Investigation of stream water quality in an agricultural and a forested watershed in Nepal

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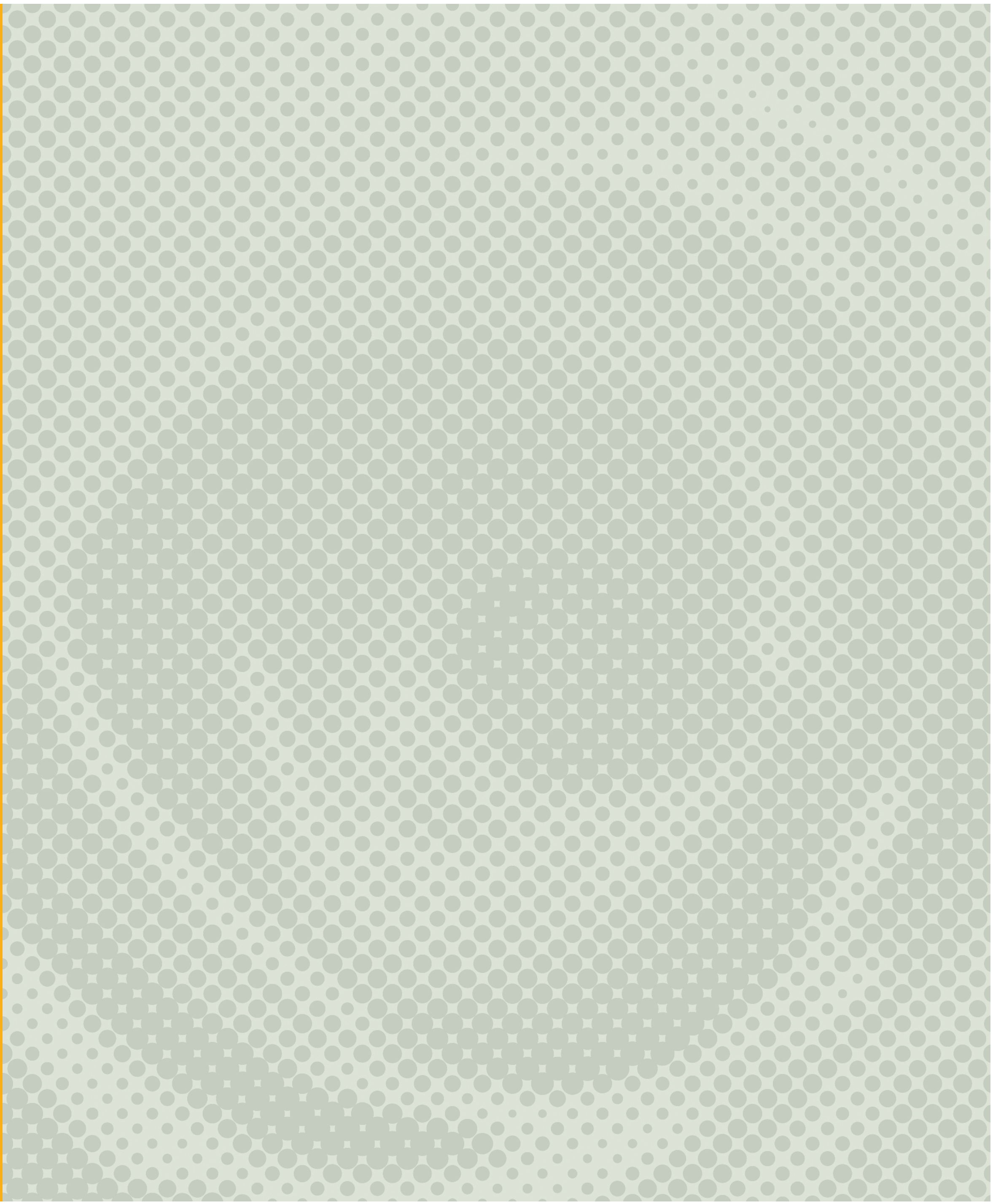

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Preface

The subject of watershed management is broad and a comprehensive assessment is necessary to achieve understanding about the dynamics affecting stream water quality. This study is limited to a selection of water quality parameters with the aim to gain knowledge about stream water quality and the effects from land use differences. Several factors should be included in a holistic investigation; such as soil analysis and study of hydro geology; this is beyond the range of this thesis. A social survey was initially planned; however not completed due to time limitations. Still the knowledge collected is incorporated in the thesis to some extent, although not precented as results.

Acknowledgements

I wish to thank my supervisors Petter D. Jenssen and Manoj K. Pandey for guidance and for initiating the study.

Special thanks to Sudeep Hada for being a good friend and colleague during my time in Nepal. Sudeep was indispensable in both field- and lab work and together with his family he was of great support during my close to five months stay in Nepal.

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Finally I wish thank my mum for continuous backing throughout the process. I also give thanks to some dear friends (you know who you are).

Summary

Nepal has long faced difficulties regarding population growth and food production, and intensified agriculture with expansion to the steep hills has led to erosion, soil degradation and water pollution; compromising both soil and water quality.

Two watersheds with different land use pattern in the Middle hills of Nepal are investigated to assess the impact of land use differences. The study is based on stream water quality in Mahadev Khola (MK), a water resource for Bhaktapur municipality, and Ghatte Khola (GK), representing a forested and an agricultural watershed, respectively. The sampling was conducted over 16 weeks, during monsoon and post monsoon, with the main objective to investigate the agricultural impact on stream water quality compared to a forested watershed, in light of seasonal variations.

Significantly higher Nitrogen-concentration in GK compared to MK suggests chemical fertilizers to interfere with the natural inputs in the watershed, resulting in increased concentrations of total-N in GK. Turbidity, with a significantly higher monsoonal mean of 21, 9 NTU and total-N with a corresponding concentration of 1, 825 mg/l both appear to be a direct result of agricultural land use. Both parameters are significantly higher also during monsoon compared to post monsoon (p = 0, 000 for both parameters). Still, the use of level terraces appears to some extent to prevent excessive erosion.

On the contrary, Phosphorus appears to be naturally occurring with high concentrations of P in both streams; 1319 µg/l and 1089 µg/l in MK and GK, respectively. Stream pH of 7, 42 and 7, 56 in MK and GK respectively indicates together with no liming practices a neutral soil with low retention of P. A low correlation coefficient between P and turbidity indicates P to be in solution and available to crops, which may explain the farmers practice of application of urea (Nitrogen fertilizer) rather than NKP. This suggests a system with a naturally occurring bio available P-source. The correlated fluctuations in MK and GK (R^2 = 94, 1 %) also during post monsoon indicates P to enter streams via runoff and a common hydro geological pattern.

The high concentrations of P exceed the recommended limits for reservoirs and for streems emptying into lakes and have potential to cause algal growth, however this was not reported as a problem at the reservoir.

Sammendrag

Nepal har lenge stått ovenfor utfordringer relatert til befolkningsvekst og matproduksjon. Intensifisert jordbruk med ekspandering til bratte dalsider har resultert i erosjon og tap av næringsstoffer som påvirker både jord- og vannkvalitet. I tillegg bidrar utilstrekkelige sanitetsforhold til mangel på rent drikkevann.

To nedbørsfelt med ulikt bruksmønster i Nepals Mid hills er undersøkt. Studiet er basert på 16 ukers måling av vannkvaliteten i elvene Mahadev Khola (MK) og Ghatte Khola (GK) (Khola = liten elv), som representerer henholdsvis et skogsdominert og et jordbruksdominert nedbørsfelt. MK er vannkilde for Bhaktapur municipality, og den eneste av overflateopphav. Vannprøvetaking ble utført under monsoon og post monsoon, med hovedmål om å undersøke hvordan ulikt bruksmønster, jordbruk og skog, påvirker vannkvaliteten i elvene i lys av sesongvariasjoner.

Signifikant høyere nitrogen-konsentrasjon i GK sammenlignet med MK antyder at kjemisk mineralgjødsel påvirker det naturlige systemet, med resultat i høyere N-konsentrasjon i GK. Både turbiditet og N viser signifikant høyere gjennomsnittsverdier under monsoon sammenlignet med post monsoon med verdier på henholdsvis 21, 9 NTU og 1, 825 mg/l, og virker å være et direkte resultat av jordbruk i nedbørsfeltet. Begge parametre er også signifikant høyere under monsoon sammenlignet med post monsoon innad i nedbørsfeltet (p = 0, 000 for begge parametre). Likevel virker terrassejordbruket til en viss grad å forhindre erosjon.

I motsetning til N virker P å være naturlig forekommende i begge nedbørsfelt og ikke et resultat av ulik driftsform; med konsentrasjoner på 1319 µg/l og 1089 µg/l i henholdsvis MK og GK. En pH i MK og GK på henholdsvis 7, 42 og 7, 56 indikerer, sammen med ingen kalkingspraksis i jordbruket, en nøytral jord med lav retensjon av P. Korrelasjon mellom P-fluktasjoner i MK og GK (R^2 = 94, 1 %), også under post monsoon, indikerer at P tilføres elvene både via avrenning og grunnvann. Lav korrelasjonskoeffisient mellom turbiditet og P antyder P å være i løsning og dermed tilgjengelig for avlinger.

Den høye P-konsentrasjonen overstiger anbefaling om P-konsentrasjon i inntak til reservoar og kan potensielt føre til algeoppblomstring både i vannreservoaret til MK, samt i roligere vann nedstrøms, men dette var ikke rapportert.

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Acronyms and Abbreviations

BOD	Biochemical Oxygen Demand
DNA	Deoxyribonucleic acid
DSCWM	Department of Soil Conservation and Watershed Management
DWSS	Department of Water Supply and Sewerage
DO	Dissolved Oxygen
EcoSan	Ecological Sanitation
EC	Electrical Conductivity
EUWFD	European Union’s Water Framework Directive
FYM	Farm Yard Manure
GDP	Gross Domestic Product
HKH	Hindu Kush Himalayan (region)
ICIMOD	International Centre for Integrated Mountain Development
MDG	Millennium Development Goals
N	Nitrogen
NSET	National Society of Earthquake Technology
OM	Organic Matter
P	Phosphorus
RNA	Ribonucleic acid
SOM	Soil Organic Matter
TDS	Total Dissolved Salts
VDC	Village Development Committee
WatSan	Water and Sanitation
WHO	World Health Organization

WSS	Water Supply and Sanitation
WSSD	World Summit on Sustainable Development

Introduction

There is seen an increase in global food demand over the past decades, with the leading cause being population growth (Foresight 2011). Particularly in developing countries has the increased food demand led to expansion and intensification of agriculture, resulting in eroded soils and degraded waters. The Hindu Kush Himalaya (HKH) -region in Asia is of those facing the most serious consequences, and Nepal is no exeption (FAO & UNEP 1999).

To meet the market demand agricultural land use in Nepal has expanded to the steep uplands of the Mid hill region, where natural vegetation and forest has been converted into rainfed agriculture (Upadhyay 1993; ICIMOD 2003). This has resulted in excessive translocation of soil and nutrients (Brown et al 1999; Collins & Jenkins 1996), and as a consequence soil degradation in Nepal has escalated every year (Karki 2006). The topography and climatic conditions makes the Mid hills especially prone to rain induced erosion, with about 80 percent of the precipitation falling during monsoon season from May to September, often during few and extreme rainfall events. Additionally altered food habits and intensified farming systems have resulted in nutrient mining, which in turn affects the quality of the crops (Shah 2005; Brown et al 1999; Sillanpää 1982).

Application of chemical fertilizers aims to prevent unsustainable farming practices, however applications are often insufficient and nutrients are frequently lost through leakage and runoff. As a result, many watersheds in Nepal suffer from acidification (Schreier et al 1995), and both surface- and ground waters faces degradation, in rural- as well as urban areas.

The majority of Nepal’s big cities and peri-urban areas suffer from water scarcity and water pollution (Rajbhandari 2008). Centralized sewage systems and dysfunctional septic tanks pollute surface waters, while leakage from pit latrines aggravates ground waters. In the Millennium Development Goals (MDGs) of September 2000, target 7c aims to: “halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation” (UN 2010). In Nepal the sanitation goal is far behind schedule, and although the goal for drinking water is reached, many people in Nepal still lack access to safe drinking water. Water treatment is often unsatisfactory, and an additional risk of pollution in the distribution system makes good water quality fundamental, in both a social and ecological perspective.

Two watersheds in the eastern periphery of Kathmandu Valley are investigated to assess how different land use patterns affect the quality of stream water. The study is based on stream water quality in Mahadev Khola (MK) and Ghatte Khola (GK), which represents a forested and an agricultural watershed, respectively. MK is one of three main water suppliers for Bhaktapur municipality, and the only of surface origin.

The main objective will be to investigate how land use affects stream water quality in the respective watersheds, with relevant pollution type being eutrophication. In conclusion there will be conducted a classification of the streams according to the European Union's Water Framework Directive. Analyses are limited to physical and chemical parameters related to land use and fertilizers. The thesis seeks to emphasize the importance of a holistic management as a step towards environmental and social sustainability.

Objectives and scope of study

1.1 Motivation and Rational of the study

The study was initiated by Petter D. Jenssen and Manoj K. Pandey as a result of a visit to the study area in 2006. Since 2008, field training related to sustainable water and sanitation at the Institute of Engineering (IOE), Kathmandu, was organized on a yearly basis. During the course there was observed a degraded sub watershed; believed to be result of deforestation, erosion and improper agricultural practices. This motivated a study of stream water quality in relation to land use differences, and two local watersheds; one of which had potential for degradation, were to be investigated. As I was introduced to the subject I decided to dedicate my thesis to this topic, in this particular area.

My motivation is a general and genuine interest in environmental issues, and particularly in the coexistence between man and nature related to sustainable management of water- and soil resources. Developing countries like Nepal are in need of attention towards watersheds in risk of deterioration, especially concidering a continous population growth and ongoing climatic changes.

1.2 Objective of study

The purpose of the study is to examine and compare the water quality in two watersheds of 6 km^2 and 11 km^2 in the eastern periphery of Kathmandu Valley. The streams Mahadev Khola (MK) and Ghatte Khola (GK) run through watersheds dominated by forest and agriculture, respectively. The main aim will be to assess if and how land use has affect on the stream water quality, and investigate the affect of seasonal consequences on the respective streams. The streams are (potential) water sources for local and downstream population and the water quality will be evaluated keeping this in mind. Additionally it will be assessed weather the streams show sign of contamination from failing sanitary systems, by analyzing for *Escherichia coli* (*E.coli)*; most and foremost in MK, which is water source for Bhaktapur municipality. The results will conclusively be used in classifying the stream water quality based on standards set by European Union's Water Framework Directive (EWFD).

Prior to the study it is hypothesized that the agricultural dominated watershed (GK) will show higher turbidity and nutrient content compared to the forested watershed (MK), as a result of increased erosion and runoff. Analysis of physiochemical parameters and *E.coli* will together with rainfall data make out the foundation of the assessment.

Specific objectives:

i. Describe the study area with focus on potential sources of pollution, mainly from agricultural land use.
ii. Implement an assessment and comparison of the water quality in the two streams, seen in light of land use within the respective watersheds.
iii. Investigate the seasonal changes between monsoon and post monsoon, and assess how seasons affect the two streams, independently.
iv. Examine if there is sign of significant fecal contamination in MK watershed.
v. Conduct a classification of the streams according to EU's Water Framework Directive (EUWFD).

2 Background

2.1 Socioeconomic situation

Nepal's Gross Domestic Product (GDP) grew by 3, 6 percent in the fiscal year of 2013 (ADB 2013). Although there is seen a reduction in poverty during the past decades, Nepal is still amongst the poorest countries in the world and listed as number 157 of 187 countries on the Human Development Report; with a Human Development Index of 0,463 (UNDP 2013). The population was of about 30 million people in 2012 and the current population growth rate is of 1, 77 percent (Index Mundi 2013).

The overall poverty rate in Nepal was 25, 2 percent in 2010 (The World Bank 2013), and average annual salary is 2, 400 USD (214, 080 NPR), which is amongst the world's lowest incomes. However, Nepal has seen great improvements during the past decades, with a life expectancy of 38, 5 years in 1960 (Index Mundi 2013) rising to 66, 7 years for women in 2012 (The World Bank 2013), and over the same time period the proportion of children in school age attending primary school has risen from one in five to four in five (UNDP 2010).

Of Nepal's population more than 80 percent live in rural areas and rely on agriculture for income and employment (IFAD 2013). The agriculture sector is one of Nepal's pillars, making out 40 percent of the GDP (MOAC 2010) and employing 70 percent of the population (US AID 2013). Still, food insecurity is a subject of great concern, and many farmers are dependent on subsides to afford chemical fertilizers.

About half of Nepal's children below the age of five suffer from mal-nutrition (Andersen et al 2005) and rural areas often lack access to basic services such as health care, proper sanitation and clean drinking water.

2.2 Water and Sanitation

As much as 80 percent of illness and death in developing countries is water related (UN 2003), and is often a result of poor water- and sanitation facilities. Worldwide, one in six people lacks access to safe drinking water, whereas 2, 6 billion people (i.e. 80 percent) lack access to improved sanitation facilities (WHO & UNICEF 2010).

During the Millennium Declaration of September 2000 the UN Summit established the Millennium Development Goals (MDGs) where target 7c aims to: “Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation” (UN 2010). According to WHO, improved drinking water sources includes sources “that, by nature of their construction through active intervention, are protected from outside contamination, particularly fecal matter”, whereas improved sanitation facilities are facilities “that ensure hygienic separation of human excreta from human contact” (WHO & UNICEF 2010).

Nepal’s national water supply coverage was 37 percent in 1990 (DWSS 2012) and increased to more than 80 percent in 2012, hence reaching the MDG water target (DWSS 2012). The total sanitation coverage increased from 6 percent to 50 percent over the same period, and the MDG sanitation target is not likely to be fulfilled untill 2030 (Wateraid Nepal 2011).

