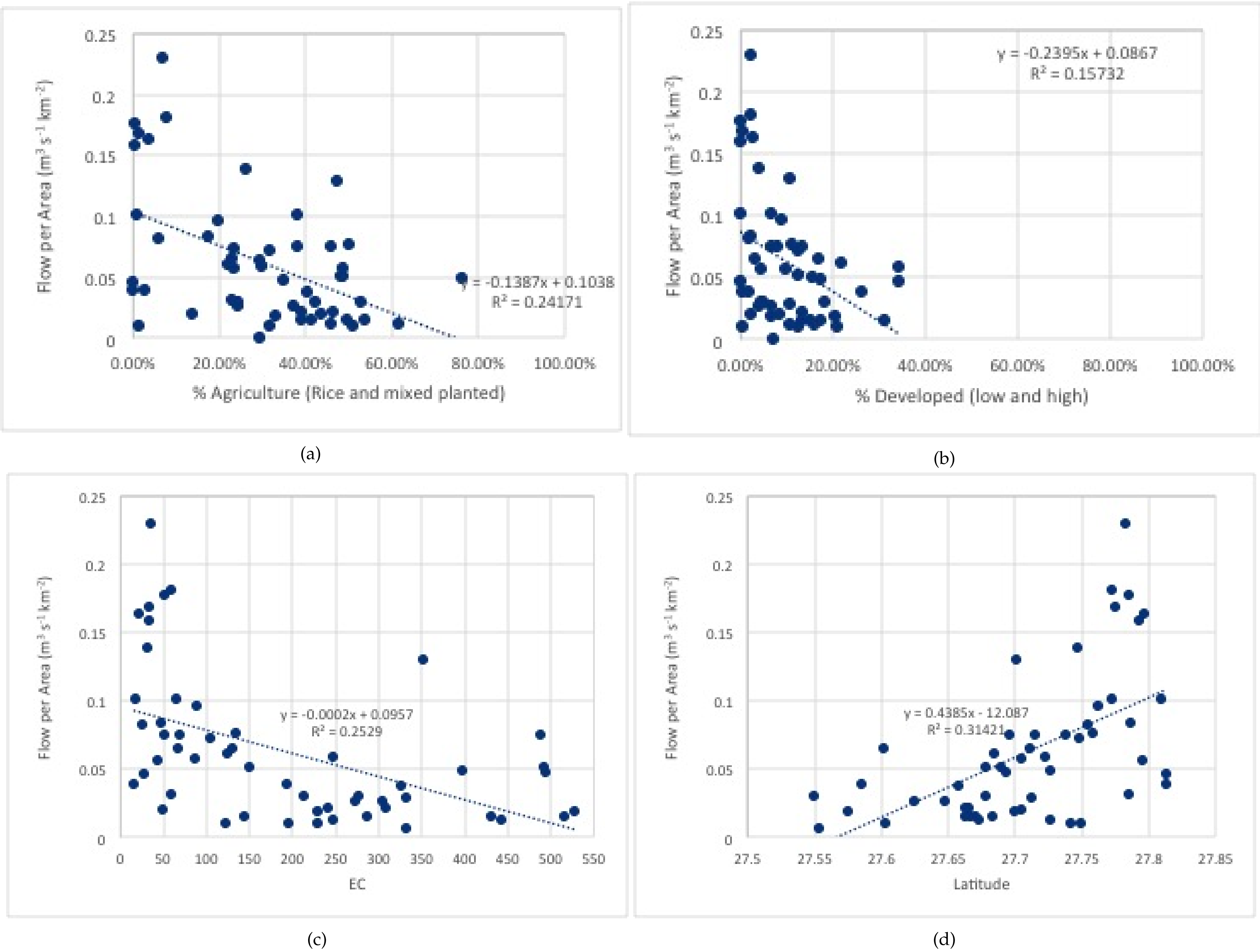

Flow per Area (m^3 s^{-1} km^{-2})
% Agriculture (Rice and mixed planted)
y = -0.1387x + 0.1038
R² = 0.24171
(a)
% Developed (low and high)
y = -0.2395x + 0.0867
R² = 0.15732
(b)
EC
y = -0.0002x + 0.0957
R² = 0.2529
(c)
Latitude
y = 0.4385x - 12.087
R² = 0.31421
(d)

Figure 11.5

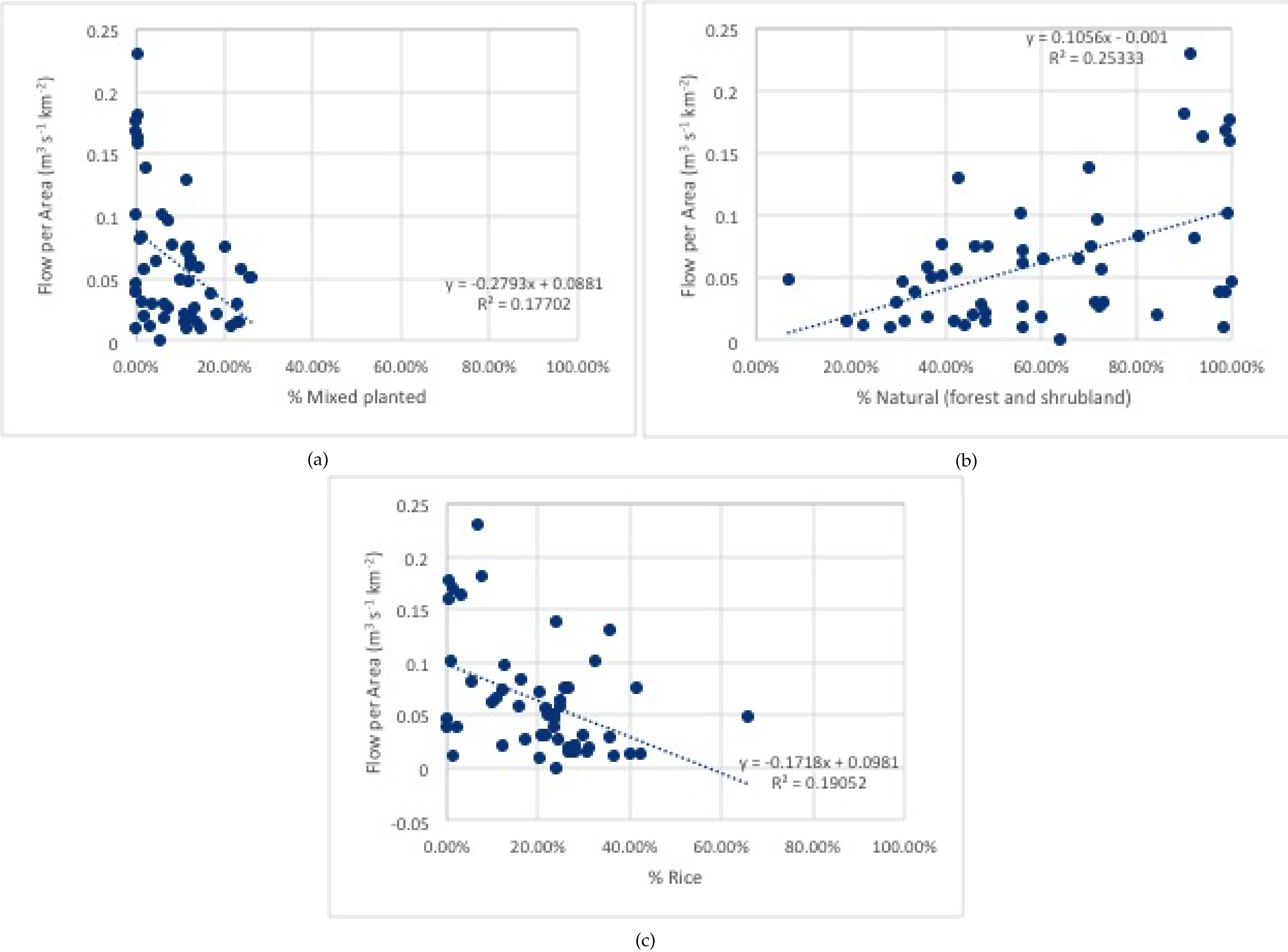
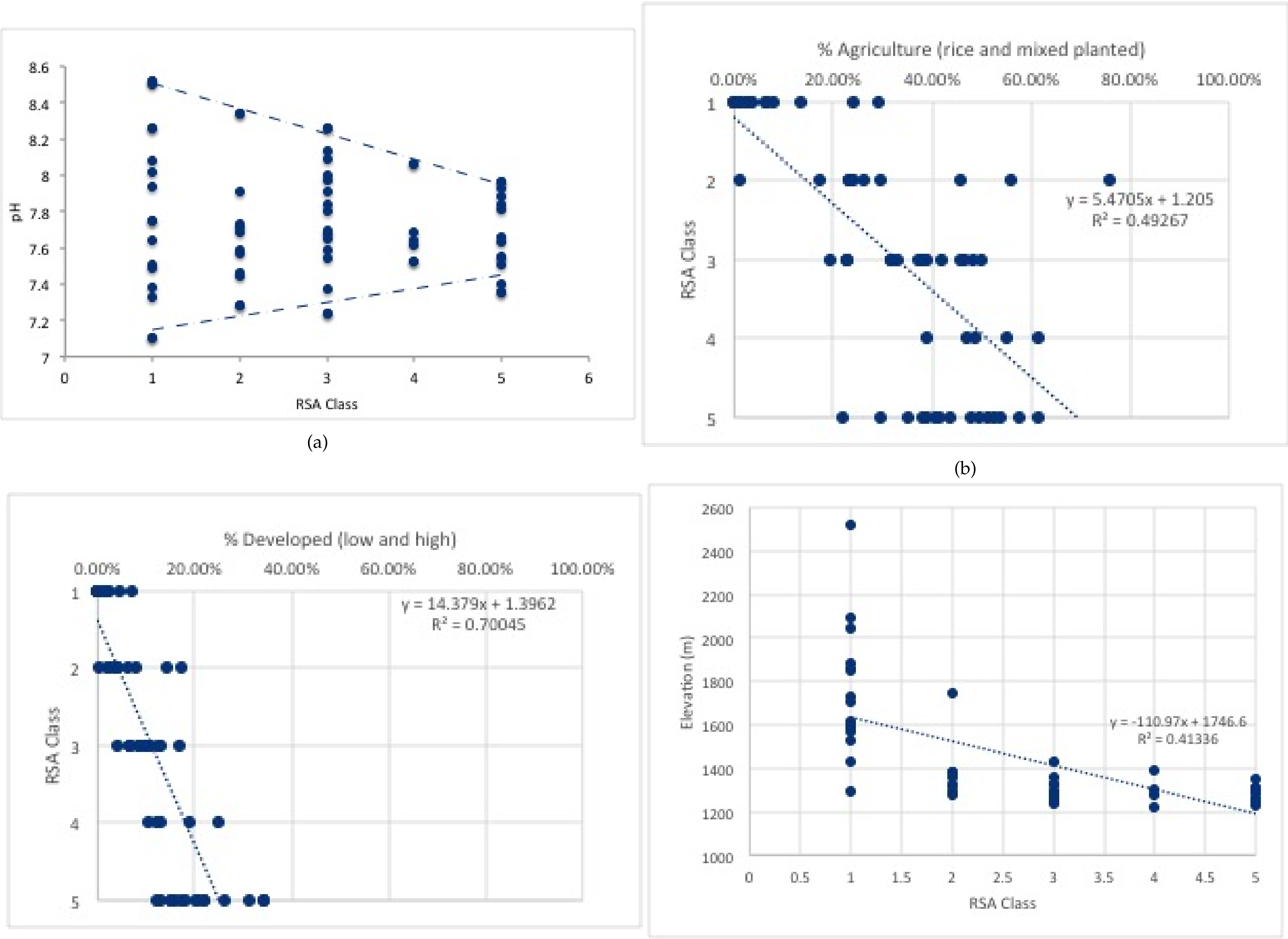
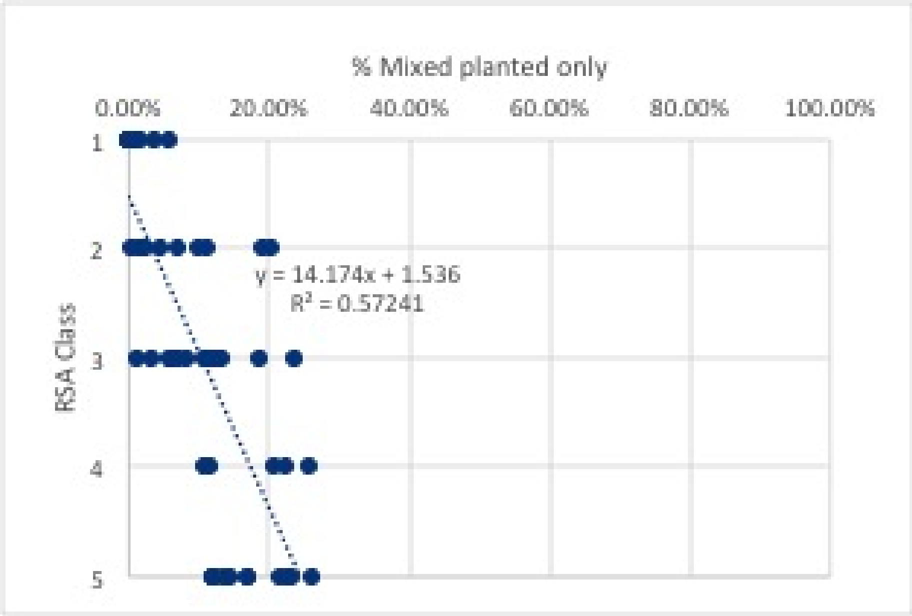

