Physical and Chemical Assessment of Streams in the sub-Andean Amazon, Peru

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ABSTRACT

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In Latin America ecologically sensitive areas are not sufficiently protected and the rainforest is continuously decreasing due to deforestation. In the sub-Andean highland rainforest this is an increasing problem because it increases contamination of fresh water in streams where many people take their drinking water. To lack access to clean drinking water is to lack an important human right. Therefore it is important to decrease negatively human impact on stream water and work towards a sustainable environment in this part of the world which still can satisfy people's needs and interests and also improve the quality of life.

In this project we have evaluated the water quality and the variation of the water quality along two streams located in a sub-Andean region of the Amazon in Peru. By combining two physical assessments based on physical parameters in two scales, in a riparian area and in a drainage area, with a chemical assessment based on concentrations of water quality variables in stream water we have tried to define the effects of the increasing impact of human activities on water quality in the streams. Methods based on habitat assessments for riparian reaches are today being used by non-governmental organizations in the sub-Andes and have many advantages in developing countries. Above all it is financially effective as it demands few resources. In this study we modified a common method for physical riparian assessment, namely the Stream Visual Assessment Protocol, SVAP. The method functioned well in order to get an overview of the physical habitat and could also be linked to some chemical water variable concentrations in stream water indicating that physical structures as width and intactness of riparian vegetation affects water quality. As a tool for local landowners and for educational purpose of the interactions between riparian land and stream water the method is good but as a predictor of drinking water quality we recommend a chemical analysis of the water as a complement. In the Drainage Area Assessment we analysed the sub-basins in the Shima and Cumbaza catchments using satellite images and DEM-files in GIS. The percentage of forest upstream the sites was determined as well as the area, mean elevation and mean slope of the sub-basins. Through this the impact of deforestation on water quality could be analysed. The results indicated that such an analysis is not sufficient in order to classify drinking water quality. Also in this case we recommend a chemical analysis as a complement.

Comparing the two basins the total deforestation was higher in the Cumbaza basin whereas the result pointed at a generally higher eutrophication in the Shima basin. The most polluted site was found in Cumbaza, site C1, which was the site located just downstream the largest city in the study area. The conclusion of this study is that both methods for physical assessments are useful when evaluating the water quality for aquatic life. However, neither of them could be used alone but needs to be complemented by a chemical assessment in order to evaluate drinking water quality. Furthermore, the SVAP method gives a good picture of how the physical habitat is changing along the streams and both habitat methods can be used in the future in order to compare how the conditions have been changing.

Keyword: Peru, Amazonas, sub-Andes, rainforest, water quality, water assessment, deforestation, physical assessment, stream reach assessment, SVAP, drainage area, GIS

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REFERAT

Fysisk och kemisk analys av vattendrag i sub-Andeska Amazonas, Peru

Sara Lindgren
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I Latinamerika skyddas inte ekologiskt känsliga miljöer tillräckligt och den, för världen, så viktiga regnskogen, Amazonas, minskar i areal på grund av fortsatt skövling. I sub-Andeska höglandet är skövlingen ett växande problem inte minst p.g.a. att den leder till ökad kontamination av sötvatten i floder där många människor hämtar sitt dricksvatten. Att sakna tillgång till rent dricksvatten är att sakna en viktig mänsklig rättighet. Det är därför viktigt att minska ner på mänskliga aktiviteter som kan få negativa effekter på vattendrag i denna del av världen och sträva efter att nå en hållbar utveckling som inte äventyrar människans behov och intressen.

I detta projekt har vi utvärderat vattenkvaliteten och dess variation längs med två floder i den sub-Andeska regionen av Amazonas i Peru. Vi har försökt att definiera de effekter som en ökad mänsklig aktivitet kan ha på vattenkvaliteten i floderna genom att kombinera två fysiska utvärderingsmetoder, baserade på fysiska parametrar, med en kemisk undersökning, baserad på koncentrationer av valda vattenkvalitets variabler vid provplatser längs med floderna.

Metoder för habitatundersökningar av strandzoner har många fördelar i utvecklingsländer och används idag av många icke-statliga organisationer i sub-Anderna. Framförallt är sådana metoder finansiellt effektiva eftersom de är ytterst resurssnåla. I detta projekt modifierade och implementerade vi en metod, Stream Visual Assessment Protocol (SVAP), för habitat utvärdering av strandzoner för att bestämma vilken påverkan strukturen av strandzonerna har på vattenkvaliteten i floderna Cumbaza och Shima och även hur strukturen förändras längs med floderna. Metoden visade sig fungera bra för att ge en översiktlig bild över det fysiska tillståndet längs med de båda floderna och samband hittades mellan fysiska parametrar och koncentrationer av vattenvariabler vilket indikerar att fysiska strukturer som t.ex. bredd och fragmentering av strandvegetation påverkar flodvattnets kvalitet. Metoden kan användas som ett redskap för lokala markanvändare i undersökning av den egna marken och i rent undervisningssyfte, där den kan visa på interaktionerna mellan strand och flodvatten. När det däremot handlar om att klassificera dricksvattenkvalitet räcker det inte enbart med en SVAP utvärdering utan vi rekommenderar en kemisk analys av vattnet som ett komplement.

I den andra fysiska metoden undersöktes vilken påverkan skogskövlingar och geomorfologin uppströms de valda provplatserna har på vattenkvaliteten. Andelen skog och geomorfologin bestämdes med hjälp av satellitbilder och DEM-filer i GIS. Resultatet visade att en sådan undersökning inte var tillräcklig när det gäller att klassificera vattnet som dricksvatten och därför rekommenderar vi även här en kemisk analys som ett komplement.

Resultatet från denna studie visade på en högre grad av skogsskövling i Cumbaza avrinningsområde jämfört med Shima avrinningsområde och på en högre grad av övergödning i Shima jämfört med Cumbaza. Den mest förorenade provplatsen var den längst nedströms i Cumbaza. Sammanfattningsvis kan ingen av de fysiska utvärderingsmetoderna användas utan kompletterande kemiska analyser för att bestämma dricksvattenkvaliteten men båda metoderna kan ge en bild av den generella vattenkvaliteten för t.ex. akvatiskt liv. Vidare ger SVAP metoden en bra bild över hur fysiska strukturer ändras längs med vattendragen och både SVAP analys och skogsutbredningskartor kan användas i framtiden för att jämföra hur förhållandena förändrats.

Nyckelord: Peru, Amazonas, sub-Anderna, regnskog, vattenkvalitet, vattenanalys, avskogning, habitatanalys, SVAP, avrinningsområde, GIS

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PREFACE

This essay is a master thesis in Environmental and Aquatic Civil Engineering at Uppsala University. The thesis is carried out within the frame work of a Ph.D. project (School of Pure and Applied Natural Sciences, University of Kalmar), the aim of which is to increase the understanding of how deforestation and increasing land use affect the chemistry in the superficial environment (soil, sediment and water) in the sub-Andean Amazon.

The thesis has been supervised by Lina Lindell at the department of the School of Pure and Applied Natural Sciences, University of Kalmar and Allan Rodhe at the Department of Earth Sciences, Uppsala University, has been subject reviewer.

The two authers have written the thesis together but due to examination technical reasons each of the authors have had special responsibility for the following chapters. Sara Lindgren: chapters 2.1, 2.2.2, 2.2.4, 3.1.2, 3.2.2, 3.3.1 and results and discussion about the Shima River; Alexandra Röttorp: chapter 2.2.1, 2.2.3, 2.2.5, 3.1.1, 3.2.1, 3.3.2 and results and discussion about the Cumbaza River.

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Thanks to EMAPA, Tarapoto, for analysis and logistics when working in the field in Shima. Special thanks to Raul Prieto for giving us your support and help during our stay in Tarapoto and Saposoa and for the warm hospitality you and your family showed us.

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Finally, thank you to Karl-Erik and Lilly Hallin for financial support.

Sara Lindgren and Alexandra Röttorp,
November 2008


The authers Sara Lindgren (left) and Alexandra Röttorp (right) accompanied by two young guides.

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1 INTRODUCTION

1.1 GENERAL

The Amazon rainforest is the largest and most biodiverse rainforest in the world. It is home to about one third of the world´s species. The warm humid climate, the variety of ecosystems together with large areas with coherent primary forests and plentiful of prey contributes to a unique environment for flora and fauna. The forest is still not fully explored and new species are still being discovered (WWF, 2008).

The Amazon covers an area of six million square kilometres and is mainly located in Brazil (about 60 %) but stretches out over the territory of eight more countries in South America namely Bolivia, Colombia, Ecuador, Guiana, French Guiana, Peru, Surinam and Venezuela. Through its terrain flows the largest river (by discharge) and the second longest river in the world, the Amazon River. It runs from the Andes Mountains in Peru through Brazil before it discharges into the Atlantic Ocean. The river is home for about 2000 fish species plus mammals and reptiles and makes up for 1/5 of the earth's fresh water flow. Because of this it is today considered the world most important river system (WWF, 2008). The fact that the Amazon River also is the only one of the world’s largest rivers that is still close to its natural state makes it a unique place on earth (McClain, 1999).

Today the Amazon experiences an extensive pressure from increasing human populations and infrastructure advances. One of the main problems this brings is that the deforestation can continue and increase. Some important reasons causing the deforestation are the extraction of wood, opening up land for livestock and giving space for large-scale farming, e.g. production of soya beans. However, the main reason for the deforestation today is the small scale agriculture (WWF, 2008). In humid tropical forests most of the nutrients are found in the vegetation which means that the soils often are very poor in nutrients. In the rainforest the decomposition of dead organic material falling down from the vegetation returns nutrients to the soil and makes it possible for new plants to grow in the forest. In cultivations this natural recycling of organic material is disrupted (Cunningham, 2003).

In Peru the practise of small scale agriculture is common and the dominating form of preparing land for cultivation is by slash-and burn agriculture, i.e. after deforestation, the ground is burned in order to open up for land. This technique is today one of the biggest threats for the rainforests in the world. The technique has been practised by indigenous populations in the Amazon for a long period of time as it has turned out to function well in order to receive culturable land from nutrient poor soils in the rainforest. The ground is however only used for a short time as it needs time to recover in between harvests. Problems arise when an increasing population intends to put more pressure on the land. This leads to too little time for the soils to recover i.e. the recycling process does not get enough time. As a result the soil loses its fertility and the agriculture output decreases. Typical for the remaining vegetation after deforestation is also the lower biomass, the homogeneous structure and the loss of abundance of species which exist in the primary forests. This increases the risk that areas with bare ground are exposed to both rain and sun. By this follows an increase in leakage of nutrients and metals that normally should have been retained by the vegetation, to stream water due to increased runoff and release from the root zone (Williams et al., 1997). Many prior studies from Brazil have shown such leakage of for example nutrients such as phosphorus and nitrogen (Neill et al., 2001; Thomas et al., 2004; Williams & Melack, 1997). People turn to other places where new devastations will occur when the soil is no longer suitable for cultivation and the problems tend to escalate.

The highland rainforest in the sub-Andes (the border region between the Andes and the lowland rainforest) is considered to have the greatest biodiversity in the Amazon. Due to big differences in altitude this area is experiencing big variations in climate which provides for different types of ecosystems and an important abundance of species. The area is also a huge source of metals and nutrients and the geology within the region is easily weathered. As the highland rivers sweep away eroded material to the lowland an increased runoff in this area, due to e.g. increasing deforestation, could affect quantities of nutrients and metals in stream waters in a much greater scale. Since decades it has been known that transportation of particles, minerals and nutrients from distant tributaries are found downstream in the Amazon River when a large amount of sediment is transported from the Andes. Studies of the complexity of the biogeochemistry of this hydrological system have answered many questions but a lot is still to learn before it is thoroughly understood (McClain et al., 2008).

The contribution of major ions is plausible to be extensive, especially from the Peruvian Andes, as elevated concentrations have been found in Andean tributaries. It is therefore of big interest to investigate how the water quality in smaller streams in the highland rainforest in the sub-Andes in Peru is affected by the increasing human activity within the area. Prior studies have shown that such small scale studies are important in order to understand the effects of human impact on streams (Neill et al., 2006). Both the effects of deforestation in small scale watersheds as well as the effects of increasing pressure on habitats adjacent to streams are important to consider. Results from research show that it is, above all, the character of the riparian vegetation that regulates certain water chemical parameters such as nutrients (Buffler, 2005; Neill et al., 2001).

In summary, maintaining good water quality in streams in the sub-Andes of Peru is something that is of highest importance for the sustainability of the whole eco-region and all its species, including humans. Furthermore, as the quality in highland streams also influences lowland water systems, the effects of human pressure on these streams can lead to changes in the bigger tributaries and in the enormous Amazon River.

1.2 OBJECTIVES

The objective of this study is to investigate the impact of deforestation and land degradation on water quality in two streams located in the Andean Amazon. This will be done by comparing measured chemical concentrations in the two streams with: 1) a physical habitat assessment of riparian reaches along the streams and 2) the percentage of forest cover in the upstream areas drained by the streams. The comparison will also be used to evaluate if a physical habitat assessment of riparian reaches is a useful method for investigation of water quality in this area.

Our hypothesis is that an impaired physical structure in the riparian reach can lead to deterioration in water quality along a stream. Furthermore we hypothesize that increased deforestation has a negative impact on the water quality.

1.3 OVERALL STUDY AREA

Almost 60 % of the land area in Peru is covered by the Amazon rainforest, *la Selva*. It is located on the eastern side of the Andean mountain chain and of Peru's 28.4 million inhabitants only 5% live in this area, which is a quite isolated area with only few roads. The rainforest is divided into two areas, the highlands (or the cloud forest) on elevations above 700 m a.s.l. and the lowland rainforest, below 700 m a.s.l. The precipitation is high in the whole area and the soils are nutrient poor due to heavy weathering. *La Selva* is drained by large rivers like Marañon, Huallaga and Ucayali which are all tributaries to the Amazon River, the largest river in the world by volume. Among the principal products in this area are wood, rubber, rise, fruits, coffee, tea, petroleum and natural gas (Palm, 2007).

This study was carried out in the department of San Martin (Figure 1) in a sub-Andean region of the Amazon. The region has both highland and lowland rainforest (elevation 200 m a.s.l. and 3000 m a.s.l.). The department has an area of about 50, 400 km^2 (Encarnación, 2005) and a population around 670, 000 (INEI 2005). 119,000 of those live in Tarapoto which is the biggest city in the department. The population in this Andean region is growing, mostly due to immigration from coastal areas, the lowland rainforest and the Andes. This increases the pressure on the resources, especially on primary forest. Due to wide use of the slash and burn method to open up land for agriculture and pasture, the primary forest is constantly decreasing.

Figure 1 Map showing the department of San Martín in Peru, with bordering countries.

There is no or little regulation of the trade with land[1] (Cedisa, 2006). Around 25% of the area of San Martín is deforested according to grupo técnico de la ZEE in San Martín (Ramírez, 2005). A great part of San Martín is affected by severe or very severe human induced soil degradation according to soil degradation maps made by FAO/AGL (FAO/AGL 2007-05-11). The local people in the area are extremely dependent on the water resources in their daily life, and water from the rivers is used as drinking water, in many parts, without any kind of treatment. Only a very small part of the inhabitants have access to treated drinking water.

[1] Interview with people during field study.

Figure 2 Map showing the departments of Peru and the location of Cumbaza and Shima basins in San Martín.

Within the region of San Martin two watersheds, Cumbaza and Shima (Figure 2), were selected as study areas for this project. Both basins are located in the highland rainforest and are part of the Peruvian Yungas. The Yungas are characterised by high levels of endemic flora and fauna species and its extreme biodiversity makes it internationally important (Nagel, 2005). Today an uncontrolled migration flow together with an unsustainable slash and burn agriculture put pressure on the environment in this whole region (Nagel, 2005).

The deforestation within the Cumbaza and Shima watersheds is extensive and the effects of the human activity in the watersheds vary between 0 and 100%. The land within the watersheds is used as pasture for cattle and for agriculture with crops such as coffee, rice and fruits (Gordon et al., 2001). Other effects may be caused by extraction of wood or petroleum. So far only one petroleum deposit has been found but in an area consisting of primary forest (IIAP, 2004). The human activities within the watersheds will affect the water quality in the streams, which depends both on the conditions of the adjacent bank and on activities in the whole catchment. At some places within the watershed the pressure on the streams from human activity is especially striking when many people are living directly nearby the streams, using the stream and close sub-streams for washing and bathing on a daily basis. These activities as well as those related to transports within the area will directly affect the condition in the investigated streams.

2 THEORY

2.1 PHYSICAL ASSESSMENT OF STREAMS

In this section we will describe how a physical assessment of a land area close to a stream can be used as a complement to chemical analyses of stream water in order to evaluate water quality within a certain area. Different physical methods are described in Section 2.1.1.

A very common notion one comes across when working with a physical assessment for stream water quality is "riparian zone". We have already mentioned the importance of this zone when it comes to the regulation of nutrients, but this zone also influences a range of other parameters studied in this report. It therefore needs some special attention and a summary of its functions is presented in Section 2.1.2.

Many of the described methods are based on information given from people familiar with the area where the investigation is taking place and/or from the landowner. Therefore it is often necessary to conduct interviews to be able to fulfil the requirements of the physical assessment methods. In this chapter (Section 2.1.3) we therefore also present some interview techniques.

2.1.1 Physical assessment methods

Streams are complex ecosystems which include biological, physical and chemical processes. If one of these processes is disturbed the others will also be affected (SVAP, 1998). Furthermore, extensive research has shown that there is an interaction between the conversion of forested land to agricultural land and the reducing overall water quality (Waggoner, 2006). Physical activities such as farming adjacent to streams and pasture lands for cattle, swimming and those activities related to transports within an area will directly affect the condition of the streams (Gordon et. al, 2001). Therefore it is of utmost importance to use a stream assessment method that also takes into account physical activities. With an assessment directly connected to human activities on land one will get a more conclusive picture of the condition of a watershed. Furthermore, assessments based on physical parameters have also proved to be financially effective. This is a great advantage in a developing country. A physical assessment also provides familiar formulations about ecological health which makes it easily intelligible for common people (Sustainable Land Stewardship Institute International). There are different physical methods to use for stream condition investigations (Obropta, 2007) that also take into account physical activities. Below is a short description of the most common ones.

“The Stream Visual Assessment Protocol (SVAP) method” was developed by the Natural Resource Conservation Service within the U.S. Department of Agriculture (National Resources Conservation Service, 1998). The idea behind it was that one wanted to help farmers to get more aware about their farmlands and the problems associated with them. The protocol provides an assessment based primarily on physical parameters and gives a first approximation of stream condition. It is considered easy to use because the method is predominantly based on visual evaluation of the surrounding land. By this also follows that no expensive equipment is necessary during the investigation. The method is easy to learn and to understand, and it can be used as a tool for teaching farmers about conservation of water sources.

The SVAP protocol consists of two principal sectors. The first is the identification section, which records the identity and location of the stream reach as well as the width of the active channel. Knowledge about the active channel width helps to characterize the stream. The second is the assessment section which records the scores for up to 15 assessment parameters. These parameters are Channel condition, Hydrologic alteration, Riparian zone, Bank stability, Water appearance, Nutrient enrichment, Barriers to fish movement, Instream fish cover, Pools, Insect/Invertebrate habitat, Canopy cover, Manure presence, Salinity, Riffle embeddedness and observed Macro-invertebrates. Not all of these parameters have to be applicable for investigation of one specific site. The parameters are graded on a scale from zero to ten depending on how well they agree to some given criteria (SVAP, 1998).

“The Rapid Bio Assessment Protocol and Habitat Assessment method” developed by the U.S. Environmental Protection Agency (EPA) compares habitat features, water quality and biological parameters with a reference site. This method is most useful when there are resources available to conduct biological surveys (US Environmental protection agency, 2006).

“The Save Our Stream method” is a national watershed education and outreach program that is directed by the Izaak Walton League, one of the earliest conservation organizations in the United States. It was formed in 1922 to save the outdoor environment in America for future generations. Many major and successful conservation programs that America has in place today can be traced directly to a League activity or initiative. The method conducts water quality evaluations based on indicators such as water appearance, stream bed stability etc. However, the major parameter scored is the amount of macroinvertebrates from the stream as well as identifying these and rating the water quality based on the tolerance level of the organisms found and the diversity of organisms in the sample (The Izaak Walton League of America).

“The Stony Brook-Millstone Stream Watch Program method” has been launched by the Stony Brook Millstone Watershed Association to monitor water quality within a watershed drained by The Stony Brook and the Millstone River located in Mercer

County, New Jersey, USA. The method consists of three parts, including chemical sampling, biological assessment based on the presence of macroinvertebrates and assessment based on physical features similar to those scored in the SVAP-method (Stony Brook- Millstone Watershed Association).

2.1.2 Riparian zone

There are a number of different ways to define a riparian zone. This is because the choice of definition depends on the situation or objective and the background of the person or group undertaking the definition (Lee et. al, 2004). The word “riparian” comes from the Latin word “riparius” which means “bank”. This refers to the bank of a stream, simply meaning the land adjacent to a body of water or life on the bank of a body of water. In some definitions of a riparian zone this word is applied literally and the riparian zone is defined as the dense vegetation situated along the bank of a stream or other body of water. Others choose to define the riparian zone more broadly and include not only the vegetation on the bank but also the aquatic vegetation growing in the stream.