Neither urban nor rural areas in Nepal have average sanitation coverage above 50 percent (UNICEF & WHO 2012); however the proportion of people with access to sanitation services is by far greater in urban areas compared to rural. Both Kathmandu and Bhaktapur District, in which the study area is located, are above the average coverage of water and sanitation (UNICEF & WHO 2012).

However; improved sanitation is not equivalent to safe and sustainable sanitation. In developing countries like Nepal, improved sanitation often means pit latrines or pour-flush latrines; and inappropriate technology, soil- and water table conditions often leave ground water prone to pollution (Rajbhandari 2008). Conventional latrines with septic tanks, and also sewage treatment systems, often have poor or none sanitizing- or nutrient removing process prior to discharge into the environment. Considering this the number of people in need of hygienic and sustainable sanitation is higher than the estimated 2, 6 billion (WHO & UNICEF 2010).

2.2.1 Ecological Sanitation (EcoSan)

Benefits

Ecological Sanitation acknowledges human waste as a resource rather than a waste product (Vinnerås 2002), and aims to protect soil and water from deterioration and pollution, by closing the nutrient cycle (Fig. 1).

Toilet waste contains up to 80-90 percent of the nitrogen (N), phosphorus (P) and potassium (K) (Vinnerås 2002). A reuse of these in a hygienically safe manner has great potential as locally obtained fertilizer (Vinnerås 2002) and is by many seen as more appropriate than conventional systems (Jenssen et al 2004).

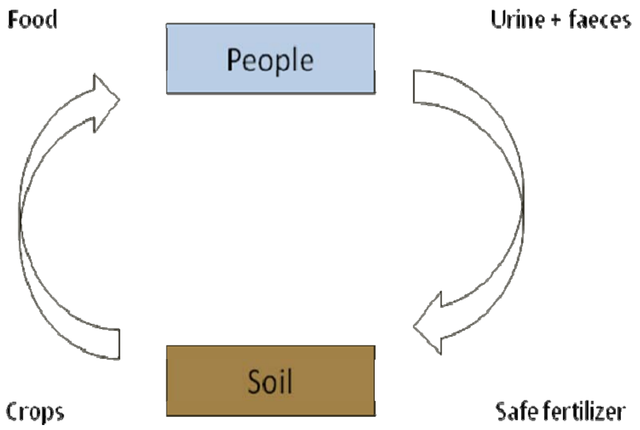


Figure 1 The nutrient cycle in Ecosan is about closing the loop; prevention of pollution and recycling of nutrients. (Modified from http://www.ecosanres.org/about.htm)

EcoSan in Nepal

A pilot project on Ecosan toilet technology in Nepal was initiated in 2002 and carried out by ENPHO with financial support from the World Health Organisation (WHO). More than 500 Ecosan toilets were taken in use within five years; the majority located within peri-urban areas of Kathmandu Valley.

Challenges

There is a misconception amongst users that the commercial water toilets, which are more expensive and more water demanding, are the best option for waste disposal. Due to lack of regulations, the environmental protection is not particularly valued by the users and it is not uncommon for the polluted blackwater to be discharged directly into surface waters. Locals do however recognize the benefits of using humus formed in toilets to enhance soil fertility. Still, lack of land on which to utilize the fertilizer is of the main arguments against scaling up the Ecosan latrine technology in Nepal (Rajbhandari 2008). For it to function successfully there is need of education and communication as well as adaption to local conditions.

Urbanisation is escalating in developing countries, and Nepal is facing the most rapid urbanization trend in the South Asian sub-continent (Rajbhandari 2008), hence the need of proper and eco-friendly sanitation is increasing. In future development of both urban and rural areas sustainable sanitation practices are crucial in both a social and ecological perspective.

2.3 Geography, Geology and Climate of Nepal

Geography and Geology

Nepal is located in southern slope of the Himalayas, Asia; land-locked between the Tibetan Plateau and China in the north and India in the south, on latitudes 26º22’N - 30º27’N and 80º4’E - 88º12’E (Fig. 2). The land area makes out 147 181 km^2, which of rugged hills and mountains cover about 75 percent, containing eight out of ten of the world’s highest mountains, including the Mount Everest (8848 m-asl).

From south to north Nepal can be divided into five distinct morpho-geotectonic zones; (1) Terai Plain (2) Sub Himalaya (Siwalik Range), (3) Lesser Himalaya (Mahabharat Range and mid valleys), (4) Higher Himalaya and (5) Inner Himalaya (Tibetan Tethys). Seen from a mineral point of view, the Terai has potential resources such as gravel, sand, ground water and petroleum (Kaphle 2011). The sub-Himalayas have resources such as construction materials, petroleum and natural gas, whereas metallic- and industrial minerals, marble and gemstones are potential resources in the Lesser Himalaya. In the Higher Himalaya one can find precious and semiprecious stones, marble and metallic minerals (Kaphle 2011) and the Tibetan Tethys zone is mainly has resources such as limestone, gypsum, brine water (salt), as well as natural gas (Kaphle 2011).

Figure 2 Map of Nepal bordering to China and India, with capital Kathmandu. (Source: google images).

Kathmandu Valley

Kathmandu Valley is located in the Mid hills (lesser Himalaya) and encloses Kathmandu-, Lalitpur- and Bhaktapur district. The valley covers about 656 km^2 with elevation ranging from 457 – 2732 meters; surrounded by the Mahabharat mountain range, which is the origin of all streams and rivers draining the valley.

Kathmandu Valley was once a lake and consists of a variety of fluvio-lacustrine sediments on top of bedrock (Yoshida & Igarashi 1984). The origin of the lake valley started about 120 000 years ago after a tectonic uplift in the southern rim, damming up for the proto-Bagmati River. As the southern edge continued to rise the lake shifted northwards and was at its highest approximately 30 000 years ago, where from it drained in several stages (Yoshida & Igarashi 1984). The lake is believed to empty approximately 10 000 years ago, leaving a fertile soil which later attracted settlements.

Climate and Ecological zones

Nepal mainly has a subtropical monsoon climate with five seasons; summer, monsoon, autumn, winter and spring. Temperatures range from sub zero to 40 ° C and snow occasionally falls during winter, above 2500 m-asl. Annual rainfall is 1280 mm (CBS 2010) with the majority falling during monsoon season from May to September.

Laterally Nepal can be divided into five ecological zones (Fig. 3), and three main zones. The Terai, Mid-Hills and Mountains create three east-west running belts which are vertically divided by Nepal's North- to South-flowing river system. *The Terai region* (23 percent) covers the southern lowland plains bordering India, and is formed and fed by three major rivers running down the Himalaya. The Terai has a subtropical to tropical climate and is known to be more fertile than the upper hills due to deposition of silts and nutrients during monsoon season. Agriculture in the Terai and Siwalik zones is primary dominated by rice (*Oryza sativa*), wheat (*Triticum* spp.), legumes and oil seeds. The erosion in the uplands and deposition of sediments in the lowlands occationally creates problems, and the region is frequently experiencing flash floods and eroded river banks (Sthapit & Tennyson 1991). In the *Mid Hill Region* (42 percent) crops are similar to those in the Terai, with additionally maize and pulses (legumes). The forests consist to a large extent of Sal *(Shorea robusta),* which can achieve a height of 45 m (148 ft). This region has a subtropical climate below 1200 meters and alpine climate starting above 3600 meters, in the transition to the Mid mountain Region. The population is high in the valleys, but notably lower above 2000 meters. The region is influenced by deforestation and soil deteoriation, mainly due to erosion and agricultural expansion (Gilmour 1988; Eckholm 1975). The *Mid- and High Mountain regions* (Himalayan) (35 percent) experience severe surface soil erosion, forest degradation and overgrazing (Gilmour 1988; Eckholm 1975).

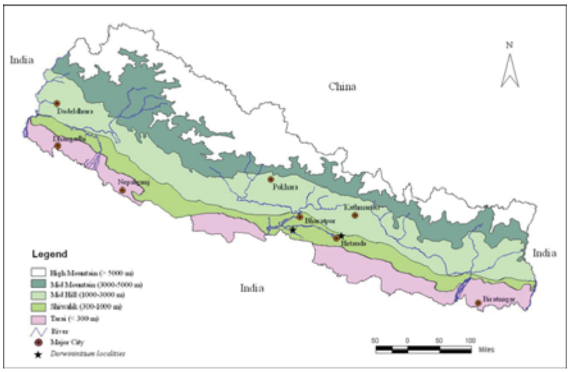


Figure 3 Map over Nepal and the five ecological zones; Terai, Shwalik, Mid hills, Mid mountains and High mountains (listed from south to north). (Source: Budha et al 2012).

2.4 Rivers and River Basins

Nepal is well known for being rich in water resources, despite the challenges of clean drinking water. The estimated total renewable water resource in Nepal is 237 km^3 $year^{-1}$ of which 225 km^3 is from surface sources and 12 km^3 from groundwater sources (WEPA 2013). Water availability per capita in 2001 was 9600 m^3 $year^{-1}$ (WEPA 2013). Nepal is a part of the Ganga Basin, and an estimated 6000 rivers included rivlets and tributaries are distributed on the three major river systems Kosi, Narayani and Karnali (listed east to west) (WEPA 2013).

Nepali rivers can be classified into three main groups, based on origin:

1) *Snow-fed rivers* are the major river systems such as the Koshi Gandaki, Kamali and Mahakali, which originate from snow and ice in the Himalayan regions. The flow is perennial and flows during the dry period. These rivers are a reliable water source for irrigation, and they also have potential for hydropower.
2) The second group originates from mountainous and hilly regions in *the Mid hills* and has flow regimes supported by monsoon and ground water, the latter preventing them from emptying out during dry season. Examples of this kind are the Baghmati-, Kamala-, Rapti-, Mechi-, Kankai- and Babai River.
3) The third river type originates in the *Siwalik zone* and the flow is for the most part dependent on monsoonal precipitation, which may result in significant flow depletion during dry season. Tinau, Banganga, Tilawe, Sirsia, Manusmara, Hardinath, Sunsari and several other smaller rivers are of this kind.

2.5 Land use and Agriculture

Soil deterioration and declined soil fertility is a severe problem in Nepal, mainly due to over exploitation of soils and intense rainfall. Intensified agriculture in combination with monsoon seasons result in translocation of soil and loss of nutrients (Ya and Murray, 2004).

Agriculture occupies about 18 percent of Nepal's total land use whereas forest, snow and pasture make out 38 -, 15 - and 13 percent, respectively (Fig. 4) (Pariyar 2005). Limited arable land combined with population growth and altered food habits has pushed the system to its limits. Of Nepal's farmers 61 percent lack food sufficiency (NARC 2010), and especially the production of cereal crops is not keeping up with the population growth (CIP 2010).

In areas with sufficient irrigation, intensification has led to a doubling and sometimes tripling of the crops (Brown et al 1999), however this intensification is found to increase soil erosion on a long term (Tiwari et al 2009). The reason for the overall drop in productivity is believed to be decline in soil quality; however the processes behind the depletion have been poorly documented.

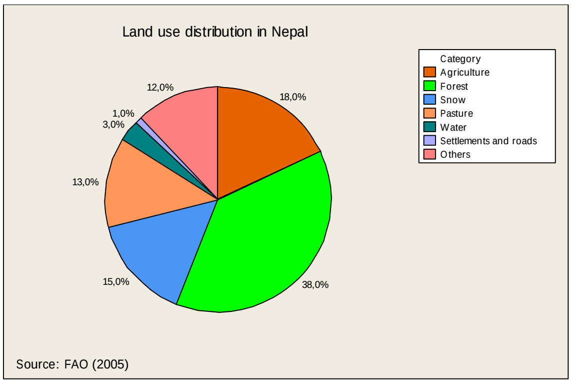


Figure 4 Pie chart of land use distribution in Nepal (From Pariyar 2005).

2.5.1 The Mid Hills

From the 1960's there was seen a decline in crop yields in the Mid hills (ADB/HMG(N) 1982), where expansion of agriculture to the steep uplands led to imbalanced agro-ecosystems (ICIMOD 1994). Forest was removed to expand croplands, and approximately 70 percent of the arable land in the region is rainfed hill slopes (Bari), whereas the rest is irrigated (Khet) (FAO 1992).

In 2008/2009 a comparison between ecological regions revealed the Mid hills to be in a food-deficit state, whereas the Terai was found to produce surplus food (CIP 2010). The main reasons for the deficiency in the hills are the constraints related to financial capability, infrastructure, and market availability, in addition to the limited croplands.

Terracing

Terracing is used on sloping cultivated land as a measure to reduce soil erosion. The most frequent cropping system on Bari land (rainfed terraces) is maize-millet, occupying 69 percent of the Middle mountain region (Tiwari et al 2009).

Terraces with a slope of up to 20 percent (Fig. 6) are used for rainfed crops such as maize, millet and wheat, whereas level terraces are most commonly used in rice cultivation in the lower part of the hills. Terracing helps in conserving moisture and reduces erosion during monsoon season, however steep sloped bari land with nutrient demanding crops and insufficient application of manure in combination with high rainfall, is found to suffer from degradation (Gardner & Gerrard 2003).

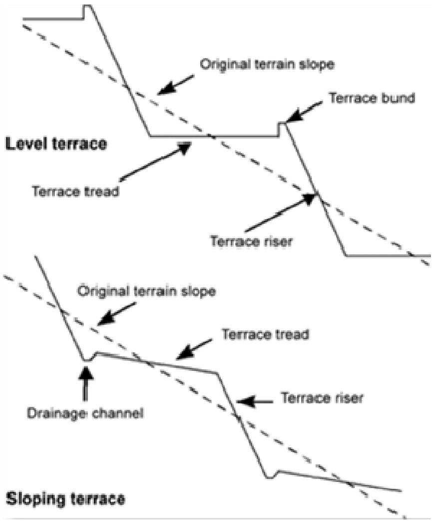


Figure 5 Level terrace with terrace bund (ridge) and sloping terrace with drainage channel, without bund.

Watershed conditions

A watershed is defined as the area from which all surface runoff drains through a common point. Degradation of watershed concerns water resources rather than land productivity; however, the two are closely related, as loss of nutrients and soil particles often result in decline in water quality by entering the water ways. The Department of Soil Conservation and Watershed Management (DSCWM) states that “Watershed condition is an estimated index representing the current state of soil erosion in an area in comparison with that under natural or “well managed” condition”.

After a survey investigating the state of watersheds in the Mid hills in 1980, 0 -, 3 - and 16 percent of watersheds were classified as very poor, poor and in fair condition respectively, whereas 18 percent and 63 percent was found to be in good and excellent condition, respectively (Fig. 5) (Nelson et al 1980). Although the majority was described as good-excellent, the way to degradation was thought to be short. Both Kathmandu and Bhaktapur District were classified as poor (Shresta et al 1983).

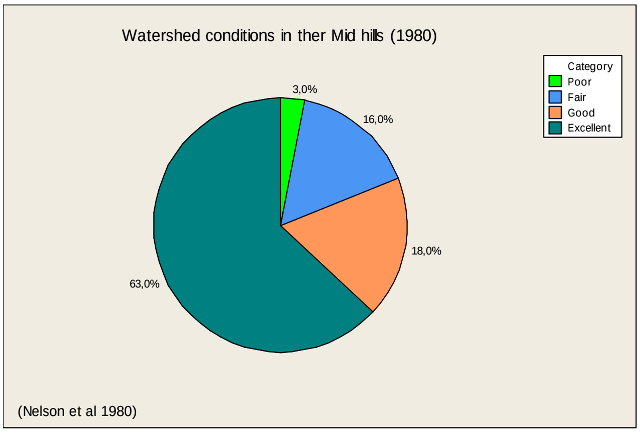


Figure 6 Condition distribution of watersheds the Mid-Hills (1980); Very poor: 0 %, Poor: 3 %, Fair: 16 %, Good: 18 %, Excellent: 63 %.

Of Nepal’s soils, 48 percent and 62 percent are estimated to be low in total-N and organic matter, respectively (Table 1), whereas 35 percent, 27 percent are low in available phosphorus and available potassium, respectively (Jaishy 2000).

Table 1 Summary of soil fertility status in Nepal in 2000. (From Jaishy 2000).

Soil fertility parameters	*Number of samples analyzed*	*Low (%)*	*Medium (%)*	*High (%)*
Total Nitrogen	9872	48	41	11
Av. phosphorus	8942	35	24	41
Av. potassium	9522	27	33	40
Organic matter	7520	62	33	5

Av. Available

Deforestation and Erosion

According to ICIMOD (2010), Nepal's deforestation rate is of about 1, 6 percent per annum. Rural livelihoods still relies on forest resources for fuel and timber, and this has had adverse impacts on flora and fauna. As a result land cover has changed and land degradation progressed (ICIMOD 2010).

In a well managed forest there will be a minimum of soil erosion; about 5-10 t ha^{-1} $year^{-1}$, whereas mismanagement may increase soil erosion to about 40-200 t ha^{-1} $year^{-1}$ (Karki 2006). According to Carson (1992) a loss of 20 t soil ha^{-1} in the Mid mountains would include the loss of 300 kg OM, 15 kg N, 20 kg P and 40 kg K, suggesting soil erosion to be a major contributor to soil deterioration.

Soil degradation

Soil deterioration is changes in physical, chemical and biological soil properties which result in negative effects of crop production (Karki 2006). Soil erosion from agricultural sloping land is the leading cause of land degradation, resulting in soil- and nutrient loss as well as declined physical structure, which of plants and micro organisms is dependent. In Nepal 1, 3 million tons of nutrients are estimated to be displaced annually, and mainly from sloping agriculture in the Mid hills (MOPE 2004). Furthermore 500 000 tons $year^{-1}$ of soil nutrients are lost through crop harvesting, which of only about 16, 7 percent is estimated to be returned in the form of organic and mineral fertilizers (MPE 2000).