Flow per Area (m3 s-1 km-2)
% Mixed planted
y = -0.2793x + 0.0881
R² = 0.17702
0.25
0.2
0.15
0.1
0.05
0
0.00%
20.00%
40.00%
60.00%
80.00%
100.00%
(a)
Flow per Area (m3 s-1 km-2)
% Natural (forest and shrubland)
y = 0.1056x - 0.001
R² = 0.25333
(b)
Flow per Area (m3 s-1 km-2)
% Rice
y = -0.1718x + 0.0981
R² = 0.19052
-0.05
(c)

Figure 11.6

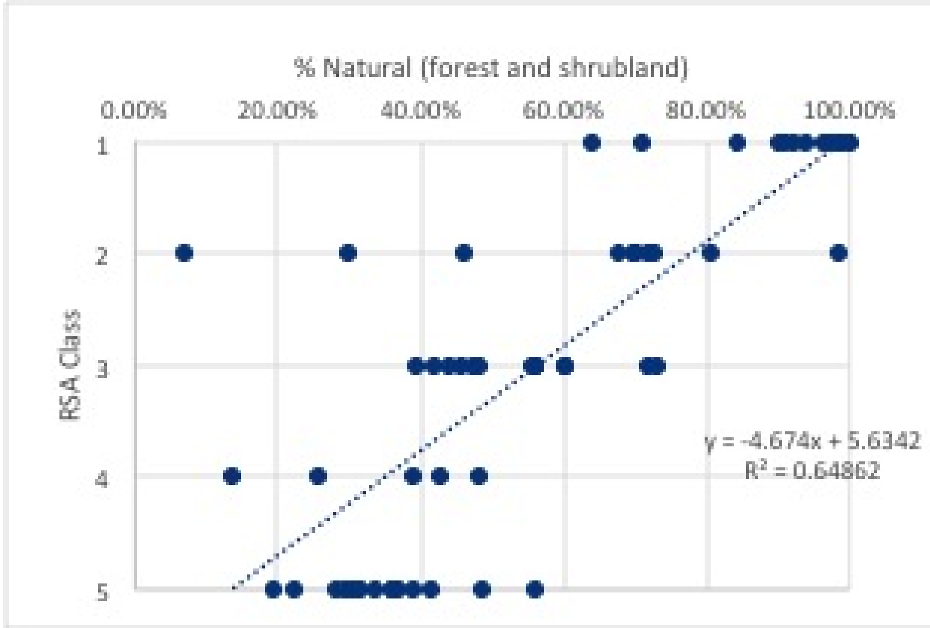


(a) (b) (c) (d)

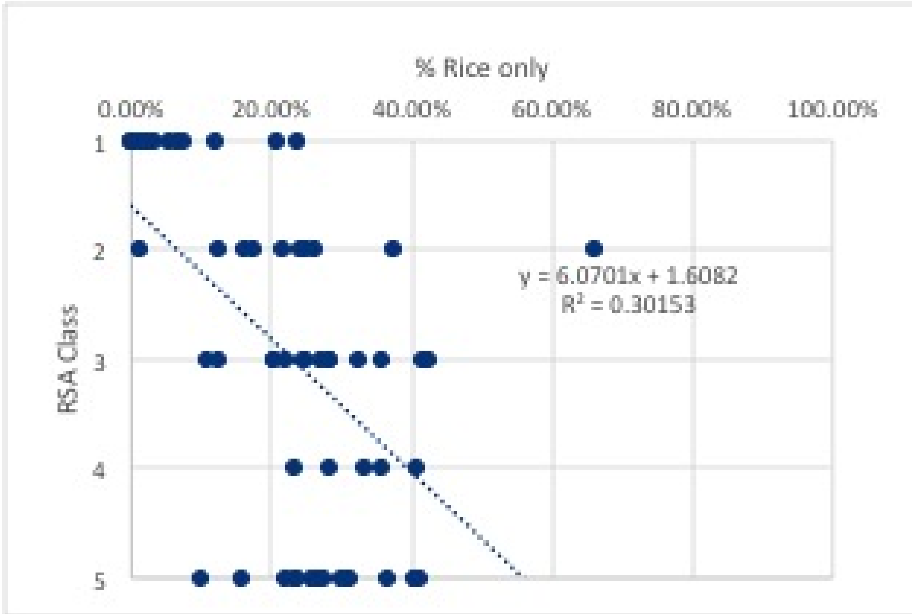
Figure 11.7



(a)

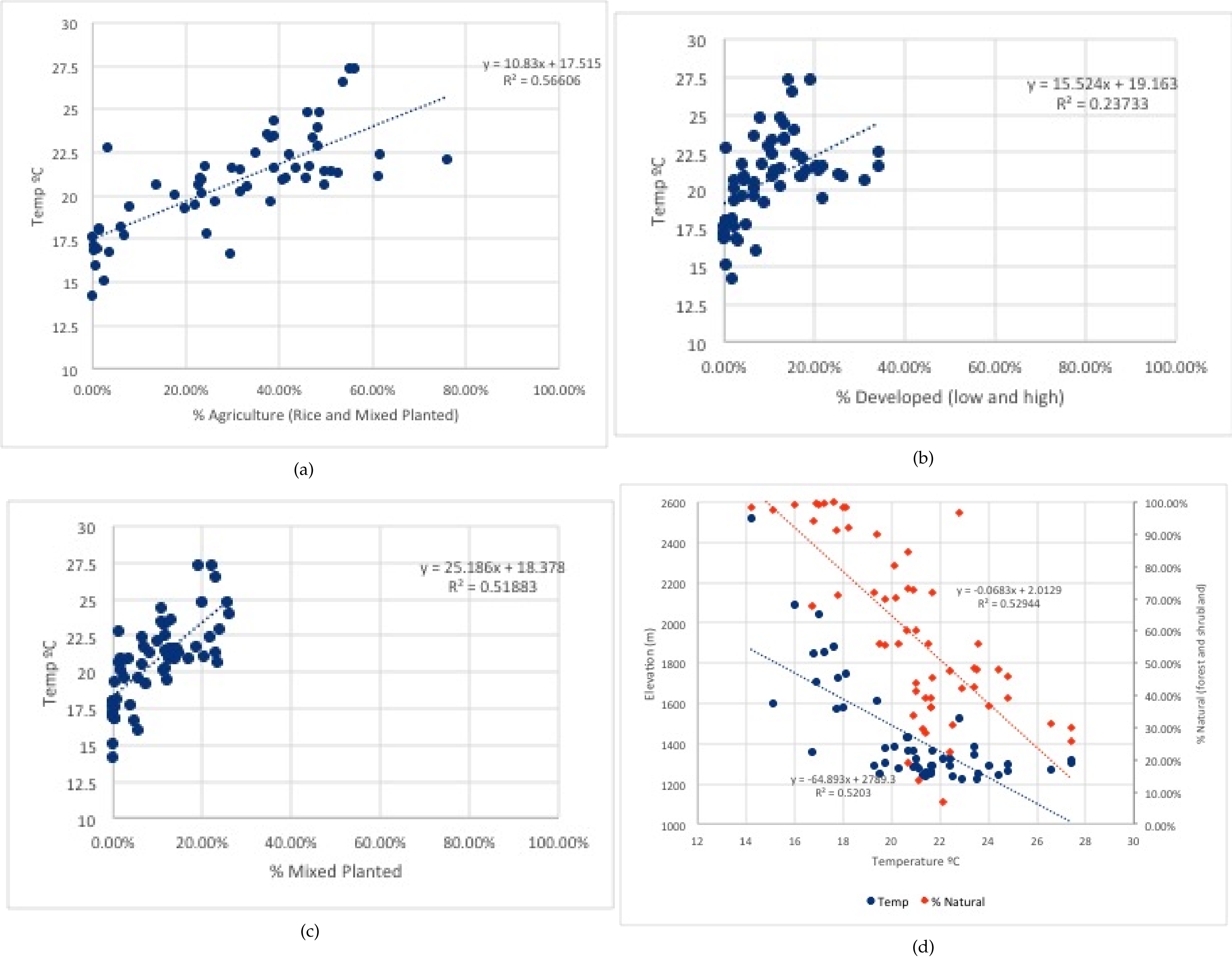


(b)