The riparian zone functions as a buffer zone which regulates the flow of many elements between surrounding land and the stream water. For example, trees and plants in the riparian zone can reduce the water velocity and increase the travel paths of the water. It can therefore result in deposits of sediment and attached nutrients. In addition, dissolved nutrients can be adsorbed by organic material and the mineral soil or be taken up by plants (Brady & Weil, 2002). Other elements, such as metals and contaminants can also be adsorbed or/and be taken up by plants in a similar way. Furthermore the vegetation zone helps to stabilize the stream banks by protecting the soil surface from impacts such as heavy rainfall and thereby decrease the risk of heavy erosion (Buffler, 2005) and partly by its soil holding capacity where the roots help to bind the soil (Brady & Weil, 2002; Buffler, 2005). The zone also provides habitat for stream biota, fish and terrestrial insects and shade of the water surface which reduces water temperatures and offers protection of aquatic water organisms by increasing the oxygen holding capacity of the water. Last, but not least, it provides organic material for stream biota (SVAP, 1998). The optimal design of a riparian zone is one that is densely vegetated and not overly trampled. That is how it should be built up to function at its best and be an effective buffer in order to decrease the amount of elements from reaching the stream water and thereby protect the stream health. Furthermore it should also have a width of six to sixty metres, although ten metres is usually sufficient to obtain most of the removing benefits (Brady et al., 1999). Many earlier studies have stated that the width is the most important variable in determining the effectiveness of the buffer to control the flow of contaminants into the streams (Buffler, 2005; Stream Visual Assessment Protocol, 1998). The land use adjacent to the riparian zone can easily affect the function of the zone and therefore it is important that the land use is carefully managed (Brady & Weil, 2002). Figure 3 shows an example of a riparian zone on both sides of a stream.

Figure 3 Riparian zone on both sides of the Shima River, Peru
(Photo: Lindgren & Röttorp, 2007).

2.1.3 Interview methods

When conducting an interview as a part of fieldwork based on sampling two stages are involved in the selection of respondents. The first is identification of a sampling frame or survey area and the second is choosing individuals or households from within that sampling frame. Undefined village boundaries in rural areas and virtually inaccessible villages (the village beyond a river or among rugged terrain) are problems that may occur in the field. A good understanding of the study area will therefore help to determine how important the inclusion or exclusion of a certain remote place is (Devereux & Hoddinstt, 1992).

Interviews can take different forms. They can be structured, typically with a set questionnaire, they can be unstructured with information written down as it emerges or they can consist of a combination of these two. In the structured interview there is a danger that the research excludes interesting facts respondents might wish to add as it is based on a formal questionnaire. On the other hand a large number of data can be obtained relatively quickly. In the unstructured interview there is no questionnaire and the interviewer has a chance to encourage respondents to talk on topics about which they have much to say and are interested in. It has been found that the respondents often find this method friendlier and less intimidating than the formal interview. Furthermore this method is especially useful at an early stage of fieldwork, for group discussions and for questions about bigger issues such as life history and local history. The drawback with an unstructured interview is the unrepresentativeness. For example, collecting information about human activities within an area only from old people risks losing perspective on how young people view different kind of activities. The responses may also be difficult to compare as each individual leads the discussion towards own interests (Devereux & Hoddinstt, 1992).

Group interviews are very useful as a kind of brainstorming where one can complement one another and cross-check things as names, numbers, dates and events. Also participating observation is a good approach. Eating and living in a community as well as communicating with the population help to get insights into events and activities that would not have been understood if one remains an outsider (Devereux & Hoddinstt, 1992). In other words, participating will result in a wider perspective on the research topic.

2.2 CHEMICAL ASSESSMENT OF STREAMS

In this chapter we introduce some variables interesting to analyse when assessing water quality, both from an environmental and a health point of view. These are mainly chemical variables but also biological.

We will first (Section 2.2.1) present ions of the most abundant elements in fresh water, so called major ions. These may be useful for characterising streams. We will then discuss the main nutrients that affect stream water quality namely phosphorus and nitrogen. Increasing levels of human activities can result in an increase of these nutrients in the stream water and cause eutrophication as well as have negative effects on human health. Together with carbon these are also the most important nutrients for the function of a natural riparian ecosystem. All three nutrients are described in Section 2.2.2.

In streams many metals exist naturally due to weathering processes and they are transported to the streams with ground water. In Section 2.2.3 we will look at the presence of aluminium and iron in stream water and how they affect water quality and human health.

Section 2.2.4 discusses two biological parameters, chlorophyll A and bacteria. Chlorophyll is a useful indicator of increased human activities. Bacteria and other microorganisms in drinking water is one of the biggest threats to human health in developing countries. We present here two common indicators of microorganisms; E. coli and Total Coliforms.

The physio-chemical parameters (Section 2.2.5) have been used in this study to estimate the quality of stream water. We have chosen pH, conductivity, dissolved oxygen and total suspended solids (TSS).

2.2.1 Cations and anions

The ions of the most abundant elements in fresh water, also called major ions, are sodium, calcium, magnesium, potassium, chloride, sulphate and carbonate. As these ions are the most abundant ions in natural waters they are useful for characterising streams. Ions reach rivers mainly from weathering of minerals in the soil or ion exchange in the soil and are transported to surface waters with the ground water. The accumulation of some ions increases due to industrial effluents, acid precipitation or from fertilizers (Brady et al. 2002; Chapman et al., 1996).

Generally the major ions have no great impact on human health and are not considered as environmental threats, but the ion concentrations are important when estimating the water quality (Chapman, 1996; Hounslow, 1995).

Calcium

Calcium exists in water as ions (Ca^{2+}) or as precipitated calcium carbonate. In soils it is found in minerals, which dissolve due to weathering processes. This occurs especially from minerals containing the salts calcium carbonates and calcium sulphates. Examples of such minerals are gypsum and limestone. Calcium is an essential element for all animals and for plant growth. An important role of calcium is its ability to decrease the toxicity of some metals. It has been proven that hard water (containing more calcium ions than soft water) decreases the toxicity of aluminium. Calcium also contributes to a functional buffer system and thus protects soils and water against acidification. Calcium is an alkaline earth metal and generally the largest contribution to the hardness of water. The calcium concentration in fresh water is usually less than 15 mg/L but may be as high as 100 mg/L in areas with carbonate rocks (Zumdal, 1997; Walker et al., 2001; Brady et al., 2002; Chapman et al., 1996 and Howells, 1986).

Magnesium

This is the second important element contributing to water hardness and as calcium it is an alkaline earth metal. Its salts are, except for magnesium hydroxide, very soluble why it is almost always found as ions (Mg^{2+}) in water. Magnesium is more easily affected by low pH or low clay/organic content in soils than is for example calcium. Magnesium is therefore more easily leached from upper parts of the soil to lower or to ground water. Ferromagnesian minerals contribute to magnesium ions in the water as do some carbonate rocks. The concentration in water may vary between 1 and 100 mg/L (Brady et al., 2002; Bydén et al.; Zumdal, 1997).

Potassium

Rocks containing potassium are generally very resistant to weathering processes. This leads to naturally low concentrations; often less than 10 mg/L. Potassium is an essential plant nutrient and thus often found in fertilizers. Potassium has no real negative impact on the water quality. However, if concentrations are elevated it may indicate leakage from cultivations and possible eutrophication. The leakage of potassium from soils increases with increasing pH and/or calcium ions (Capman et al., 1996, Brady et al., 2002).

Sodium

Sodium is often found as ions (Na^{+}) as its salts are very soluble. It is one of the most common elements on earth and is found in all natural waters. It is also found in plants and animals as it is an essential element to all organisms. The concentrations in fresh water vary a lot and depend mostly on the surrounding soils. Elevated concentrations may originate from industrial effluents (Hounslow, 1995; Chapman et al. 1996).

Carbonate and hydrogen carbonate

Depending on the kind of minerals present in the soil surrounding the stream, carbonates and bicarbonates derive mostly from CO_2 from the air solved in the water and from minerals. If the surface water is warm, less CO_2 may be solved. The hardness of the water is influenced by carbonate content as CO_3^{2-} may bind to Ca^{2+} and precipitate as salt (Bydén et al., 2003; Chapman et al., 1996).

Sulphate
The contribution of sulphate to rivers is mostly from weathering processes. Anthropogenic emissions to the air (i.e. combustion of petroleum products) may precipitate in another area, contributing to the sulphate concentration in that particular location. In natural waters the concentration varies between 2 and 80 mg/l (Bydén et al., 2003; Hounslow, 1995; Chapman et al., 1996).

Chloride
Chloride is not toxic to humans but it could be to plants at high concentrations. It is found in most natural waters and almost always as ion (Cl^-). In streams it origins from the weathering of rocks, atmospheric deposition from oceanic aerosols and leakage from agriculture or sewage effluents. Elevated concentrations in streams can indicate faecal contamination (Bydén et al., 2003; Chapman et al., 1996).

2.2.2 Nutrients

Phosphorus
Phosphorus is a reliable indicator of human effect on streams and is therefore often used as an important parameter in water analysis (Chapman & Kimstach, 1996). In the soil and water phosphorus can be bound to minerals and organic materials (particle bound phosphorus) or being dissolved. The transformation between the different forms is described by the phosphorous cycle (Figure 4). The movement from soil to water is regulated by plant uptake, runoff and leaching (Brady & Weil, 2002).

The quality of the riparian zone is very important because it regulates nonpoint source pollution including phosphorus. As the vegetation in the buffer can take up available forms of phosphorus it plays a great role in the retention of phosphorus in the soil, reducing the inflow of phosphorus to the streams. One plant available form of dissolved phosphorus is PO_4 (phosphate), which derives from weathering of phosphorus rich minerals, mineralization of organic phosphorus (decomposition of organic material to plant available material) and desorption of phosphorus which through immobilization has been absorbed by micro organisms (Figure 4). Earlier studies have shown decreasing phosphorus concentrations with increasing width of the riparian zone and that an increasing riparian zone generally reduces particulate phosphorus better than PO_4. Other factors that affect the retention of phosphorus in the riparian zone are kinetic factors e.g. reaction rates, particle size, and adsorption capacity of the soil and contact time in the soil (Buffler, 2005).

Phosphorus is one of the main contaminants from agricultural sources[2] and both particulate and dissolved forms from applied manure and fertilizers are carried into streams by runoff. Adsorption of plant available phosphorus to soil particles occurs readily in clay soils due to their high specific particle surface area (Buffler, 2005). Soils with high iron and aluminium contents tend to adsorb more phosphorus than other soils at low pH (<6). The adsorption makes the phosphorus unavailable for plants and thus increases the risk for phosphorus runoff. The dissolved form is known to increase in streams with increasing runoff from pasture land (Brady & Weil, 2002); Hounslow, 1995).

[2] Source: Lecture in Aquatic ecology (2005), Uppsala University

Dissolved phosphorus can also reach streams by leaching (vertical movement in the soil) and therefore bypass the riparian buffer. This is a concern in nearly saturated soils. Studies have shown that high concentrations of phosphorus in stream water are related to the ability of nutrients to bypass the riparian zone, and that the buffer in such cases is ineffective in reducing nutrients and other contaminants from adjacent land uses (Buffler, 2005).

The major effect of high phosphorus concentrations in streams is the increasing eutrophication which causes low oxygen concentrations in the water and death for many organisms in the water (Brady & Weil, 2002).

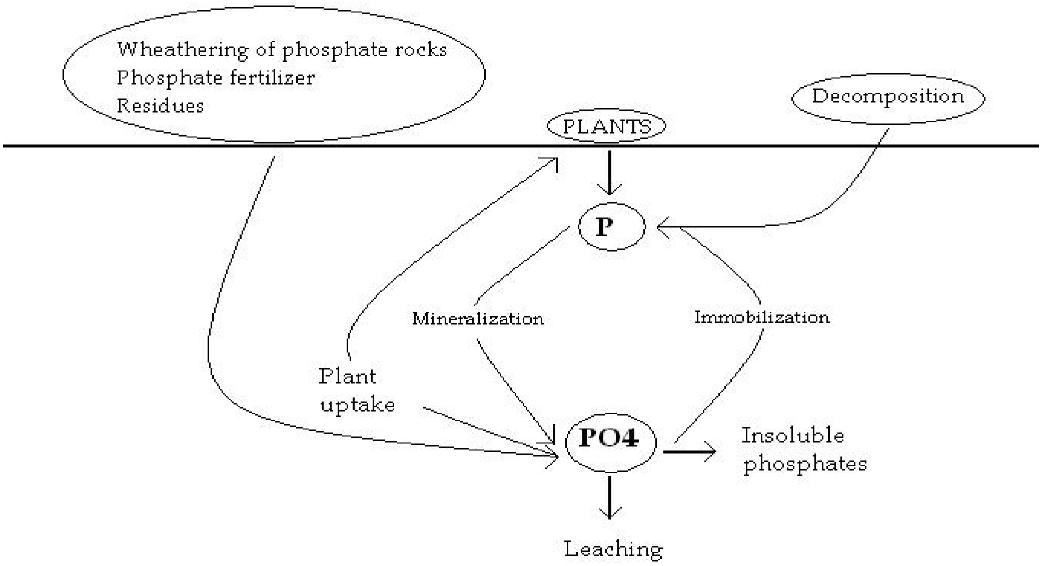


Figure 4 The phosphorus cycle. After having been eroded phosphorus can reach streams through runoff or it can bypass the riparian zone through leaching (if in dissolved form). Plant available phosphorus is regulated through the processes of mineralization and immobilization.

Nitrogen

Nitrogen is an important nutrient for plant and animal growth and function. Like phosphorus, it is one of the main contaminants from agricultural sources (Buffler, 2005).

There are different forms of organic and inorganic nitrogen in fresh water.[3] These are:
· Dissolved inorganic nitrogen: Nitrate (NO_3), Nitrite (NO_2), Ammonium (NH_4)
· Dissolved organic nitrogen: amino acids and organic macro molecules
· Particulate organic nitrogen: plankton

The transformations of nitrogen in the environment are described by the nitrogen cycle (Figure 5). Organic matter decomposes into ammonium which can fix to clay materials or undergo nitrification, the oxidation of ammonium to nitrite and then nitrate. Furthermore the nitrate can undergo denitrification which is a natural process that occurs in the soil under certain conditions where microbes reduce NO_3 to dinitrogen

[3] Source: Lecture in Aquatic ecology (2005), Uppsala University

(N_2) which is a gas released to the atmosphere (Figure 5). The required conditions for denitrification are an appropriate microbial population, a soluble carbon source for the metabolic function of microbes, a moist soil and low oxygen conditions (Buffler, 2005).

Nitrogen is one of the most studied nutrients when it comes to uptake and leaching related to the riparian zone. The riparian zone influences nitrogen dynamics through plant uptake and denitrification. If the riparian zone lacks the conditions necessary for denitrification, plant uptake plays the greatest role in retention of nitrogen in the soil. The plants can readily take up the forms NO_3 and NH_4 (Buffler, 2005). There is some evidence that the riparian zones of small tropical forest streams are effective at removing NO_3 produced in adjacent uplands (Neill et. al, 2001). There are also studies that have shown that the NO_3 concentrations in streams are reduced with increasing width of the riparian zone (Buffler, 2005).

Sometimes nitrogen bypasses the riparian area and reaches the stream, neither infiltrating the soil nor being taken up by plants. This could be the case for NO_3. The largest sources of nitrogen to streams are livestock feedlots and nitrogen fertilizer on land adjacent to streams. Because nitrogen levels in soils generally are not sufficient for optimum crop production it is often added as fertilizer and used on fields (Buffler, 2005). Since the dominant form of nitrogen in fertilizer is NO_3, an increasing concentration of NO_3 in stream water indicates a leakage of nitrogen fertilizer from farm lands that is bypassing the buffer zone (Walker et al., 2001).

Ammonium can also reach the streams by leaching, which is also the case for nitrite. Usually the concentrations of these forms are low in natural fresh water systems and for nitrite this can be explained by the fact that NO_2 is instable and easily changes into NO_3 if there is enough oxygen in the water. Increasing concentrations of nitrite can be found naturally in deep wells where the water lacks oxygen. Increasing concentrations of ammonium come from inputs as point sources, where ammonium is the most dominant form of nitrogen. This ammonium is highly soluble and readily leached into groundwater (Brady & Weil, 2002).

Decreasing infiltration rates is another factor that affects the nitrogen losses in soil and increases its concentration in stream water. A soil with low infiltration rates will have increased rates of nitrogen losses through increasing overland flow (Buffler, 2005).

There is also some evidence that the NH_4 concentration in stream water is increasing with decreasing oxygen concentration in the water, and also that ammonium in groundwater is associated with naturally high contents of iron and humus (Brady & Weil, 2002).

One of the main concerns regarding too high concentrations of nitrogen in stream water is, as for phosphorus, the increasing risk of eutrophication. In addition, increasing concentrations of nitrogen also has a direct effect on human health (Section 2.3) (Livsmedelsverket, 2005).

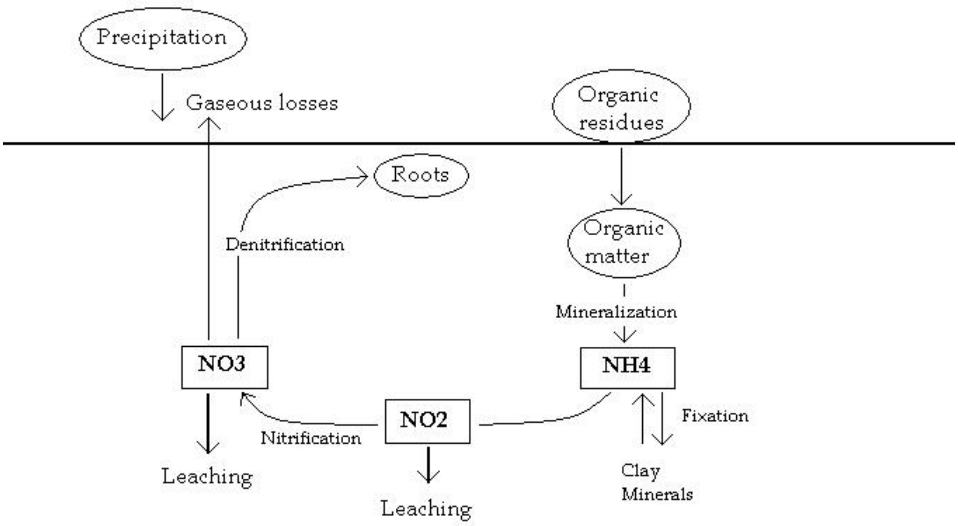


Figure 5 The nitrogen cycle.

Dissolved organic carbon, DOC

Dissolved organic carbon (DOC) is the name used to describe the thousands of dissolved components found in water that derive from organic materials such as decomposed matter from plants and animals. DOC is an important component in the carbon cycle and serves as a primary food source in aquatic food webs. DOC can be present in two different forms, either allochthonous, which means that it originates from within the lake itself, or it can be autochthonous, meaning that it originates from the immediate surroundings produced in rivers, reservoirs and lakes. There are different potential sources of DOC such as atmospheric deposition, forest canopy, forest floor pool of decaying litter and humus, soil organic matter, plant roots and fungi, wetland peat deposits, aquatic sediments, aquatic detritus and aquatic organisms (Kritzberg et. al., 2006).

A concern regarding DOC is that it can alter the chemistry of the aquatic ecosystem, thus contributing to acidification of weakly buffered, freshwater systems. Furthermore DOC has the ability to form complexes with trace metals. These complexes can end up in the stream water where they can be dissolved. A high organic carbon concentration can make the water brownish or tea coloured. This can be explained by the erosion of soils and the leaching of substances from organic matter which contributes acids to the streams and colours the water (Brady & Weil, 2002).

2.2.3 Biological Parameters

Some bacteria can be used as indicators for microorganisms in water. Microorganisms carrying diseases are easily spread by water used as drinking water to humans. This is a big threat to human health in developing countries. According to WHO unsafe water supply, sanitation and hygiene are responsible for 88% of diarrheal diseases in the world, diseases which kill 1.8 million people every year (WHO).

Bacteria

Waterborne diseases, such as cholera, are a large problem in developing countries. Tests of microbiological content are thus extremely important when classifying water for drinking. The diseases are spread by pathogens (microorganisms carrying diseases) which mainly derive from faeces of humans, other warm blooded animals, or birds. The pathogens end up in surface water due to non-treated or insufficiently treated sewage water and from non-point sources. These non-point sources may be cattle with access to the river or passing the river, wild animals, or humans in areas without sanitation facilities (Botkin et al., 2003; Bydén et al., 2003).

Pathogens that derive from human faeces can be divided in five groups; bacteria, viruses, helminthes, protozoans and fungi. The number of possible organisms that carry diseases are almost infinite and to analyse them all would be very time consuming and expensive. The solution is to analyse the presence of indicator organisms. Most common is to analyse Total Coliforms. Total Coliforms are faecal bacteria (not to be mixed with faecal coliforms which also are commonly analysed) with some specific criteria, e.g. they may live during anaerobic conditions (facultative anaerobic), they are gram-negative, meaning their cell walls are different from gram-positive bacteria (a way to differentiate bacteria into two groups) etc. This group also contains many bacteria that derive from other sources than human or animal wastes and is thereby not very specific (Botkin et al., 2003; Kadlec et al., 1996). Another more precise indicator to analyse is E. coli (*Eschericha coli*). It is the most common colon bacterium in warm blood mammals. The E. coli group indicates the presence of faecal matter from humans and animals. There are many different types of E. coli bacteria. Most of them are not dangerous but some may lead to lethal diseases. (Bydén et al., 2003; Kadlec et al., 1996).

Bacteria (and other pathogens) are sensitive to variations in temperature, pH and other environmental conditions. Changes in these conditions may lead to a dye-off effect when bacteria end up in water and it also means that the water samples collected for the analysis of indicator bacteria are sensitive. If colonies of E. coli are found during the analysis the water is not suitable for drinking (see 4.4.2) (Berghult et al., 2004; Bydén et al., 2003; Kadlec et al., 2003).