Intense rainfall often results in a wash out of base cations such as Ca, Mg, Na and K; leading to acid soil conditions (Shah 2005). Application of fertilizers can further promote acidification, resulting in binding of P to micronutrients such as iron (Fe), copper (Cu), manganese (Mg) and zinc (Zn), preventing plant availability of P. In Nepal approximately 50 percents of soils are acidic, with the majority located in the Mid mountain region (Triphati 1999).

Compost and Farm Yard Manure (FYM)

Farmers have a long tradition of collecting, composting and applying forest litter, kitchen waste and farm yard manure (FYM) on soil to improve crops and maintain fertility. FYM consist of animal manure and other organic materials such as animal bedding or materials used as absorbent for feces and urine. A mixture of FYM and other organic wastes is stored and organic matter and nutrients are converted to more stable forms which function as soil improver (Rynk et al 1992). The mixture is applied and often incorporated in the soil during plowing or tillage, contributing with OM and micro- and macro nutrients as well as physical improvments such as soil structure and water holding capacity. Despite positive effects of tillage (mixing and aeration) the practice can have a negative effect on soil aggregates and may increase weathering and nutrient loss.

Compared to chemical fertilizers compost has a more long lasting effect, however the practice is time- and labor consuming, and over exploitation of forest litter is threatening the sustainability of the farming system (Paudel 1992). This causes a dilemma, as decreased application of compost leads to decrease in SOM which may lead to declined soil fertility and reduced nutrient balance (Regmi et al 2005).

Chemical fertilizers

The green revolution brought increased use of chemical fertilizer to Asian countries in the 1960’s (Gulati & Sharma 1995), and application became common practice amongst Nepalese farmers. The fertilizers were meant to improve agricultural practices; however, the amount has often been insufficient. According to FAO (1977), imbalanced use of fertilizers led to nutrient deficiencies, one of the main contributors to soil deterioration. According to World Development Indicators (WDI) Nepal used 17, 7 kg chemical fertilizer per hectare of arable land in the years 2008-10, including NPK and ground rock phosphate (WDI 2013), in addition to animal and plant manure (FYM).

2.6 Parameters related to water quality

2.6.1 Turbidity

Turbidity is a measure of the waters "cloudiness" which may be caused by suspended material such as sediments, mineral- or organic particles or microscopic life such as algae or microbes. These compounds may be a result of waste water discharge, urban- or rural/agricultural runoff, eroding stream banks or excessive algae growth. High organic matter content in water will show as a yellow/brownish color.

Suspended solids may block sunlight for aquatic vegetation, and can also lead to increased temperatures and decreased dissolved oxygen (DO) due to absorption of solar energy. Particles may additionally attract- and give transport to pesticides or other pollutants.

2.6.2 PH

pH refers to concentration of hydrogen ions and is equal to the negative logarithm of $[H^+]$. The scale ranges from 0-14, where above 7 is referred to as basic (alkaline) whereas readings below 7 is acidic (Pierzynski et al 2005).

pH is an important factor in water quality as it interferes with biochemical reactions which can cause harm or death to aquatic life. Decreased pH increases the solubility and bioavailability of nutrients (e.g. N, P and C) and metals (e.g. Cu and Cd), which can increase algal blooming or lead to heavy metal toxicity in aquatic life.

In most natural waters pH ranges from 6, 5 – 8, 5 (Loon & Duffy 2005), depending on the dissolved substances from bedrock, soil, and vegetation, as well as anthropogenic interference in the watershed. In soil, leaching of metals and replacement by hydronium ions is a contributor to soil acidity, which can be damaging to crops (Pierzynski et al 2005).

2.6.3 Electrical Conductivity

Electrical conductivity (EC) is a measure of total dissolved salts (TDS), and describes the waters ability to pass an electrical current. EC may be result of inorganic dissolved solids such as chloride-, nitrate-, sulphate- and phosphate anions, or magnesium-, sodium-, calcium-, iron- and aluminum cations (Pierzynski et al 2005). Runoff from agricultural areas is often found to have increased EC as a result of chemical fertilizers. Kværner et al (1994) found EC in drainage water from agricultural land use to be in the range of 7-34 mS/m.

In stream water EC is commonly affected by the geology and soil material through which the water flows, and is often related to size of the watershed. Ground water inflow may increase EC, depending on geology, thus springs may be a source of dissolved salts in streams. Anthropogenic contributors to EC can be livestock- and human waste, discharge from septic tanks, fertilizers in runoff, pesticides, herbicides or road salt.

2.6.4 Nitrogen

Nitrogen (N) is the limiting growth factor under natural conditions and an essential part of chlorophyll and build-up of amino acids and DNA (Hodges & Crozier 1996). In the environment N occurs in different oxidized states, and is transformed chemically and biochemically in processes most often involving oxidation (loss of electrons) or reduction (gain of electrons).

Overall the deposition of inorganic N is of fossil fuel combustion origin. However, commercial chemical N fertilizers from agriculture are a significant source of N-output in the environment. Organic sources of N are commonly bio solids, animal manure, crop residues, waste water discharge and industrial by-products from rural and urban areas.

In the atmosphere N is present mainly as dinitrogen gas (N_2); making out approximately 78 percent of the atmospheric gases (Hodges & Crozier 1996). N_2 is in a non-available form and is restricted for biological life. Physical and biological processes such as fixation, ammonification (decay), nitrification and denitrification are responsible for making atmospheric N available to higher life forms.

Application of (excessive) N fertilizers is of the major contributors of degraded waters. N moves easily through water and translocates through leakage and runoff, especially in combination with heavy rainfall. Some of the N below the root zone may be lost to the atmosphere via denitrification, but this is not extensive in cultivated soils with good aeration. Contrary, in soils with high OM-content and poor drainage, denitrification is more likely to occur, as the OM provides energy to microorganisms.

Inorganic N can lead to excessive aquatic production and water degradation and mostly in marine waters where N is the limiting nutrient. N in groundwater may cause serious disturbances in the form of eutrophication, when entering surface waters. The nutrient boost can lead to excessive primary production; especially populations of blue-green algae may rise, threatening to degrade water quality.

The WHO guideline suggests 50 mg/l nitrate as the limit for safe consumption of drinking water (WHO 2006).

Fixation

Terrestrial fixation of N_2 into ammonia (NH_3) is done by free-living bacteria (Pierzynski et al 2005). Ammonia is further converted into organic compounds. Some bacteria such as *Rhizobium*, live symbiotic in the root nodules of legumes where they produce ammonia in exchange of carbohydrates (Pierzynski et al 2005); accordingly cultivating legumes in nutrient depleted soils may contribute to N enrichment.

Industrial N fixation (Haber-Bosch process since 1909) which generates commercial fertilizers from ammonia is estimated to contribute to 30 percent of the world's total N fixation (Smith et al 2004). In short, the N_2 reacts with $3H_2$ to produce 2 NH_3. Combustion of fossil fuels and fixation leads to a variety of nitrogen oxides (NO_x) (Pierzynski et al 2005).

Mineralization

Mineralization refers to the microbial decomposition of organic forms of N (i.e. protein and nucleic acids) to inorganic forms such as NH_4^+-N (Fig.7) The majority (> 95 percent) of N in soils is organic N (Pierzynski et al 2005), hence the conversion to bioavailable forms such as ammonium (NH_4^+-) and nitrate (NO_3^-) is a significant part of a natural ecosystem.

Plants absorb nitrate- or preferably ammonium ions (NH_4^+) from soil water via root hairs and utilize it for building of amino- and nucleic acids and chlorophyll. Subsequently animals utilize plants as N source. Bacteria or in some cases fungi, further digest the organic N from plant and animal residues back into ammonium, in the process known as ammonification or mineralization. Ammonia is the end product after bacterial decomposition, and is the most reduced form of N.

Nitrification

Nitrification is the bacterial conversion of ammonia (NH_3) into nitrites (NO_2-) and further into nitrate (NO_3^-) (Fig. 7). A different type of bacteria oxidizes nitrite into nitrate, which is a crucial process as accumulated nitrites can be toxic to plants. In water, high concentrations of nitrites may cause a lethal “brown blood disease” in fish. Due to the high solubility of nitrates, and due to the soils frequent resistance to retain anions, excessive nitrate tend to leach to ground water where it causes degraded water quality.

Denitrification

The process of denitrification most often occurs under anaerobic conditions, where bacteria such as *Clostridium* and *Pseudomonas* reduce oxidized forms of nitrogen back into N_2 gas. The preferred electron acceptors, in the order of most to least favourable, are Nitrate (NO_3^-), nitrite (NO_2^-), nitric oxide (NO) and nitrous oxide (N_2O), whereof the latter may finally be reduced back into dinitrogen (N_2) (Fig. 7).

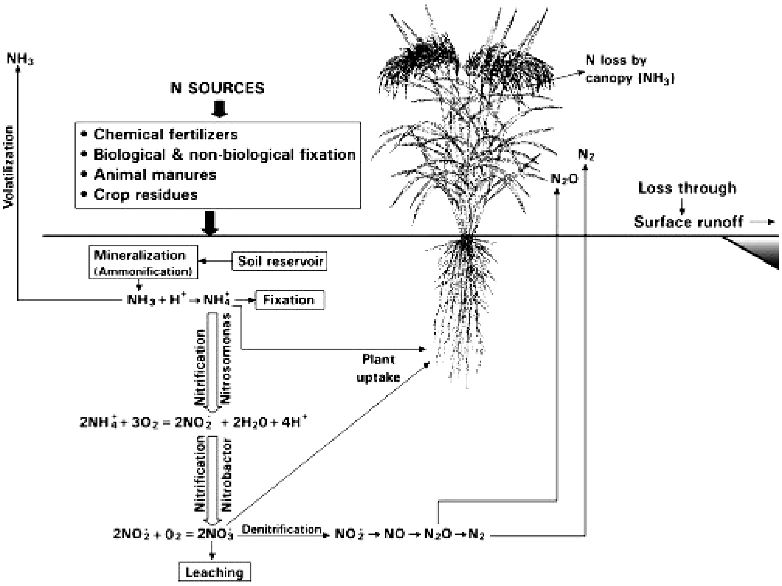


Figure 7 Simplified version of the nitrogen cycle in a soil-plant system. (From Fageria, N. K., & Baligar, V. C. (2005). Enhancing nitrogen use efficiency in crop plants. *Advances in agronomy*, *88*, 97-185).

2.6.5 Phosphorus

Phosphorus is a nonmetallic element listed with atomic number 15 in the periodic system. P is an essential macronutrient for plant growth, and an important component in nucleic acids, DNA, RNA, ATP, and in the building of cell membranes (phospholipids).

A natural P-source is phosphate rich rock, which will release P as result of weathering, erosion and to some extent leaching (Sinclair et al 1993). Although P is widely abundant in nature, it does not occur naturally as elemental P, due to its high reactivity. As mineral, P is present in its maximum oxidized state; orthophosphate (PO_4^{3-}), which is the component in phosphate rock. In natural systems such as soil and water P exists as different forms of phosphate (PO_4), primarily as organic - (P_o) or inorganic P (P_i), whereof inorganic compounds are available for plant uptake. The most common anthropogenic sources of P are runoff nonpoint sources from agricultural land use, or point sources from sewage discharge from residential areas or from phosphate mining.

P-pools in soil

Phosphorus in soil can be viewed as three different pools:

1) *P in solution* is a pool consisting mostly of orthophosphates. The low solubility of P_i makes this a small pool, leading to less productivity in soils that are low in P, or in P-fixing soils. The transport distance from P being in solution and till plant uptake is short, however despite low mobility, rainfall or irrigation may increase the movement of dissolved P.

   Most of the phosphate in solution has a tendency to react with iron (Fe)-, aluminum (Al)-, calcium (Ca) and magnesium (Mg) compounds, forming precipitates. Of these precipitates, only the Ca-phosphates are relatively available to crops in acid soils, as found by Krogstad et al (2005) investigating P availability from sludge.

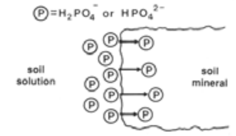
   If not replenished on a regular basis, P in solution will rapidly be depleted.

2) *The Active* pool is P in its solid phase, which is the main source of the phosphates in solution. This pool consists of inorganic phosphates which has adsorbed to small soil particles by reacting with elements such as Ca, Al or Fe, or with easily mineralized organic P, and formed to some extent soluble solids (Fig. 6a). The active P is released to

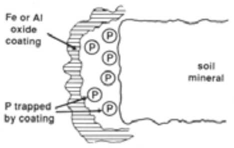
the soil solution from where it is utilized by plants. This solubilization is a chemical process driven by a chemical non-equilibrium between the active P pool and P in solution. Depletion of the P in solution initiates new release from the active P-pool; meaning soil fertility (with respect to phosphate) is correlated to the soils capability of releasing the active P. In cases where soil particles have low levels of adsorbed P and still high P adsorption capacity, they may act as a sink of phosphate. Under acid conditions the main P-adsorbers are generally Fe- and Al-oxides.

Soil pH is an important factor determining the fate of active P is soil, as P tends to be fixed by Ca under alkaline conditions and by Fe and Al under acidic conditions (Krogstad et al 2005).

3) *The fixed phosphate pool* consists of very insoluble inorganic- and organic phosphate compounds, resistant to mineralization. Fixed P is P bound to the extent it is regarded as a part of the mineral, and is not available for leaking into the soil solution like the active P is, and is thus not available for plant utilization. Compared to the active pool, these phosphate compounds are more crystalline in structure, less soluble and to little or none extent available for plant uptake. The fixed P can stay in the soil for several years without much impact on soil fertility. There may however, exist a slow conversion between the fixed P-pool and the active P-pool in soils. Fixed P will contrary to active P to little or none extent be influenced by pH. In cases of soils high in Fe, the particles will be covered by a layer of Fe-oxide (Fig. 8b), causing P that used to be adsorbed (active), to be inclosed and no longer be available for plants.



(a) P diffusion with time into soil mineral



(b) P occlusion by coating on mineral surface

Figure 8 (Source: McLaren & Cameron 1994)

P as fertilizer

P in chemical fertilizers and in manure is of the soluble and available kind (i.e. active). Some of this P will dissolve into the soil solution and be absorbed by plants, while some will bind or adsorb to particles and become part of the active P pool. P which is not absorbed by plants will with time bind more strongly and become fixed. The majority of the applied phosphorus becomes immobile or unavailable, as it adsorbs, precipitates or is converted to organic forms (Holford 1997). Application of more P than crops absorbs may increase soil fertility, but much of the P will become fixed and not available to crops.

Transportation

Mobilization of P can occur in soluble form or bound to organic compounds, soil particles or to colloids (Haygarth et al 1997), however due to strong affinity towards soil particles P in runoff is most often transported from upland areas to surface waters adsorbed to eroded soil particles/colloids or as organic phosphates (Fig. 2). Transportation of dissolved P in runoff happens rarely, and subsurface transport is thought to be negligible (Hansen et al 2002).

Sandy and peat soils more likely to loss of dissolved P, whereas loam and clay soils are more likely has got higher binding capacity.

Phosphorus in water

In natural waters P occurs as soluble reactive P (SRP), soluble unreactive P (SUP) or particulate P (PP) (Rigler 1973), of which the sum are termed as total P (TP). Separating soluble and particulate P is done by filtering the water sample through a 0, 45 µm membrane filter.

Streams and watershed-dynamics

In a stream system the phosphorus cycle tends to move phosphorus downstream as the current carries decomposing plant and animal tissue and dissolved phosphorus. It becomes stationary only when it is taken up by plants or is bound to particles that settle as sediments. This way sediments can be a potential P source which can cause eutrophication on later on.

Variations in particulate P concentration can also be expected in relation to storm events in different seasons during the year. An important factor is the depletion of particulate P pools in areas of source such as fields or river banks, or in the river system itself (i.e. resuspention of sediments). For example; particulate P sources like manure or fertilizers, which have been stationary during growth season, can be triggered during storm events in later seasons. In streams, higher concentrations of dissolved reactive P is more likely during drier seasons, as it is less diluted, whereas particulate P concentration is likely to be higher during wet seasons. The primary cause of annual/seasonal variation most likely linked to the quantities of water leaving the watershed. *(*Gburek et al 2005).

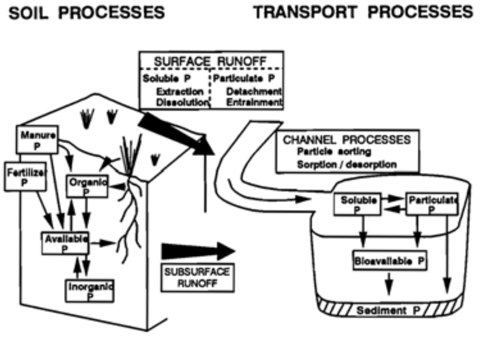


Figure 9 Factors influencing availability of phosphorus in soils and water. (From Sharpley, A. N. and A. D Halvorsen, in *Soil Processes and Water Quality,* R. Lal, Ed., Advances in Soil Science, Lewis Publishers, Boca Raton, FL, 1994.)

2.6.6 Dissolved Oxygen

All aquatic organisms depend on a certain amount of Dissolved oxygen (DO) to sustain life, therefore DO is an important ecological indicator of water quality. DO in water is dependent on physical, chemical or biochemical conditions, and enters water via photosynthesis in aquatic biota or in the water-atmosphere interface.

Concentration of DO in water depends on temperature, salinity and atmospheric pressure. The gas solubility increases with both decreasing temperature and decreasing salinity, and the degree of oxygen saturation, and also partial pressure, will change with altitude. Accordingly solubility of oxygen will decrease as the pressure decrease, and DO decrease with altitude (Loon & Duffy 2005).