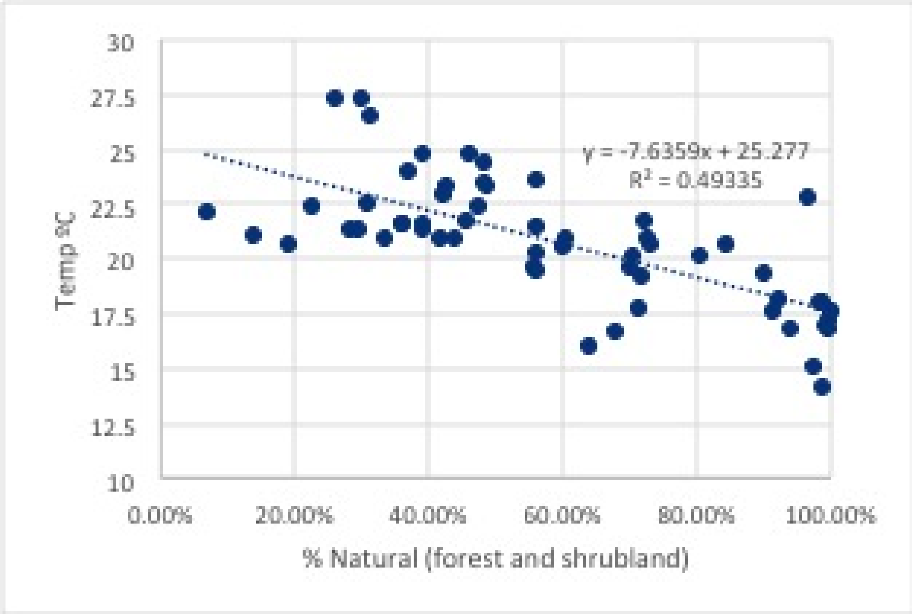
(c)

Figure 11.8

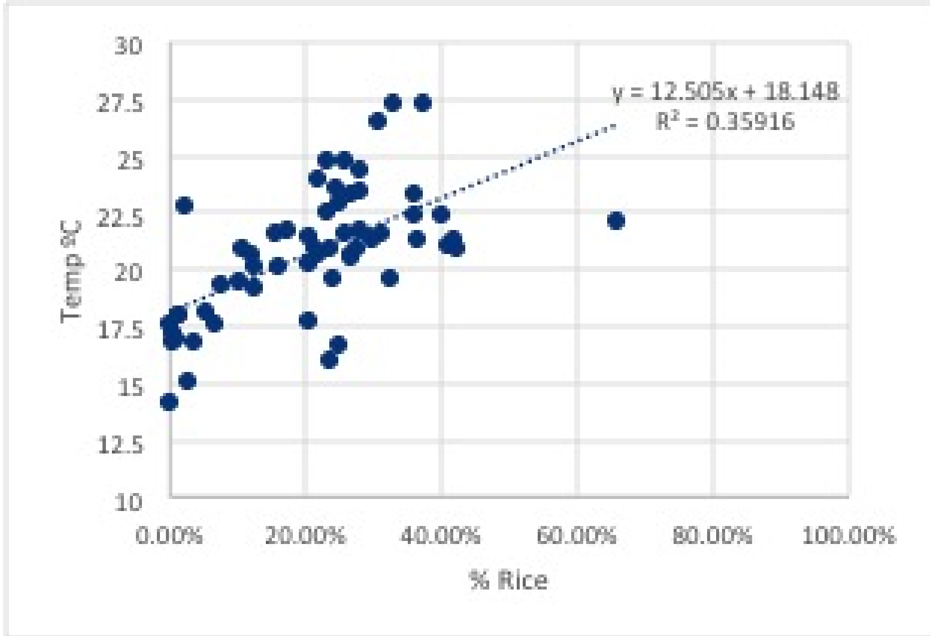


Temp ºC
% Agriculture (Rice and Mixed Planted)
y = 10.83x + 17.515
R² = 0.56606
(a)
Temp ºC
% Developed (low and high)
y = 15.524x + 19.163
R² = 0.23733
(b)
Temp ºC
% Mixed Planted
y = 25.186x + 18.378
R² = 0.51883
(c)
Elevation (m)
Temperature ºC
% Natural (forest and shrubland)
y = -0.0683x + 2.0129
R² = 0.52944
y = -64.893x + 2789.3
R² = 0.5203
Temp
% Natural
(d)

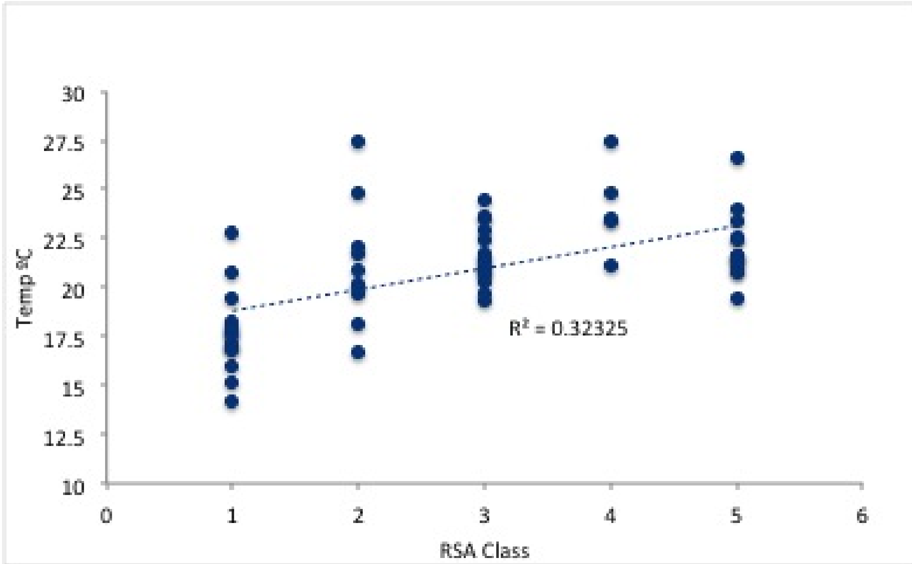
Figure 11.9



(a)



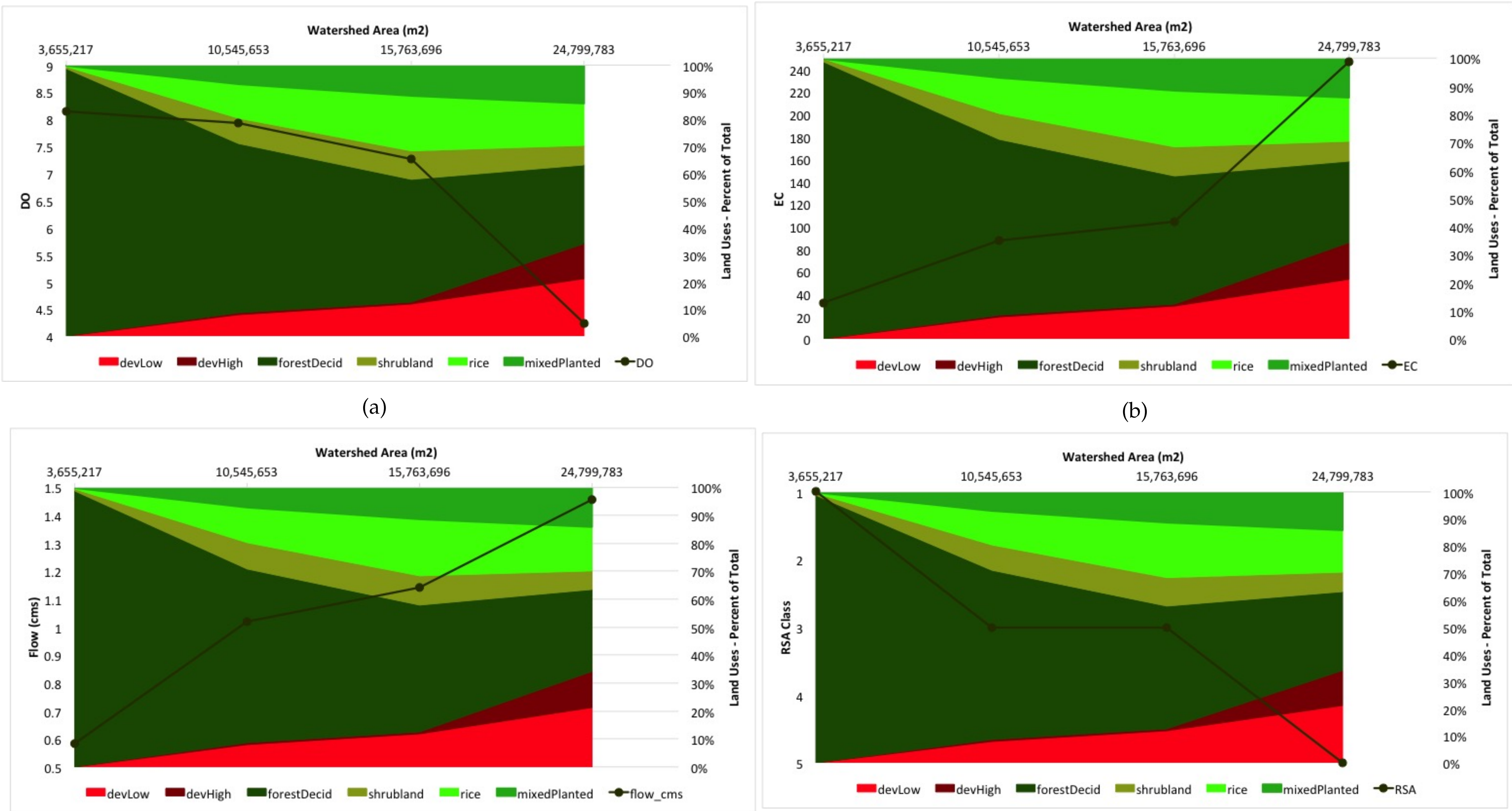
(b)



(c)

Figure 11.10

Appendix D: Landuse vs. Water Quality Parameters



(a) (b) (c) (d)

Figure 11.11: DO, EC, RSA and flow changes over the different landuse areas (%) per measurement point in the Dhobi watershed.