Bacteria need a carbon source to survive. This may be organic or inorganic carbon depending on the type of bacterium. Therefore streams containing high concentrations of organic matter may increase the amounts of bacteria. Particles may lead to increased amounts of bacteria in the water as they give bacteria both a carbon source and surface to attach on. (Bydén et al., 2003).

Chlorophyll A

There are three types of chlorophyll, A, B and C. The B and C types usually exist in very low quantities and are therefore often neglected. Measuring the chlorophyll A gives an estimation of the quantity of chlorophyll in living organisms at the time of sampling. High amounts of chlorophyll A indicate eutrophication, especially together with high levels of phosphorous compounds, and may be expected in agricultural areas. The primary production depends not only on the amount of absorbed light, but also on the presence of nutrients in the water (which increase with eutrophication). The colour of the water may also be affected by the amount of algae and thus the chlorophyll content. Even though chlorophyll is not dangerous to humans, water containing a lot of algae is not recommended for drinking[4] (Bydén et al., 2003). Streams in tropical forests generally contain very low biomass of green plankton why low concentrations of chlorophyll A are expected in these areas[5].

2.2.4 Metals

Aluminium and Iron
Aluminium is the most abundant metal on Earth; it constitutes about 8 % of the earth's crust. In streams, aluminium can be present in two forms, either dissolved in the water or bound to organic substances as humus (particulate bounded). pH is the most important factor controlling the toxicity of aluminium. Acid conditions drastically increase its solubility and consequently its toxicity. Aluminium is not easily dissolved but in acid environments (pH <4) it mostly occurs dissolved as the ion Al^{3+} (Rosseland, 2006; Gerhardt, 1995).

A concern regarding aluminium in stream water is its toxicity for fish. Aluminium ions can change the cell functions among fish and make the gills produce too much mucus and clog together. This reduces their normal function, causing impaired oxygen uptake. The fish gills may be damaged to such degree that it leads to death. Toxic effects have also been identified among invertebrates (Rosseland, 2006; Gerhardt, 1995).

Iron occurs naturally and in the water it can be present in two forms, either dissolved as Fe^{2+} and Fe^{3+} or it is bound to humus. It is essential to many living organisms and may accumulate within organisms (Walker et al., 2001).

There are concerns regarding high concentrations of iron in water as this can cause deposits of iron oxide on plants (Bydén et.al., 2003). Too high concentrations can also affect the gills on fish causing impaired uptake of oxygen. The risk decreases with increasing pH and increasing amount of humus in the water (Walker et al., 2001).

The presence of high concentrations of iron and aluminium together results in higher stress responses in fish than does the presence of either aluminium or iron ions (Rosseland, 2006).

Both aluminium and iron can be taken up by plants and thus a hypothesis is that forest devastation may increase the concentration of these metals in stream water, as the ability of the vegetation to bind the metals decreases.

2.2.5 Physio-chemical parameters

pH
The concentration of hydrogen ions in water is commonly reported as pH ($pH = -\log[H^+]$) and is used to measure the acid balance. When estimating water quality, pH is an important variable because the acidity of the water affects the aquatic life as well as chemical reactions. The pH in surface water depends primarily on the buffer capacity

[4] Source: Lecture in Aquatic Ecology (2006), Uppsala University
[5] Source: Personal communication with Jan Johansson, Department of Ecology and Evolution, Uppsala University

(that neutralizes hydrogen ions) in the water which in turn depends on the minerals in the surrounding soil. If mineral weathering minerals increase in upstream areas, the amount of calcium and magnesium ions transported to the surface waters increases and consequently also the buffer capacity of the stream. The buffer capacity also depends on the carbonic acid system, which in turn depends on the amount of dissolved carbon dioxide. Acidic rain may decrease the pH, especially water with low buffer capacity. But the pH also depends on the biological life, bacterial decomposition may lead to release of acids from the microorganisms (Bydén et al., 2003; Walker et al., 2001; Chapman et al., 1996).

In fresh water pH usually varies between 6.0 and 8.5. Both a higher as well as a lower pH may cause environmental problems. A low pH induces the toxicity of some elements e.g. mercury. A high pH has a negative impact on many living organisms. The largest threat for aquatic life is a sudden change in pH, since many organisms may have a difficulty to adapt to this (Bydén et al., 2003; Chapman et al., 1996).

Conductivity

Conductivity, or electric conductivity, is used to estimate the concentrations of ions in water through measuring the ability of the water to conduct an electric current. In fresh waters the conductivity usually varies between 1 and 100 mS/m. In polluted waters it often exceeds these values. Conductivity is useful when it comes to comparing the result with other streams or lakes and may be useful to estimate how pollutions from an effluent spread. An increased conductivity may depend on high surface runoff and not necessarily origin from pollution. A higher concentration of ions is found in water with a high conductivity, but the conductivity also depends on the charge of the ions why it is difficult to calculate the exact concentration of ions only from the conductivity. The concentration of ions may be calculated by adding a factor determined specifically for each location. A high concentration of certain ions is unhealthy for humans (Livsmedelsverket, 2005; Bydén et al., 2003; Chapman et al., 1996).

Dissolved Oxygen

Oxygen is dissolved in the water mainly from the atmosphere, but water plants may contribute since the photosynthesis produces oxygen. The ability of surface water to dissolve oxygen depends on its temperature; at 26° C the water may dissolve 8 mg/L but cold water dissolves more oxygen. Close to the surface of running water the oxygen concentration may increase to 100 % saturation. The dissolved oxygen (DO) is consumed in chemical reactions in the water and in the decay of organic and biological matter, especially at the bottom where dead material is decomposed. If the organic material entering the water increases, e.g. due to eutrophication, the oxygen demand of microorganisms metabolising the material increases. A decreased concentration of DO may then be observed and indicate increased human activities in the area[6] (Bydén et al., 2003).

All aquatic life depends on oxygen and thus a decrease in DO has negative effects on many organisms. Some species demand higher oxygen concentrations than others and will thus disappear from the location, and most fish species die, if the DO concentration decreases below 2 mg/L. A low oxygen concentration may give water a less pleasant

[6] Source: Lecture in Aquatic Ecology (2006), Uppsala University

odour (if less than 80 % saturation) but is not dangerous to humans (Bydén et al., 2003; Chapman et al., 1996).

TSS

TSS, or total suspended solids, is the total amount of particles that would remain in the filter after filtration, often with a pore size of 0.45 µm. The particles could be any material, organic or inorganic, that could be filtered with a standard filter (often 1µm in pore size). It is related to the turbidity which in running water is mainly related to inorganic particles. Increasing amount of particles in the water increases the risk of presence of bacteria as the particles serve as food source for bacteria and other disease carriers (Bydén, 2003; Chapman et al., 1996).

2.3 GUIDELINES

Classification of eutrophication level

In order to get an idea of which concentrations of total phosphorus (phosphate + organic bound phosphorus) in a river that causes eutrophication Naturvårdsverket (the Swedish environmental protection agency), has established a classification based on concentrations of total phosphorus in fresh water systems (Table 1).

Table 1 Classification of the eutrophication level for fresh water systems (Naturvårdsverket, 1999).

Class	Eutrophication level	Total-P (mg/L)
1	Low	≤0.013
2	Moderate	0.013-0.025
3	High	0.025-0.050
4	Very high	0.050-0.100
5	Extremely high	>0.100

Drinking water quality

The term “drinking water” refers to any kind of water used by consumer for drinking, in other beverages or for preparing food. Requirements on the quality of drinking water encompass all the countries in the European Union (EU) and are being incorporated into the Swedish legislation by Livsmedelsverket which is the National Food Administration of Sweden (NFA), (Livsmedelsverket, 2005). The guidelines for drinking water, from NFA and Peruvian limit values, are presented in Table 2.

Cations and anions

As mentioned in Section 2.2.1 ions generally have no or little impact on human health. One of few effects could be diarrhoea if the sulphate values are high, but only together with sodium and magnesium (Bydén, 2003). Therefore no values for ions are found in the column “unacceptable drinking water” (Table 2). The guidelines presented are though recommendations for a good, healthy drinking water and can be used as comparison. It is though important to consider the natural levels of ions in natural waters.

Nutrients

The NFA has limits for all forms of nitrogen in drinking water. High concentrations of nitrate, nitrite and ammonium can increase the risk for waterborne diseases. Particularly high concentrations of NO_2 in drinking water (above acceptable values) may directly affect the health due to deteriorated uptake of oxygen in the blood. This leads to serious, even fatal, consequences for bottle-fed infants less than three months of age. Drinking water with nitrite concentrations above acceptable limit values are recommended not to be given to children under one year of age. It has also been proved that prolonged intake of nitrite concentrations above acceptable limit value can result in negative effects on the adrenal glands (Livsmedelsverket, 2005). Concentrations of NO_3 above acceptable limit value will indirectly affect the health in the same way as nitrate because nitrate can transform into nitrite within the human body. Table 2 shows limits for the nitrogen forms set by NFA.

The NFA has no limits for phosphorus or DOC in drinking water (Livsmedelsverket, 2005).

Metals

Aluminium may be dangerous for human health due to its effects on the nervous system and NFA has set the limit value for aluminium in drinking water to 0.100 mg/L for "outgoing water". For iron there are no proven effects on human health and the limit is set on criteria based on taste (Livsmedelsverket, 2005).

Biological parameters

As seen in Table 2 chlorophyll A does not have any limit value. Chlorophyll is not dangerous to human but may indicate presence of nutrients. Among the parameters in Table 2, the E. coli and Total Coliforms are the most important to estimate the acceptance of the water as drinking water. A number of diseases may threat human health if there are microorganisms present in the water (Section 2.2.3).

Physio-chemical parameters

No limit value for TSS is given by NFA but there is a Peruvian limit value of 30 ppm. The most important of these parameters are EC and pH. pH should not increase above 10.5 and the value is preferably between 7.5 and 9.0 for a good drinking water. Values above or under these values in streams are not dangerous to humans as extremely acid or basic water is very seldom found naturally. The critical value for EC set by NFA is 250 mS/m in drinking water in order to regulate the amount of ions in drinking water.

Table 2 Limits for drinking water by the National Food Administration in Sweden (Livsmedelsverket, 2005) and Peruvian limit values (Estandar de calidad ambiental, Grupo N°4: Conservacion del ambiente acuatico)

Parameter	**Unacceptable limit values**[7]	**Accepted limit values with remark**[8]		**Peruvian limit values for drinking water**
	Drinking water at consumer[9]	**Outgoing water**[10]	**Drinking water at consumer**[11]	
Cations and anions				
Calcium (mg/L)	-	-	100	-
Magnesium (mg/L)	-	-	30	-
Potassium (mg/L)	-	-	-	-
Sodium (mg/L)	-	-	100	-
Carbonate (mg/L)	-	-	-	-
Chloride (mg/L)	-	-	100[12]	-
Sulphate (mg/L)	-	-	100	-
Nutrients				
Ammonium (-N) (mg/L)	-	-	0.4	0.04 (ammonia)
Nitrate(-N) (mg/L)	12[13]	-	5	5
Nitrite (-N) (mg/L)	0.15[14]	0.03	-	-
Phosphate	-	-	-	-
DOC	-	-	-	-
Biological parameters				
Chlorophyll A	-	-	-	-
Escherichia coli (ucf/100 mL water sample)	exists	-	-	-
Total Coliforms (ucf/100 mL water sample)	10	exists	exists	3000
Metals				
Aluminium (mg/L)	-	0.100[15]	-	-
Iron (mg/L)	-	0.100[16]	0.200[17]	-
Physio-chemical parameters				
Dissolved Oxygen/ Oxidation ability (mg/L O_2)[18]	-	-	4.0	≥5.0
Electric conductivity (mS/m)	-	-	250[19]	-
pH (pH units)	10.5		<7.5 >9.0[20]	<6.5 >8.5
TSS (ppm)	-	-	-	30

[7] Directly or indirectly health-based limit value
[8] The limit value is health-based or based on criterions for taste.
[9] i.e. for drinking water from a distribution plant, water tanks or food business or for drinking water tapped on bottles for sale.
[10] i.e. for water from a water purification plant *before* distribution
[11] i.e. for drinking water from a distribution plant, water tanks or food business or for drinking water tapped on bottles for sale.
[12] The limit value takes into account that the water should not damage the pipes.
[13] Indirectly health-based limit value at the consumer.
[14] Directly health-based limit value at the consumer.
[15] Health-based limit value.
[16] The limit value is based on criterions for taste.
[17] The limit value is based on criterions for taste.
[18] Permanganate index
[19] The limit value is set for a temperature of 20°C. It takes into account that the water should not damage the pipes.
[20] The limit value takes into account that the water should not damage the pipes.

3 METHODS

3.1 STUDY AREA

3.1.1 Cumbaza

The Cumbaza basin is located in the north eastern part of the department of San Martín, partly in the province of Lamas and partly in the province of San Martín (Figure 2). Due to many economic activities connected to the river, the Cumbaza River is considered one of the most important rivers in this area. This is partly caused by the location of the biggest city of the department of San Martín, Tarapoto, which is situated in the lower parts of the Cumbaza basin, just by the river (Ministerio de agricultura et al., 2006).

The population is mainly located to the cities in the south of the basin, but several villages are found also in the northern part and the whole valley is overall a rather populated area. Tarapoto is the biggest city in the Cumbaza basin. Located close to Tarapoto are also Morales and Banda de Shilcayo. Due to the immigration in the whole department, these cities have more or less grown together. The high immigration rate is a problem both in the cities and in the countryside. Some inhabitants in the rural areas are indigenous but most people have a mixed background. Most of the villages can be reached by car which is not the case in the highest parts of the basin (Cedisa, 2006; Lange, 2006).

The Cumbaza River and its tributaries are important for the people living in the rural area as they use the water as drinking water, often without any treatment. Due to increased use, probably caused by immigration and population increase, the water level in the tributaries is decreasing[21]. In Tarapoto the private water company EMAPA is responsible for the water supply. This water has been treated before arriving to the customer. For Tarapoto EMAPA takes water from the Cumbaza River or from its tributaries. This means that all water used in the city originates from and is dependent on the contribution of water from the tributaries in the higher parts of the basin (Cedisa, 2006).

Rice, palm tree (for palm tree oil) and crops are cultivated in the farmlands surrounding Tarapoto. To supply the fields with water, a canal was built upstream of Tarapoto in the 1980s (Lange, 2006). The canal diverts great amounts of water, and the riverbed downstream of Tarapoto has been observed completely dry during periods of little rainfall[22], partly because of the irrigation canal. Two other canals are found along the Cumbaza River and all together they can divert 3.75 m^3/s (Ministerio de agricultura et al., 2006). Palm tree and rice are also the most cultivated crops in the whole Cumbaza basin. Other common crops are banana, maize, coffee, sugar cane, beans, yucca, cotton and fruits.

Cordillera Escalera is a mountain chain and the drainage divide the north eastern part of the basin. It is also an area of conservation. The extraction of resources from this area is limited and the nature and biological diversity is protected according to the plan of conservation. The conservation area is almost 150 000 ha big. The north eastern part of

[21] Interview with people during field study.
[22] Personal observations.

the Cumbaza basin is found within this protected area (Cedisa, 2006; Ministerio de agricultura et al., 2006).

Inrena (*Instituto Nacional de Recursos Naturales)* divides the basin of Cumbaza into three parts; highlands, hills and lowlands. The highlands is the area with an elevation of 1000-1800 m a.s.l. and with a gradient as high as 50% in some parts. The hilly area is defined as the area between 700 and 1000 m a.s.l., e.g. the areas around and north of San Roque de Cumbaza (Figure 7). The lowland is the area with an elevation of 200-700 m a.s.l.. Natural fluctuations of water flow often result in erosion and the lowland is most affected by these fluctuations (Ministerio de agricultura et al., 2006).

Climate

In the highland area the average temperature is 22.0 °C. However, the variation in elevation affects the local temperature and precipitation. In the highest parts (1700 m a.s.l. and above) the average temperature can be as low as 17.0 °C. There is no clear division between a rainy and dry period, as in the lowland area, instead it is very humid all year around. The average precipitation is very high, between 2000 and 3000 mm/year (Ministerio de agricultura et al., 2006).

The climate in the hilly area is also humid (83-89 % relative humidity) and the average temperature varies between 20.0 and 24.0 °C. The average precipitation is 1500-2000 mm/year and the most intense period of precipitation is between October and April.

The average temperature in the lowland varies between 24.8 and 27.1 °C. The relative humidity is lower (77-86%) as well as the average precipitation, 1000 - 1400 mm/year. The rain period is during the same months as the hilly area, October to April. Table 3 shows precipitation data for Tarapoto which is situated in the lower parts of the basin (Cedisa, 2006; Ministerio de agricultura et al., 2006).

Table 3 Average precipitation and temperature at two weather stations in Tarapoto (INRENA, 2006).

Altitude of station (m)	Precipitation (mm/year)	Mean temperature (°C)
313	1240	26
356	1269	*

* Mean temperature is not given for this station.

Land use

Agriculture is one of the most important economic activities. Other economical activities are cattle and forestry. Companies are also interested in the land to extract petroleum. An oil deposit has been found in the protected area in Cordillera Escalera and plans are currently made to start the extraction (Cedisa, 2006; Lange 2006).

3.1.2 Shima

The Shima basin is a part of the larger Saposoa basin which is prioritized by WWF Peru (World Wildlife Fund) because of its high values and relatively intact ecosystems. Today WWF is working together with the authorities, institutions and inhabitants towards an Integrated Development Plan which focuses on sustainable forest management, conservation of biodiversity and protection of the water springs and intakes in the Saposoa basin. As a part of Peruvian Yungas and the prioritized region of Saposoa it is important to protect the ecological values within the Shima basin.

Even if the migration flow into the Shima region today is not as extensive as to the rest of the Saposoa region one environmental problem is, as for the Cumbaza region, that farmers use slash and burn techniques to prepare fields for cultivation. Many of these fields are located adjacent to the stream and thus the changes taking place on these fields are likely to affect the stream directly. Today all people living in Shima use the water from the stream and its tributaries on a daily basis. The streams are natural locations for the daily hygiene and also an important source for drinking water.[23] Where the stream water is used directly as drinking water the quality of it is of course of highest importance.

The population in the Shima basin is mainly concentrated to the villages in the southern part of the basin. The largest village within the basin is El Dorado, it is possible to reach the village by car a couple of times per day from the city of Saposoa, the largest town within the Saposoa basin. In the northern parts most people live in *tambos*[24] in remote areas far from the closest neighbour or in smaller villages often consisting of only a few tambos.

Climate

The average temperature within the Saposoa basin varies between 21.4°C in the highlands and 32.0°C in the lowlands (weather station of SENAMHI in Saposoa). The Shima basin has two rain periods, the first between February and April and a second between October and November. The precipitation average is 1500 mm/year but increases to an estimated 2500 mm/year in the surrounding mountains. The drier period is from June to September (Nagel, 2005). Figure 6 (below) shows mean monthly temperature and mean monthly precipitation for the Saposoa basin.

[23] Interview with people during field study.

[24] *Tambo*: Shelter constructed in the Peruvian Amazon. These can be built for temporary use or more robustly built in order to function as a permanent house.

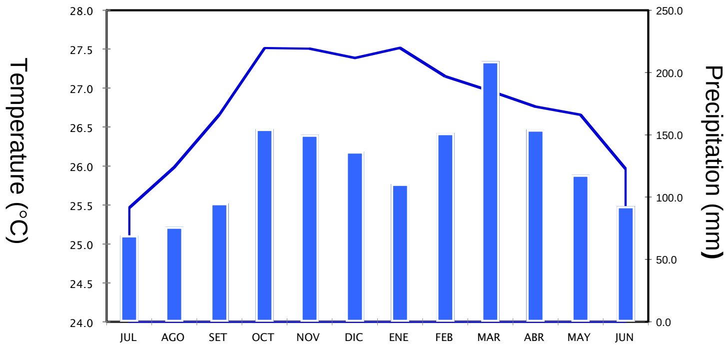


Figure 6 Mean monthly temperature (1999-2006) and mean monthly precipitation (1967-2006) for the Saposoa basin (diagram from SENAMHI, Peru).

Land use
Important economic activities are agriculture, cattle, forestry and fishery. The most common crops for cultivation are coffee, bananas and cacao (Nagel, 2005).

3.2 SAMPLING LOCATIONS

3.2.1 Cumbaza

The Cumbaza River is flowing in a south eastern direction (Figure 7). It is born in the mountains of Cor dillera Escalera which forms the drainage divide in the north-east and limits the Cumbaza basin. The Cumbaza River is almost 60 km long and has 35 important tributaries (Ministerio de agricultura et al., 2006). The Cumbaza River discharges into the Mayo River about 10 km south of the city of Tarapoto, which later joins the Huallaga River. The Huallaga River is a tributary to the Maranon River which is one of the main rivers forming the Amazon River (GIS analysis 2008; Lange, 2006).

Before departure SPOT satellite images (resolution: 10 m) were studied in order to choose six sampling locations. The sites were selected considering the surrounding fields and vegetation. In arcGIS maps were made to have an overview over the catchment in the field (see Section 3.3.2).

The site furthest downstream (called C1) is situated just south of Tarapoto, close to the airport. Five more sites were selected upstream in the river. The sites C1-C3 are all located close to Tarapoto and they are easy to reach by car. People visit these places every day, especially C1 where a road crosses the river (in the water) about 10 metres downstream from the site. Sites C4-C6 are located in a more remote area. This area is characterized by small-scale farmlands. C4 and C5 are frequently visited but by far less people than the sites further downstream. The areas around C6 and partly around C5 are part of the conservation area Cordillera Escalera (Cedisa, 2006). Figure 7 shows the location of the sites and in Table 4 a summary of the description of the sites along the Cumbaza River is given. The description of the riparian zone, water and land use gives an idea of the appearance of each site. The coordinates of the sampling sites are found in Appendix 4.