Microbes play a key role when it comes to loss of oxygen in surface waters, in that they decompose organic matter, a process which consumes oxygen and lead to lower DO. Therefore, low DO is often an indication of significant amounts of organic matter in the water. The use of oxygen in decomposing long-chained organic molecules will leave more stable end-products such as carbon dioxide, water, phosphate and nitrate (Leopold & Dunne 1978). Additionally, respiration of plants and animals will consume dissolved oxygen and release CO_2.

Generally DO concentration < 3 mg/l cause stress to aguatic organisms whereas ≥ 7-8 mg/l is considered healthy or only slightly polluted (DNR n.d).

2.6.7 BOD-5

Biochemical oxygen demand (BOD) refers to amount of oxygen consumed by micro organisms in the decomposition of OM in a water sample and is used as an indicator for organic pollution. OM typically originates from debris of wood and leaves, dead plant- and animal tissue, manure, failing septic systems, effluent from wastewater treatment and plants. Natural unpolluted waters should have a BOD-5 below 5 mg/l (Murdoch et al 1996).

BOD-5 is measured over five days, after incubation at 20 degrees Celsius and is mostly expressed as milligrams of dissolved oxygen per liter sampling water.

2.6.8 Fecal coliform bacteria - *E.coli*

Thermo tolerant coli-form bacteria consist of four groups of bacteria, where of *E.coli* originates in the intestine of warm blooded animals incl. humans and birds. Bacteria such as *Escherichia coli, Citrobacter, Klebsiella, Enterobacter, Serratia, Erwinia* and *Yersinia* are all positive for the traditional coli-form test (Membrane Filter procedure), however *Escherichia coli* appears to be the only one of fecal origin (Romprè et al 2002). *E. coli* are usually not harmful in itself, but it indicates presence of pathogenic bacteria that can cause diseases such as Typhoid, Dysentery, Hepatitis and Cholera.

In general, pathogenic microorganisms have a short survival time in the environment, and are therefore difficult to discover in water. Great quantities of fecal coli-form bacteria in stream water indicate recent fecal contamination, and there is likeliness of finding other pathogens. However, the fecal contamination is not necessarily of human origin.

High concentrations of fecal coli-forms can typically be result of domestic sewage overflow or a result of animal waste as in areas with grassing livestock and insufficient waste water treatment (Rompré et al 2002). In testing of drinking water, analyzing for total coli-form bacteria and *Escherichia coli* is the most frequently used method.

Bathing in contaminated water is potentially hazardous as there is risk for swallowing pathogens, or of pathogens entering the body through skin, nose or ears. This may cause diseases such as typhoid, hepatitis, astyphoid fever, gastroenteritis and ear infections. A concentration of 500 cfu/100 ml is classified as excellent and 1000 cfu/100 ml as acceptable for bathing, according to EU standards (Table 12).

A way to determine a more human-specific source would be measure of other human intestinal bacteria such as streptococci or enterococci; however an indicator that is exclusive to humans has not been identified. Enterococcal bacteria are believed to be steadily associated with sewage of human origin, but the testing procedure is complicated and time consuming.

3 Methodology

3.1 Study area

The study area is located in the in the eastern peripheri of Kathmandu Valley (Fig. 10), about 20 km east of Kathmandu municipality. Mahadev Khola (MK) and Ghatte Khola (GK) flow through two adjacent watersheds (Fig. 6), with elevations ranging from 1400 meters to 1850 meters. Both streams are perennial with an all year flow which is significantly lower during dry season. Both streams are tributarys to the Baghmati River.

The geology is dominated by Kulikhani formation (Stocklin & Bhatterai 1977), in MK watershed (Annex No. 1), with occationally intrusion of gneiss. Kulikhani formation (described by Stocklin & Bhatterai 1977), is a local name metamorphosed sedimentary rock which mostly consists of a variation of fine grained mica schist, quartzitic schist /micaceous quartzite and quartzitic schist/ and shistose quartzite (Stocklin & Bhatterai 1977). The grain distribution varies with layers, which are thin and occasionally laminated, while sometimes crossed and graded, as result of metamorphosis. Quartz varies from 10 to 70 percent. The Kulikhani formation has a lustrous greenish/grey color tone with lighter tones in quartz dominated areas.

Figure 10 Kathmandu Valley with Ghatte khola (GK)- and Mahadev khola (MK) watershed in the far East.

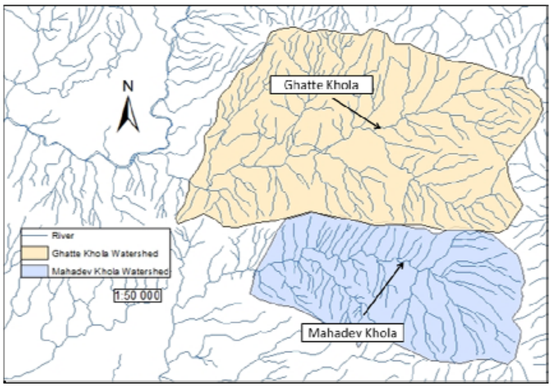


Figure11 GK watershed (northern) and MK watershed (southern).

3.1.1 Mahadev Khola Watershed (MK)

MK watershed (Fig. 11+12) is located in Bageshwari National Park in Bhaktapur District. MK is one of three main sources supplying Bhaktapur Municipality with water, and the only of surface origin. The starting point of MK is Mahadev Pokhari in eastern Nagarkot VDC, from where it flows in an east-west direction about 5 kilometers along the border between Nagarkot VDC in the North and Bageshwari VDC in the South.

The watershed covers about 6 km^2 with an elevation difference of approximately 700 meters (Table 2). The watershed is dominated by a mixture of leafy forest, thereamongst Pippal *(Ficus religiosa)* and Saal *(Shorea robusta)* and, with less dens forest in the slope towards Nagarkot road (Photograph No. 6, Annex IIA). Nagarkot is a popular tourist area with several hotels and small shops along the road. Small patches of agriculture (< 5 percent) are located on the northern- and upper eastern slope (Fig. 12).

An army training center is located in the eastern periphery, covering an area of about 1 km^2 (1800 ropanis) (Fig. 12). Barracks houses 500 soldiers on a regular basis, plus an additional 1500 during training periods, which is told to be most of the time.

Despite of forest preservation and MK being a drinking water source, there is anthropogenic activity in the area such as sanitary facilities and grazing of livestock and the mentioned agriculture. No fencing was observed along the stream, and locals commonly take baths and wash clothes at accessible locations along the stream.

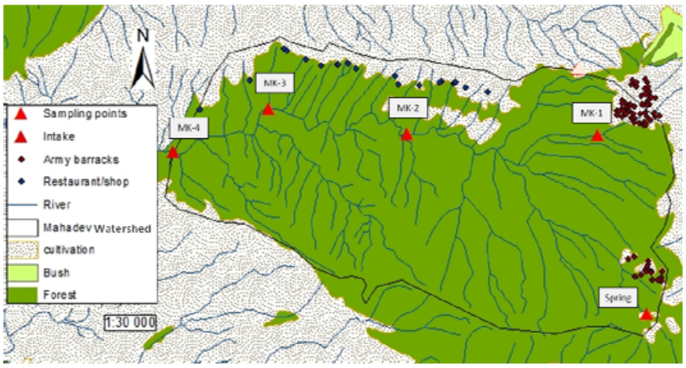


Figure 12 Mahadev watershed with land use and sampling points MK-1 to MK-4 + spring. (MK-4 = Intake).

Potential pollution - sanitation

Several septic tanks for sewage disposal were observed during survey in the Army training center. Septic tanks in the area are commonly opened bottom and function as soak pits. Additionally a lower secondary school (Kalika School) with 250 students is located in the upper slope between sampling points MK-2 and MK-3. The school practice pour-flush toilets, which is common practice in most of the settlements.

There is no sewage treatment plant, landfill sites or larger poultry farms or slaughter houses in the area. Some garbage collection for solid waste was observed, and organic waste was commonly used as manure.

3.1.2 Ghatte Khola Watershed (GK)

GK watershed covers about 11 km^2 and is located noth of and adjacent to MK watershed (Fig. 13). The stream runs from east to west along the border between Nagarkot and Sangkhu Suntol VDC, the latter belonging to Kathmandu District. Sampling sites are marked as GK-1 and GK-2 (Fig. 13).

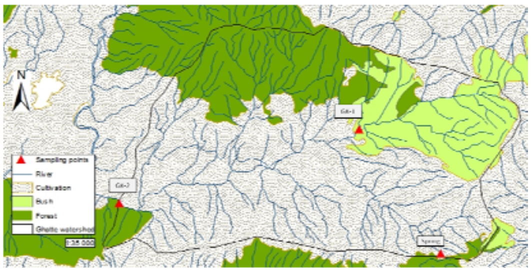


Figure 13 GK watershed with land use distribution and sampling points; GK-1, GK-2, and GK-Spring (Gadgade).

Land use- Agriculture

GK watershed is dominated by level terraces (Bari) with ridges/bunds (Photograph No. 4-7, Annex IIB). Cropping pattern is rice-wheat, which is predominant in Nepal. Vegetation, bush and trees are observed occationally along the banks, and along smaller tributaries (Picture No.1-2. Annex IIB). Seedlings of rice are planted in the beginning of monsoon season (May) and harvested in October/November, followed by tillage and followlingly wheat sowing. Maize is cultivated in the upper slopes and also harvested Oktober/November. Additionally farmers cultivate seasonal vegetables such as spinach, cauliflower and cucumber in kitchen gardens close to the house.

According to locals farmers use the chemical fertilizer Urea (CON_2H_4) prior to every crop. The pesticide Metacid is applied simultaneously for both rice and wheat. Some farmers informed to apply the insecticide Nuwan, for vegetables. In addition to chemical fertilizers farmers apply compost and FYM.

There are small farms and settlements spread mainly in the southern slope of the watershed (Nagarkot VDC), and in the east (Kattike village). Sanitation practices are similar to those in MK watershed.

3.2 *Primary Data Collection*

Field work

The field work was carried out during the time period of August 08th 2012 – December 08th 2012, with the purpose of covering both monsoon season and post monsoon. Results for 14-16 weeks are precented, where of week 1-6 (starting on August 18_{th}) represent monsoon season whereas week 7-16 is post monsoon. The time prior to sampling start was spent getting familiar with the study area, locating streams and deciding on sampling points. The sites of choice were determined after considering land use, availability and with thought of distribution along the stream. Forest density, terrain, wildlife and climatic conditions had to be taken into consideration.

Organizing field- and lab work offers challenges in a developing country like Nepal, and managing of time and logistics was considered when deciding on sampling sites and frequency.

Implementation of a social survey was attempted to gather more detailed information about the activity in the watershed. Questionnaires were distributed to a random selection of locals. As the response rate was low it was seen as necessary to do individual interviews, however time and language limitations resulted in few interviews and findings were not sufficient to present as results. Still the knowledge collected from the survey, as well as conversations with vlocals are taken into consideration when discussing the results.

Water sampling

The water sampling was conducted once a week, for up to 16 weeks for some parameters, at a total of nine different locations; whereof five locations (including spring) in MK (Table 2), and three locations (including spring) GK (Table 3).

The stream water is analyzed for the following parameters:

a. Turbidity (NTU)
b. pH
c. Conductivity (µS/cm)
d. Total-N (mg/l)
e. Total-P (mg/l)
f. Dissolved Oxygen (DO) (mg/l)
g. Biochemical Oxygen Demand (BOD) (mg/l)
h. *E.coli* (cfu/100 ml)

Since water from MK is distributed as drinking water, samples were taken also at the intake, prior to transport to the reservoir, where it is treated and distributed to Bhaktapur municipality. Table 2 shows the different sampling locations, with corresponding Geographical Positioning System (GPS) coordinates and elevation.

Table 2: Sampling locations along Mahadev Khola (including spring), w/GPS coordinates and elevation.

Location name	*Code - map reference*	*Latitude*	*Longitude*	*Elevation*
Mahadev Pokhari Spring	Spring	27°41’35.30’’N	85°31’10.75’’E	2135 m
Near Gadgade	MK-1	27°42’19.96’’N	85°30’59.05’’E	1866 m
Lama Tole	MK-2	27°42’21.58’’N	85°30’04.08’’E	1637 m
Sallagari	MK-3	27°42’27.24’’N	85°29’24.49’’E	1548 m
Muhan Pokhari	MK-4	27°42’17.67’’N	85°28’56.03’’E	1452 m

Table 3: Sampling locations along Ghatte Khola (including spring), w/GPS coordinates and elevation.

Location name	*Code - map reference*	*Latitude*	*Longitude*	*Elevation*
Gadgade Spring	Spring	27°42’40.0’’N	85°30’46,8’’E	1810 m
Kattike	GK-1	27°43’29.8’’N	85°30’16,9’’E	1529 m
Telkot Temple	GK-2	27°42’59.31’’N	85°28’22.5’’E	1394 m

At each sampling site pH-meter (Rocker) and conductivity-meter (HANA) was used to measure pH, conductivity and water temperature. Samples were collected in two BOD bottles (300 ml) and one plastic bottle (300 ml), except from springs and reservoir, where BOD and DO was not measured. The sampling bottles were rinsed three times in the sampling water before the sample was taken in the middle of the stream according to standard methods. At location 2 ml of $MnSO_4$ and 2 ml of KI was added a BOD bottle using a rinsed pipette, whereupon the content was mixed 16 times by moving the bottle in the shape of an eight. After precipitation of the reagents the mixing procedure was repeated. The samples were put in a cooler that held below 4 degrees Celsius. Due to time aspect and the labs opening hours, the samples were stored in the cooler till the next morning.

Lab analyses

Water analyses were conducted in the laboratory at Nepal Academy for Science and Technology (NAST), with the supervision of Tista Prasai. Methods are conducted according to General Experiments on Physiochemical Parameters of Water, by Rajbhandari (2005). See Annex No. III. for method description.

3.3 Secondary data collection

Rainfall data registred at Nagarkot station was collected from Meteorological Department, Kathmandu. Results from this study are based on weekly samples and the summarized rainfall for the six days prior to the sampling day.

Geological- and landuse data was collected from GIS shape files provided by National society of earthquake technology – Nepal (NSET), Kathmandu.

3.4 Data analysis

Quantitative data collected during field work is analyzed with Minitab 16, with Statistical ANOVA tests. Paired t-test at a 5 percent confidence level was conducted to test for difference between the two streams. Normal distribution and independency between the weekly results, was assumed. ANOVA- Tukey test was conducted for testing of changes in concentrations or values along the stream, and difference as result of time within stream (Mahadev). Linear regression was conducted to assess correlation between parameters such as turbidity and phosphorus. The variability in the results is presented in table or in Annex as boxplots and/or standard deviation (STD) and standard error of means (SE).

In the presentation of data, the averages for MK are based on four different sampling points representing the stream (MK-1 – MK-4), whereas GK is represented by two different sampling points (GK-1 and GK-2). The weeks are given numbers from 1-16, starting from August 18th. (Total-N and total-P were measured from week 3).

3.5 Typification and Classification

EU's Water Framework Directive (EUWFD 2000), was incorporated in EØS in 2009. The new directive has collected the earlier fragmented themes such as drinking water, swimming water, nitrates, pollution etc., into an overarching framework with the main goal being to protect water bodies with a sustainable management which includes the whole ecosystem, thus achieveing a more holistic watershed management. The directive is based on a classification system with five categories ranging from very good to very bad, on the basis on the natural state of the water body.

Prior to classification there was implemented a typification, based of size of watershed, elevation, calcium content and turbidity. This will be implemented for MK and GK, with the best possible adjustment.

4 Results

4.1 Comparison of water quality in MK and GK (including seasons)

The results show higher turbidity, pH, EC and total-N-concentration in GK compared to MK. Total-P-concentrations are found higher in MK, however both streams have high concentrations and show similar fluctuations over the sampling period. When looking solely at monsoon season, there is found significant difference between MK and GK for the parameters; turbidity, pH, EC and total-N, which all are higher in GK.

Turbidity

There is found significantly higher turbidity in GK compared to MK when looking at the whole period (p =0,000, Table 4), and graphs for both streams indicate a decrease in turbidity from monsoon to post-monsoon (Fig 16a). Mean values for all weeks are 5, 65 (± 3, 9) NTU and 13, 5 (± 8, 02) NTU for MK and GK, respectively (Table 4), while corresponding values for monsoon season is and 10, 07 (± 1, 43) NTU and 21, 92 (± 4, 78) NTU (Table 5). During post monsoon mean value in MK was 2, 7 (± 0, 97) NTU compared to 7, 92 (± 3, 2) NTU. GK was significantly higher than MK during both seasons (monsoon: p = 0,001; post monsoon: p = 0,000) (Table 5).

Turbidity in GK show a higher correlation with rainfall compared to MK, with a regression fit of 72, 5 percent compared to 50, 4 for GK and MK respectively (Fig. 14).

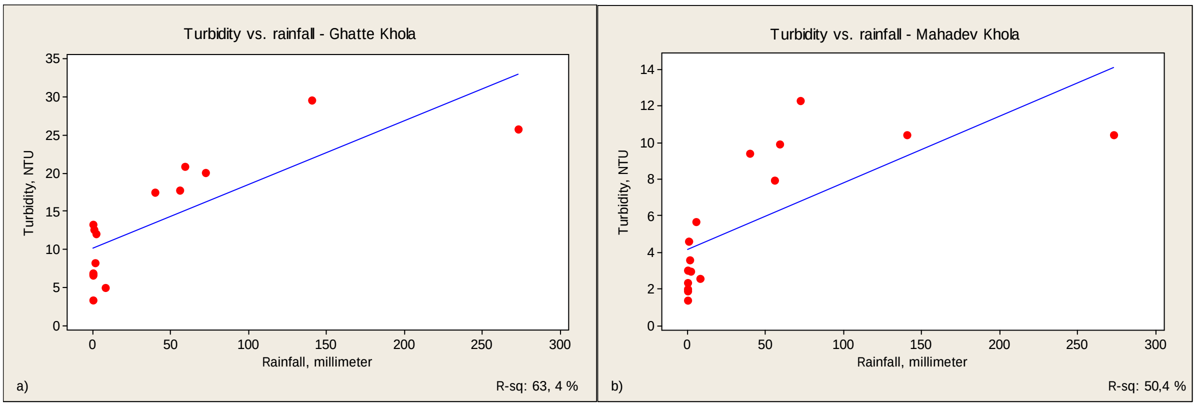


Figure 14 Regression fit for turbidity vs. rainfall in GK and MK, with R-sq of 63, 4 percent and 50, 4 percent, respectively.

pH

The mean pH for the whole periode is 7, 58 (± 0, 15) and 7, 42 (± 0, 33) in GK and MK, respectively. GK is significantly higher in MK in the all weeks average (p = 0, 034) and during monsoon season (p = 0,0 11) (Table 5), however there is not found difference between the two during post monsoon (p = 0, 564). Graph show similarities over the period (Fig. 16b).