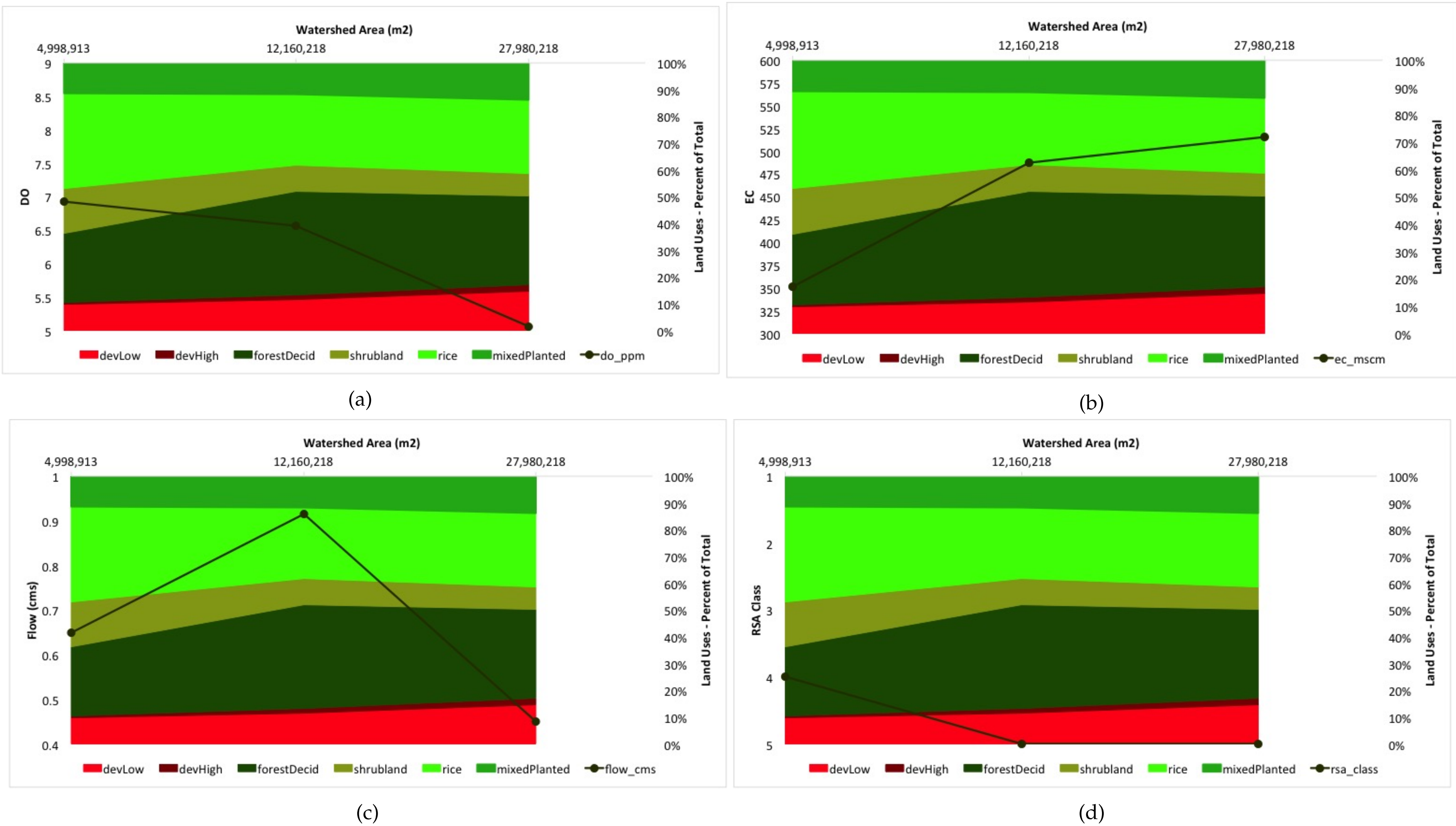


Figure 11.12: DO, EC, RSA and flow changes over the different landuse areas (%) per measurement point in the Balkhu watershed.

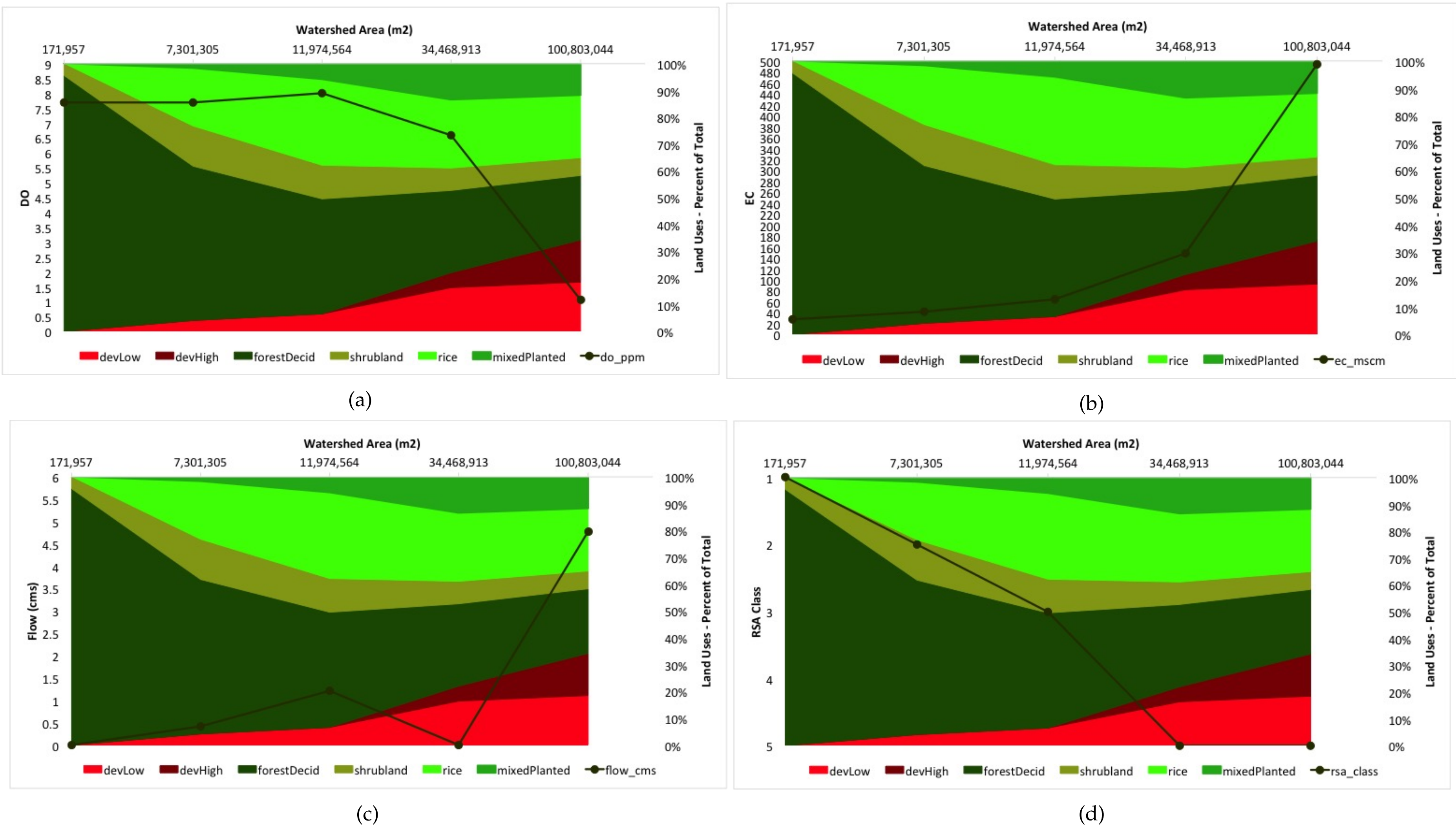


Figure 11.13: DO, EC, RSA and flow changes over the different landuse areas (%) per measurement point in the Bishnumati watershed.