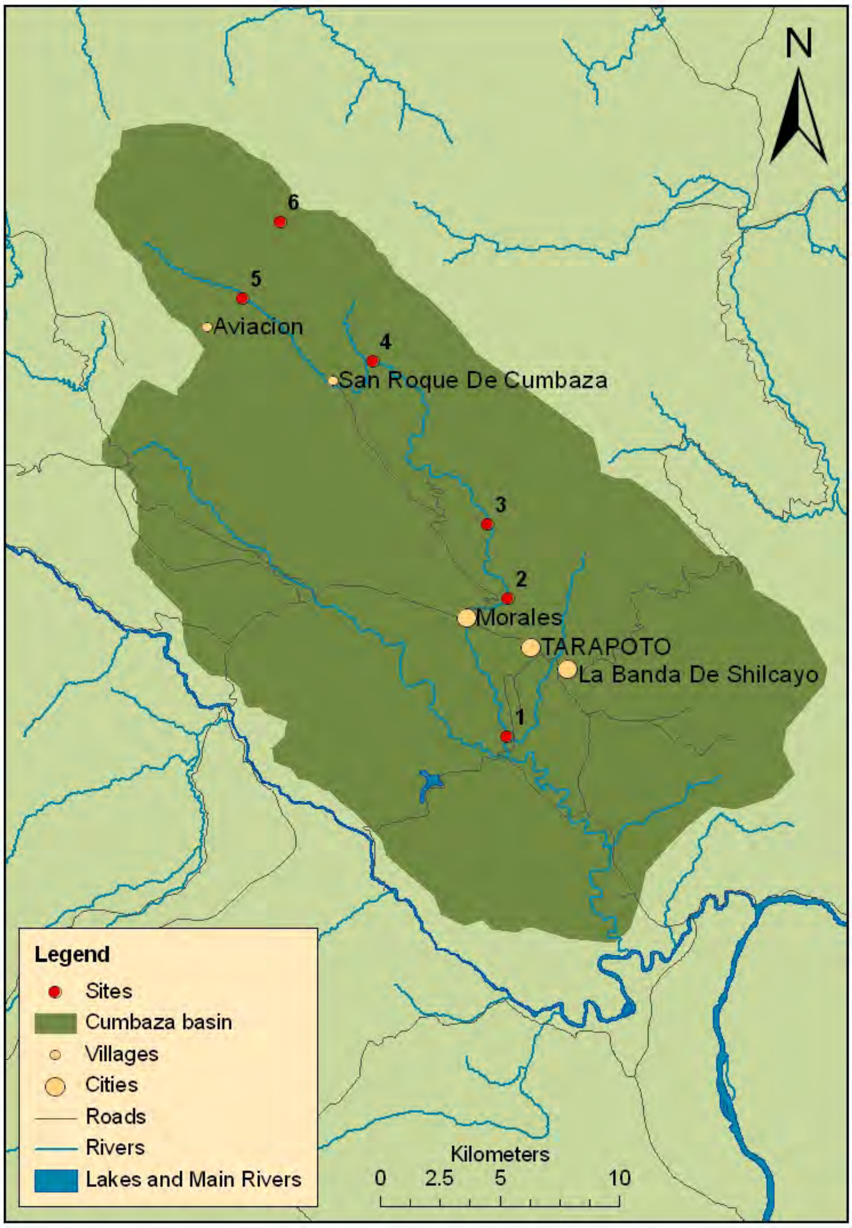


Figure 7 Map showing the sites in the Cumbaza basin. Only the cities and villages mentioned in the text are shown on the map.

Site C1: Located downstream from Tarapoto and the airport. A lot of pollution is washed down into the river from the city. A road passes through the river. There is no or little forest and the vegetation on the banks is lower than at the other sites, consisting mainly of bushes and grass, see Figure 8. The water is used only for car washing. People collect sediment from the river bottom to add to concrete. Figure 8 shows a photo of site C1.

Figure 8 The site C1, looking downstream (Photo: Lindgren & Röttorp).

Site C2: Buildings are located close to the river. There are farmlands, both large and small, close to the river. People pass here or in the close surroundings everyday and a road reaches all the way down to the stream. The water is used both for bathing and washing. Only secondary vegetation is found here and it is less dense than upstream, see Figure 9. Still the riparian zone is quite intact.

Figure 9 A short distance upstream site C2 (Photo: Lindgren & Röttorp).

Site C3: This site is a popular recreation spot but the water is also used for washing and as drinking water. There are large farmlands in this area and the vegetation around the river is mostly secondary forest, see Figure 10. A big rice plantation receives water from the river upstream through a canal.

Figure 10 Site C3, looking upstream (Photo: Lindgren & Röttorp).

Site C4: This site is located in the hilly area, about one kilometre downstream from the village San Roque de Cumbaza in an area that is partly protected. The forest contains primary forest but also secondary - especially a bit upstream where some deforestation occurs. Tourists regularly visit this area but overall only a few find their way here. There are a few small cultivations close to this site but not adjacent to the riparian zone (Figure 11). The water is used mostly upstream from this site, closer to San Roque.

Figure 11 Site C4, looking downstream (Photo: Lindgren & Röttorp).

Site C5: This site is situated close to the village of Aviación with farmlands along one side, but not seen from the site (Figure 12). A path is also passing through the river why people and animals cross the river here several times a day. There is also a *tambo* (see footnote 24) close to the river where people rest and cook. The water from the stream at this location is used for water supply; washing etc. The stream is surrounded by mostly primary but also secondary forest.

Figure 12 Site C5 (Photo: Vasques).

Site C6: This site is situated in an area with primary forest (Figure 13). There are no cultivations or other human activities found in the adjacent areas. There is little human activity in this area, though the interest from tourists to visit the primary forest and a famous waterfall a bit downstream is increasing.

Figure 13 Site C6 (Photo: Lindgren & Röttorp).

Table 4 Summary of physical properties of the sites along the Cumbaza River (Analysis in GIS, personal observations).

Site	Sampling elevation [m a.s.l.]	Land use in the surroundings	Riparian vegetation	Water use
C1	236	Plantation of bushes/low trees. The leaves are used for house construction.	Grass on the left bank. Low trees/bushes on the right bank.	Washing of cars. Sediments of the bottom are used for cement.
C2	298	Small and large farmlands close to the river	Trees and bushes. Secondary vegetation	Swimming and washing.
C3	344	Large farmlands. Large scale rice production upstream.	Trees and bushes	Water extraction about 2 km upstreams for plantations. Washing and swimming, popular recreation spot.
C4	559	Eco tourist area. Cultivations 2-3 km upstream.	Primary and secondary	Drinking, swimming, washing.
C5	761	A village with cultivations close to the river.	Primary and secondary	Drinking, swimming, washing.
C6	1347	None	Primary	No known use of water

The described area is the area of the sub-basin up-streams each site and the mean elevation is the mean elevation calculated for each sub-basin.

3.2.2 Shima

The Shima River is running from the mountains in the remote areas in the north of the basin in a south-east direction until it discharges into the larger river Saposoa (GIS analysis, 2008). The length of the stream is about 26 km. The Saposoa River then goes into the river Maranon which confluences with the river Ucayali and is given the name of the Amazon River.

Six locations were chosen along the river (Figure 14) to encompass drainage areas exposed to a variety of land-use activities. The sites were chosen by investigation of SPOT satellite images (resolution: 10 m) over the basin. Maps over the Shima basin, to be used in the field, were then created in different resolutions in ArcGIS. (The geographic coordinate system used was GCS WGS 84 and the project coordinate system was WGS 1984 UTM Zone 18S). The sampling locations were numbered beginning with the site closest to the outflow, S1 at 330 m a.s.l., to the most upstream site, S6 at 770 m a.s.l.. Sites S1 and S2 are located close to the city of Saposoa and are easily reached by motorcycles. Site S3 is located within a walking distance of about two hours from the closest village while S4-S6 are all located in more remote areas. The most common land use on adjacent land to the sites are different kinds of crops but there are also areas for pasture land and a slash and burn agriculture. Appendix 4 lists the definitive coordinates of the sampling sites.

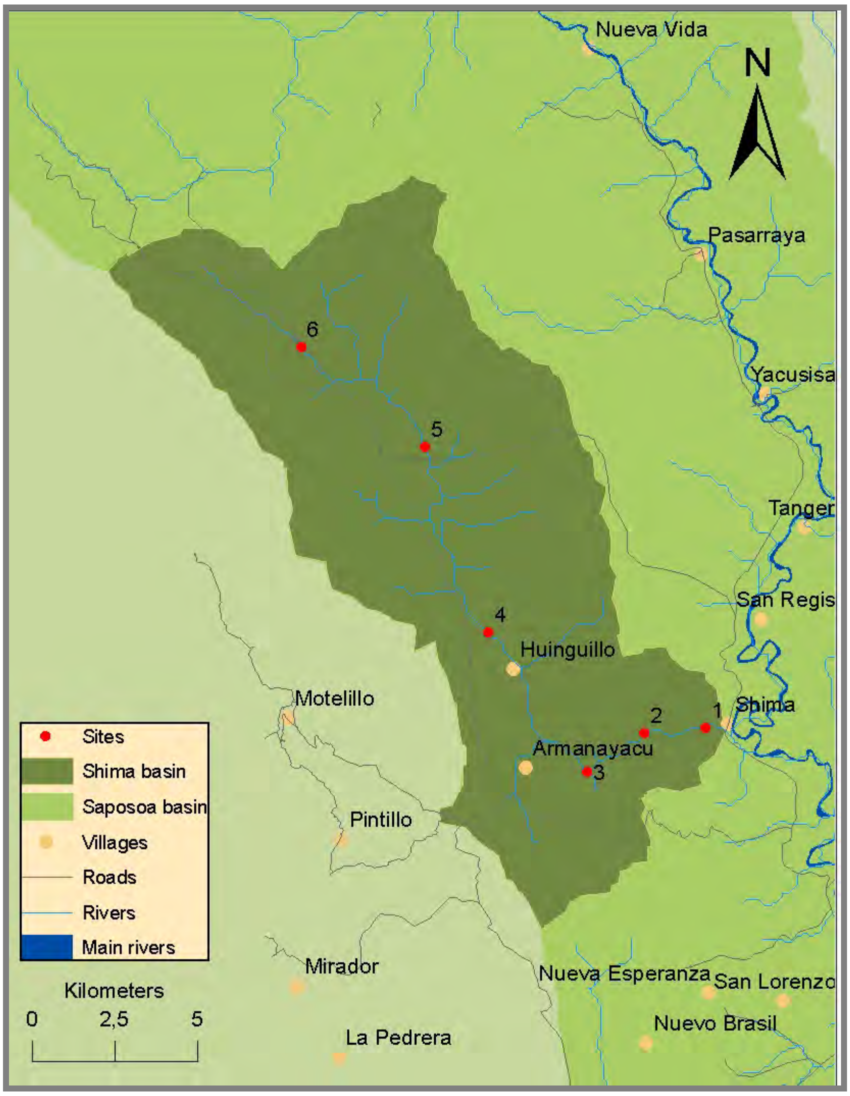


Figure 14 Map showing the sampling sites along the Shima River.

Below follows a closer description of the land uses within the investigated areas. A summary of the locations is found in the end of the section (Table 5).

Site S1: This site is situated close to a banana field and an enclosed pasture land. The character of the terrain in the surroundings along the stream bank at one side makes this site easily accessible for people but also for animals grazing on the pasture. Activities such as washing and bathing are very common. The vegetation is partly primary.

Figure 15 Site S1 (Photo: Lindgren & Röttorp, 2007).

Site S2: A water withdrawal is located 100 metres upstream from this site. Not many people are visiting this site, although the access is quite easy as a path reaches almost right down to it. It is not common for animals to use this path either, even though it cannot be excluded that they do. The vegetation is dense and partly primary.

Figure 16 Site S2 (Photo: Lindgren & Röttorp, 2007).

Site S3: This site is situated close to large fields of rice, maize, cacao and bananas. No chemicals are used on these crops. People use the water here for laundry, washing and bathing. The vegetation is partly primary on both sides of the stream but is more fragmented on the left side (looking downstream).

Figure 17 Site S3 (Photo: Lindgren & Röttorp, 2007).

Site S4: A field with rice and/or cacao is situated about 80-100 metres directly above this site. Animals such as horses and cows have access to the stream and people use the water for washing and bathing. The vegetation is mainly secondary.

Figure 18 Site S4 (Photo: Lindgren & Röttorp, 2007).

Site S5: A larger cropping field is located about 20 metres just above the riparian zone directly above the site. Very few people visit this site but among those few that do visit bathing can occur. There is no evidence of animals even though it is probable that horses and/or donkeys walk along the path stretching along the field. The vegetation is dense at this site and mostly secondary.

Figure 19 Site S5 (Photo: Lindgren & Röttorp, 2007).

Site S6: A slash and burn farming site is situated at a distance of 4-5 metres from the stream. People living nearby use the water for washing (approx. 5 people). A smaller village is located about 100 metres upstream and people there also use the water for washing and bathing. There is evidence of some manure just close to the riverbank which proves that animals may have access to the stream. The vegetation is partly primary.

Figure 20 Site S6. The stream (left) and adjacent slash and burn field (right). (Photo: Lindgren & Röttorp, 2007).

Table 5 Summary for the study site locations along Shima (Analysis in GIS, personal observations).

Site	Sampling elevation [m a.s.l.]	Land use in the surroundings	Riparian vegetation	Water use
S1	330	Banana field (closets distance from the bank is 5 m) Enclosed pasture land (70 m upstream from the site).	Mainly primary.	Extensive use for bathing and washing.
S2	440	Water withdrawal (100 m upstream from the site).	Mainly primary.	Partly bathing.
S3	580	Large field with rice, maize, cacao and bananas just next to the stream. A small habitation is situated just next to the stream bank.	Mainly primary.	Bathing, drinking.
S4	620	Field with rice and/or cacao (80-100 m right above the stream).	Mainly secondary.	Bathing, washing.
S5	670	Large field of bananas (20 m above the riparian zone directly above the site).	Mainly primary.	Partly bathing during certain periods of time.
S6	770	Slash and burn agriculture (4-5 m from the stream).	Mainly primary.	Bathing (only practiced by very few people), washing.

3.2.3 Geology

Within the Cumbaza basin there are seven geological formations; Oriente, Chonta, Vivian, Chambira, subrecent Alluvial deposits, Yaharango and Sarayaquillo while within the Shima basin, there are six different formations; Oriente, Chonta, Yaharango, Subrecent Alluvial deposits, Sarayaquillo and Ipururo (GIS analysis, 2007; IIAP, 1994).

Table 6 gives a description of the characteristics of the different geological formations within the two basins. The most dominating bedrock in both basins is sandstone and limestone.

Table 6 Characteristics of the formations found within the two basins, Cumbaza and Shima (IIAP, 2004; Tarbuck & Lutgens, 2002).

Geological formation	Characteristics
Subrecent Alluvial deposits	Formed during the epoch of *Pleistocene* (about 1.5 million years ago). Contains of soil or sediment deposited by running water. The deposits contain both fine particles as silt or clay as well as larger particles of sand and gravel.
Ipururo	Formed during the epoch of *Miocene* (about 24 million years ago). Consists of lime rich clays and stones. In the middle section volcanic sediments can also be found.
Chambira	Formed during the *Oligocene* (about 34 million years ago). An era of depositions from lakes and rivers in this area. Contains calcium rich clays, often reddish, claystone and limestone.
Yaharango	Formed during the epoch of *Paleocene* (about 65 million years ago). Contains reddish to greyish silts interbedded with sandstone. May also contain lime and gypsum.
Vivian	Formed in the later part of the geological period of *Cretaceous* (about 84 million years ago). Derives from delta sedimentation or from sedimentation in shore areas.
Chonta	Formed in the later part of the geological period of *Cretaceous* (about 89 million years ago). Derives from delta sedimentation. Consists mainly of micritic limestone (limestone surrounded by clay).
Oriente	Formed in the early part of the geological period of *Cretaceous* (about 136 million years ago). Consists of sandstone and layers of limestone.
Sarayaquillo	Formed during the period of *Jurassic* (about 195 million years ago). Consists of eroded material that has formed sandstone through bounding with quartz and/or feldspar. Sometimes it can contain stratum of salt and gypsum. The colour is often reddish.

Cumbaza

Characteristic for the soils in the Cumbaza basin is the calcium rich clays due to the eras with sedimentation that have created e.g. formation Yahuarango. This is one of the dominating formations in the Cumbaza basin. Other dominating formations are formation Oriente, Subrecent Alluvial deposits and the Chambira formation. The formations stretch from the North West to the south east of the basin, see Figure 21. In the north eastern part of the basin the Sarayaquillo formation is found. This is a part of the Cordillera Escalera. This formation borders the formation Oriente which can be found in all parts of the sub-Andean mountain chain. This formation is also the result of sedimentations. South of this formation follows bands of Chonta and Yahuarango formations. Thin bands of formation Vivian are found in the west part of the basin, mixed with the Chonta and Yahuarango formations. In the south the Chambira formation is found and north of it Subrecent alluvial deposits are dominating the area (IIAP, 1994).

The sites C6 and C4 are both located in the formation Oriente, the sites C5 and C3 are located in the Chonta formation. The site C2 is situated in the formation Yahuarango, while C1 is found in an area containing subrecent alluvial deposits.

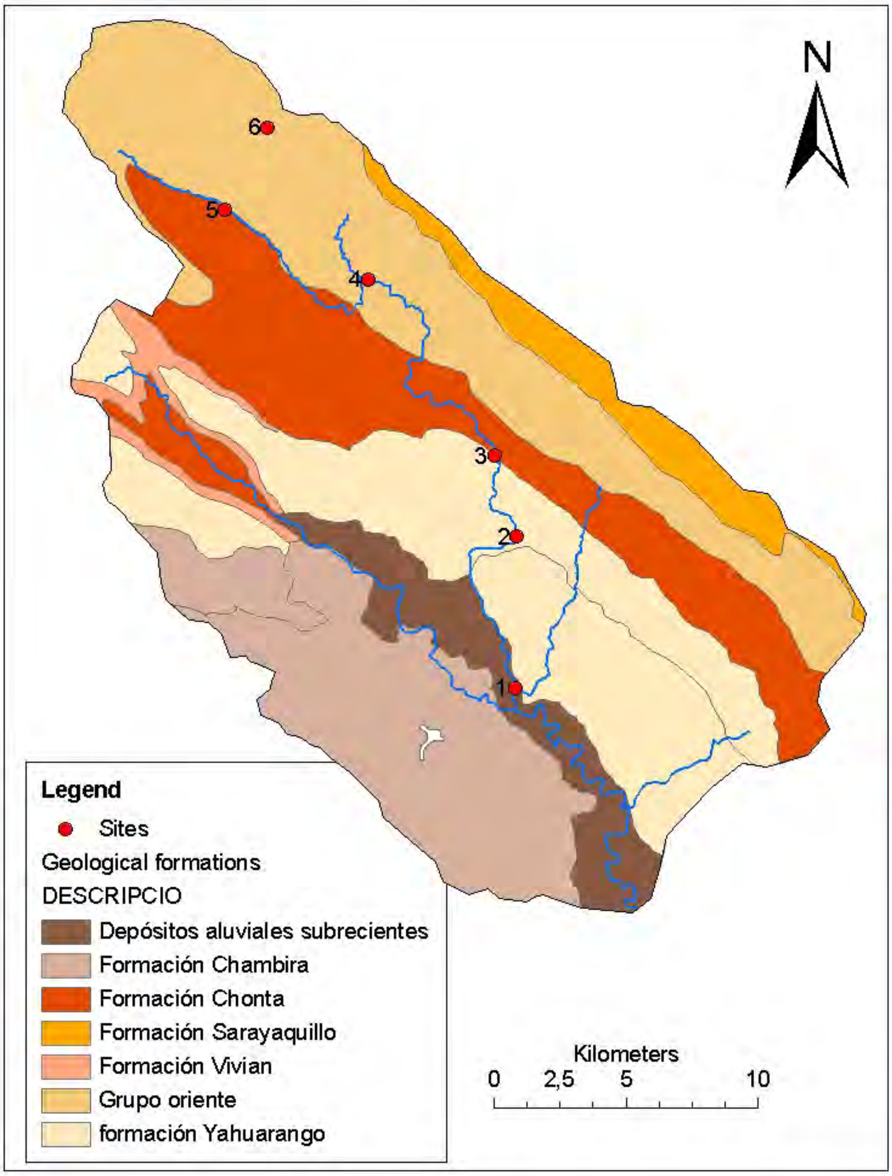


Figure 21 Geological formations and location of the study sites in the Cumbaza basin.

Shima

Within the Shima basin the dominating formations are Yaharango and Oriente which both also are common throughout the entire sub-Andean mountain chain (GIS analysis, 2007; IIAP, 1994). Formation Yaharango is the most dominating of these two and forms a broad band which stretches from the north to the south (Figure 22). Oriente is the dominating one in the north-western part of the basin but can also be found in the southern part. Subrecent Alluvial deposits dominate the region closest to the outflow and borders Ipururo further upstream. Sarayaquillo stretches as a thin band in the southern part of the basin and Chonta runs through the eastern side of the total basin. Our investigated sites are located on three of these formations, S1 on the most recently formed deposit (Subrecent Alluvial deposits), S2 and S6 on the sand- and limerich Oriente and finally S3-S5 on the sandstone rich Yaharango (GIS analysis, 2007).