GK is not found to have seasonal difference in pH (p = 0, 149), whereas in MK pH is found to be lower during monsoon compared to post monsoon (p = 0, 03) (Table 6).

Electrical conductivity (EC)

Over all weeks GK is found to have higher EC compared to MK, with values of 62, 7 (± 15, 02) compared to 54, 25 (± 12, 34) (p = 0, 006), also when looking at monsoon and post monsoon isolated (p = 0, 021 and p = 0, 06, respectively). Results show similarities in fluctuations in both pH and EC (Fig 16c).

In GK there is not found seasonal variation for EC, however in MK EC is found higher during post monsoon (p = 0, 034) (Table 6).

Total-N

Total-N concentrations have all week means of 1,169 mg/l (± 0, 47) and 0, 43 mg/l (± 0,238) in GK and MK respectively. The concentration is significantly higher in GK (p= 0, 000) (Table 4), and there is not seen similarities in fluctuation over the period (Fig. 16d). GK show higher total-N during monsoon season compared to post monsoon (p = 0, 000) (Table 5), with a maximum of 2 mg/l in week 5 (Fig. 16d), with a following decline over the following weeks. MK show less fluctuation, but is also significantly higher during monsoon (p = 0, 002) (Table 6) with a mean concentration of 2,025 mg/l (± 0, 05) compared to 0, 574 mg/l (± 0, 268) in post-monsoon.

Total-P

The all weeks mean of total-P was found as 0, 1319 mg/l (± 0, 0649) and 0, 1089 mg/l (± 0,047) in MK and GK, respectively (Table 4). MK was found to have higher total-P concentrations compared to GK both during monsoon season (p = 0, 056*) and post monsoon (p = 0, 005) (Table 5).

The streams have similar total-P-fluctuations throughout the whole time period, with peaks at week 6 and week 10 (Fig 16e). The total-P-concentration in both streams show a decreasing trend during the sampling period with exception of week 10 and 11, which have the highest concentrations during post monsoon, (Fig. 16e). The total-P- in week 10 is higher than any week during monsoon season, with 0, 289 mg/l and 0, 227 mg/l for MK and GK, respectively. Regression fit reveal a correlation of 94, 1 percent between total-P concentrations in GK and MK (Fig. 15).

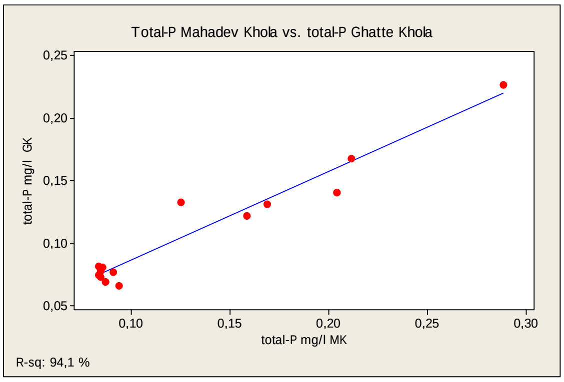


Figure 15 Correlation between concentration of total-P in Mahadev Khola (MK) and Ghatte Khola (GK), with R-sq: 94, 1 percent.

BOD_5 and DO

Results show no significant difference between or within the streams for either DO or BOD (Table 4, 5, 6). All weeks mean values of DO are found as 7, 77 mg/l (± 0, 612) and 7, 80 (± 0, 69) in MK and GK, respectively (Table 4) whereas corresponding concentration of BOD_5 is 1, 06 mg/l (± 0, 61) and 0, 97 mg/l (± 0, 93). There are seen similar fluctuations for DO in the two streams over the sampling period (Fig. 16f), however DO does not appear to be significantly influenced by temperature; correlation is not found between temperature and DO in either stream (not shown).

E.coli

The findings of *E.coli* reveal low concentrations with averages of 160 cfu/100 ml and 157 cfu/100 ml in MK and GK. There is not found difference in *E.coli* -concentrations between the two streams (p = 0,714), nor is there found seasonal variations.

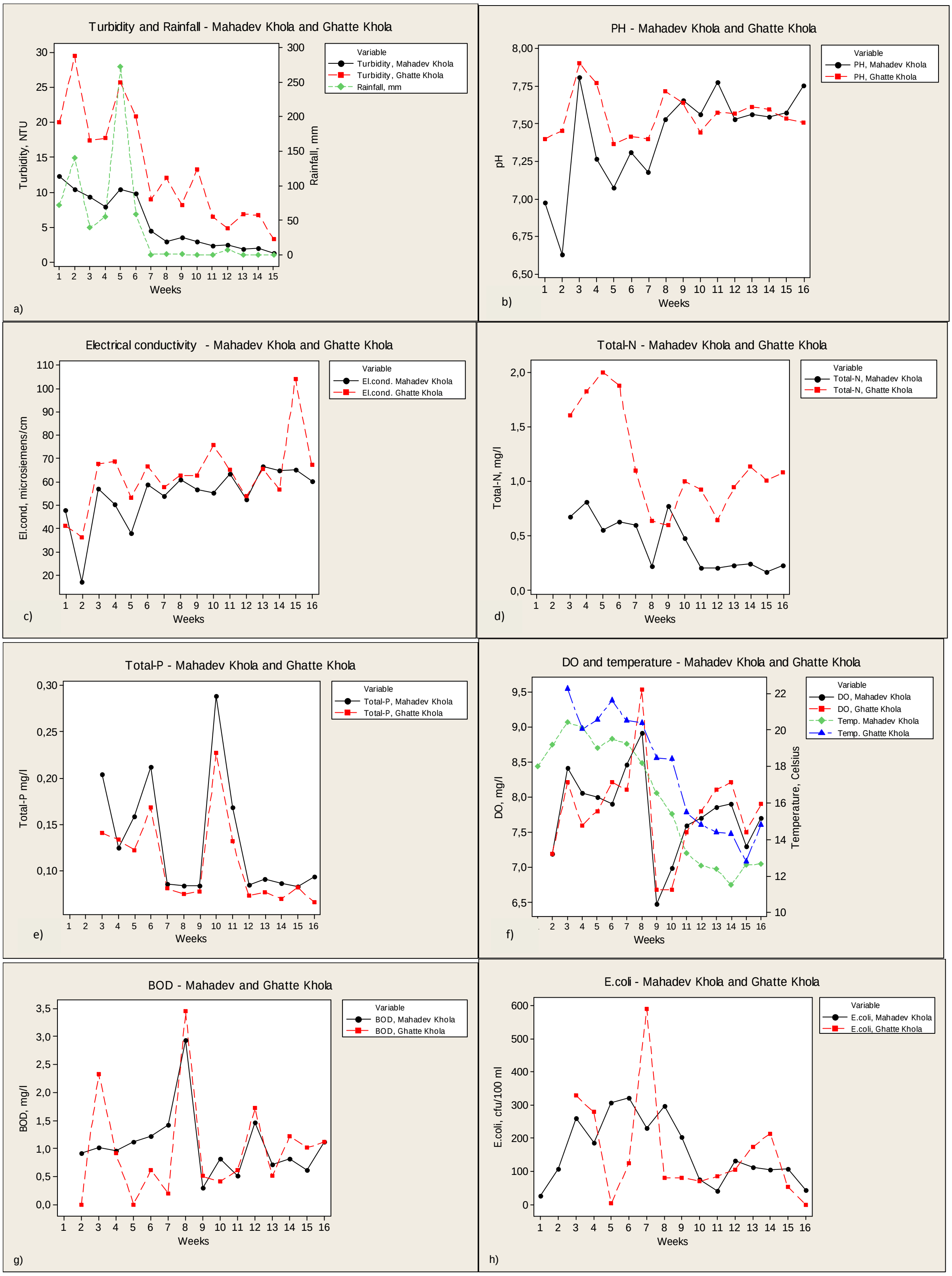


Figure 16 a-h: Time series plots for Mahadev Khola and Ghatte Khola for a; turbidity and rainfall (minus week 7), b; pH, c; Electrical conductivity, d; total nitrogen, e; total phosphorus, f; biochemical oxygen demand (BOD), g; dissolved oxygen (DO) and temperature, h; *E.coli.* Monsoon season: week 1-7; Post monsoon: week 8-16.

Table 4: Mean values of Turbidity, pH, El. conductivity, total-N, total-P, dissolved oxygen (DO), biochemical oxygen demand (BOD) and *E.coli*, in Mahadev Khola and Ghatte Khola. P-values (paired T-test, α = 0, 05)

Parameter	*Mahadev Khola*		*Ghatte Khola*		*P-value*
	Mean	*StDev/ SE mean*	*Mean*	*StDev/ SE mean*	
Turbidity (NTU)	5,65	3,9/ 1,01	**13,52**	8,02/ 2,07	**0,000**
PH	7,42	0,33/ 0,081	**7,58**	0,15/0,038	**0,034**
El.cond. (µS/cm)	54,25	12,34/3,09	**62,72**	15,02/3,75	**0,006**
Tot-N (mg/l)	0,43	0,238/0,064	**1,169**	0,47/0,126	**0,000**
Tot-P (mg/l)	**0,1319**	0,0649/0,017	0,1089	0,047/0,013	**0,001**
E.coli (cfu/100 ml)	173	98,7/26,4	157	157,6/42,1	0,714
DO (mg/l)	7,767	0,612/0,158	7,804	0,694/0,179	0,638
BOD (mg/l)	1,061	0,611/0,158	0,973	0,93/0,24	0,624

Table 5: Mean values in Mahadev Khola and Ghatte Khola, during monsoon and post-monsoon, for parameters; Turbidity, pH, Electrical conductivity, total-N, total-P, DO, BOD and *E.coli,* with p-values corresponding to the bold values in the table being significantly higher.

	Monsoon					*Post-monsoon*				
Parameter	*Mahadev Khola*		*Ghatte Khola*		*P-value*	*Mahadev Khola*		*Ghatte Khola*		*P-value*
	Mean	*St.Dev*	*Mean*	*St.Dev*		*Mean*	*St.Dev*	*Mean*	*St.Dev*	
Turbidity, NTU	10,07	±1,43	**21,92**	±4,78	**0,001**	2,7	±0,97	**7,92**	±3,2	**0,000**
pH	7,18	±0,395	**7,55**	±0,227	**0,011**	7,57	±0,164	7,56	±0,093	0,564
El.cond. µS/cm	44,83	±15,5	**55,49**	±14,35	**0,021**	59,9	±5,08	**67,1**	±14,35	**0,06**
Total-N, mg/l	0,666	±0,111	**1,825**	±0,167	**0,001**	0,336	±0,208	**0,906**	±0,205	**0,000**
Total-P, mg/l	0,175	±0,041	0,141	±0,02	0,056	**0,115**	±0,066	0,096	±0,05	**0,005**
DO, mg/l	7,92	±0,445	7,8	±0,43	0,428	7,7	±0,689	7,8	±0,816	0,257
BOD, mg/l	1,04	±0,122	0,77	±0,958	0,565	1,069	±0,757	1,074	±0,951	0,976
E.coli, cfu/100 ml	269	±60,7	185	±148,4	0,453	135	±84,1	145	±167,4	0,833

Table 6: Seasonal mean values during monsoon and post-monsoon in Mahadev Khola and Ghatte Khola, for turbidity, pH, conductivity, total-N, total-P, BOD, DO and *e.coli*. P-value corresponds to the bold value in the table being significantly higher than value representing the other season.

	Parameter		*Monsoon*		*Post-monsoon*		*p-values*
			Mean	*Std.dev*	*Mean*	*Std.dev*	
Mahadev Khola	**Turbidity**	NTU	**10,075**	1,425	3,004	1,318	**0,000**
	pH		7,178	0,395	**7,569**	0,164	**0,03**
	Cond.	µS/cm	44,829	15,5	**59,905**	5,081	**0,034**
	tot-N	Mg/l	**0,666**	0,111	0,335	0,208	**0,002**
	tot-P	Mg/l	0,175	0,041	0,115	0,066	0,071
	BOD	Mg/l	1,044	0,122	1,069	0,757	0,92
	DO	Mg/l	7,916	0,445	7,693	0,689	0,466
	E.coli	Cfu/100 ml	202	118	135	84	0,257

	Parameter		*Monsoon*		*Post-monsoon*		*p-values*
			Mean	*Std.dev*	*Mean*	*Std.dev*	
Ghatte Khola	**Turbidity**	NTU	**21,917**	4,783	7,922	3,197	**0,000**
	pH		7,552	0,227	7,561	0,093	0,931
	Cond	µS/cm	55,492	14,347	67,060	14,348	0,149
	tot-N	Mg/l	**1,825**	0,167	0,906	0,205	**0,000**
	tot-P	Mg/l	**0,141**	0,020	0,096	0,050	**0,016**
	BOD	Mg/l	0,77	0,96	1,074	0,95	0,577
	DO	Mg/l	7,8	0,43	7,8	0,82	1,000
	E.coli	Cfu/100 ml	185	148	145	167	0,679

Springs

Both springs are found to have high concentrations of total-P, with mean concentration for all weeks of 0, 104 mg/l and 0, 116 mg/l for MK-spring and GK-spring, respectively (Table 7).

Table 7: Mean values of turbidity, pH, conductivity, total-N, total-P and *e.coli*, in Mahadev Pokhari (MK-Spring) and Gadgade (GK-Spring), measured over the whole period.

Spring		*E.coli (cfu/100 ml)*	*Turbidity (NTU)*	*pH*	*El.cond. (µS/cm)*	*tot-N (mg/l)*	*tot-P (mg/l)*
MK-Spring	Mean	73,813	1,993	6,144	33,550	0,115	**0,104**
	St.Dev	115,594	1,650	0,501	12,653	0,088	0,074
GK-Spring	Mean	72,429	5,126	6,868	67,238	1,419	**0,116**
	St.Dev	152,901	4,188	0,561	28,126	1,032	0,052

4.2 *Water quality changes along the sampling stations*

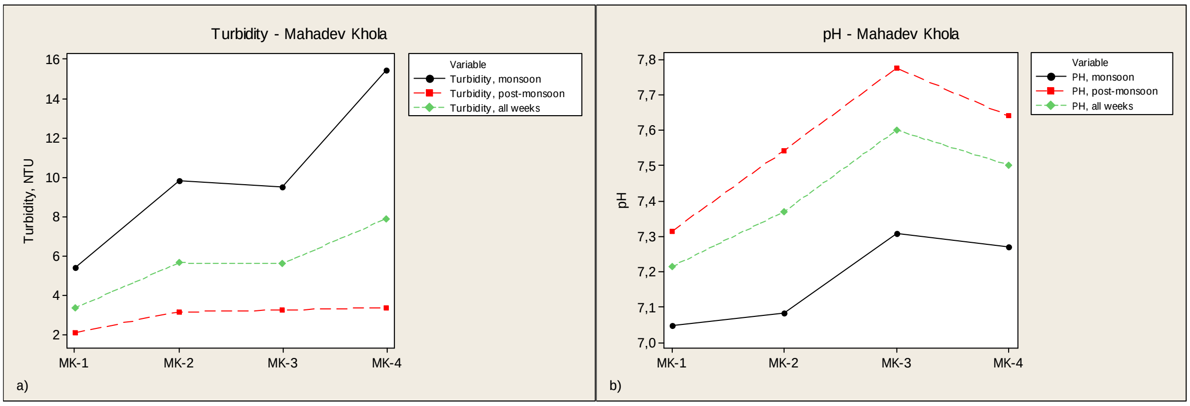
4.2.1 Mahadev Khola- Sanitation related

Tukey test find a significant difference between sampling sites for total-N, total-P and EC, with p-values of 0, 000, 0, 01 and 0, 000, respectively (Table 8). Both total-N and EC is significantly higher at sampling point MK-1 whereas total-P is significantly lower at MK-1 compared to the other sampling points, and have a somewhat increasing tendency downstream.

Graph for turbidity show tendency of increasing downstream, particularly during monsoon season (Fig. 17a), with significant difference between sampling poing MK-1 and MK-4 (p < 0, 05, Table 8). EC have the highest mean value during post monsoon, with 103, 1 µS/cm (± 25, 95), in contrast to 62 µS/cm (± 36) during monsoon season.

Mean concentrations of *E.coli* show an increasing tendency downstream, however, there is no significant change between sampling points (p= 0, 511) (Table 8), and the concentrations are low. The highest concentration is found on MK-4 (the intake) during monsoon season, with 281 cfu/100 ml, compared to 155 cfu/10 ml during post monsoon.

pH shows slightly increasing tendencies downstreamand MK-1 and MK-3 are found to be significantly different (p < 0, 05, Table 8).