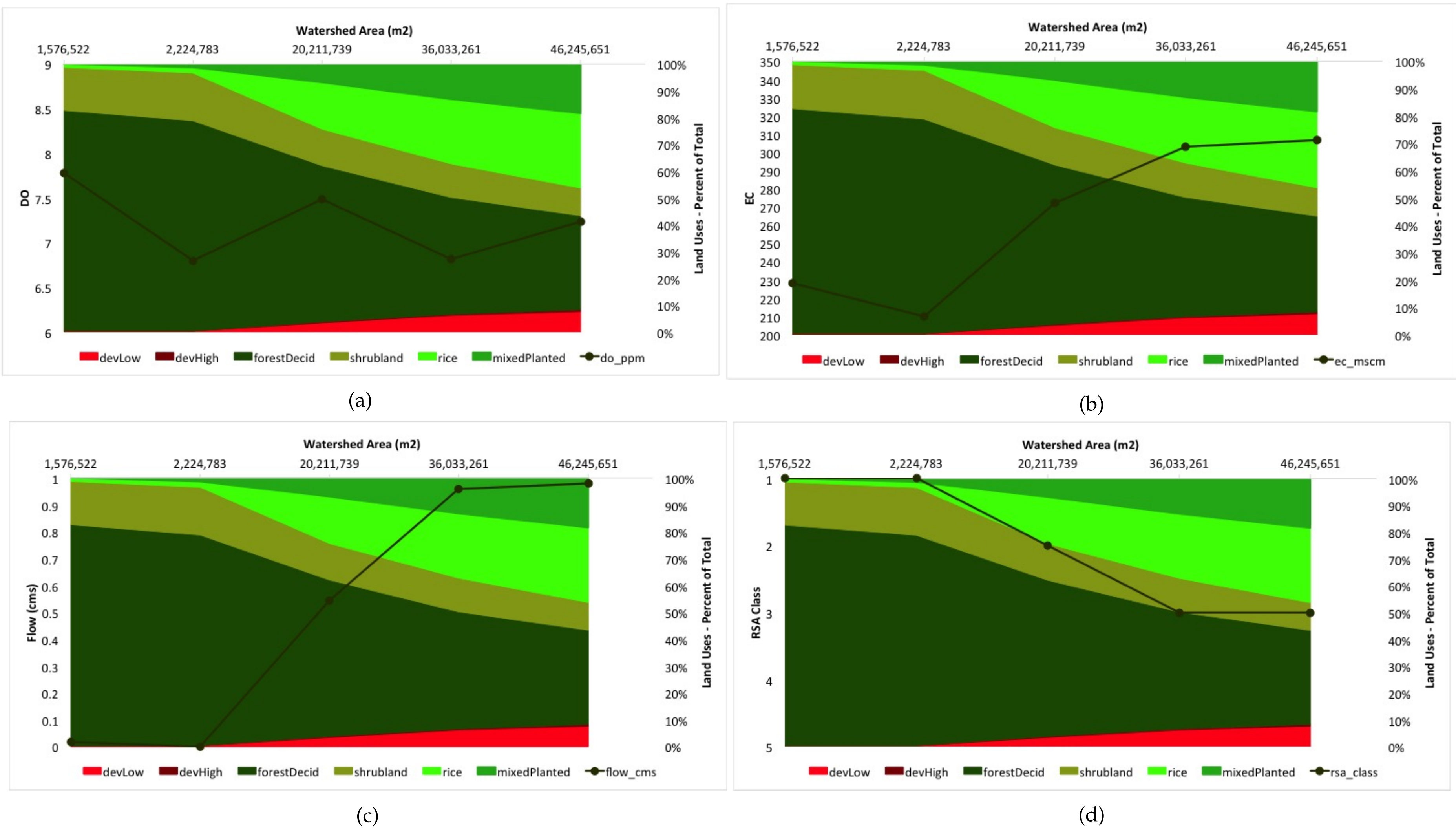


Figure 11.14: DO, EC, RSA and flow changes over the different landuse areas (%) per measurement point in the Godawari watershed.

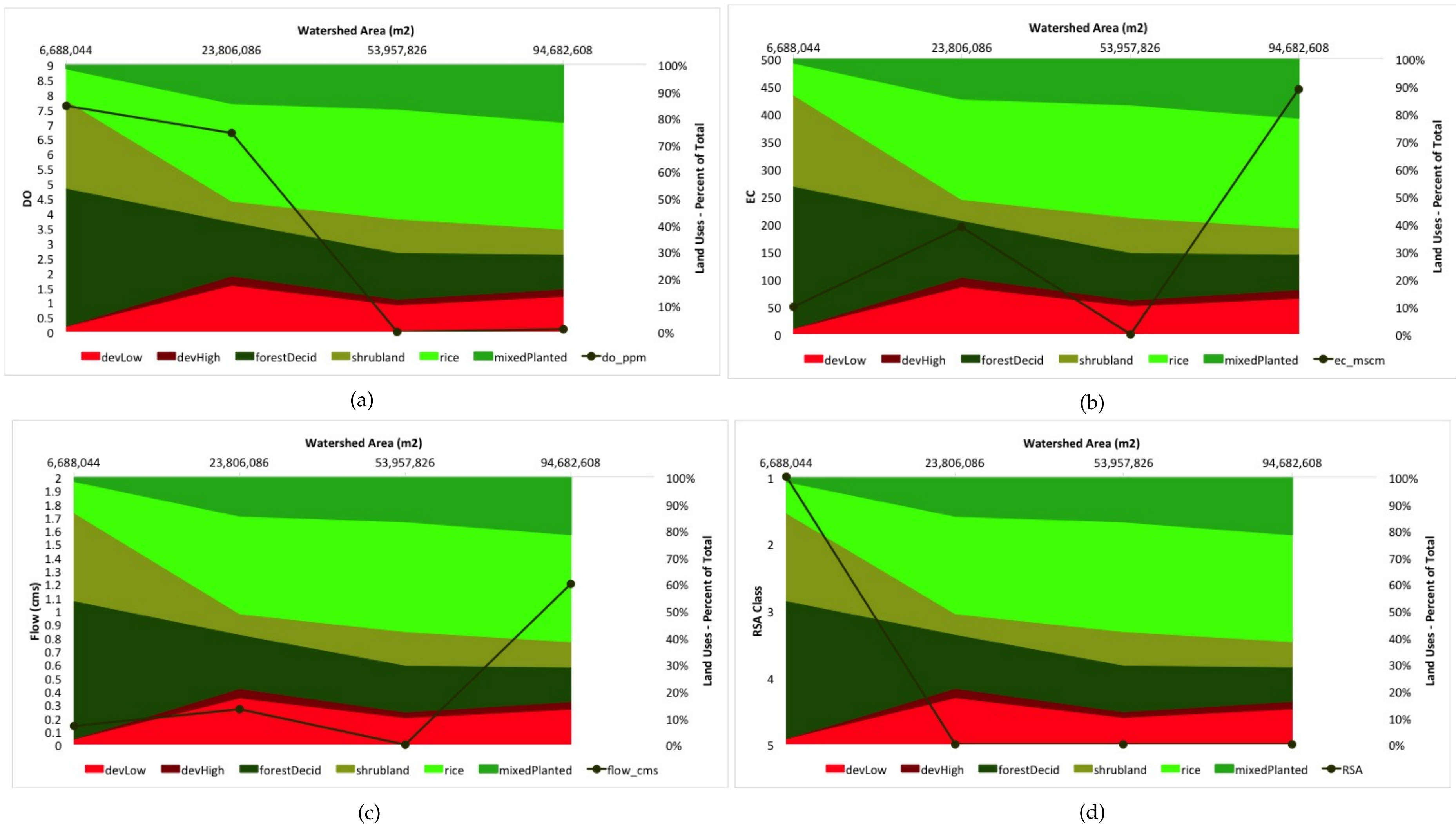


Figure 11.15: DO, EC, RSA and flow changes over the different landuse areas (%) per measurement point in the Hanumante watershed.

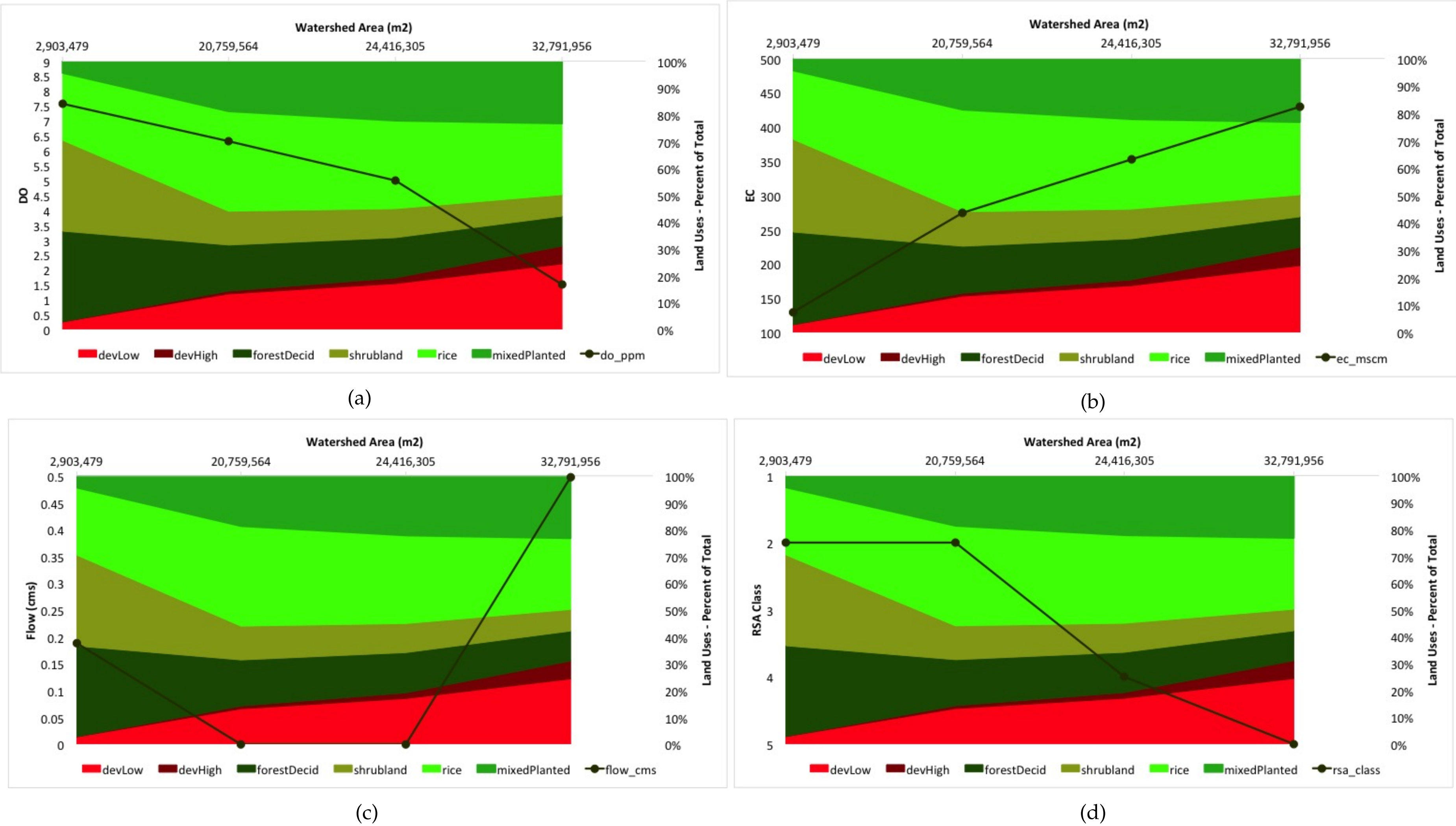


Figure 11.16: VDO, EC, RSA and flow changes over the different landuse areas (%) per measurement point in the Kodkhu watershed.