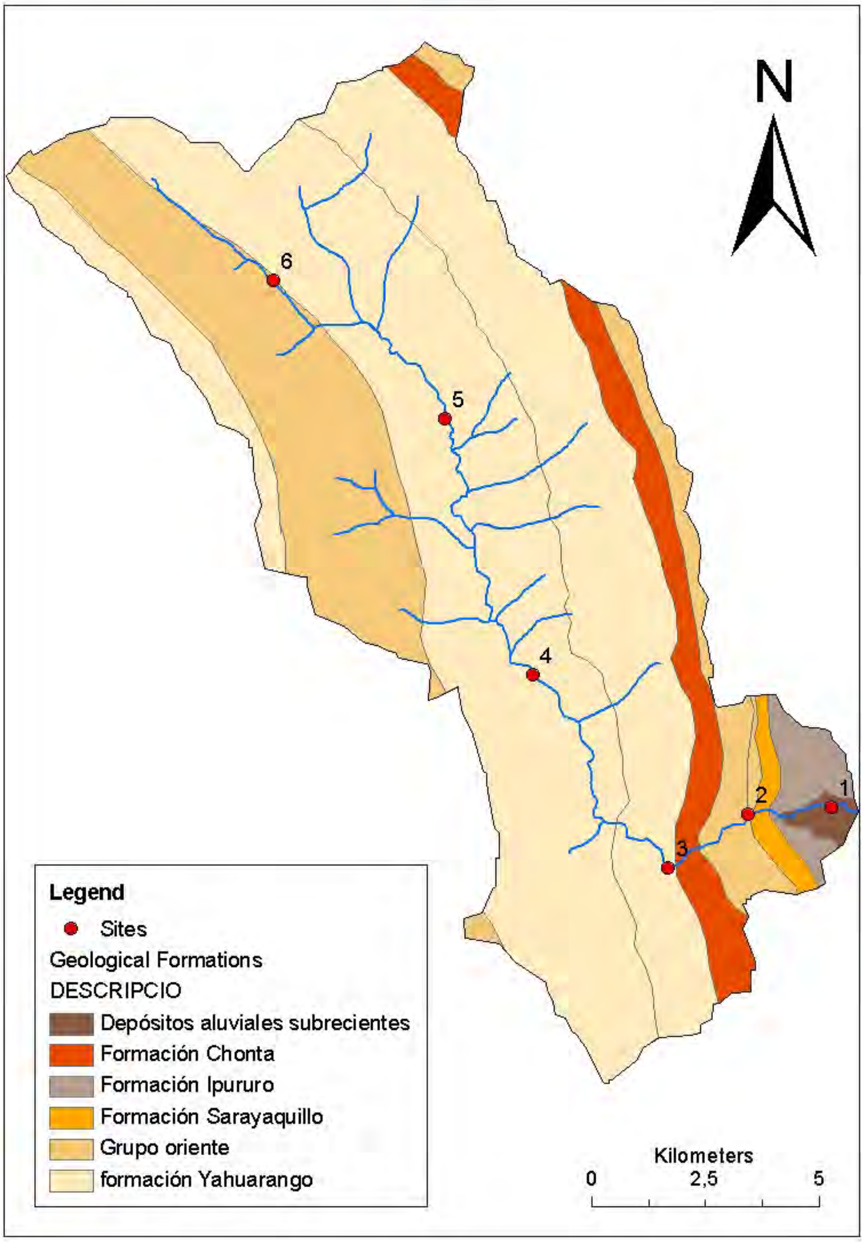


Figure 22 Geological formations and location of the study sites in the Shima basin.

3.3 PHYSICAL ASSESSMENT

The first part of the physical assessment (Section 3.3.1) contains the choice of Stream Reach Assessment for this study, the modifications applied to it to better suit our objectives as well as the method used for estimating the physical parameters of the chosen method. Interviews were conducted in order to assist the assessment. At the end is a description of our choice of interview method and how they were conducted.

The second part (Section 3.3.2) discusses the analysis of the watersheds which was made in GIS (Geographic Information System). It is divided in two parts; the geomorphology where the method to find the physical properties of the two catchments is described and the estimation of percent forest in each sub-basin.

3.3.1 Stream Reach Assessment

Choice of physical assessment

In order to function as a representative method for physical assessment in a developing country, with the aim that the local people should be able to use the method, we set up a number of criteria that had to be fulfilled. These criteria were**:**

i. Easy to use: The method has to be easy for the local land users to learn and to use. The aim is that they should be able to use it to get a comprehensive view of a specific land area.
ii. Financially effective: This is a criterion of utmost importance as the method should be suitable for use in a developing country where financial resources are restricted.
iii. Include parameters that are linked to human activities that are common within the studied area: The aim is to give a picture on how increasing human activity affects the stream and which of the activities that has most adverse effects on the stream ecosystems.

In this project we have compared some of the most common physical assessment methods and consideration has been taken on how well they fulfil the project criterions. The methods reviewed were those already presented in chapter 3: Stream Visual Assessment protocol (SVAP) (SVAP, 1998), Rapid Bioassessment Protocol and Habitat Assessment (US Environmental protection agency, 2006), Save Our Streams (The Izaak Walton League of America) and Stony Brook-Millstone Stream Watch Program (Stony Brook- Millstone Watershed Association). All of these methods fulfilled the criteria fairly well, although all except one are primarily based on biological parameters. As the purpose of *this* project (Section 1.2) was to predominantly use parameters based on physical features, as a complement to the chemical assessment, we excluded methods which to a large degree are based on the study of macroinvertebrates and those which are most useful in situations where there are resources available for biological surveys. Because the SVAP method to the least degree relies on biological surveys we chose this method. It also fulfils the first two criteria described above very well and also the third criterion when some minor modifications were applied to the method.

Modifications to SVAP method
For SVAP to fulfil our given criterions of a physical method and to make SVAP work under the circumstances of this project and to better suit the study area some modifications were made. We excluded the parameters "Insect/invertebrate habitat" and "Observed macro-invertebrates" (Section 2.1.1) as these are based on biological knowledge and do not suit within the frame work of this specific project. Furthermore, we excluded the parameter "Salinity" (Section 2.1.1) because it is already part of the chemical assessment. As a replacement for these three parameters we added three new parameters that we thought would give *this* study more adequate results. The three added parameters are: Structural intactness of the riparian zone, Human waste and Human activity. The parameter Structural intactness is one of the parameters in a habitat assessment used in the Andean Amazon (Waggoner, 2006) and the parameter Human waste is one of the parameters used in habitat assessments in Hawaii (National Resources Conservation Service, 2001). The parameter Human activity we developed ourselves. All three were added to the previously listed parameters presented in Section 2.1.1. The total amount of parameters used for this project then became 15.

Field SVAP procedures
When first arrived at the sampling site we estimated the total size of the stream reach to be investigated. The total area to be investigated was determined by measuring the active channel width, which is the stream width at the bank full discharge[25] (Figure 23). This was done by a tape measure at the spot chosen for fulfilling the criteria for good measuring flow. The length of the investigation area upstream and downstream from the chosen spot was defined as 6 times the active channel width. The distances were measured at right angles with a tape measure where it was feasible. A GPS meter was used in places with inaccessible terrain. The width of the riparian zone functioned as borders to the investigation area on each side of the stream (Figure 24). Thereafter we evaluated all the 15 parameters included in the modified SVAP model. For each parameter the evaluation resulted in a score, between one and ten, which was registered in the SVAP protocol (Appendix 1). The sums of all scores at each site were then divided by the total number of measured parameters at the site. This gave an index between one and ten for each site and a measure on the quality of the physical habitat as well as on water quality; < 6 = "poor", 6.1-7.4 = "fair", 7.5-8.9 = "good" and > 9= "excellent".

[25] By the bank full discharge one usually means the flow rate that forms and controls the shape and the size of the active channel.

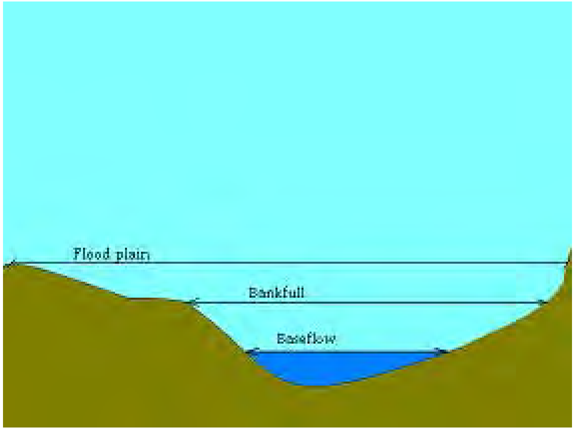


Figure 23 Base flow, bank full and floodplain locations.

Figure 24 Assessment area with distances.

SVAP parameters
Below follows a description of the SVAP parameters within this project (starting with the three added parameters) and also a description over *how* the parameters were estimated in the field. See Appendix 2 for information on the criteria on which the scores are based.

· **Intactness of the riparian zone**
As mentioned earlier (Section 2.1.2) the riparian zone has many functions. For example it helps to bind the soil and regulates the flow of many elements. We also mentioned (Section 2.1.2) that the optimal design is a riparian zone that is densely vegetated and not overly trampled. Considering these factors a riparian zone with gaps in the vegetation might function less optimally as compared to an intact buffer and the grade of intactness might influence element transport through the riparian zone.
This parameter was graded through estimation of the percentage of the riparian zone that was lacking vegetation. A percentage distribution was used to assist the estimation (Appendix 3). We scored each side individually and then used the lower of the two SVAP-scores for the protocol.

· **Human waste**
Different kinds of waste material from people living adjacent or visiting the streams and waste that drains from houses may run straight into the streams and contaminate the water. This parameter was graded after the evidence of all kind of waste material found within the site.

· **Human activities**
Many people use the investigated streams on daily basis. Activities as washing-up, doing laundry and bathing are common and it is likely that these activities have negative effects on the overall water quality. We graded this parameter after how common activities as washing-up, doing laundry and bathing were within the site. This information was obtained through interviews (see below).

· **Channel condition**
This parameter is based on signs of channelization or straightening of the stream done by humans. This parameter has a direct relation to an increase in deforestation that leads

to an increase in flood flows. The parameter was scored through estimation of the degree to which stream banks and stream bottoms have undergone alterations from the natural condition.

· Frequency of flooding

Flooding is important to maintain channel shape and function as well as to maintain the physical habitat and plants. If a river has no access to its flood plain, due to no regular flood flow, it will decrease the suitability of the rivers to transport sediment. This can result in wider and shallower rivers due to an increase in deposition of sediment. Conversely, an increase in flood flows leads to an increase in the transport of sediment and can result in erosion of the bank and the channel. The parameter was graded after how often the flood plain experiences flooding. This information was obtained through interviews (see below).

· Riparian zone

A healthy riparian zone is one of the most important elements in a healthy ecosystem. The vegetation in the riparian zone contributes to the nutrient flow between the bank and the stream. A number of characteristics, directly negative on the streams, will follow as a result of an insufficient amount of riparian zone. These are:
- The infiltration of the water in the ground will decrease causing surface runoff to increase. The surface water is of comparatively bad quality.
- The amount of shade over the stream will decrease and results in warmer water that does not have the same ability to dissolve oxygen as cooler water**.**
- The risk of erosion will increase due to a smaller amount of roots that can stabilise the bank.

This parameter was graded by measuring the width of the riparian zone on three chosen transects on each side of the river. All transects were chosen so that they together, as good as possible, represented the complete riparian zone (Figure 25). Where the riparian zone was composed of rugged terrain the distance was measured with a GPS, otherwise simply by a tape measure. A mean value was calculated for each side and this value represented a certain score according to the SVAP scoring sheet. The value that corresponded to the lowest SVAP-score was entered into the protocol.

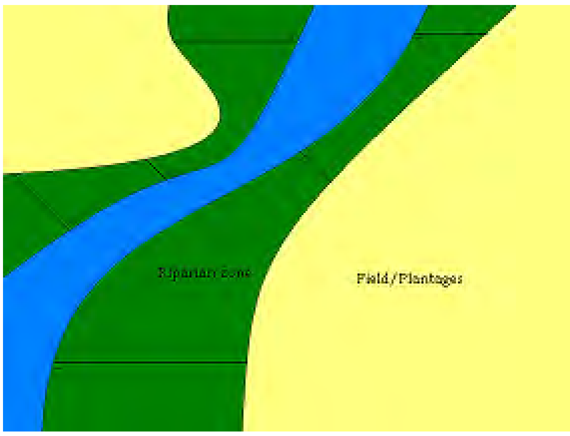


Figure 25 Three perpendicular transects on each side of the stream.

· **Bank stability**
Human activities such as forest devastation, farming and constructing paths for transports and animals etc can result in unstable banks. These banks have a great sensitivity for erosion. Roots that normally stabilise the bank disappear since these activities reduce the soil thickness. This thin soil consists to a larger degree of sand and gravel and has a higher tendency of collapsing than thicker soil. This parameter was graded after how many different types of signs for erosion we could find within the site.

· **Barriers to fish movement**
A good environment for fish is a strong criterion for good water quality. Barriers formed by humans such as tunnels, dams and other constructions for withdrawals of water from the river can block the movement of fish or other aquatic organisms in the river. This may cause isolation of populations. This parameter was graded after the variety and abundance of barriers available within the site.

· **Instream fish cover**
The potential for the maintenance of a healthy fish habitat is dependent on the variety and abundance of habitat and cover available in the stream. The habitats are also an indicator of the ability for the fish to recover from any kind of disturbance. As was stated for "Barriers to fish movement" a good environment for fish is a strong criterion for good water quality. This parameter was graded after the variety and abundance of habitat and cover available within the site.

· **Pools**
Stream reaches with pools with deep and stationary water are important resting and feeding places for fish. Characteristic for a healthy stream is the mix of shallow and deep pools. We graded this parameter after the variety and abundance of pools. To assist this investigation we used a measuring-rod.

· **Canopy cover**
Shading of a stream keeps the water cool. Cool water has a greater oxygen holding capacity than warm water which limits algal growth. The increase of devastation of riparian zones may result in a smaller amount of shading and consequently increased water temperatures in the stream.
This parameter was graded through estimation of the percentage of the stream covered by the vegetation. A percentage distribution was used to assist the estimation (Appendix 3).

· **Riffle embeddedness**
Riffles are areas where the water is breaking over rocks or other debris. The degree to which gravel and cobble substrate are surrounded by fine sediment relates directly to the suitability of the stream as a habitat for fish spawning. Figure 26 shows an example where stones are partly embedded in sediment in the Shima River. We graded this parameter through estimation of the percentage of the gravel and cobbles covered with sediment. A percentage distribution was used to assist the estimation (Appendix 3).

Figure 26 Stones partly embedded in bottom sediment (Photo: Lindgren & Röttorp, 2007).

· Water appearance

This parameter is all about the amount of suspended material in the water. Suspended material in the water causes turbidity which is an indicator of water clarity or the ability of dissolved material to spread and absorb light. Turbulent water allows smaller amount of light to penetrate into the water. This can reduce the photosynthesis among photosynthetic organisms in the water and in turn reduce the amount of oxygen produced by these aquatic organisms. The result could be a lack of oxygen in the water. This parameter was graded visually by investigating how clear the water appeared to be. Pictures from a reference site were used as a comparison. Figure 27 shows examples of waters (from the Shima River) with different appearance.

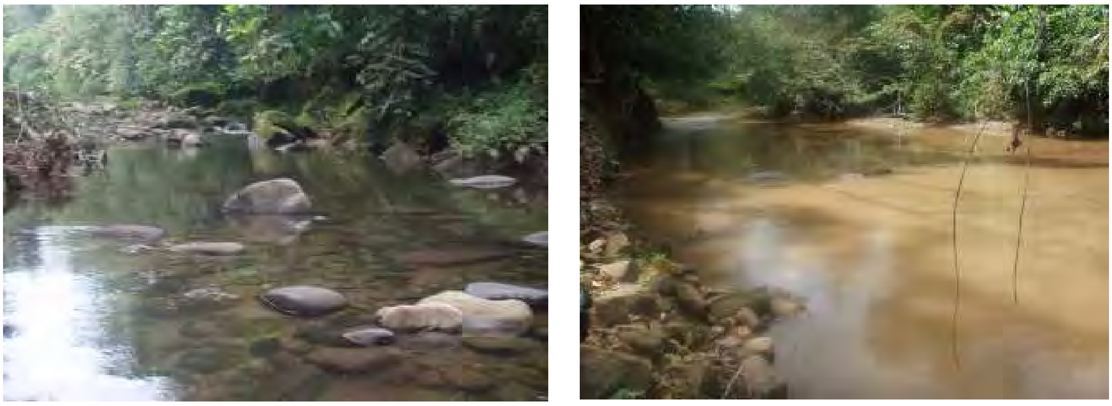


Figure 27 Water with a clear appearance (left) and water with a great amount of suspended material (right) (Photo: Lindgren & Röttorp, 2007).

· Nutrient enrichment

The amount and type of aquatic vegetation in the stream can work as an indicator of the amount of oxygen in the water. Decomposition of aquatic vegetation results in an increased consumption of oxygen among decomposers. This results in a decreased amount of oxygen in the water which creates stress among the organisms living in it. Agricultural activities can result in increased amounts of organic material in the streams and thereby have an enrichment effect. This parameter was graded by visually estimating the colour of the water and the amount of algae on stones and other material covered by the water. Pictures from all of the sites along one river were compared to give a relative score. The left picture in Figure 28 is from the site most upstream, C6, in Cumbaza and shows stones that lack algal growth whereas the right picture is from the site downstream Tarapoto, C1, in Cumbaza and shows massive algal growth.

Figure 28 Stones with a lack of algal growth (left) and stones with a great amount of algal growth (right) (Photo: Lindgren & Röttorp, 2007).

· Manure presence

Manure from livestock, which are given access to the streams or are grazing on adjacent land, may through runoff enter the water and contaminate it. The manure will increase the eutrophication and thus increase the demand of oxygen among aquatic organisms. This parameter was graded after the evidence of livestock having access to the riparian zone and of manure within the site.

Interviews

Since our intention was to get out as much information as possible about activities going on within the assessment area we chose an informal (semi-structured) interview method in order to score the parameters, "Frequency of flooding", "Pools", "Manure presence", "Human waste" and "Human activity". Such an unstructured method gave us the opportunity to let people speak about their own experiences more freely and about things they knew something about (Section 2.1.3). People living within the study area or people using it on a daily basis are very familiar with the investigated streams and their surroundings. Our choice of respondents was therefore people working with us in the field as these people lived in the area or were familiar with the area through regular visits. Where it was possible we also visited people living close to the investigated areas for complementing information or in order to get more adequate information. We had some questions prepared although we did not have questionnaires to be filled for the respondents. Furthermore, as a group interview has many benefits when it comes to cross-checking for example numbers (Section 2.1.3), we often gathered a group of people for the interviews. We prioritized discussions around dinner tables and cooperation in other different social activities to increase our understanding of the local people's way of living in order to get a more complete picture of how *they* perceive *their* environment.

The questions asked were:

- How common is flooding at this site?
- Are there any irrigation ponds within a distance of three to five kilometres from this site?
- How common is it that people come down to this site? Which activities are most common among the people that visit the location?
- How common is it with cattle coming down to this site?

3.3.2 Drainage Area Assessment

This analysis was made using DEM-file (resolution: 90 m) and SPOT satellite images (resolution: 10 m) in ArcGIS. The geographic coordinate system used for these files was GCS WGS 84 (and the project coordinate system was WGS 1984 UTM Zone 18S). From the DEM-file the catchment of Cumbaza was modeled. This is usually done by cutting out a part of the DEM-file to use in the modeling, but these operations were not supported by the program due to the size of the DEM-file. Instead the polygon of the area was converted to a raster and the tools *Reclassify* and *Times* were used to cut out a smaller part of the DEM-file. The Cumbaza basin was delineated using the flow accumulation tool. The tools *Reclassify* and *Times* were also used. The final basin was drawn by hand. The Shima basin already existed as a shape file (Lina Lindell, 2007) and we only had to cut it out from the DEM-file.

The coordinates (Appendix 4) for the sampling sites in both watersheds were obtained from the GPS used in the fieldwork. These coordinates were used to locate the sites in ArcGIS, the program used for these analyses. From the site coordinates together with the DEM-file the extent of each sub-basin was calculated. This was done through calculating the pour point with the tool *Snap pour point* in arcMap. The pour point for each sub-basin was used together with the flow accumulation file in the tool *Watershed* to calculate the sub-basin as a raster. The raster was converted to a polygon representing the actual sub-basin. The twelve sub-basins were then used for further analysis.

Geomorphology
The following geomorphological characteristics were determined with GIS for each sub-basin; site elevation (also obtained from GPS meter in field), mean elevation, mean slope and area. We chose to determine the mean elevation and slope in arcScene using TIN-files. The fill-files of the sub-basins were converted to TIN-files in arcScene. The statistics of the TIN-file showed the mean elevation and mean slope of the sub-basin. It also showed the minimum elevation which is the site elevation. The area was calculated in arcMap using the tool *Area* and the DEM-file for the actual sub-basin as input.

Forest Cover
A digital land use classification carried out by unsupervised classification in ArcMap – Image Analysis 9.2 (Lina Lindell, 2007) was obtained. The aim was to combine the classes containing forest and the classes that did not. This was done by comparing the classification files with the original satellite images. From the values from the attribute table the percent forest covering each sub-basin was calculated in Excel. The results from this analysis were not sufficiently good and therefore another method was carried out as well. In this method the original satellite images were used to identify areas without forest. These areas were identified visually and drawn by hand as polygons in a shape file. The shape file was clipped for each sub-basin and each area was calculated. The percent of land not covered by forest gave the percent of forest calculated in Excel when comparing the sub basin area calculated earlier for each sub-basin. The DEM-file for the Cumbaza basin did not exactly mach the satellite image, thus the sub-basins in Cumbaza did not exactly match the image and were therefore moved to overlap better with the satellite image. The last method resulted in a much better estimation of the forest cover (percentage of forest upstream a site).