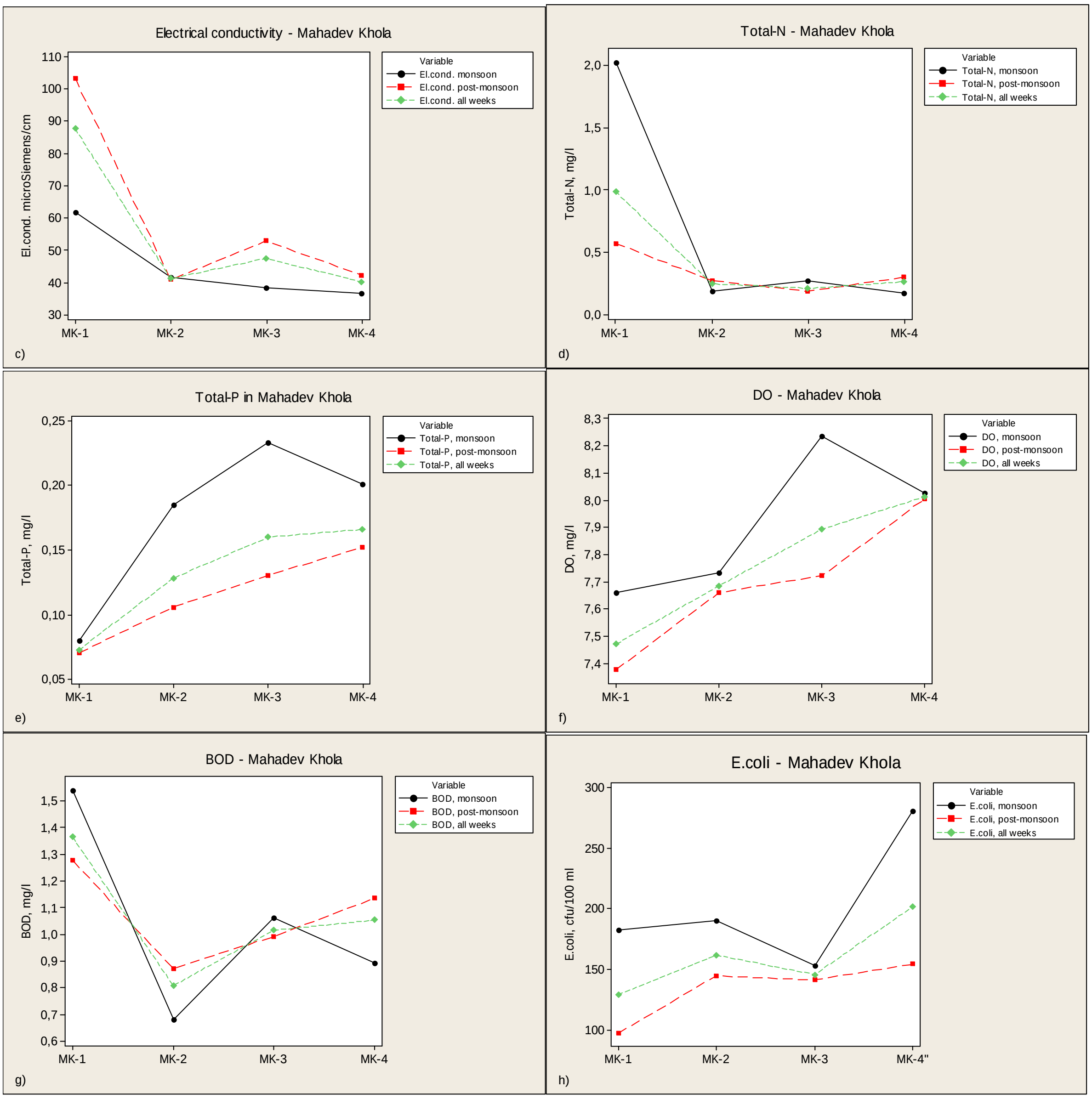


Figure 17 Change along Mahadev Khola (MK) including seasonal variation, from sampling point MK-1 to MK-4, for parameters: a; turbidity, b; pH, c; conductivity, d; total-N, e; total-P, f; dissolved oxygen (DO), g; biochemical oxygen demand (BOD) and h; *E.coli.*

Table 8: Mean values for turbidity, pH, el. conductivity, *E.coli*, total-N, total-P, BOD and DO, in sampling site MK-1 – MK-4 in Mahadev Khola. Mean values not sharing letters (A or B) are significantly different from each other, with p < 0, 05.

Parameter	*Sampling site*	*(All weeks)* *Mean*	 *St.Dev*	*Grouping info*	
Turbidity	MK-1	3,38	2, 14		B
	MK-2	5,68	4, 1	A	B
	MK-3	5,63	3, 87	A	B
	MK-4	7,93	6, 83	A	
PH	MK-1	7,22	0, 32		B
	MK-2	7,37	0, 32	A	B
	MK-3	7,60	0, 46	A	
	MK-4	7,50	0, 37	A	B
El. Conductivity	MK-1	87,65	35, 5	A	
	MK-2	41,39	9, 5		B
	MK-3	47,62	22, 6		B
	MK-4	40,35	7, 81		B
Total-N	MK-1	0,988	0, 716	A	
	MK-2	0,251	0, 269		B
	MK-3	0,214	0, 213		B
	MK-4	0,266	0, 260		B
Total-P	MK-1	0,073	0, 035		B
	MK-2	0,128	0, 064	A	B
	MK-3	0,160	0, 084	A	
	MK-4	0,166	0, 108	A	
DO	MK-1	7,47	0, 80	A	
	MK-2	7,69	0, 54	A	
	MK-3	7,90	0, 78	A	
	MK-4	8,01	0, 89	A	
BOD	MK-1	1,37	0, 98	A	
	MK-2	0,81	0, 59	A	
	MK-3	1,02	0, 85	A	
	MK-4	1,05	0, 87	A	
E.coli	MK-1	130	119	A	
	MK-2	162	147	A	
	MK-3	146	140	A	
	MK-4	202	155	A	

4.2.2 Ghatte Khola - Effect of agricultural land use

Between the two samplings points GK-1 and GK-2 there is found a significant increase in turbidity, total-N, total-P and BOD$_5$ from GK-1 to GK-2 (p = 0, 004; 0, 005, 0, 003 and 0, 052 respectively; Table 9). There is also seen increase in EC (p = 0, 061; Table 9).

Graphs for all parameters show an increase from GK-1 to GK-2 for both seasons except from pH which show a decrease from GK-1 to GK-2 during monsoon season (Fig 18b), however there is not found significant difference in pH between the sites (Table 9).

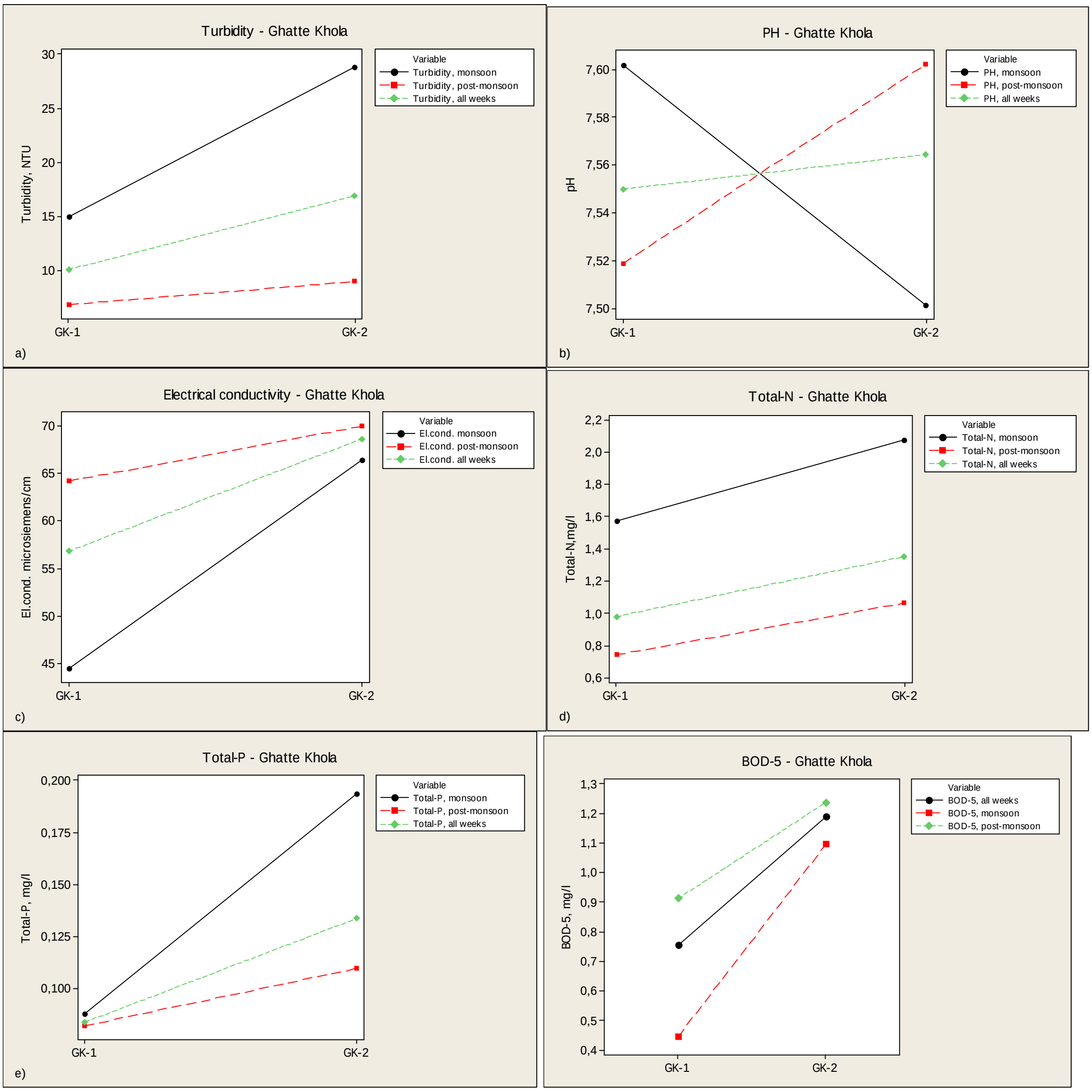


Figure 18 Change in water quality from upstream (GK-1) and downstream (GK-2) in Ghatte Khola, for; a) Turbidity, b) pH, c) Conductivity, d) total-N, e) total-P and f) BOD-5 (obs; labels in different order).

Table 9: Seasonal mean values for turbidity, pH, el.conductivity, *e.coli (remove)*, total-N, total-P and BOD, in sampling site GK-1 – GK-2, Ghatte Khola.

Parameter	*Sampling site*	*(All weeks)* *Mean*	*St.Dev*	*p-value*
Turbidity (NTU)	GK-1	10,12	5,43	
	GK-2	**16,92**	11,64	**0,004**
PH	GK-1	7,55	0,272	
	GK-2	7,56	0,19	0,439
Conductivity (µS/cm)	GK-1	56,82	28,11	
	GK-2	68,62	8,67	0,061
Tot-N (mg/l)	GK-1	0,983	0,498	
	GK-2	**1,354**	0,551	**0,005**
Total-P (mg/l)	GK-1	0,084	0,047	
	GK-2	**0,134**	0,062	**0,003**
BOD (mg/l)	GK-1	0,757	0,952	
	GK-2	1,189	1,136	0,052

4.3 Typification and Classification of MK and GK

4.3.1 Typification

The natural conditions in the study area are not easily transferred to the classification system in the EU's Water Framework Directive (EUWFD 2000). Norwegian mountain streams at higher elevations often have a lower pH compared to the mean values of 7.2 and 7.6, in MK and GK, respectively. Lower pH in high elevation watersheds in Norway are often a result of thin soil cover, which makes surface waters more directly affected by rainfall chemistry, hence acidic conditions. Additionally, organic acids from marshes and areas dominated by pine forest will commonly lower the pH in waters.

MK and GK have some suspended solids and additionally high pH, also in the forest dominated watershed. In Norway, this is most comparable with streams found in the lowlands. Based on this the elevation is not taken into consideration in the typification of the streams. For this reason the classification values are compared to those of lowland streams. It is important to emphasize that this is not optimal approach; however it gives some indication about the ecological condition of the streams.

According to WFD (Vanndirektivet 2009), one can use the following typification for both MK and GK:
R-N1/R-N4 (table 10), which is the same typification as L1/L4 used in Norway (Direktoratsgruppa for gjennomføringen av Vanndirektivet 2009). R-N1/R-N4 is the code used for streams with small watersheds (10-100 km^2), high calcium concentrations (> 4 mg/l), and with clear water regarding to color (< 30 mg Pt/l).

Table **10.** Typification of Mahadev Khola (MK) and Ghatte Khola (GK) (EUWFD 2000).

Stream	**Size of Stream (watershed)**	**Elevation**[a]	**Calcium content**[b]	**Humus content**[c]	**Turbidity (median)**[d]	**N GIG type code**[e]
Mahadev Khola	Small (10-100 km^2)	Lowland (<200 masl)	High (> 4 mgCa/l)	Clear (low) color (< 30 mgPt/l)	STS < 10 mg/l	R-N1/ R-N4
Ghatte Khola	Small (10-100 km^2)	Lowland (<200 masl)	High (> 4 mgCa/l)	Clear (low) color (< 30 mgPt/l)	STS < 10 mg/l	R-N1/ R-N4

a Chosen as best comparison.
b Calcium content was not measured. Assumtions are made based on geology, pH and conductivity.
c Humus content is based on evaluation of color.
d Turbidity (medianvalue; SFT 1997
e System/code is comparable with other Nordic countries.

4.3.2 Classification

According to SFT 2004, the condition of both MK and GK is classified as “very poor”. Turbidity is significantly higher in GK compared to MK (p = 0, 00), with means of 13, 5 and 5, 7, respectively.

Median turbidity over the whole sampling periode, of 13.5 NTU and 5.8 NTU in GK and MK respectively, was used as the reference (Table 11). The streams are classified to be in “very poor” condition regarding turbidity, according to SFT (2004). Mean total-P-cocentration also term both streams as “very poor” using the L1/L4 system (Table 12). Mean total-N concentration is classified as “good” in MK and “poor” in GK (Table 11).

pH is mainly regarded up against metal (aluminum) concentrations in solution and survival of fish in this system (salmonides; trout and salmon). pH is high in both MK and GK, and the streams are classified as very good (since potential toxic metals for fish would precipitate out of solution).

According to EU’s Bathing Water Standards for *E. coli* (Directive, C. 2006) both streams are in excellent condition regarding *E.coli*, with means of 173 cfu/100 ml and 157 cfu/100 ml, for MK and GK, respectively (Table 13).

Table 11. Turbidity classification limits based on old system (SFT 2004).

Parameter	**I** **Very good**	**II** **Good**	**III** **Less good**	**IV** **Poor**	**V** **Very poor**	***Mahadev Khola***	***Ghatte Khola***
Turbidity, FTU	<0,5	0,5-1	1-2	2-5	>5	5.8*	13.5*

*NTU

Table 12. pH, Total-N and total-P classification limits for streams and lakes, water type LN1; R-N1 (Annual mean values, µg/l) (WFD 2000; Direktoratsgruppa for gjennomføringen av Vanndirektivet 2009).

		pH	**Tot-N, µg/l**	**Tot-P, µg/l**
Ref. Value		6, 8	275	8
Very good /Good		6, 5	375	15
Good/ Moderate		6, 1	450	21
Moderate /Poor		5, 5	700	38
Poor/ Very poor		5	1200	75
Mahadev Khola	**All weeks**	7, 2	430	132
	Monsoon	7, 2	666	175
	Post monsoon	7, 6	335	115
Ghatte Khola	**All weeks**	7, 6	1114	109
	Monsoon	7, 6	1825	141
	Post monsoon	7, 6	906	96

Tabell 13 Suitability for swimming/bathing, based on limits from EU's Bathing Water Directive (BWD) for inland waters (Directive, C. 2006).

Parameter	**Excellent**	**Good**	**Adequate**	***Mahadev Khola***	***Ghatte Khola***
E.coli cfu/100 ml	500*	900**	1000*	173	157

*Based upon 95-percentile evaluation
**Based on 90-percentil evaluation

5 Discussion

The most evident difference between MK and GK is found in turbidity and total-N-concentrations, suggesting that agricultural land use to interfere with the natural inputs, causing interference in output, i.e. stream water quality in GK, and additionally causes increased erosion.

Turbidity

Ghatte Khola (GK)

Significantly higher turbidity in GK, with 21, 9 NTU compared to 10, 07 NTU in MK (p = 0, 000) is consistent with what reported by Collins and Jenkins (1996) of increased erosion as a result of agricultural land use compared to forested land. Increased turbidity is likely to reflect a lack of forest- and vegetation cover, which leaves the soil vulnerable and increases the potential for translocation of particles via runoff. The practice of tillage prior to planting or sowing is found to increase weathering and erosion however level terraces like the ones in GK watershed are found to result in less erosion compared to sloping terraces (Shrestha 1997). Additionally are ridges (bunds) (Photograph No. 7, Annex II B) likely to prevent translocation of sediments.

There is not found correlation between nutrients (N & P) and turbidity, suggesting the suspended material in the stream water to be a result of eroded silicates or other minerals. Stream water color and BOD-concentrations indicates low content of OM.

Results suggest that 63 percent of turbidity in GK watershed can be explained by rainfall (R^2 = 63, 4 percent, Fig. 14a). Erotion along the stream banks are likely to contribute to suspended particles, and the correlation coefficient might have been higher if turbidity was tested against stream flow. A delay from rainfall to runoff, depending on size of the watershed, is likely to interfere with the correlation. (Correlation coefficient for rainfall vs. flow in MK = 0, 783, Annex IV C).

Several smaller land slides were observed during field work in GK watershed, and runoff from these sites may contribute with suspended particles in GK during rain events. More frequent observations of landslides and erosion in GK compared to MK watershed may be a result of lack of stabilizing root systems in GK.