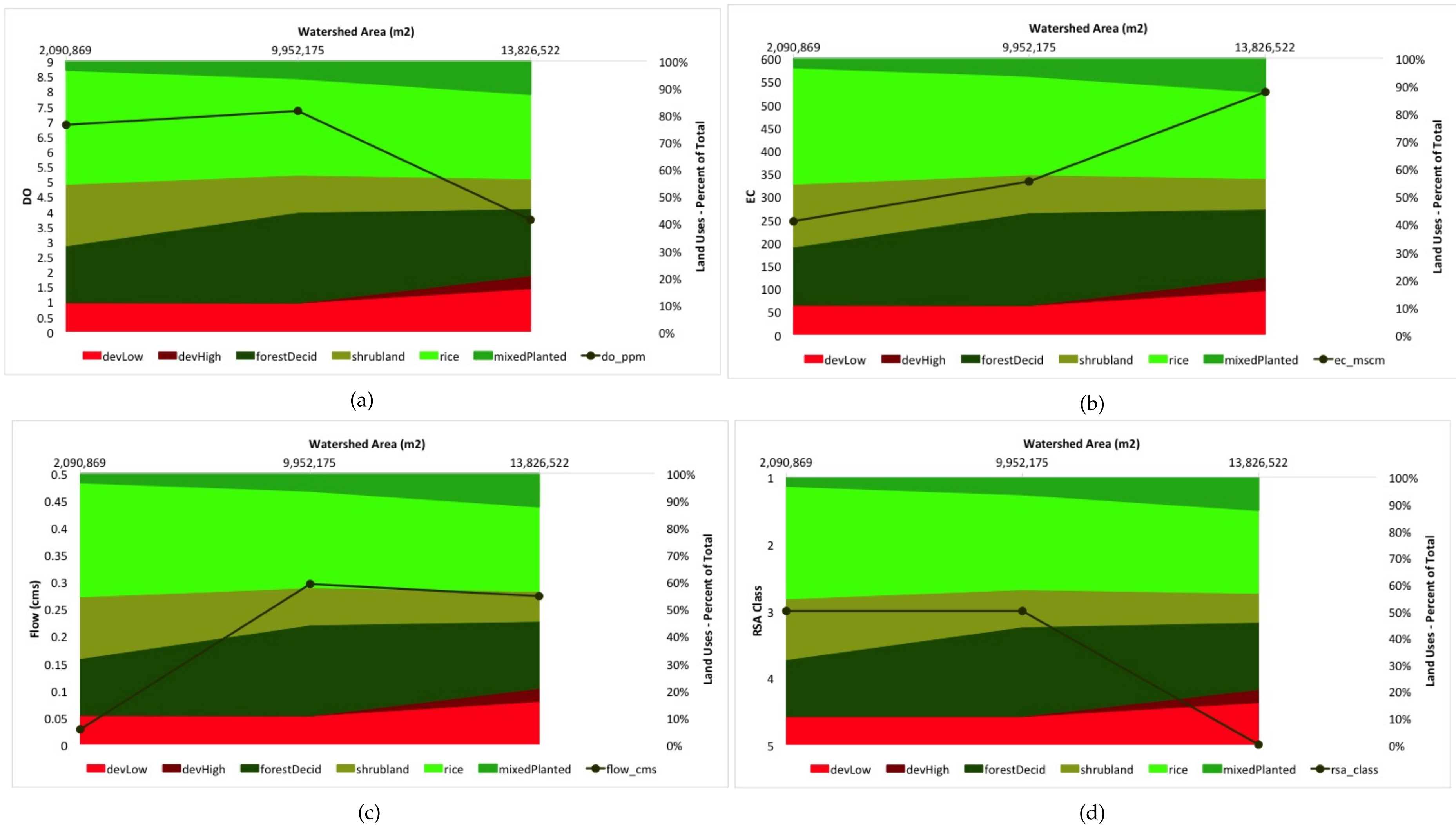


Figure 11.17: DO, EC, RSA and flow changes over the different landuse areas (%) per measurement point in the Manamati watershed.

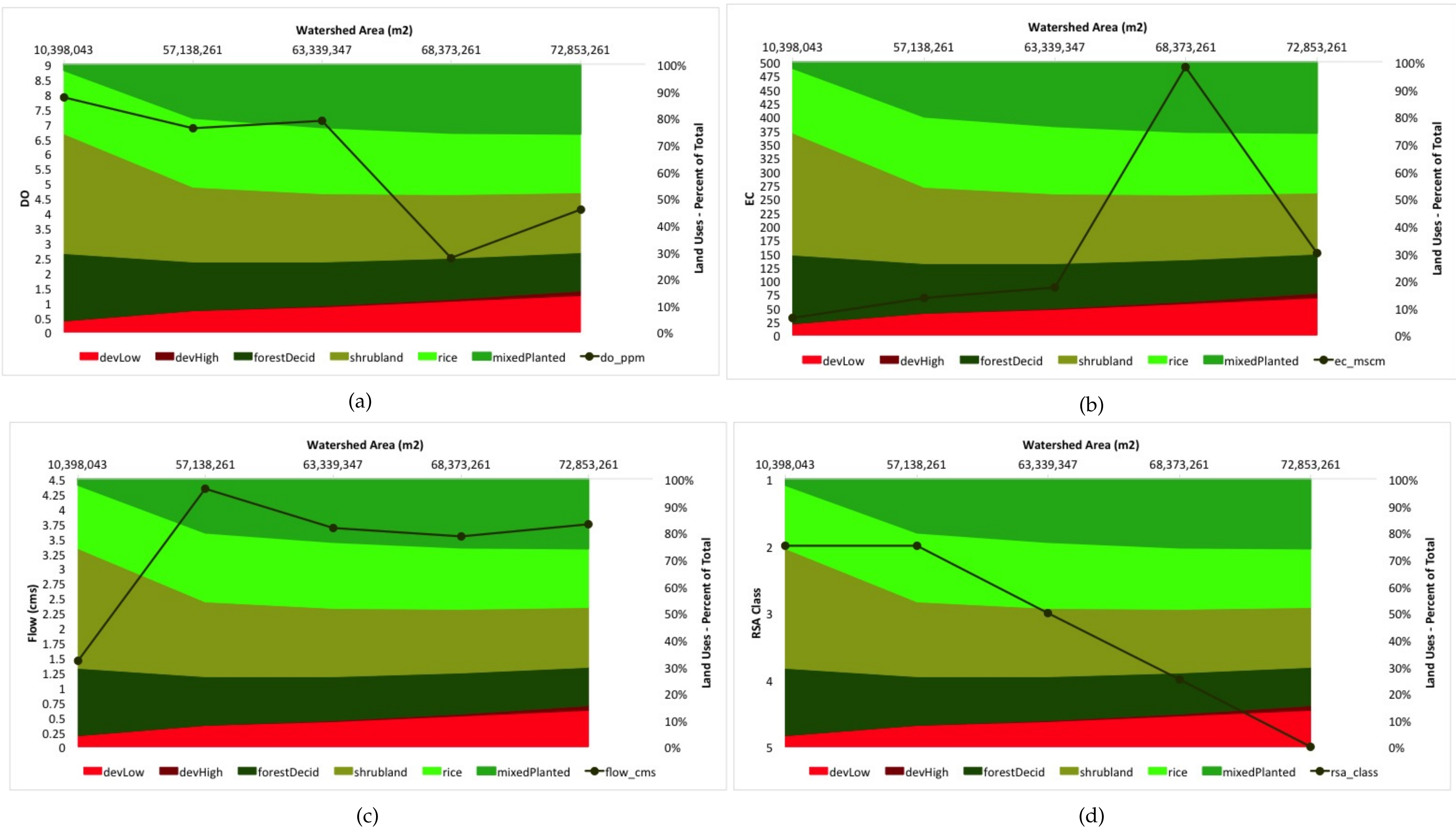
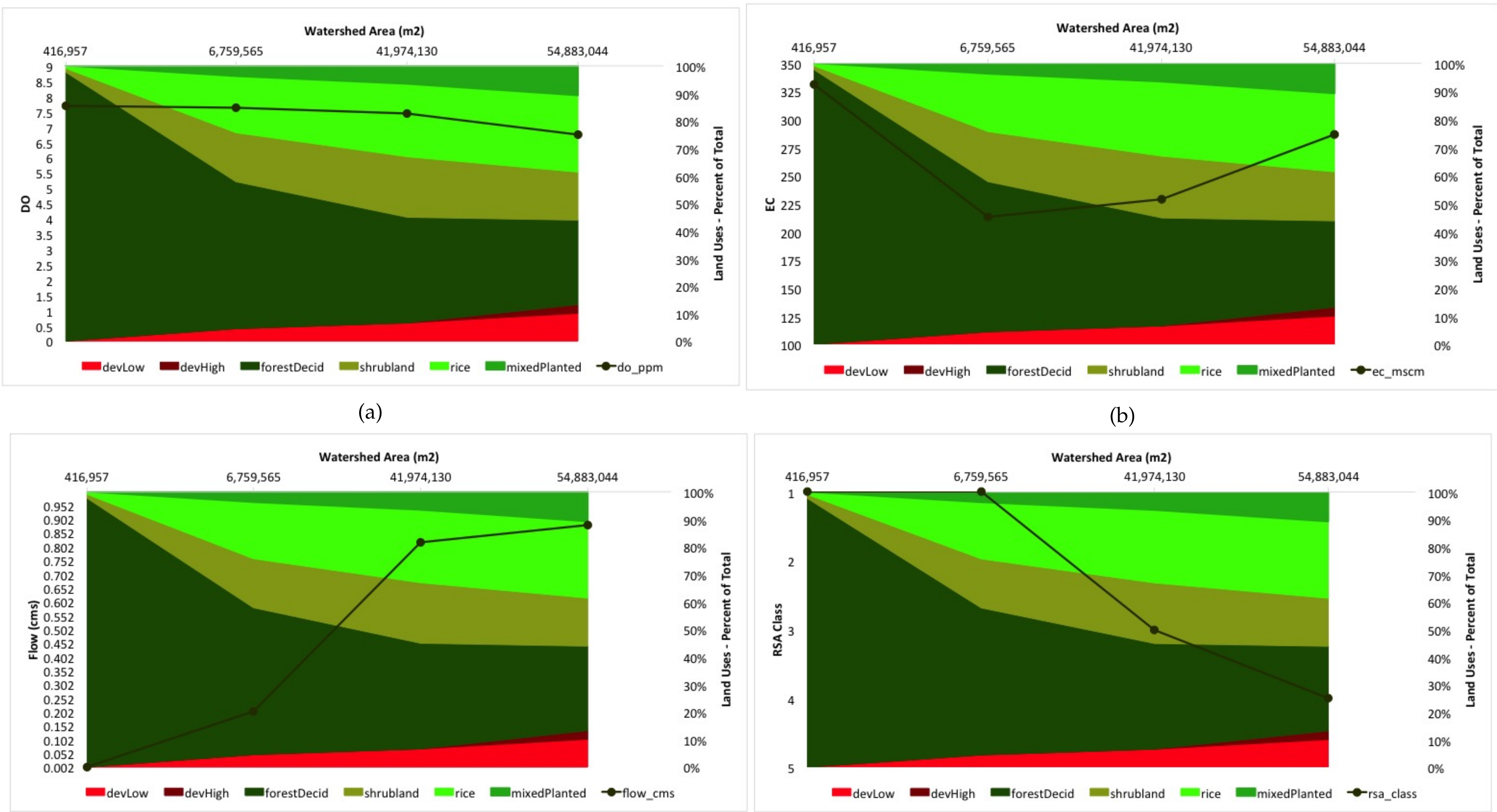