3.4 CHEMICAL ASSESSMENT

3.4.1 Water sampling

Due to logistics the fieldwork was done in the order that is shown in Table 7. The time period between the two sampling events is also presented in Table 7. The chemical variables that were sampled in Cumbaza and Shima are shown in Table 8 (Section 3.4.3). In the Shima River more variables were analyzed than in Cumbaza and thus a larger number of samples were taken.

Table 7 Summary of sampling, flow measurement and SVAP analysis at each site during the field study.

Site	Dates set 1	Measurements	Dates set 2	Measurements	Days between the sets
C1	2007-08-14	Flow and samples	2007-09-20	SVAP, flow and sample	37
C2	2007-08-13	Flow and samples	2007-09-19	SVAP, flow and sample	37
C3	2007-08-13	Flow and samples	2007-09-19	SVAP, flow and sample	37
C4	2007-08-10	Flow and samples	2007-09-12	SVAP, flow and sample	33
C5	2007-08-08	Flow and samples	2007-09-14	SVAP, flow and sample	37
C6	2007-08-09	Flow and samples	2007-09-11	SVAP, flow and sample	33
S1	2007-08-22	SVAP, flow and samples	2007-10-01	Flow and samples	40
S2	2007-08-23	SVAP, flow and samples	2007-10-01	Flow and samples	39
S3	2007-09-02	SVAP, flow and samples	2007-09-30	Flow and samples	28
S4	2007-08-30	SVAP, flow and samples	2007-09-29	Flow and samples	30
S5	2007-08-28	SVAP, flow and samples	2007-09-28	Flow and samples	31
S6	2007-08-27	SVAP, flow and samples	2007-09-27	Flow and samples	31

Measurements and collection of water samples were all done at transect 2 (the same as the flow measurements). At each site we measured temperature, pH, EC and oxygen content *in situ*. The EC meter was calibrated before each set of measurements. The pH-meter was calibrated in the field each morning and the oxygen meter was calibrated before each measurement to the air pressure. These measurements were done in the middle of the river, where also water samples were collected. We were careful to collect the samples upstream ourselves and not to collect water close to the surface water. Water samples were collected for analysis of HCO_3, Cl, SO_4, K, Ca, Mg, Na, TSS, pH, EC, CO_3, PO_4 and NH_4 in both basins. In Shima we also collected water samples for analysis of metals (dissolved and particular), DOC and NO_4^- (see also Table 8). The

DOC samples were filtered and preserved with H_2SO_4. The dissolved metal sample was filtered and both metal samples were preserved with HNO_3.

Water was filtered in order to analyse for chlorophyll A. The filtration needed several hours why it was usually done by one of our assistants, helping us in the field. Once at each site a water sample for bacterial analysis was collected and transported within 24 hours to EMAPA in Tarapoto, as the analysis needs to be performed within that period of time. It was also very important to keep the samples cool until analysis. Cooler containing ice was used for this, where also the chlorophyll A samples were kept until returning from the field.

3.4.2 Discharge

The hydrological investigation was done twice at each site and consisted of two parts; flow measurements with a floater and with a current meter. There were some occasions when it was not possible to do the measurements with the floater. This depended on rainfall or channel conditions (e.g. many rocks).

One main transect was selected (called transect 2). When selecting this transect we also considered where it was useful to do the SVAP analysis (Section 3.3.1). We also selected one transect upstream (transect 1) and one transect downstream (transect 3) the main transect. In order to obtain as good measurements as possible the selected transects had to be a part of a straight river channel with as few big stones on the bottom as possible (under water or visible stones). The first was usually possible to fulfill but the latter more difficult. Often the exact site was chosen as the part of the stream in the area with least stones. We also considered the channel width (especially as this is crucial for the site length in the SVAP) and the depth. At a too deep and/or wide site hydrological measurements would be difficult to perform and too time demanding. We tried to use the same spots for the transects at the second sampling event, if possible.

Between transects 1 and 3 the measurements with a floater were done. The widths of the transects were measured. We also measured the depth at five points at each transect. The points were selected depending on the bottom conditions and if they could be considered representative for the transect e.g. if most of the transect was very shallow we would measure more depths in the shallow part than the in deep water. From these data the cross section area was calculated at each transect and a mean value of the three cross sections was used when the discharge was calculated. The measurement with a floater was made four times at each site. As a floater we used a water sample bottle filled with 250 ml water. It was dropped upstream transect 1 and the time of floating to the transect 3 was measured. The floater did not float in a straight line in most cases and showed a different speed and path each time why we tried to alternate the point of dropping the floater.

The current meter was used at transect 2 where the amount of turns of the hydrometric propeller was measured at each of the five points. We usually measured at half the total depth of each point and at least 60 seconds at each measurement. This was then used to calculate the flow.

3.4.3 Analysis

Water samples that were to be analysed for concentrations of TSS, HCO_3, Cl, SO_4, K, Ca, Mg and Na were sent to the laboratory La Molina in Lima, Peru, after the first set of collection at both streams were completed. Samples that were to be analysed for PO_4, NH_4^+, NO_3^- and NO_2^- were sent to the laboratory Envirolab in Lima, Peru, after each set was completed (i.e. four times). Samples that were to be analysed for metals (Al and Fe) were sent to the laboratory Actlab in Canada after each set was completed (i.e. four times) and finally, samples that were to be anlysed for DOC were sent to Åbo Akademi in Turku, Finland. A summary of the variables measured in each river and which laboratories that have performed the analysis can be seen in Table 8. A short description of each method is found below.

As a complement to the laboratory analysis of DO, PO_4 and the nitrogen compounds at the sites along Shima, concentrations of these were also analyzed *in situ* in the field using portable analysis kits from HACH. The idea was to investigate whether such portable kits could be recommended in similar field studies under similar circumstances.

pH, EC and DO
pH, electric conductivity and dissolved oxygen were measured *in situ*. The meters used were Milwaukee pH97 WP (glass electrode) for pH, Milwaukee CD 601 to measure EC and a Milwaukee SM600 Oxygen Meter with immersion probe for the DO.

Chlorophyll A
The chlorophyll A samples were kept in a freezer until they were sent to Uppsala, Sweden, after the two sampling sets were finished in both streams. The analysis was done by S. Lindgren and A. Röttorp in Uppsala, Sweden, supervised by Jan Johansson at the Department of Ecology and Evolution, Uppsala University. The analyses were done by dissolving the sample in ethanol and measuring the absorption at 665 nm and 750 nm wavelength.

Cations
For the detection of calcium, potassium, sodium and magnesium the analyses were done using Atomic Absorption Spectrophotometry.

Anions
Sulphate was mixed with barium chloride and the precipitation created was measured. Chloride was mixed with silver nitrate which leads to a precipitation (potassium chromate was used as an indicator). A basic solution with ammonium and phenol produced a colour which could be measured. (Eluer, 1982)

Bicarbonate was analysed by titration with strong acid.

TSS
TSS was determined gravimetrically; the sample was filtered through a pre-weighed filter and the weight after drying was measured.

Nitrate
To analyse the concentration of nitrate, a method was used which lets the nitrite ion create a complex with brucine sulfate. The reaction took place in 13 N H_2SO_4, at a

temperature of 100 C and the change of the colour of the solution which was measured at 410 nm (Envirolab, 1971).

Nitrite
Sulfanilamide reacted with nitrite in water (acid conditions) and formed a diazonium compound. The diazonium compound was coupled with N-(1-naphthyl) ethylenediamine dihydrochloride and a reddish-purple colour was produced. The colour was analysed in a spectrophotometer at 540 nm (Envirolab, 1971).

Ammonium
Ammonium reacted with hypochlorite and phenol, using sodium nitroprussiade as a catalyst. The intensive blue coloured compound indophenole was produced, which could be analysed with a spectrophotometer at 640 nm (Envirolab, 1998).

Phosphate
Phosphate was converted to orthophosphate by sulfuric acid hydrolysis. A dilute solution of phosphorus reacted with ammonium molybdate and antimony potassium tartrate in presence of acidic medium. An antimony-phospho-molybdate complex was formed which was reduced by ascorbic acid. The intensely blue colour of the complex was proportional to the phosphorus concentration and may be measured at 660 or 880 nm (Envirolab, 1978).

Iron and Aluminium
Iron and aluminium were both analysed using mass spectrometry. Blanks and samples were spiked with internal standards (to correct for matrix differences). They were vapourised and ionized within inductively coupled plasma which was used as ion source in the mass spectrometry (Actlabs, 2006).

Bacteria
The bacteria samples were analysed within 24 hours at EMAPA in Tarapoto. The samples were incubated on agar plates in 35° for 24 hours. The colonies of Total Coliforms (metallic gold greenish colour) were calculated and moved to a membrane filter. It was incubated in 35° C for 24-48 hours (in the presence of laurel tryptose). To verify the number of Total Coliforms another incubation was done in 35°C for 24-48 hours (with a lactose medium). To obtain the number of E. coli the final incubation is replaced by in incubation in 44.5° C for 24 hours (in an EC medium with MUG). Detecting the fluorescence (ultraviolet light at a wavelength of 366 nm) gave the number of E. coli.

Table 8 Laboratories, number of samples that were sent and what these were analysed for.

Laboratory	Cumbaza (number of samples)	Shima (number of samples)	Analysis
LaMolina, Lima, Peru	12	15	HCO_3, Cl, SO_4, K, Ca, Mg, Na, TSS, (pH and EC)
Envirolab, Lima, Peru	12	15	PO_4
	12	15	NH_4^+, NO_3^- For Shima also analysis for NO_2^-
Actlabs, Ancaster, Canada		15	Metals* (part.)
		15	Metals* (dissolved)
Åbo Akademi, Turku, Finland		15	DOC
Department of ecology and evolution, Uppsala, Sweden	11	12	Chlorophyll A
Emapa, Tarapoto, Peru	6	5	E. coli, Total Coliforms

* Al and Fe

** One set includes all the six samples taken at the chosen six sites along one stream.

3.5 STATISTICAL ANALYSIS

To identify possible associations between physical conditions and the stream water chemistry we studied Spearman's correlation matrix (significance level 0.05) and scatter plots (analysis done in XLStat by Lindell, 2008). The physical conditions evaluated were state of the stream reach (SVAP), percent forest cover and topography of the upstream sub-basins. The predictor variables were the SVAP- index, individual SVAP parameters, percentage forest cover in upstream sub-watersheds, sample elevation, mean elevations for the sub-watersheds as well as slope and area for the sub-watersheds. The response variables were chemical parameters such as nutrients, metals, chlorophyll A, E. coli, Total Coliforms, electrical conductivity, pH, dissolved oxygen and dissolved organic carbon. We have also studied relations between the SVAP-index and some individual SVAP parameters namely the width and the intactness of the vegetation as well as percent forest cover at the watershed scale. These analyses resulted in information on how vegetation cover at both scales (stream reach and upstream drainage area) affects the water quality in the streams.

4 RESULTS

4.1 PHYSICAL ASSESSMENT

In this report the physical assessment of the stream reach represents the smallest spatial scale of the investigated watersheds. In Section 4.1.1 we describe the overall physical habitat (SVAP-index) for each stream followed by the score for every evaluated SVAP-parameter. The evaluated SVAP-index and the scores for each parameter at each site are presented in Table 10.

In Section 4.1.2 we present the results from the forest cover analysis made with GIS. The aim with this analysis was to be able to study how the percentage of forest changes along the two rivers and to describe how a few physical parameters differ between the sub-basins. The results are presented in Table 11.

4.1.1 Stream Reach Assessment

Cumbaza

The SVAP-index decreased along the Cumbaza River going from C6 to C1. The SVAP-index indicated a poor habitat quality at the lower sites (C1- C3) and good quality at C4 and C6. At site C5 the quality was fair (Table 10 and Figure 29).

The SVAP-index correlated with several individual physical parameters (Table 9) e.g Riparian zone (k=0.8) and Structural intactness (k=0.9). The results indicated that these two individual parameters were decreasing along the river. Human waste and Human activity, for example, also showed correlations with the SVAP index which indicated an increase in Human waste further downstream.

The Channel condition at all sites along Cumbaza was classified as “natural” and no evidence on any kind of sedimentation of the channel was found. According to the SVAP template all sites therefore were given the highest score (10) for this parameter. The Bank stability was good along the whole river and the scores varied between 7 and 8. There was no evidence that the Bank stability was better upstream than downstream. No flooding occurred along the river (only seasonal variation in water level) why every site was scored 1.

Along Cumbaza the result showed that the Riparian zone was generally wider at the sites located in the upstream parts. C4-C6 have all been scored 10 (Natural vegetation extends at least two active channel widths on each side) for the Riparian zone parameter. The other sites ranged from 2 (natural vegetation extends less than a third of the active channel width on each side) to 7 (natural vegetation extends one active channel width on each side). The Riparian zone at C4-C6 was intact but it was clearly more fragmentised further downstream, with the lowest score at C1. When it came to the Canopy cover all sites except C6 along Cumbaza were scored 1 (less than 25 % shadowed). C6 was scored ten (> 75 % of the water surface shaded by vegetation). These results indicated a more compact riparian zone (increasing the shading) at C6 than at the other sites.

Investigating the Barriers to fish movement at the sites gave all sites along Cumbaza except site C2 the score 10. Site C2 was scored 1 due to diversions for rice cultivations 1.5 km upstream from the site. Furthermore the diversion had a drop height of > 0.3 m. The Instream fish cover ranged from 9 (seven cover types) at C5 to 1 (none cover type) at C1 and the result showed generally a decrease in Instream fish cover going downstream. The pools also decreased going downstream and the scores vary from 3 (pools present but shallow) at the three sites most upstream to 1 (pools absent) at C1.

Along Cumbaza there was an increase in the Riffle embeddedness (inbedded gravel and cobbles) going downstream from C6. The scores ranged from 10 (Gravel or cobble particles are < 20% embedded in bottom sediment) to 3 (Gravel or cobble particles are > 40 % embedded in bottom sediment) for the parameter Riffle embeddedness. The result showed deterioration in the Water appearance going from C6 to C1 along the Cumbaza River. The score ranges from 10 (very clear, and no oil seen on surface or oil film or submerged objects or rocks) to 1 (strong odour of chemicals, oil, sewage and other pollutants). The results also showed a deterioration when it comes to Nutrient enrichment further downstream the Cumbaza River. These results indicated less clear water along the entire reach together with higher quantities of many species of macrophytes further downstream and increasing algal growth on stones and debris downstream.

Along Cumbaza the Manure presence was quite low across all sites. The scores ranged from 10 (no evidence at all) to 7 (evidence that livestock have access to the riparian zone). The Human wastes varied from “no evidence on human waste within the reach” (score 10) to “considerable amount of waste material within the reach” (score 3) along Cumbaza. The lowest scores were found downstream except for C5 (score 4). The Human activity within the riparian reach for the three sites most upstream ranged from 9 (only partly activity under certain periods) to 10 (no activity). The activity at the three sites most downstream along Cumbaza was on the other hand extensive (scores 1 or 2).

Shima

The physical habitat at the finest scale (stream reach scale) for each site along Shima was scored between approximately 5 and 8 (Table 10), i.e. there were sites with impaired habitat conditions but also sites with minimally impaired physical structures. The result showed that the physical habitat, based on the SVAP-index, was related to the individual physical parameters Human activity (k= 0.9), Water appearance (k= 0.9), Riffle embeddedness (k= 0.9), Nutrient enrichment (k= 0.8), Structural intactness (k= 0.7), Channel condition (k= -0.7) and Bank stability (k= 0.6) (Table 9). This indicates that increased human activities as bathing and washing within the reach, a more muddy water appearance, increased percentage of embedded gravel and stones in sediment, higher amounts of algal growth on stones, decreased intactness of the riparian vegetation, less artificial channelization or straightening of the stream and decreased stream bank stability resulted in an impaired physical habitat. Furthermore the SVAP-index decreased downstream the river (R^2 =0.56) which indicates that the physical structures were deteriorated downstream (Figure 30).

The result also indicates that the water quality, if being based on the classification scale in the SVAP-method, was “poor” at some sites (S1, S3) while “fair” or “good” at other sites (S2, S4-S6). None of the sites was classified as having excellent water quality (SVAP-index > 9) (Table 10).

Below is given a description of the physical habitat based on the individual SVAP-parameters (see Table 10 for all scores).

The Channel condition was given a very high score (9 or 10) at each site due to near "natural" conditions, i.e. no evidence of channelization or straightening of the stream was found. Due to lack of information about flooding at S1-S3 the parameter Frequency of flooding could not be scored for those sites. Site S4 experienced flooding every six to ten years and was scored 3 (most recent flooding occurred in 2006). S5 and S6 had flooding every 1.5 to 2 years and were therefore scored 10.

The scores for the Riparian zone ranged from 1 (natural vegetation covered less than a third of the active channel width on each side) to 10 (natural vegetation covered at least two active channel widths on each side). Furthermore the results indicated overall dense riparian vegetation at all sites. The parameter Structural intactness of the riparian zone ranged from 8 (approx. 20 % fragmented vegetation) to 10 (< 20 % fragmented vegetation). Some sites had moderately stable but typically high stream banks, while others had more stable and low banks, thus the parameter Stream bank stability was scored from 3 to 10.

All sites except the two located most downstream (S1 and S2) were scored with the highest score for Barriers to fish movement (10), indicating that no barriers such as dams, dikes and diversions were found. S1 and S2 were scored 7 indicating seasonal water withdrawals at those sites, which inhibit fish movement within the reach. All the sites along Shima had five or more than five different cover types for fish and the parameter Instream fish cover was therefore scored between 6 (five cover types) and 10 (>seven cover types). Most common cover types were riffles, overhanging vegetation, undercut banks and boulders.

Pools were absent at sites S1, S5 and S6 and the parameter Pools was therefore scored 1 for these sites. At S2 and S3 deep and shallow pools were abundant and Pools was scored 8 and 10, respectively. The degree to which the stream surface was shaded by vegetation at the sites varied from less than 25 % at sites S1 and S6 to between 50 and 75 % at S4. The parameter Canopy cover was therefore scored between 1 and 7.

The parameter Riffle embeddedness ranged from 3 to 10, i.e. the percentage to which gravel and cobble were embedded in sediment varied from 40 % embedded gravel and cobble to < 20 % embedded material. Scores for Water appearance ranged from 2 to 9. This indicates that the water appearance varied from being considerably cloudy most of the time and having submerged objects or rocks covered with heavy green or olive-green film to being very clear or clear but tea coloured. No major problem regarding nutrient enrichment was found. Only one site, S3, had an excess of macrophytes which coloured the water brown and the parameter Nutrient enrichment was therefore scored 2 for this site. The other sites had fairly clear to clear water along the entire reach, with low quantities of many species of macrophytes as well as little algal growth on stones and debris present. The score for these therefore ranged from 7 to 10. Manure was found occasionally in the stream or on the bank at S1, where the parameter Manure presence was scored 3, but for the other sites there was little or no evidence at all of animals having access to the reach. Evidence of human waste within the reach at the sites varied from occasional evidence to no evidence at all within the reach. Human waste was therefore scored between 7 and 10. The scores for Human activities varied quite much across the sites. Two sites, S1 and S4, had extensive human activities and were scored 1, whereas other sites had almost no activity. The most common activities at the sites were washing and bathing.

Table 9 Spearman's significant correlation coefficients for the physical environment and individual physical parameters in Cumbaza and Shima.

Physical variable	SVAP- index	
	Cumbaza	Shima
Channel condition		-0.7
Riparian zone	0.8	
Structural intactness	0.9	0.7
Bank stability		0.6
Barriers to fish movement		
Intstream fish cover	0.7	
Pools	0.9	
Canopy cover	0.7	
Riffle embeddedness	0.9	0.9
Water appearance	1.0	0.9
Nutrient enrichment	1.0	0.8
Manure presence		
Human waste	0.8	
Human activity	1.0	0.9

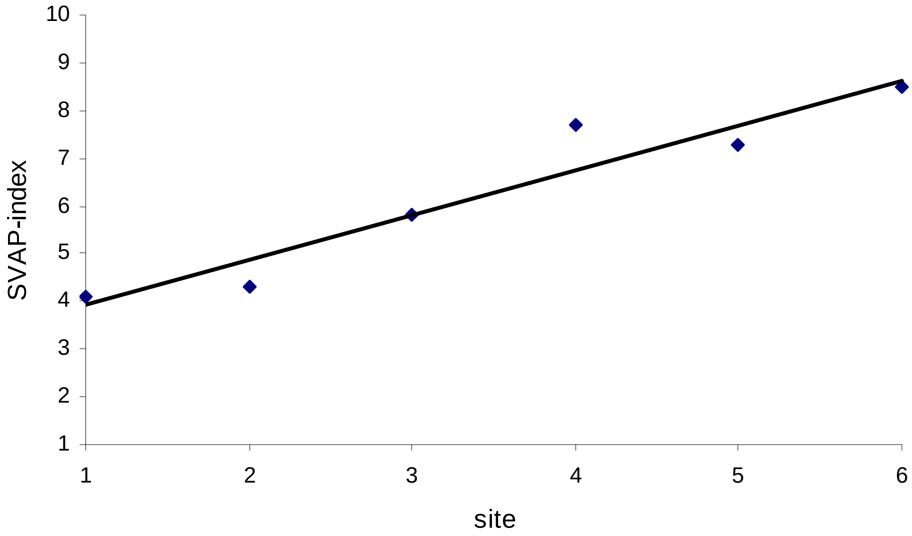


Figure 29 Average SVAP score for the sites along the Cumbaza River (R^2=0.92).