Mahadev Khola (MK)

Soil protection in form of both canopy and forest litter is likely to explain the lower turbidity in MK compared to GK, consistent with reportings from Shrestha (1997) and Collins & Jenkins (1996). Vegetation and litter is likely to prohibit splash detatchment (described by Morgan et al 1984), and reduce the acceleration in surface runoff; leaving fewer forces for translocation and transportation of particles. Still, significantly higher turbidity in MK during monsoon season compared to post monsoon suggests there to be an effect of rain induced erosion and washout of organic- or inorganic compounds.

Conductivity

Increased EC is often frequently seen in agricultural runoff as a result of increased nitrate- and/or phosphate-content and is likely to explain the findings of higher EC in GK. However, mean values of both MK and GK, of 54, 25 µS/cm and 62, 72 µS/cm respectively, are relatively low compared to findings by Kannel et al (2007), who reported an EC of 178, 7 µS/cm and 167, 2 µS/cm in rural tributaries to the Bagmati River. Still, these streams are of a higher order and closer to the Bagmati, suggesting there to be more activity in the upstream area compared to MK and GK, which are amongst the lowest orders to the Bagmati River.

Jenkins et al (1995) investigated prestine first order streams in several districts in the Mid hills and reported of differences between agricultural- and non-agricultural watersheds; with mean values of 102 µS/cm from remote sampling locations in a rural agricultural watershed. However, geological conditions were found likely to interfere and contribute to EC, making it complicated to compare the impact of land use in the area, and also to compare the findings with GK and MK watershed. The comparison between GK and MK however, which are under a similar geological influence, suggest the agricultural land use to interfere with the natural conditions in the study area in form of increased weathering and fertilizer runoff. There is some geological differences, with more intrusion of gneiss in GK and additionally recent alluvial close to sampling site GK-2; however the metasedimentary Kulikhani formation is dominating in both watersheds.

pH

Both streams appear to be well buffered with mean pH values of 7, 42 and 7, 58 in MK and GK respectively (Table 4), suggesting relatively high concentrations of bicarbonate. The higher pH in MK during post monsoon (p = 0, 03; Table 6) suggest a washout of organic acids from decaying forest litter during monsoon season. Significantly higher pH during post monsoon within MK (p = 0,03), weighs to the theori of decomposition of forest affecting the stream pH.

There is found no seasonal pH difference in GK (p = 0, 931; Table 6). Application of fertilizers could potentially lower the pH in GK as a result of acidifying nitrogen fertilizers (Shah 2005), however increased weathering may incrrelease base cations and hence prevent lowering of pH during monsoon.

Nitrogen (Total-N)

Significantly higher total-N-concentration in GK suggests chemical fertilizers to interfere with the natural inputs in the watershed and further altering the output, i.e. stream water quality in GK. Collins and Jenkins (1996) found streams in agricultural watersheds to receive more nutrients than those dominated by forest, and reported application of chemical fertilizers to significantly effect stream water quality, which is likely to be applicable for GK watershed. Also Kannel et al (2007) found chemical fertilizers to cause increased concentrations of inorganic N in rural areas in Kathmandu valley. Still, transport of N and nutrients in general is dependent on several factors such as volume of rainfall, soil properties and temperature, suggesting comparisons not to be emphasized strongly without further investigations or knowledge.

Total-N in GK and MK may be of organic or mineral origin or form; mineralized organic matter is a common source of N in natural stream systems, and the color of both MK and GK indicate low OM-content and mainly inorganic compounds. Also a constant supply from natural springs suggest the majority to be inorganic N, particularly post monsoon, as nitrite (NO_2^-), ammonia (NH_3^+) and mainly nitrate (NO_3^-), are most commonly found in ground water (Pierzynski et al 2005).

Ghatte Khola (GK)

N-concentrations seem to be a direct result of different land use patterns, consistend with what reported by Colins and Jenkins (1996). The higher total-N concentrations during monsoon season (p = 0, 000) suggest N to enter the stream via runoff. This is likely a result of the high solubility of N and that applications of fertilizers happen simultaneously with monsoon, which is the prime time for water chemistry (Collins and Jenkins 1996). Additionallt N is likely to enter the groundwater through leakage, which may be the cause of significantly higher concentrations of total-N in GK compared to MK also during post monsoon (Table 5).

Kannel et al (2007) found nitrate-N-concentrations of 1, 57 mg/l (Nakkhu Khola) and 2, 27 mg/l (Bishnumati Khola) in rural tributaries in Kathmandu valley, adjacent to fertilized agricultural areas. Additionally ammonia-N-concentrations were found to be 1, 36 mg/l and 3, 02 mg/l, correspondingly. The total-N-concentration in GK of 1, 8 mg/l during monsoon season suggests that although GK has a higher N-concentration compared to MK, the concentration is relatively low compared to the findings by Kannel et al. Still, the N-concentrations classifies the ecological quality of GK as “very poor”, according to Vanndirektivet (2009). Knowledge about factors such as watershed size, crops and soil, and details about fertilizers should be considered before a proper comparison with other watersheds.

Application of nitrogen fertilizers suggest there to potential for acidification in GK watershed (Shah 2005), however tillage and increased weathering of base cations may create a buffer capacity and prevent acidification. The mixing of N-fertilizers into the top soil in the tillage process is likely to some extent having reduced nutrient runoff-loss and may explain relatively low total-N-concentrations in GK. However there may have been a washout of N during the early stages of monsoon. Despite the mixing of fertilizers as a measure to decreace nutrient loss there may have been a higher N-loss during the early rainfalls prior to sampling period, leaving relatively low concentration in the late monsoon runoff.

The delay in sampling start compared to the planting of crops in May suggests N to have been utilized by crops. Nonetheless, concentration of N do not necessarily reflect the effectiveness of crop uptake, as N from both fertilizers and rain may be washed out before utilization, leaving high increased stream concentrations without an effective crop uptake. Considering N being the limiting growth nutrient in soil it does appear as if N exceed the total need of crops and microorganisms. Saturated soil would possibly result in more profound leakage; however this might have occurred during the early season. Jenkins et al

(1995) found low concentrations of nitrate-N despite high applications of chemical fertilizers, believed to be a result of utilization by crops.

In addition to washout and leakage, fertilizer N can possibly have been lost via denitrification. Denitrification first and foremost occurs under anaerobic conditions, which may take place in the leveled rice-terraces.. Without knowledge about infiltration capacity one can not conclude if anaerobic conditions occur, however water being trapped during rain events and reports of the area having loamy soil suggest denitrification as a result of anaerobic conditions to be a possibility.

Denitrification is also favored in neutral or alkaline conditions (Hodges & Crozier 1996), and non-liming practices in the area may suggest that soil pH allows N-loss via denitrification.

Mahadev Khola (MK)

Due to the assumption that the OM-content in stream water is low, mineralized forest litter is likely to some extent to be source of N in MK. Nitrogen is concidered the limiting factor in forest ecosystems (Vitousek & Howarth 1991).

The release of inorganic N via mineralization is dependent on several factors such as temperature, humidity, pH, microbial activity and on the organic compounds. C:N ratio of the forest litter are amongst the factors to influencing the rate of decomposition. A low C:N ratio often mean a more labile material which is more easily decomposed by microorganisms. Hence, low ratio (high N) will increase decomposition, whereas compounds with a high ratio, such as lignin, fats and resins undergo slower decomposition (Hodges & Crozier 1996). A pale soil often indicates a low content of soil organic matter (SOM), which affects the activity of micro organisms. There is not collected sufficient knowledge about the local soil or vegetation to estimate decomposition rate.

An increased concentration of N during monsoon compared to post monsoon ($p = 0,002$, Table 6) indicates organic- inorganic N-compounds to enter the stream via runoff or through leakage during monsoon. Increased mineralization of OM as a result of high temperatures during monsoon may increase the release of nutrients, there amongst N and P. Because the sampling started in the mid- closer to the end of monsoon season, there may have been a higher loss of N prior to the sampling period.

In addition to contribution of N from the forest results suggests there to be a significant contribution of N upstream of sampling point MK-1. MK-1 has an all week average close to 1 mg N/l (0, 988) which is significantly higher than sampling sites MK-2, MK-3 and MK-4 ($p < 0, 05$; Table 8). MK-1 has a mean monsoonal N-concentration of 2, 025 mg N/l (Fig. 17d), which is higher than the monsoonal average of GK, which is 1, 825 mg N/l (Table 6). Despite of a forest dominated watershed the patches of agricultural land in the eastern periphery of the watershed (Fig. 12), might contribute with N as a result of runoff or leakage from chemical or organic fertilizers. There is not collected information about crops or fertilizers at this site.

Phosphorus (Total-P)

The mean concentrations of total-P in MK and GK of 0, 132 mg/l and 0, 109 mg/l respectively, categorize the quality of both streams as “very poor” (Vanndirektivet 2009). Contrary to turbidity and total-N, the concentrations of total-P are higher in MK compared to GK during both seasons ($p = 0, 001$, Table 4). However, similar fluctuations over the period ($R^2 = 94, 1$ percent) suggests both runoff and ground water to influence the streams. The correlation during post monsoon and the peak of week 10 with the highest concentration over the period in both watersheds, suggest there to be a shared hydro geological influence contributing with a P flux over both seasons, in both MK and GK. However, both streams are found to have significantly higher total-P concentration during monsoon season, suggesting rainfall to initiate a contribution of P via runoff.

Transportation and soil conditions

P-loss as surface runoff is mostly known to happen in particulate form (Ginting et al 1998), however low correlation between P and turbidity ($R^2 = 0, 21$ percent and $R^2 =$ in GK, Annex IV) indicates that P to some extent is dissolved. Silicates or other minerals may however “interfere” with the correlation in contributing with suspended particles without P. The amount of soluble P available for transport via runoff or leakage depends to a large extent on the status of soil P and other physical and chemical conditions such as soil pH (Heckrath et al 1995).

Soils in Nepal are often reported to be acidic (Shah 2005); however findings suggest that soil conditions in the study area could be neutral or alkaline. However, relatively high pH in both streams, together with pale soil color and no-liming practices, give indications of neutral

(neutral to alkaline) soil conditions with little oxidized Fe (FeIII); conditions which reduce the retention of P and “allows” P in solution. Under such conditions dissolved P can move through the soil and may enter surface waters as dissolved P. Tropical acidic soils typically have high P retention due to the forming of Fe- and Al-oxides and hydroxides (Holford 1997) whereas neutral and alkaline soils P is more commonly adsorbed to Ca- and Mg-carbonates, increasing availability of P (Holford 1997). In calcareous soils P is commonly present as HPO_4^{-2}, whereas $H_2PO_4^{-1}$ dominates in acidic soils (Loon & Duffy 2005).

P in solution could explain the high P-concentrations in the streams and the “lack” of correlation with turbidity. Loss of P through leakage is previously thought to be insignificant, although some studies suggest leakage of P plays a more central role than previously thought (Sims et al 1998; Hooda et al 2000).

Springs in both watersheds show similar total-P concentration as in their respective streams with 0, 104 mg/l and 0, 116 mg/l in MK-Spring and GK-Spring, respectively. Generally natural background levels of total P is below 0, 03 mg/l wheras orthophosphate in natural systems range from 0, 005 mg/l to 0, 05 mg/l (Dunne & Leopold 1978) which suggest streams and springs in both watersheds to have high P-concentrations.

Ghatte Khola (GK)

P export from agriculture is well studied, but no clear pattern is defined (Kronvang et al 2003). Findings in both GK and MK suggests that dissolved P may contribute to the total-P concentration, and perhaps could analysis of particulate P and filtered orthophosphates increase the understanding regarding P loss in general.

Collins and Jenkins (1996) reported low concentrations of PO_4 in both forest dominated and agricultural dominated streams, with mean concentrations ranging from 0, 04 and 0, 05 mg/l, and suggested fertilizers to be the single source of PO_4. Kannel et al (2007) found stream water sampling stations in upper rural areas with little human occupation not toexceed 0, 37 mg/l of PO_4, wheras maximum total-P was 0, 41 mg/l. This is higher than both MK and GK; however the origin was believed to be chemical fertilizers (Kannel et al 2007), which is not applied (with P) in GK watershed.

Runoff from GK watershed may contain P from organic fertilizers and FYM. Results from GK-1 and GK-2 reveal an increase in P downstream, and higher concentrations during monsoon season compared to post-monsoon ($p = 0, 016$, Table 5) is most likely a result of runoff during and after rain events.

Additionally weathering of exposed soil may contribute with P, particularly if P is naturally occurring in the geology. The weathering of soil particles could expect GK to have higher P-concentration compared to MK, however terraces with ridges may hold back on transportation of P at a higher rate than what is released from MK watershed.

A P-rich soil/parent material in GK watershed combined with experience and long traditions of agriculture in the area may be the reason why local farmers apply urea fertilizer instead of NKP.

Mahadev Khola (MK)

In MK watershed P is likely to origin from OM. Decayed and mineralized forest litter is likely to enter the stream via runoff during rain events, as dissolved- or adsorbed P, or leached and transported in ground water.

The release of P from organic matter will dependend on the potential for decomposition, which is influenced of various factors; to large extent C:P ratio of forest litter. Lack of knowledge about the forest litter makes it difficult to estimate decomposition rate, however the temperate climate during monsoon may suggest a fairly rapid decomposition.

DO and BOD

Both DO- and BOD-concentrations suggest there to be low OM-content in both streams. Generally DO concentration < 3 mg/l causes stress to aguatic organisms whereas ≥ 7-8 mg/l is considered healthy or only slightly polluted (DNR n.d). Hence mean DO-concentrations of 7, 77 mg/l and 7, 8 mg/l in MK and GK respectively suggest healthy streams. However the dynamics of fast flowing waters may result in falsely high DO-concentrations as a result of rapid exchange of water in the water-atmosphere zone, still relatively low BOD confirms a good quality in relation to oxygen and OM.

Mean BOD-concentrations in MK and GK of 1, 06 mg/l and 0, 97 mg/l respectively is well below the limit for what is termed as natural unpolluted waters, of 5 mg/l (Murdoch et al 1996).

Eutrophication

Algae growth was not investigated during the field work, however there was observed some quantity of attatched algae on substrates along stream bottom and banks in GK, and also to some extent in MK. In streams, eutrophication is most commonly cells or colonies of cells attached to rock surfaces or sediments along the bottom or shore (Johansson 1982).

According to US EPA (1986) total-P-concentration in surface water ranging from 0, 01-0, 03 mg/l tend to not be contaminated by algae blooming. This is far below the concentrations found in GK and MK, suggesting potential for algae growth downstream in calmer waters or in sections will low flow.

The high concentration of total-P suggests MK and GK to be naturally eutrophic streams, giving both streams potential for algae growth. Both streams exceed P-concentrations recommended for streams that discharge into lakes or reservoirs of 0, 05 mg/l, and also the limit for streams not discharging into lakes or reservoirs, of 0, 1 mg/l (US EPA 1986).

The concentrations of DO are relatively high in both streams, and mean values of 7, 77 mg/l (± 0, 61) and 7, 8 MG/L (± 0, 69) in MK and GK respectively suggest good stream water quality (DNR n.d). However, in fast flowing streams DO is likely to be a result of hydrodynamics and may not be a correct reprecentative for microbial oxygen consumption. The dynamics in a stream system is more likely to transport such indicators of deteoration downstream to calmer waters. Low correlation coefficient between DO and temperature also indicates that fast flow interfares with DO concentration (not shown).

Despite high concentrations of P there were not reported problems regarding algae growth in the MK-reservoir. Being the limiting nutrient in fresh water, P leaves a potential for growth, however primary production will depend on several factors such as light conditions, hydrodynamics, temperature and growth inhibitors from other organisms (Lindstrøm 2000; Dryden & Stern 1968). Optimal elemental N:P ratio of local primary producers in the water will vary according to environmental conditions (Ekholm 2008).

Without further investigations it is unclear what is the cause of the apparently absence of algae growth despite high P-concentrations. This may suggest that the indication of P being bio available is a result of misconceptions, or that nitrogen in the reservoir is close to non-existent.

Sanitation (MK)

Low concentrations of *E.coli* suggests there to be no significant pollution from from failing sanitary systems in either watershed. There is not found changes between sampling sites in MK (p= 0, 51) and little indication of a point source pollution of *E.coli* along the stream. The occurring *E.coli* most likely originates from natural wildlife, livestock, or possibly humans occasionally practicing open defecation near the stream.

Significantly higher EC and total-N at sampling point MK-1 could suggest leakage from the army barracks in form of nitrates and possibly phosphates, although P does not show the same peak at this location. This could, however indicate urine leakage or practice of 'open urination', yet there is not found correlation between N and EC at the location (correlation not shown). Not necessarily excluding the option of urine leakage, as both EC and N may also originate from other sources such as nearby springs or organic- and inorganic compounds.

Perhaps do the patches of cultivated land in the areas upstream of the location contribute via fertilizer runoff and/or leakage. There was not collected information regarding the patches of cultivated land in MK watershed.

According to European Union's Water Framework Directive's (EU WFD) recommended bathing regulations, the water quality regarding *E.coli* is classified as "Excellent" (Table 12), which makes suggests bathing and washing in the streams to be safe.

6 Conclusion

Nepal's population growth and over-exploitation of limited arable land is threatening forests and soil fertility, and fertilizers lost through runoff and leakage compromises sustainability as well as the quality of an already scarce water resource; clean water. As climatic conditions interfere with soil and water relations in form of chemical influence and erosion, and concidering that climate change may reinforce the present rainfall patterns, it is necessary to investigate the climatic impact on the respective land use patterns and understand the influence on stream water quality.

The most evident differences between Mahadev Khola (MK) and Ghatte Khola (GK) when looking at both values and fluctuations are found in turbidity and total-N-concentration. The agricultural land use appears to interfere with the natural inputs in soil, which in turn influence the output, i.e. stream water quality in GK. Significant seasonal differences suggest rainfall to initiate translocation of soil particles and N-compounds from chemical fertilizers. However, the practice of level terraces appears to some extent to prohibit excessive erosion.