Figure 11.18: DO, EC, RSA and flow changes over the different landuse areas (%) per measurement point in the Manohara watershed.



(a) (b)

(c) (d)

Figure 11.19: DO, EC, RSA and flow changes over the different landuse areas (%) per measurement point in the Nakhu watershed.

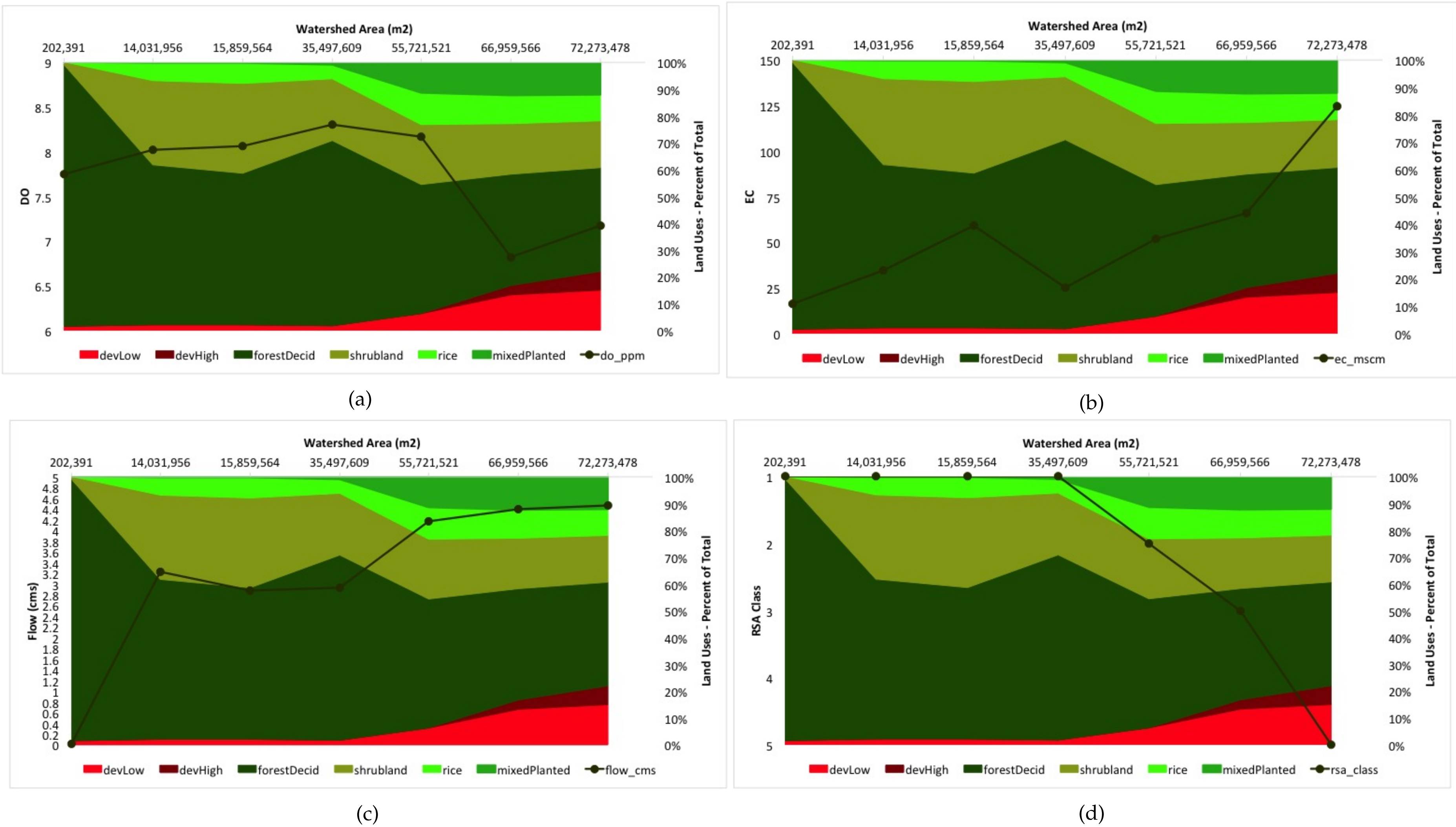
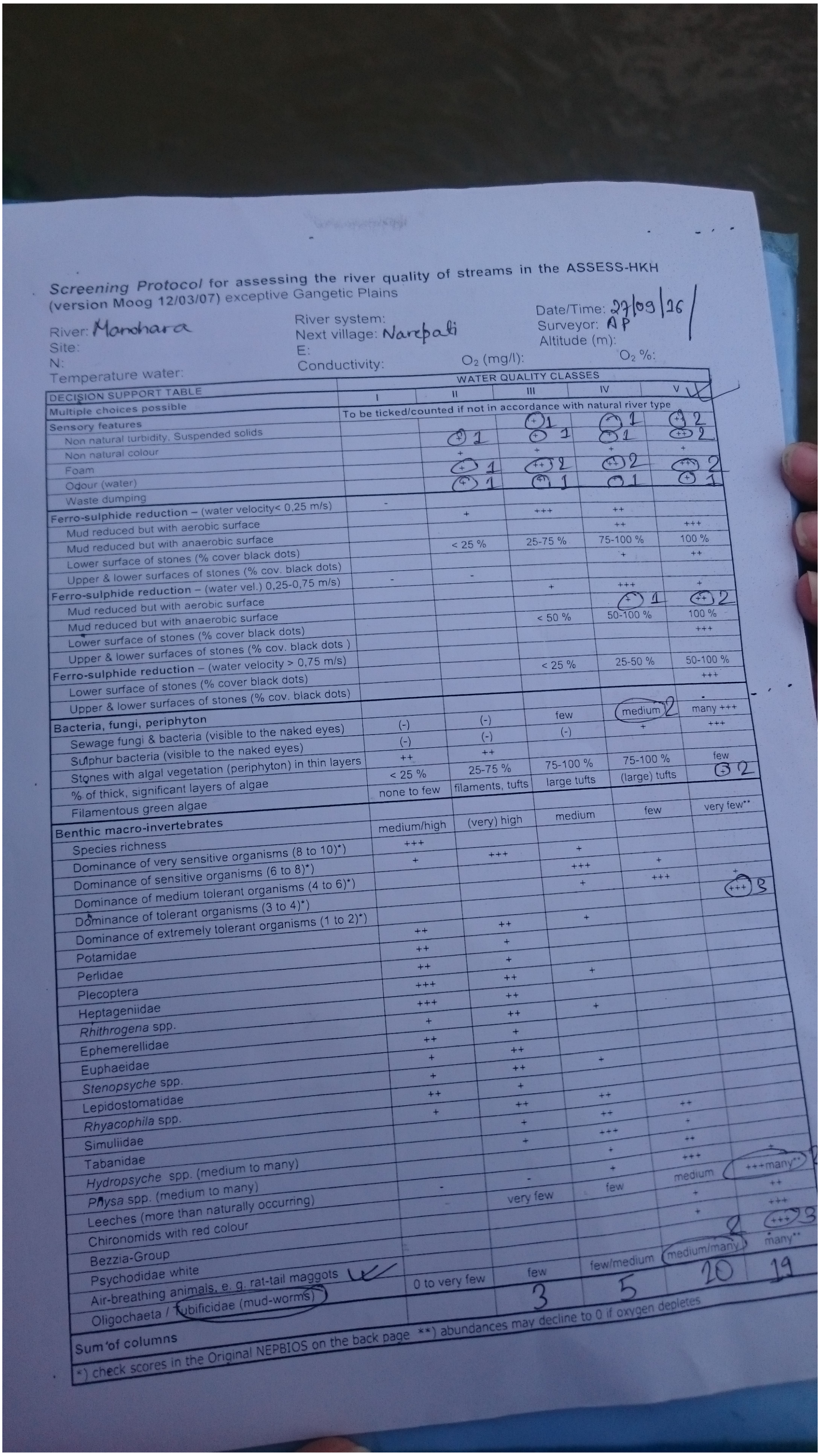


Figure 11.20: DO, EC, RSA and flow changes over the different landuse areas (%) per measurement point in the upper Bagmati watershed.