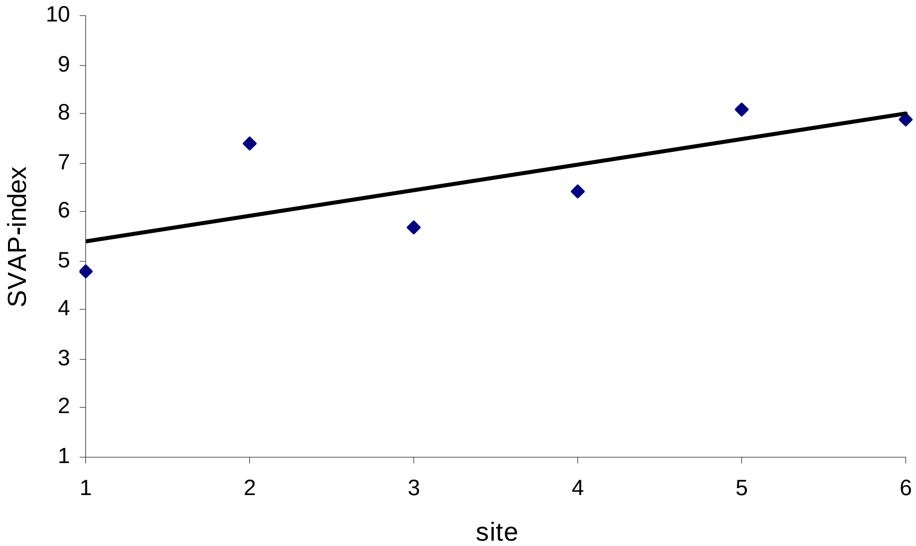


Figure 30 Average SVAP score for the sites along the Shima River (R^2=0.56).

Table 10 The score for each parameter at the sampling sites along Cumbaza (C) and Shima (S) together with SVAP-index (< 6 = “poor”, 6.1-7.4 = “fair”, 7.5-8.9 = “good” and > 9= “excellent”) and the corresponding classification of water quality according to the SVAP-template (n.d. = no data).

Site	Channel condition	Frequency of flooding	Riparian zone	Structural intactness of the rip. zone	Bank stability	Barriers to fish move-ment	Instream fish cover	Pools	Canopy cover	Riffle embeddedness	Water appearance	Nutrient enrichment	Manure presence	Human waste	Human activity	Total score	SVAP-index	Water quality
C1	10	1	7	3	8	10	1	1	1	3	1	3	10	1	1	61	4.1	Poor
C2	10	1	2	5	7	1	4	2	1	4	7	7	7	5	1	64	4.3	Poor
C3	10	1	6	7	7	9	6	2	1	5	7	7	10	7	2	87	5.8	Poor
C4	10	1	10	10	8	10	7	3	1	10	8	8	10	10	10	107	7.7	Good
C5	10	1	10	10	8	10	9	3	1	10	8	8	9	4	9	99	7.3	Fair
C6	10	1	10	10	8	10	6	3	10	10	10	10	10	10	10	115	8.5	Good
S1	10	n.d.	5	9	3	7	6	1	1	3	5	7	3	7	1	67	4.8	Poor
S2	10	n.d.	7	9	3	7	10	8	2	8	7	8	10	7	8	104	7.4	Fair
S3	10	n.d.	1	8	5	10	8	10	3	3	2	2	10	10	3	80	5.7	Poor
S4	10	3	10	9	3	10	9	3	7	5	7	7	5	10	1	96	6.4	Fair
S5	9	10	9	10	9	10	7	1	5	8	8	8	10	9	9	113	8.1	Good
S6	10	10	7	9	10	10	6	1	1	10	9	10	7	10	8	118	7.9	Good

4.1.2 Drainage Area Assessment

Figure 31 and Figure 32 show the sub-basins in the Cumbaza and in the Shima watersheds, respectively. The sub-basins were calculated from a DEM-file in GIS. The shape file containing the Cumbaza River was not corresponding exactly to the DEM-file. The tributary that enters the Cumbaza River downstream site C1 in Figure 31 enters, according to the DEM-file, the Cumbaza River upstream C1 which is more likely to be correct.

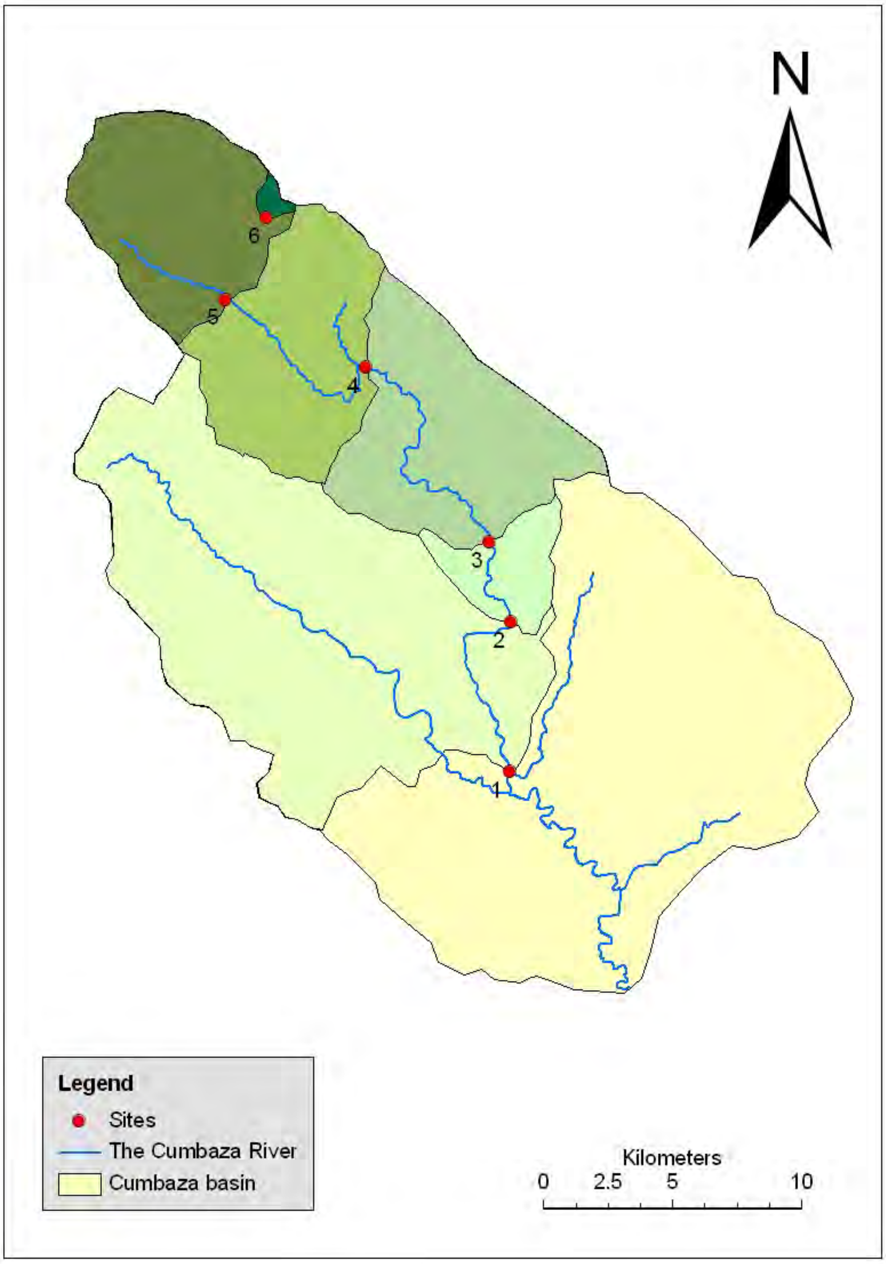


Figure 31 The sites and sub-basins in the Cumbaza watershed. The light yellow color shows the whole Cumbaza basin. The sites are numbered from 1 (most downstream) to 6 (most upstream).

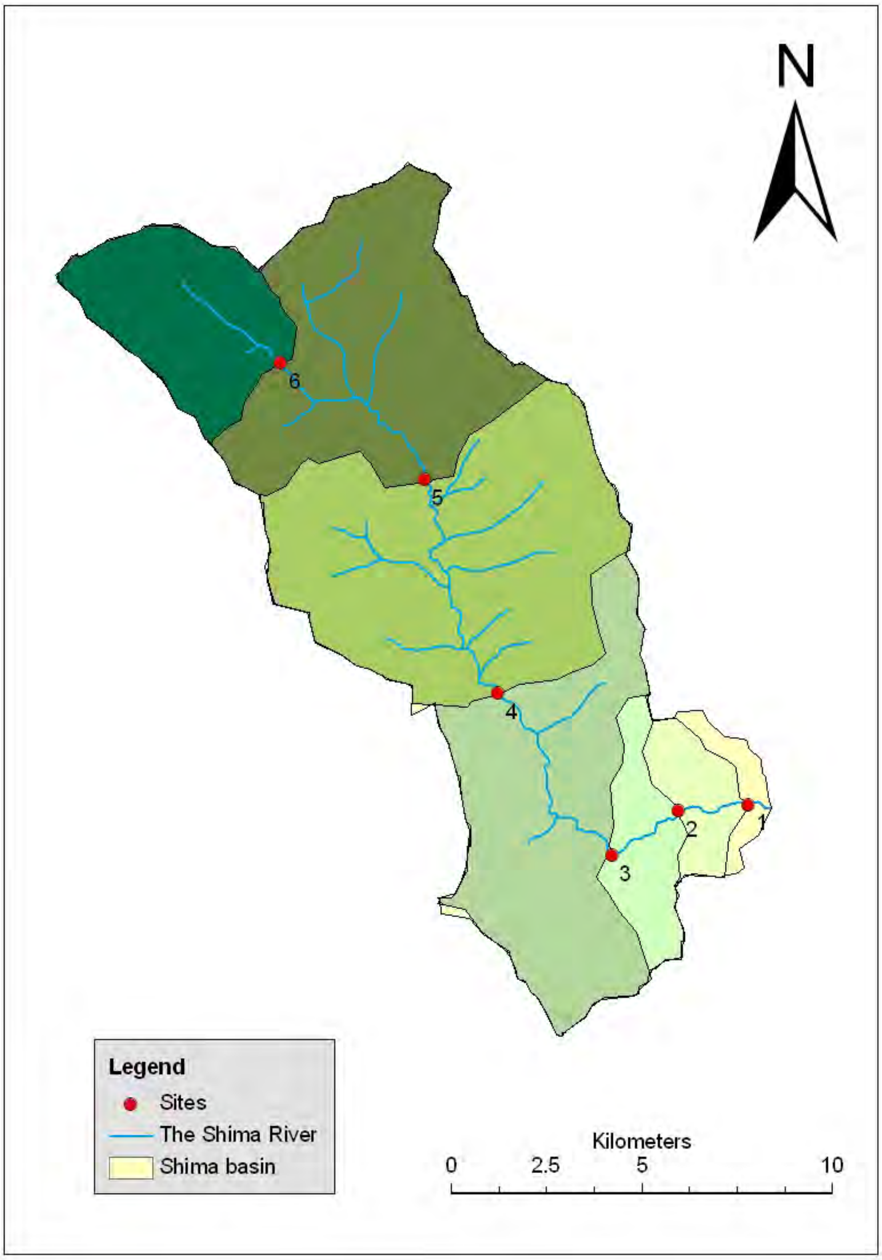


Figure 32 The sites and sub-basins in the Shima watershed.

Some geomorphological parameters were analysed in GIS for each of the sub-basins (see Section 3.3.2). Table 11 shows the physical parameters; the area of the sub-basins in Cumbaza and Shima as well as the mean elevation, mean slope and sampling site elevation. The sampling site elevation ranged from 1347 m a.s.l. and 770 m a.s.l. (at C6 and S6, respectively) and decreased downstream to 236 m a.s.l. at C1 and 330 m a.s.l at S1. In the Cumbaza basin the area of the sub-basins drained by the sampling sites varied from 1.4 km^2 to almost 340 km^2, while they in the Shima basin ranged in size from 20 km^2 to 166 km^2. The mean elevation of the sub-basins varied in Cumbaza between 690 and 1507 m a.s.l., whereas in Shima the mean elevation varied between 923 m a.s.l. and 1066 m a.s.l.. The average slope of the sub-watersheds ranged from 11° to 17° in Cumbaza and 14° to 15° in Shima (Table 11). All parameters showed a bigger difference in the variation in the Cumbaza basin than in Shima. This indicated a hillier landscape with steeper hill sides in the Cumbaza basin than in the Shima basin.

Along the Cumbaza River the percentage forest decreased when going downstream from the watershed 6 (100 %) to watershed 1 (46%), see Table 11. It was more than 50% difference between sub-watershed 1 and 6. Figure 33 shows the extent of the deforestation in the Cumbaza basin. In the Shima basin, on the other hand the deforestation was generally lower but spread rather equal over the whole basin (Figure 34). The percentage of forest upstream the site varied from 97% in watershed 6 to 78% in watershed 1, see Table 11.

Table 11 The elevation for each site, geomorphological parameters and the percentage of forest in the sub-basins in Cumbaza and Shima.

Site	Elevation at site [m]	Area of sub-basin [km^2]	Mean elevation [m a.s.l.]	Mean slope [°]	Percentage forest in the sub-basin [%]
C1	236	338.7	690	11	46
C2	298	174.3	947	16	57
C3	344	159.5	990	17	68
C4	559	98.8	1098	15	69
C5	761	47.5	1267	13	83
C6	1347	1.4	1507	17	100
S1	330	166.0	923	15	78
S2	440	169.5	935	14	78
S3	580	150.3	940	14	80
S4	620	112.8	979	15	88
S5	670	60.0	1033	15	95
S6	770	19.7	1066	14	97

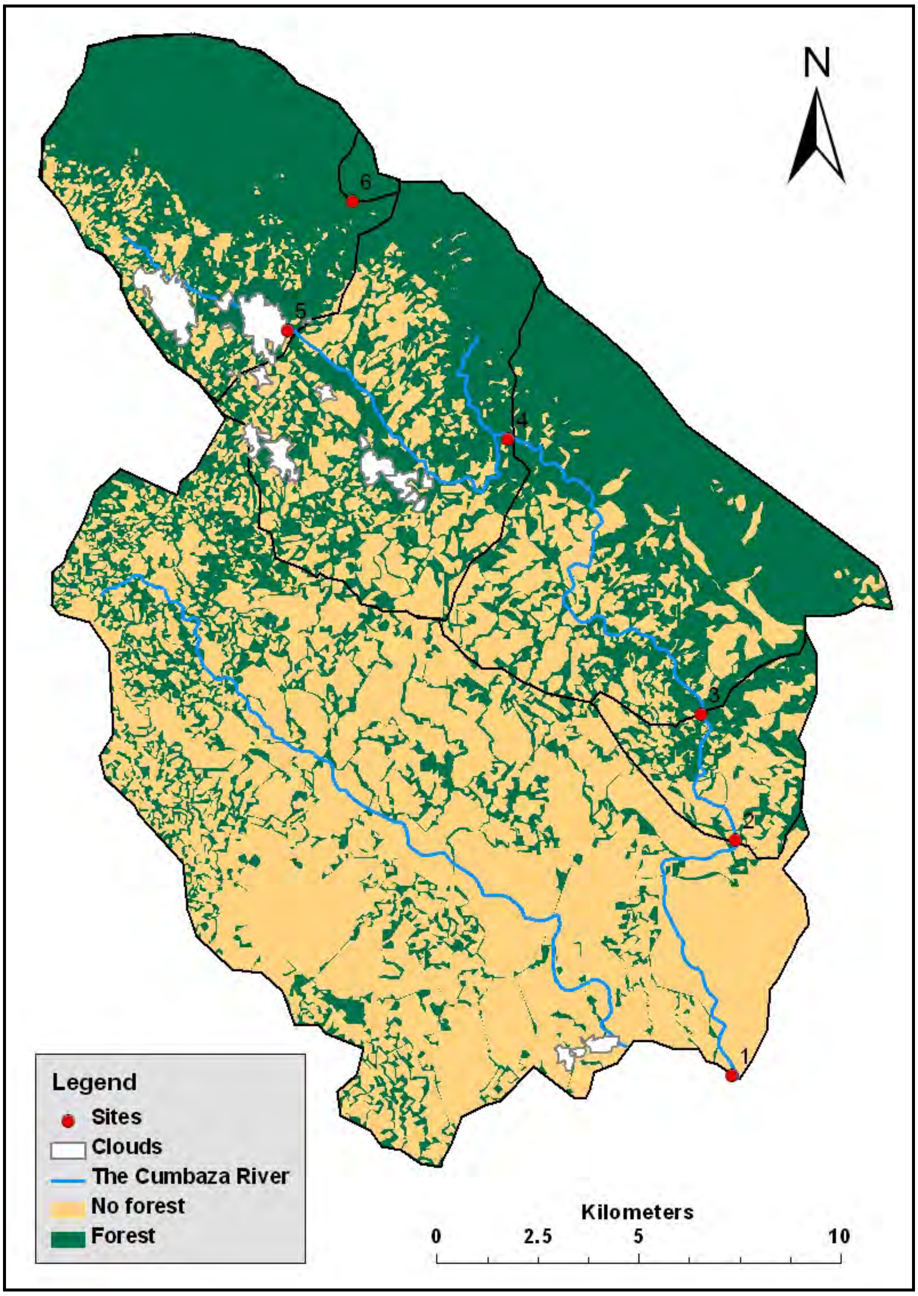


Figure 33 Forest cover in the Cumbaza basin. The dark (green) parts are forest and the light parts are deforested. The white spots were covered with clouds and could not be analysed (Classification based on original SPOT images © CNES (2002), distribution Spot Image S.A.).

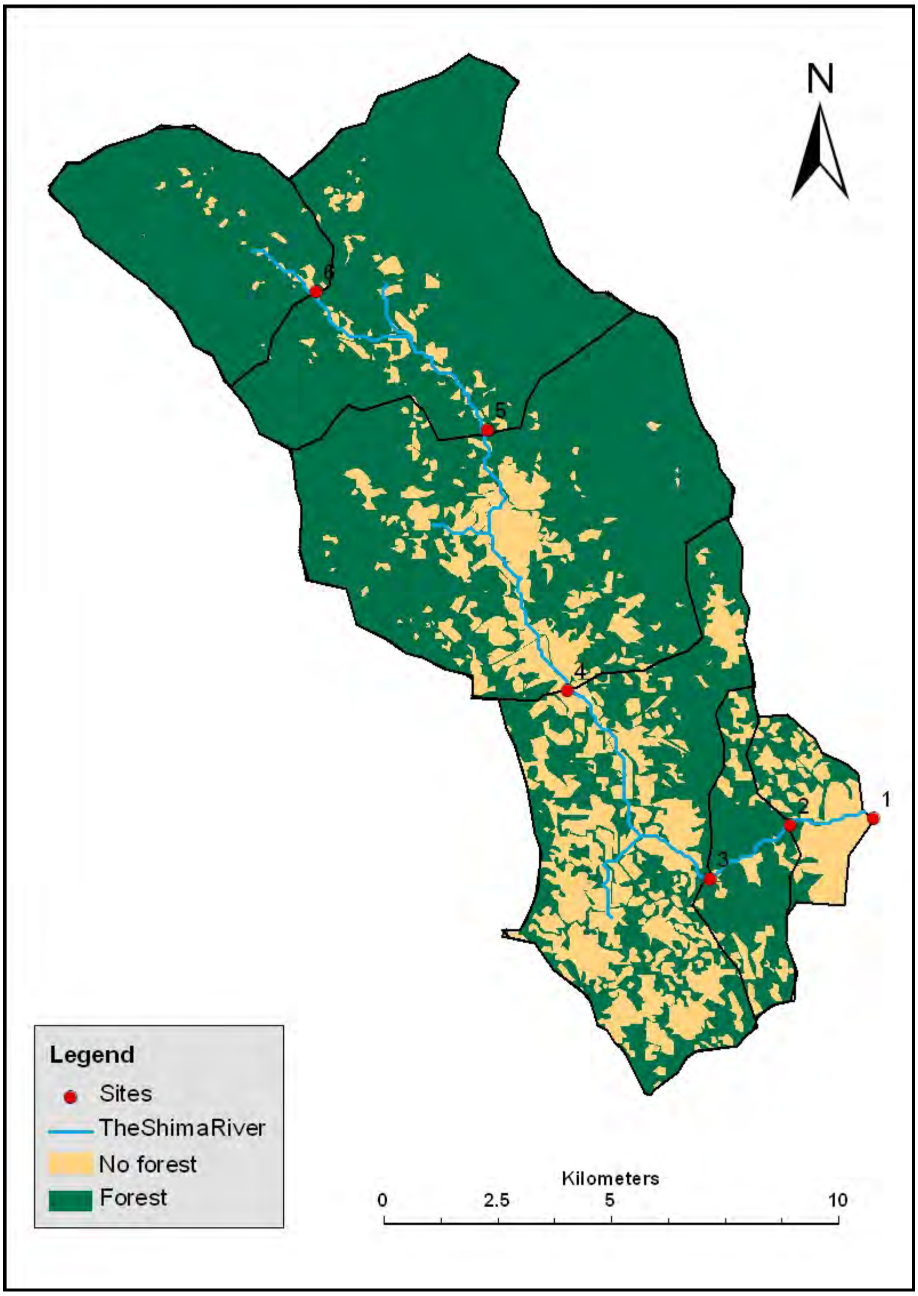


Figure 34 Forest cover in the Shima basin. The dark (green) parts are forest and the light parts are deforested (Classification based on original SPOT images © CNES (2005), distribution Spot Image S.A.).

4.2 CHEMICAL ASSESSMENT

In this section we present the results from the chemical assessment. The results are compared with Swedish limit values for drinking water quality and criterions for eutrophication. To investigate relations between water chemistry variables we have used Spearman's correlation matrix. Spearman's correlations between chemical variables are presented in Table 12 and Table 13. The measured concentrations are presented in Appendix 5 (Cumbaza) and Appendix 6 (Shima).