Both streams have high concentrations of Phosphorus and have closely related P-fluctuations over both monsoon and post monsoon, suggesting P to enter streams via runoff and via a common hydro geological pattern. A low correlation coefficient between P-concentration and turbidity indicates P to be dissolved, suggesting a neutral soil with low P-retention, allowing bio availability of P.

In MK watershed P-runoff is likely to be a result of leaching from mineralized forest litter, whereas P-runoff from GK watershed may origin from organic fertilizer/FYM and weathered soil particles. Although agriculture seems to contribute with P as a result of inputs and exposed soil, the influence does not differ from the natural forested system. Local farmers' no-liming practice and no chemical-P application is likely the result of years of experience and indicate a system with a naturally occurring bio available P-source. A soil that "allows" dissolved P, indicates neutral or alkaline conditions unlike many soils in Nepal which frequently suffer from acidification.

Further investigation of mineral composition and soil pH is adwiced to add knowledge to the watershed dynamics and to the origin and form of first and foremost P. The naturally eutrophic state of both streams leaves potential for algae growth in downstream waters and in the reservoir in which stream water from MK is collected. Despite the potential for eutrophication in the reservoir there is reported little sign of eutrophication, which opposites the indication of bio available P.

Low concentrations of *E.*coli suggest there to be no significant fecal pollution in either watershed, suggesting latrines and sanitary systems to function well.

Given the ongoing increase in population and the climatic changes, a holistic approach to watershed management, dealing with both soil- and water issues, is necessary. The use of chemical fertilizers and over exploitation of local forest resources threatens the sustainability of ecosystems, which urges for alternative solutions. Concidering that commercial sanitary systems frequently pollutes water resources, and that the agricultural sector is in continous need of nutrients and organic matter, ecological sanitation may be the measure to address both the challenge of sustainability and poverty.

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ANNEX I – Geological map

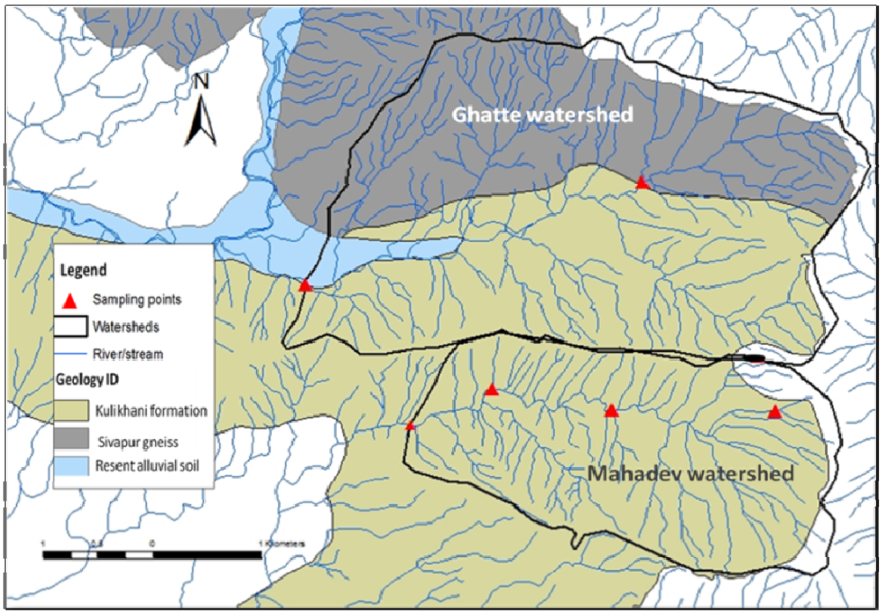

Figure 19Geological map of Ghatte Khola watershed and Mahadev Khola watershed.

ANNEX II A - Photographs of study area

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Picture 1; MK watershed, southeastern slope with dense forest, 2+3; MK with overhanging vegetation, 4; interview with locals, 5; buffalo in water hole, 6; Less dense Sal forest + grass close to Nagarkot road, 7; tNagarkot road, 8; local boy at Mahadev Khola, 9; sample at location MK-1, 10; Dense forest, seen from Nagarkot road, 11; Steep trail from MK and up to Nagarkot road, 12; washing of clothes at water source in Nagarkot village, 13; close to sampling location MK-2, 14; upper MK.

ANNEX II B - Photographs of study area

Ghatte Khola watershed


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Picture 1+2; GK with rainfed terraced rice crops during monsoon season, close to location GK-1, 3; small land slide after heavy rainfall, on the way down to GK, 4+5+6; terraces post monsoon after tillage and wheat seeding, 7; close up of terrace with ridge, 8; eroded slopes in upper GK watershed, 9; village farm house near GK, location GK-1, 10; maize after harvesting, 12+13; GK near location GK-1, 14+15+16; GK near Telkot temple, location GK-2, 17; Munks on bridge with location GK-2 in the background, 18; Trash in the stream downstream from GK-2, 19; village life in Kattike, upper Ghatte Khola watershed, with view to the Himalaya.

ANNEX III – WATER ANALYSIS

(Nepal Academy for Science and Technology, NAST)

Determination of Nitrate-N (NO3--N) - Brucine method

The Brucine method is based on the reaction between nitrate and brucine, producing a yellow color which is measured in spectrophotometer.

Requirements:

Equipment	*Reagents/Chemicals*
Test tubes with stand	Brucine-sulfanilic acid solution
Water bath (REDMEX)	Sulphuric acid (H_2SO_4) solution
Boiler	Sodium chloride (NaCl)
Pipette	Sodium arsenite
Spectrophotometer (JENWAY)	Standard Nitrate solution

Procedure:

10 mL of each water sample was placed in 50 mL test tubes and put in a cool water bath. 2 mL NaCl solution was added, followed by 10 mL H_2SO_4 solution, with the tube being swirled thoroughly by hand in between the adding. 0, 5 mL was lastly added, again followed by mixing. Following, the stand with samples/reagents was placed in a digital water bath (REXMED) at boiling temperature, for precisely 20 minutes, before it again was taken out and cooled in an ice bath. Absorbance was then read in spectrophotometer (JENWAY) at 410 nanometers. Nitrate-N concentration in the sample was found using a standard curve prepared beforehand, where dilutions from 0, 1 to 1 mg N/l at the interval of 0, 1 was analyzed using the same procedure as described above.

Determination of Ammonia-N (NH_3-N) – Phenate method

The Phenate method is based on the formation of blue color as ammonia in the sample water reacts with chemicals added.

Requirements:

Equipment	*Reagents/Chemicals*
Conical flasks, 50 mL	Phenol solution (10 %)
Watch glass	Sodium nitroprusside (0, 05 %)
Spectrophotometer (JENWAY)	Alkaline citrate solution
Volumetric flasks	Sodium hypochlorite (4 % fresh)
Pipette	Oxidizing solution
	Stock ammonium solution

Procedure:

25 mL of the water sample was kept in a conical flask, whereupon 1 mL of phenol solution, 1 mL sodium nitroprusside and 2, 5 mL oxidizing solution was added with thoroughly mixing in between. The conical flasks were covered with plastic and stored at room temperature in a dark place for minimum one hour, till a blue color developed. Absorbance was taken at 495 nm. The concentration of NH_3-N was found using standard a curve.

Determination of Phosphate-P (PO_4^{3-}-P) /Orthophosphate-P -Colorimethric method (Stannous Chloride method)

The Stannous Chloride method is based on the development of blue color, as the phosphate in the water sample get in touch with reagents. The method was chosen as it is the most suitable for the ranges of 0, 01-6 mg/l in stream water analysis.

Requirements:

Equiptment	*Reagents/chemicals*
Conical flasks	Ammonium molybdate
Pipette	Stannous chloride
Spectrophotometer	Standard phosphate solution (K_2HPO_4)

Procedure:

2 ml of ammonium molybdate was added a 50 ml sample in a conical flask, followed by five drops of Stannous Chloride solution. In the presence of Stannous Chloride, the acid is reduced to a complex of blue color. Spectrophotometric reading is taken at 690 nm within the time range of five and 12 minutes. The concentration of phosphate-P was found using the standard curve.

Determination of Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD_5) - Winklers/Iodometric method

The method is a titrimetric procedure based on the oxidizing properties of the DO in water. This method was chosen because it is the most reliable and accurate titrimetric procedure for analyzing DO, and because electrometric method with use of membrane electrodes was not an option/not available. Winkler's method is an approved standard method and is based on the principle that manganese solution added a water sample is oxidized when followed by addition of a strong alkali precipitate.

Requirements:

Equiptment	*Reagents/chemicals*
BOD bottles, 300 mL	Sodium thiosulphate, 0,025 N
Conical flasks	Alkaline potassium iodide (KI)
Burette	Manganous sulphate solution ($MnSO_4$)
Pipette	Starch
	Concentrated sulphuric acid (H_2SO_4)

Procedure:

The water sample is collected in a 300 mL BOD bottle with glass lid to exclude air bobbles. In the field, 2 mL (1 mL if 100 mL BOD bottle) of $MnSO_4$ was added below the water surface using pipette, followed by 2 mL of alkaline KI solution. A yellowish/brown color appeared. The glass stopper was put in place and the sample was shaken 16 times in the shape of an eight. After the precipitate settled the procedure of shaking the sample was repeated. The sample was stored at 4 °C.

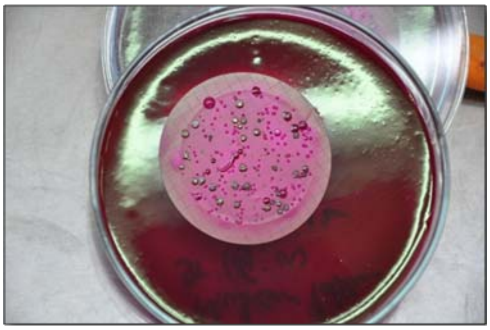
2 mL of concentrated H_2SO_4 was added in the lab, whereupon the bottle was shaken until the precipitate was dissolved. Within one hour, 50 mL of the sample was titrated with $Na_2S_2O_3$. Starch was used as indicator, and the solution became color less/blank at the end point. The concentration of DO was proportional with amount of titration and was determined by calculations.

Determination of BOD-5 is done with the same procedure, after five days incubation at 20 °C.

Calculation of Dissolved oxygen (DO):

DO mg/L = (Vol*N) of titrant*8*1000 / V_2 (($V_1 - V$) / V_1)
Where
V_1 = Volume of sample bottle
V_2 = Volume of part of content titrated
V = Volume $MnSO_4$ and KI added

Determination of E.coli – Membrane Filter Methode



Requirements:

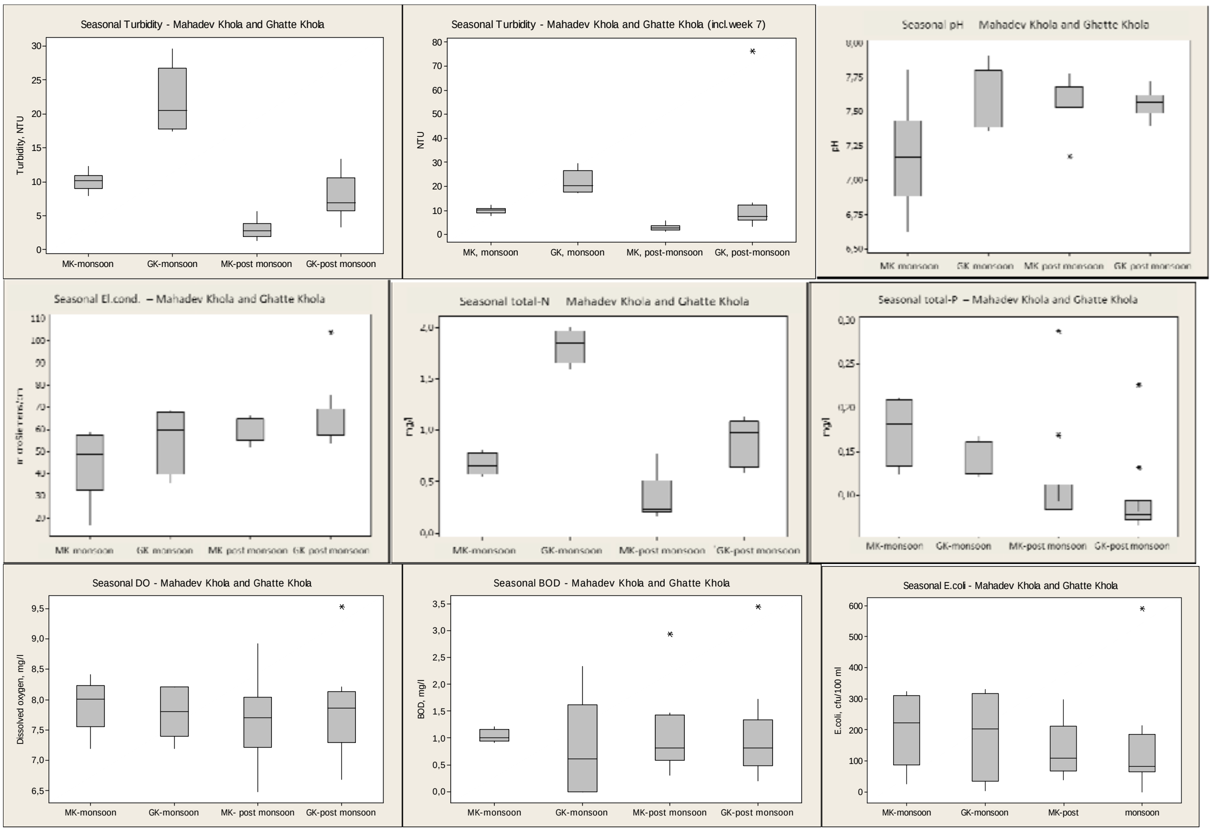
Equiptment	*Reagents/chemicals*
Watman Membrane filter, 0.45 µm	M Endo Agar: Hi Media
Vakuum pump	
Petri dish	
Digital Colony Counter (ROCKER Galaxy 230)	

Procedure:

100 ml water sample was filtered through Watman membrane filter, 0, 45 µm, using a vakuum pump. The filter was placed then on in petri boxes containing M Endo Agar media, before incubated in at 37 °C. After 48 hours the coliform forming units were counted with a Digital Colony Counter (ROCKER Galaxy 230), shown as metallic spots in the picture.

ANNEX IV – Additional results

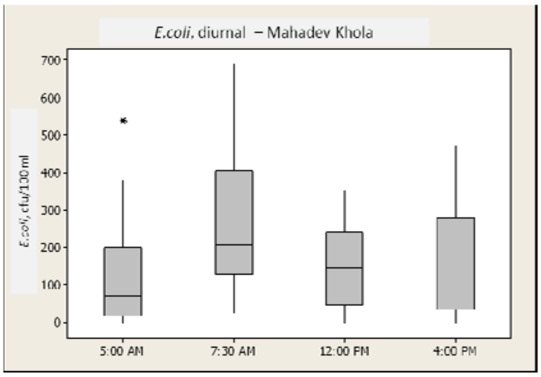
A MK vs. GK – monsoon and post monsoon



Boxplots of the parameters; turbidity*, pH, electrical conductivity, total-N, total-P, DO, BOD and *E.*coli.

*In testing with turbidity in GK an outlier representing week 7 was removed, as it showed turbidity as high as 76 NTU. Although several parameters reveal some "abnormal observations"/outliers, this observation is suspected to be due to a rare event prior to sampling. Above is precented boxplots with and without week 7.

B – diurnal variations in Mahadev Khola

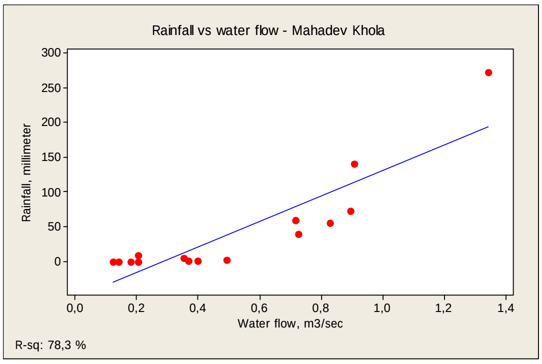


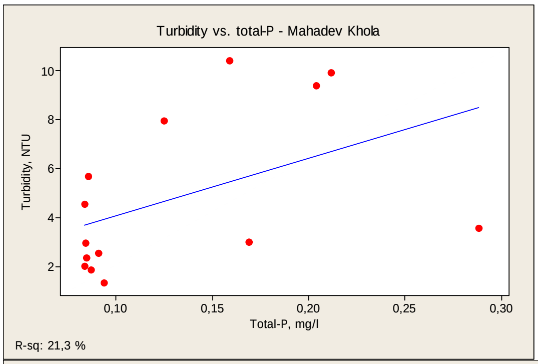
Diurnal variation in concentration of *E.coli* in Mahadev Khola.

Table 14: Diurnal mean values of turbidity, conductivity, total-N, total-P and *E.coli* in Mahadev Khola (05:00, 07:30, 12:00 and 16:00) with p-values of significance (α=0,05) in difference between times. Sampling was done post-monsoon only.

	Time								
Parameter	*05:00*		*07:30*		*12:00*		*16:00*		*p-value*
	Mean	*St.Dev*	*Mean*	*St.Dev*	*Mean*	*St.Dev*	*Mean*	*St.Dev*	
Turbidity	2,82	1,92	2,85	1,64	2,55	1,21	3,41	1,25	
El. Cond.	55,04	15,42	41,22	15,11	43,90	3,31	42,40	2,82	0,03
Total-N	0,23	0,11	0,26	0,23	0,31	0,28	0,24	0,14	0,915
Total-P	0,23	0,27	0,13	0,04	0,15	0,12	0,13	0,06	0,463
E.coli	135,50	180,44	272,10	197,67	152,10	109,02	154,50	154,82	0,225

C - CORRELATIONS





Rainfall vs. Waterflow:

Waterflow was measured only in Mahadev Khola, manually using a floating stick and stop watch . The discharge was calculated.