Appendix E: Example of RSA form



Screening Protocol for assessing the river quality of streams in the ASSESS-HKH
(version Moog 12/03/07) exceptive Gangetic Plains

River: Mandhara
Site:
N:
Temperature water:

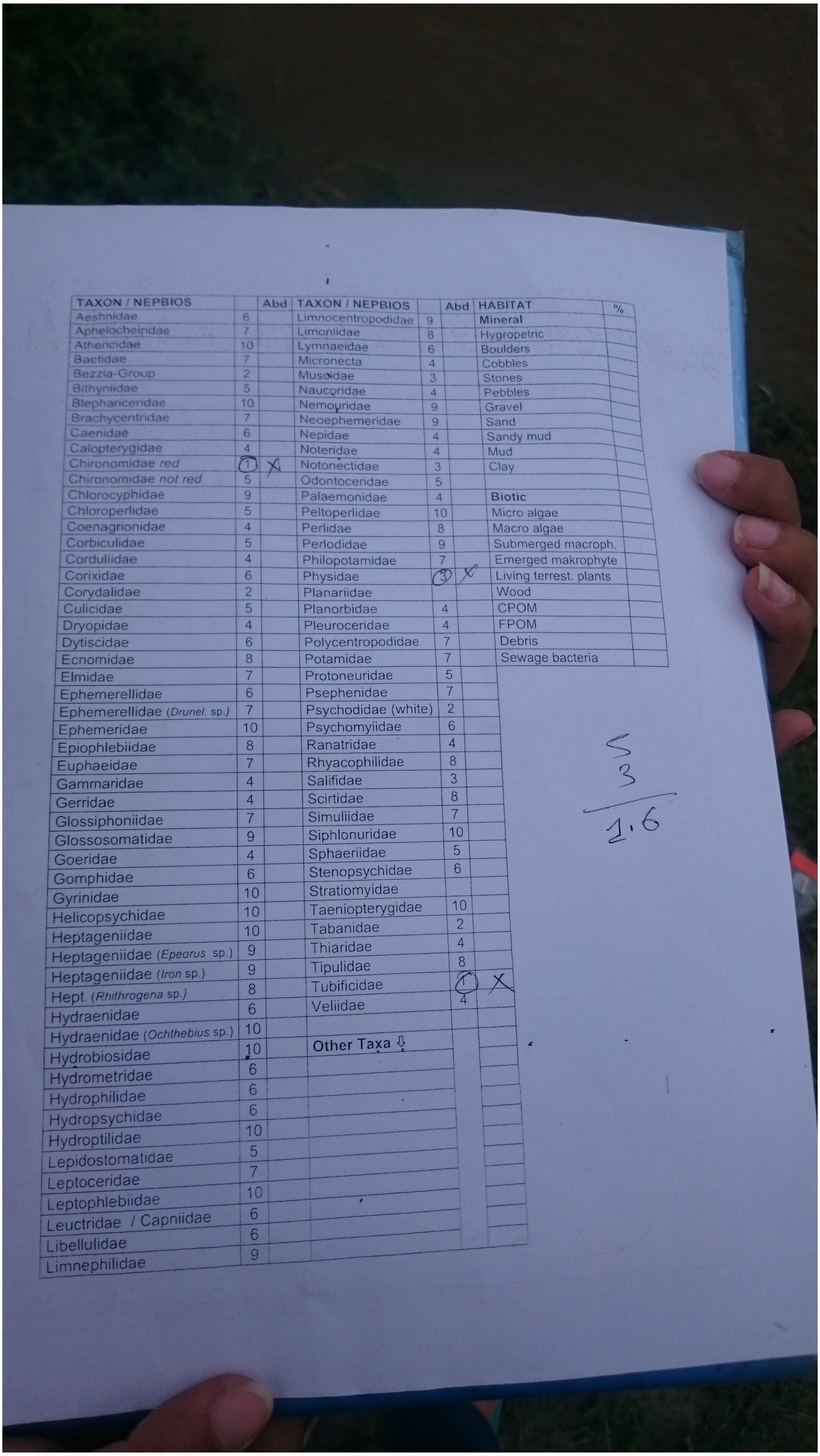
River system:
Next village: Narepali
E:
Conductivity:

O_2 (mg/l):

Date/Time: 27/09/16
Surveyor: AP
Altitude (m):
O_2 %:

DECISION SUPPORT TABLE	WATER QUALITY CLASSES I	II	III	IV	V ✓
Multiple choices possible	To be ticked/counted if not in accordance with natural river type				
Sensory features					
Non natural turbidity, Suspended solids			(+) 1	(+) 1	(+) 2
Non natural colour		(+) 1	(+) 1	(+) 1	(++) 2
Foam		+	+	+	+
Odour (water)		(+) 1	(++) 2	(++) 2	(+++) 2
Waste dumping		(+) 1	(+) 1	(+) 1	(+) 1
Ferro-sulphide reduction – (water velocity< 0,25 m/s)	-				
Mud reduced but with aerobic surface		+	+++	++	
Mud reduced but with anaerobic surface				++	+++
Lower surface of stones (% cover black dots)		< 25 %	25-75 %	75-100 %	100 %
Upper & lower surfaces of stones (% cov. black dots)				+	++
Ferro-sulphide reduction – (water vel.) 0,25-0,75 m/s)	-	-			
Mud reduced but with aerobic surface			+	+++	+
Mud reduced but with anaerobic surface				(+) 1	(++) 2
Lower surface of stones (% cover black dots)			< 50 %	50-100 %	100 %
Upper & lower surfaces of stones (% cov. black dots)					+++
Ferro-sulphide reduction – (water velocity > 0,75 m/s)					
Lower surface of stones (% cover black dots)			< 25 %	25-50 %	50-100 %
Upper & lower surfaces of stones (% cov. black dots)					+++
Bacteria, fungi, periphyton					
Sewage fungi & bacteria (visible to the naked eyes)	(-)	(-)	few	(medium) 2	many +++
Sulphur bacteria (visible to the naked eyes)	(-)	(-)	(-)	+	+++
Stones with algal vegetation (periphyton) in thin layers	++	++			
% of thick, significant layers of algae	< 25 %	25-75 %	75-100 %	75-100 %	few
Filamentous green algae	none to few	filaments, tufts	large tufts	(large) tufts	(+) 2
Benthic macro-invertebrates					
Species richness	medium/high	(very) high	medium	few	very few**
Dominance of very sensitive organisms (8 to 10)*)	+++				
Dominance of sensitive organisms (6 to 8)*)	+	+++	+		
Dominance of medium tolerant organisms (4 to 6)*)			+++	+	
Dominance of tolerant organisms (3 to 4)*)			+	+++	+
Dominance of extremely tolerant organisms (1 to 2)*)					(+++) 3
Potamidae	++	++	+		
Perlidae	++	+			
Plecoptera	++	+			
Heptageniidae	+++	++	+		
Rhithrogena spp.	+++	++			
Ephemerellidae	+	++	+		
Euphaeidae	++	+			
Stenopsyche spp.	+	++			
Lepidostomatidae	+	++	+		
Rhyacophila spp.	++	+			
Simuliidae	+	++	++		
Tabanidae		+	++	++	
Hydropsyche spp. (medium to many)		+	+++	+	
Physa spp. (medium to many)			+	++	
Leeches (more than naturally occurring)	-	-	+	+++	+
Chironomids with red colour		very few	few	medium	(+++many**) 2
Bezzia-Group				+	++
Psychodidae white				+	+++
Air-breathing animals, e. g. rat-tail maggots ✓				8	(+++) 3
Oligochaeta / Tubificidae (mud-worms)	0 to very few	few	few/medium	(medium/many)	many**
Sum of columns		3	5	20	19

*) check scores in the Original NEPBIOS on the back page **) abundances may decline to 0 if oxygen depletes



TAXON / NEPBIOS		Abd	TAXON / NEPBIOS		Abd	HABITAT	%
Aeshnidae	6		Limnocentropodidae	9		**Mineral**	
Aphelocheiridae	7		Limoniidae	8		Hygropetric	
Athericidae	10		Lymnaeidae	6		Boulders	
Baetidae	7		Micronecta	4		Cobbles	
Bezzia-Group	2		Muscidae	3		Stones	
Bithyniidae	5		Naucoridae	4		Pebbles	
Blephariceridae	10		Nemouridae	9		Gravel	
Brachycentridae	7		Neoephemeridae	9		Sand	
Caenidae	6		Nepidae	4		Sandy mud	
Calopterygidae	4		Noteridae	4		Mud	
Chironomidae *red*	(1)	X	Notonectidae	3		Clay	
Chironomidae *not red*	5		Odontoceridae	5			
Chlorocyphidae	9		Palaemonidae	4		**Biotic**	
Chloroperlidae	5		Peltoperlidae	10		Micro algae	
Coenagrionidae	4		Perlidae	8		Macro algae	
Corbiculidae	5		Perlodidae	9		Submerged macroph.	
Corduliidae	4		Philopotamidae	7		Emerged makrophyte	
Corixidae	6		Physidae	(3)	✗	Living terrest. plants	
Corydalidae	2		Planariidae			Wood	
Culicidae	5		Planorbidae	4		CPOM	
Dryopidae	4		Pleuroceridae	4		FPOM	
Dytiscidae	6		Polycentropodidae	7		Debris	
Ecnomidae	8		Potamidae	7		Sewage bacteria	
Elmidae	7		Protoneuridae	5			
Ephemerellidae	6		Psephenidae	7			
Ephemerellidae (*Drunel.* sp.)	7		Psychodidae (white)	2			
Ephemeridae	10		Psychomyiidae	6			
Epiophlebiidae	8		Ranatridae	4			
Euphaeidae	7		Rhyacophilidae	8			
Gammaridae	4		Salifidae	3			
Gerridae	4		Scirtidae	8			
Glossiphoniidae	7		Simuliidae	7			
Glossosomatidae	9		Siphlonuridae	10			
Goeridae	4		Sphaeriidae	5			
Gomphidae	6		Stenopsychidae	6			
Gyrinidae	10		Stratiomyidae				
Helicopsychidae	10		Taeniopterygidae	10			
Heptageniidae	10		Tabanidae	2			
Heptageniidae (*Epeorus* sp.)	9		Thiaridae	4			
Heptageniidae (*Iron* sp.)	9		Tipulidae	8			
Hept. (*Rhithrogena* sp.)	8		Tubificidae	(1)	X		
Hydraenidae	6		Veliidae	4			
Hydraenidae (*Ochthebius* sp.)	10						
Hydrobiosidae	10		**Other Taxa ⇩**				
Hydrometridae	6						
Hydrophilidae	6						
Hydropsychidae	6						
Hydroptilidae	10						
Lepidostomatidae	5						
Leptoceridae	7						
Leptophlebiidae	10						
Leuctridae / Capniidae	6						
Libellulidae	6						
Limnephilidae	9						