4.2.1 Cumbaza

The pH along the Cumbaza River increased slightly downstream (Figure 35). This was shown by a strong negative correlation between pH and site elevation (k=-0.8). All Spearman´s correlations between chemical variables are found in Table 13. Concentrations of dissolved ions (Ca, Mg, K, HCO, Na, SO_4 and Na) also increased along the river and were highest in the point closest to the outlet (C1), see Figure 53. In Figure 52 the sum Ca and Mg ions (hardness) is shown. It was clearly increasing going downstream. The pattern along the river was very similar for all these ions (k≥0.9). For the other ions (SO_4, Cl) the same trend with the highest value at C1 was seen (Figure 55). There was a large difference between the maximum and the minimum value for EC (Table 12) where the values for the two sets at site C1 (52 mS/m and 55 mS/m) were much higher than for the other sites (Figure 37). The values did not, however, exceed the recommendations from NFA for drinking water (250 mS/m).

The measured values for phosphate were very high (2.09 and 2.42 mg/L, respectively) at the most downstream site (C1), exceeding the recommendations from NFA (Table 2). At the other sites the phosphate values were too low to be detected (Figure 47). The concentrations of dissolved oxygen (DO) were adequate at all sites along the river except at C1 where DO was low. The DO shows a negative correlation with phosphate (k=-0.6). There are no correlations between these nutrients and chlorophyll A. For ammonium, the values were very low at the sites C2-C6 and similar for the two sampling events except for C6 (0.25 and 0.04 mg/L respectively), see Figure 49. The measured values at C1 were much higher than at the other sites (4.78 and 3.35 mg/L for each sampling event) and exceeded the recommendations given by NFA. This site would be classified as having a very high eutrophication grade by the Swedish Environmental Protection Agency as both the phosphate and ammonium concentrations are high (Section 2.3). The chlorophyll values at C1 are clearly higher (2.6 μg/L and 3.1 μg/L) than at the other sites (0.4-1.9 μg/L) where the values of chlorophyll A is low (Figure 39). The only exception is from the second set at C6 where the value was found to be 2.4 μg/L. The TSS only correlated with phosphate (k=0.6).

The tests for Total Coliform bacteria and E. coli bacteria showed high amounts of bacteria at all sites (C6 were not measured), see Figure 41 and Figure 43. The trend with the highest values at C1 as has been seen for other parameters was not seen for E. coli and Total Coliforms. There was a strong correlation between E. coli and Total Coliforms (k=0.9) but they did not correlate with any other chemical or physical parameters.

Variation in rainfall resulted in different water flow for the two sampling events at C3 and C4 but the flow was otherwise very similar at the two sampling events. The flow varied along the river with the highest flow at C4 and C3 for both sets of measurement (Figure 45). The lowest flow was found at C1 for both sampling events. The analysis of chemicals parameters showed that their concentrations were very similar between at the two events. Spearman's correlations did not show any correlations between flow and the chemical variables with the exception of ammonium (k=0.6). In Appendix 5 the results of the analysis of chemical variables are given.

4.2.2 Shima

The water at the sampling sites along Shima was slightly basic, pH ranged from 7.1 to 8.3 with highest notation at S1 (Figure 36). Water temperature varied from 23°C to 27°C. There was very little variation in Ca and Mg concentrations along the river. The Mg concentration was low (<4.5 mg/L) at all sites whereas the Ca concentration was high at each site (between 40 mg/L-62 mg/L). The hardness of the water (Mg+Ca) ranged from 1.0 to1.5 mmol/L with the highest measured value at S6 (Figure 54). The concentration of the other dissolved ions was also very similar along the river except for an enrichment of Na^+, and Cl^- at site S1 and of SO_4^{2-} at S6. Figure 54 and Figure 56 show the concentrations of cations and anions, respectively. Elevated concentration of Cl was 177 mg/L. The conductivity varied from 28 mS/m to 70 mS/m with highest notion at S1

Figure 38). Positive correlations were found with the ions, Ca (k=0.6), Mg (k=0.8), Na (k=0.8) and Cl (k=0.9). Concentrations of non-dissolved solids suspended in the water (TSS) usually were below 40 ppm. Exception was at S4 where the concentration was elevated (140 ppm) during the first sampling event.

Concentrations for PO_4 were very high at all sites (median concentration, 0.15 mg/L). Elevated concentration was found at S4 (0.34 mg/L) (Figure 48). The concentrations of NO_3-N and NH_4-N varied across the sites and between the two sampling events (NO_3-N< 0.37 mg/L and NH_4-N < 0.04 mg/L). For the first sampling event the NO_3-N concentration at three of the sites (S1, S5 and S6) was too low to be detected at all. Among other water variables NO_3-N was positively related to DOC (k=0.7) and negatively related to dissolved oxygen (k=-0.7) whereas the NH_4-N concentration tended to increase with higher concentrations of the soluble metals Al (k=0.9) and Fe (k=0.7) and decrease with higher concentrations of Mg (k=-0.6). Concentrations of NO_2-N varied across sites with elevated concentration at S4 (0.06 mg/L). There was no significant evidence of any correlation with NO_2-N and other water variables.

Dissolved oxygen varied between 7.3 mg/L and 9.0 mg/L and DOC concentrations between 1.2 mg/L and 5.4 mg/L with the highest notion at S3. The chlorophyll A concentration was very low at all sites (< 2.9 µg/L) (Figure 40) and no relations between other water variables were found.

The results for bacteria showed presence of E. coli and Total Coliforms at all five sites where samples were taken. The highest numbers of E. coli (190 ufc/100 mL) and Total Coliforms (5600 ufc/100 mL) were measured at site S5, see Figure 42 and Figure 44.

Concentrations for total Al exceeded 0.100 mg/L at three of the sites (Figure 50) and concentrations of total Fe exceeded 0.100 mg/L at every site. Elevated concentrations for total Al and Fe were measured at S4 (0.797 mg/L and 0.555 mg/L respectively). There were peaks in particulate Al (781 µg/L) and Fe (525 µg/L) at S4 during the first sampling event. Both particulate and soluble Al as well as particulate Fe had strong correlations with pH (k=-0.8), i.e. the concentration of total Al and particulate Fe is increasing with lower pH. Particulate Al was also related to water temperature (k=-0.7) and particulate Fe was also strongly negatively correlated with conductivity (k=-0.6). There were peaks in soluble Al (41 µg/L) and soluble Fe (80 µg/L) at S3. Soluble Fe was negatively related (k≤-0.6) to several dissolved ions (Ca, Mg, Na and Cl). The soluble Fe and Al concentrations were generally higher during the second sampling event. Overall the particulate form of both Al and Fe is the most dominating one at all sites.

Discharge was similar along the river and between the two sampling events ($Q<2.035$ m^3/s). One exception is site S4 where discharge was elevated at the first sampling event (Figure 46). Among water variables the discharge was negatively related to Ca (k=-0.6). No other significant correlations were found between discharge and other water variables. However, scatter plots show indications of a relation between increasing PO_4, Fe and Al concentrations in the stream water with increasing flow whereas no such clear correlation between measured flow and the concentrations of the nitrogen forms was found.

Table 12 lists minimum, median and maximum values of all variables measured along the Shima River. All significant Spearman's correlation coefficients between the chemical variables themselves and with the discharge are presented in table 14. The entire list of all chemical values measured at every site and also the measured discharge at every site is shown in Appendix 6.

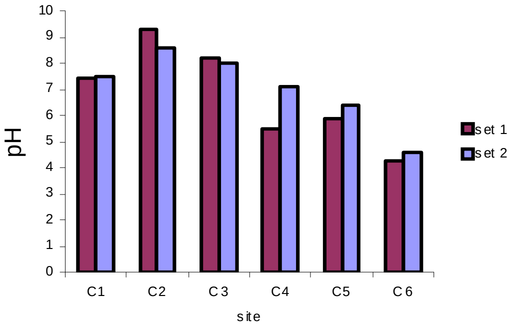


Figure 35 Measured pH along the Cumbaza River.

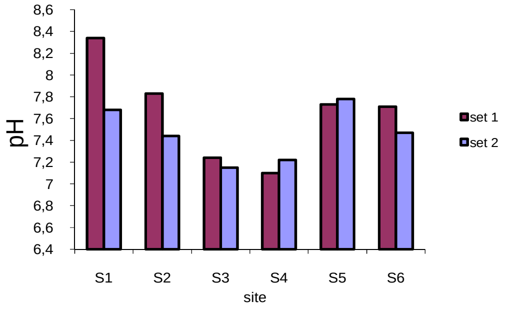


Figure 36 Measured pH along the Shima River.

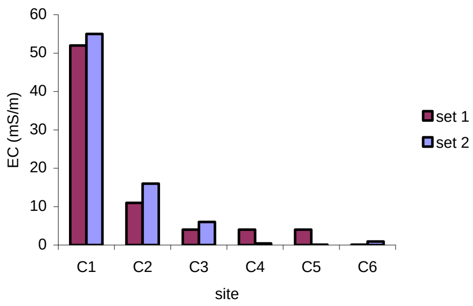


Figure 37 Measured EC along the Cumbaza River.

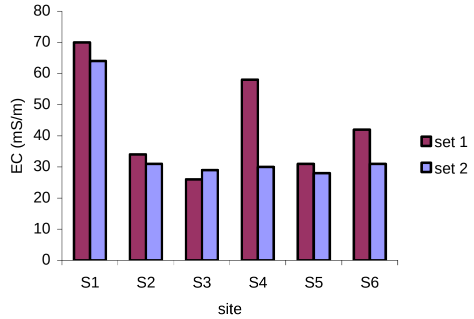


Figure 38 Measured EC along the Shima River.

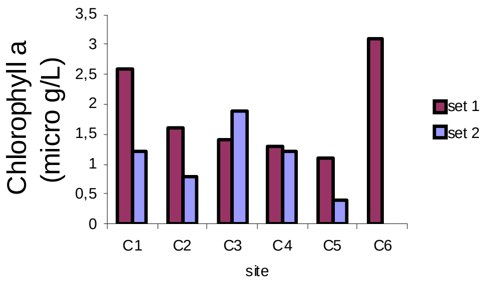


Figure 39 Measured chlorophyll A along the Cumbaza River.

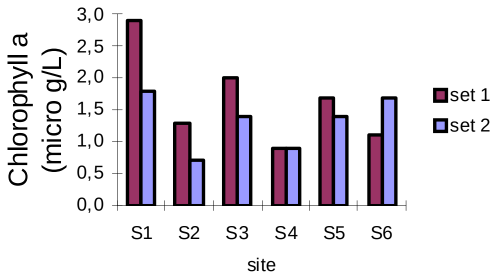
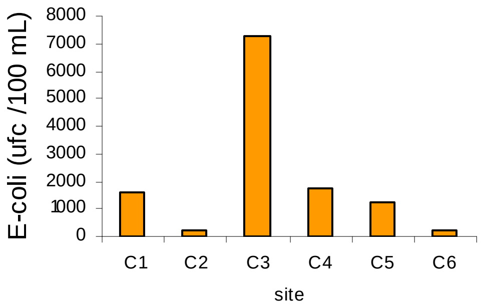


Figure 40 Measured chlorophyll A along the Shima River.



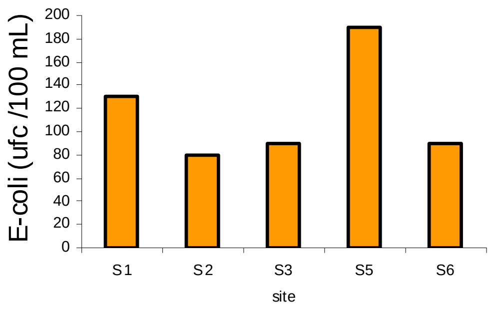
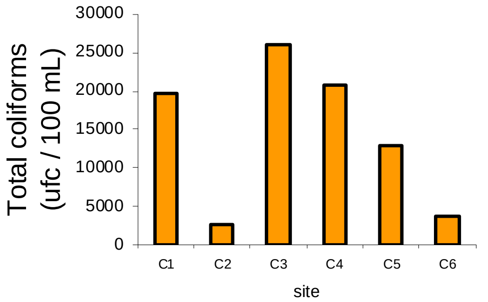


Figure 41 Analysed amount of E. coli along the Cumbaza River.

Figure 42 Analysed amount of E. coli along the Shima River.



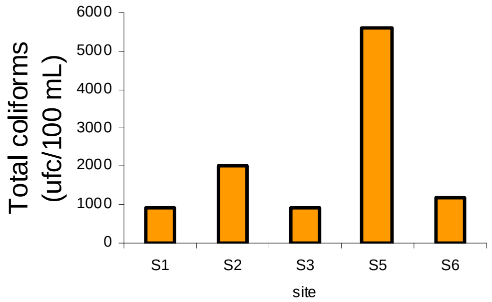
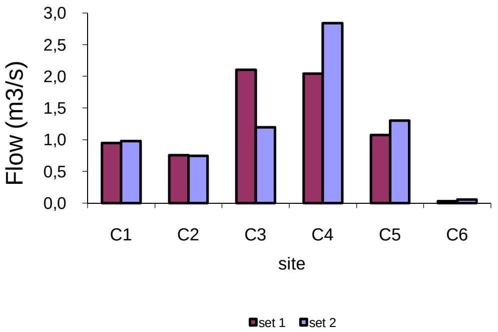


Figure 43 Analysed amount of Total Coliforms along the Cumbaza River.

Figure 44 Analysed amount of Total Coliforms along the Shima River.



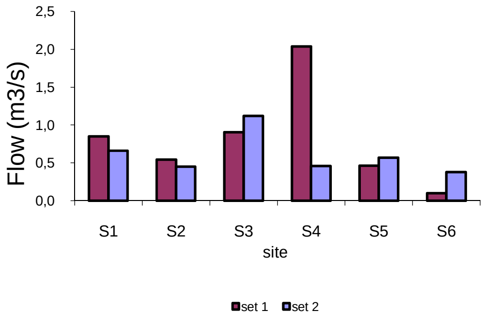


Figure 45 Measured discharge along the Cumbaza River.

Figure 46 Measured discharge along the Shima River.

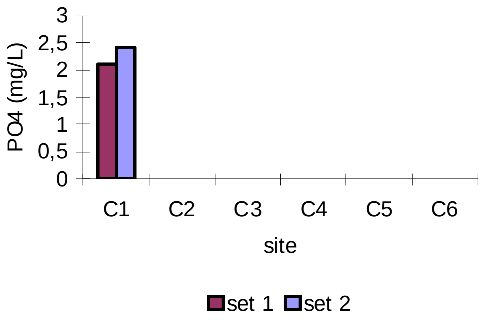


Figure 47 PO_4 along the Cumbaza River. For C2-C6 the concentrations were below detection limit.

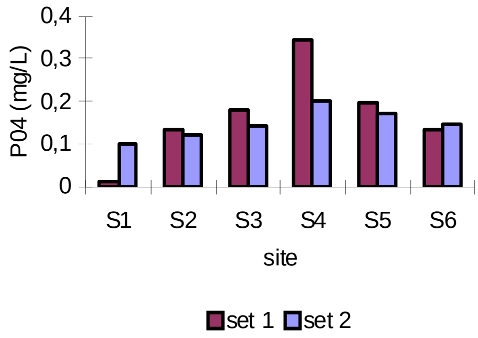


Figure 48 PO_4 along the Shima River.

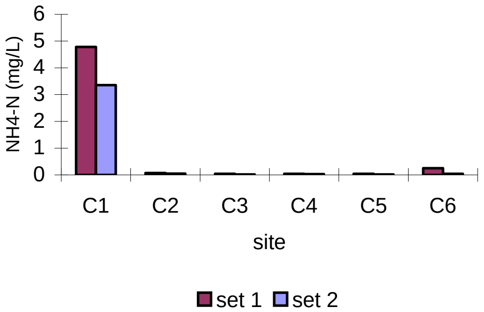


Figure 49 NH_4-N along the Cumbaza River. For C2-C6 the concentrations were below detection limit.

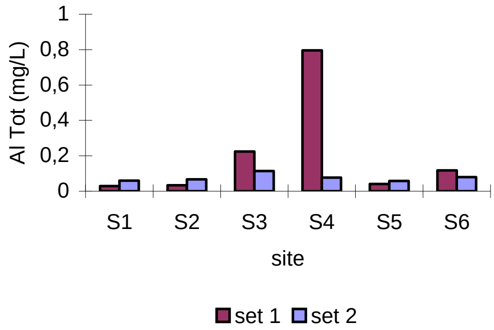


Figure 50 Total Al along the Shima River.

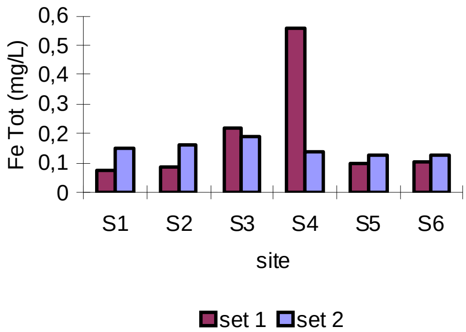


Figure 51 Total Fe along the Shima River.

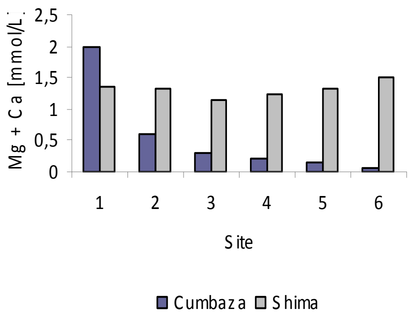


Figure 52 Sum of Magnesium and Calcium ions in Cumbaza and Shima Rivers.

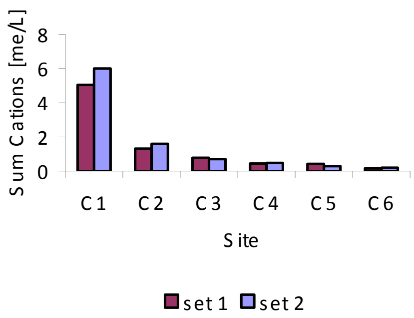


Figure 53 Sum cations along the Cumbaza River.

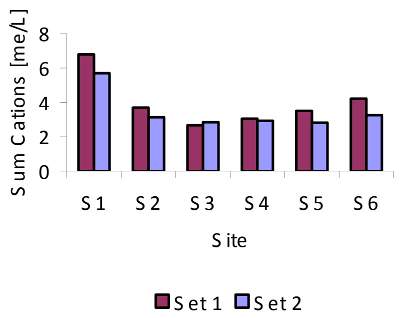


Figure 54 Sum cations along the Shima River.

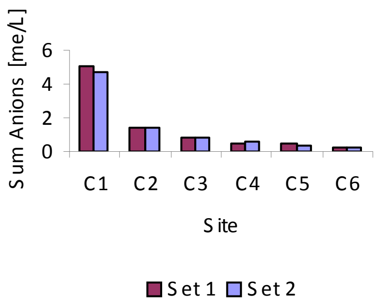


Figure 55 Sum anions along the Cumbaza River.

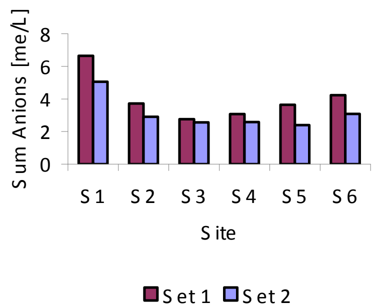


Figure 56 Sum anions along the Shima River.

Table 12 Water quality variables for the Cumbaza and Shima Rivers. Numbers in bold exceed the recommendations from the National Food Administration of Sweden. For details about limit values see chapter 2.3 (n.d.= no data).

	Cumbaza			Shima			Limit values for drinking water (NFA)	
Variable	**Max**	**Min**	**Median**	**Max**	**Min**	**Median**	**Unacceptable**	**Acceptable with remark outgoing/at user**
T (°C)	32	18	24	27	23	25		
pH	9.3	4.3	7.3	8.3	7.1	7.6		
EC (mS/m)	55	0.1	4	70	26	31	250	
TSS (ppm)	67	11	39	140	16	27		
DO field (mg/L)	9	3	7.4	9.0	7.3	7.7		
PO_4 (mg/L)	2.098	0.0035	0.0035	0.34	0.01	0.15		
NH_4 (mg/L)	**4.78**	0.02	0.04	0.04	0.01	0.03		0.4
NO_3 (mg/L)	n.d	n.d	n.d	0.37	0.11	0.13	12	5
NO_2 (mg/L)	n.d	n.d	n.d	**0.06**	0.01	0.02	0.15	0.03
DOC (mg/L)	n.d	n.d	n.d	5.4	1.2	2.6		
Chlorophyll A (µg/L)	3.1	0.4	1.3	2.9	0.7	1.4		
Ca^{2+} (mg/L)	67.1	1.8	8.1	61.8	39.7	46.1		100
Mg^{2+} (mg/L)	11.3	0.4	1.2	4.5	2.31	3.1		30
K^+ (mg/L)	7.8	0.4	1.2	2.7	1.2	1.6		
Na^+ (mg/L)	34.9	0.2	0.9	89.9	9.2	13.1		100
HCO_3^- (mg/L)	213.6	4.9	29.0	186.7	97.6	141.9		
SO_4^{2-} (mg/L)	23.3	0	0.5	16.5	0.1	0.4		100
Cl^- (mg/L)	28.4	1.8	7.1	**177**	9	17		100
E. coli (ufc/100 mL)	**7300**	**190**	**1405**	**190**	**90**	**90**	presence per 100 mL	presence per 250 mL
Total Coliforms (ufc/100 mL)	**20800**	**3800**	**16250**	**5600**	**900**	**1200**	10 per 100 mL	10 per 250 mL
Al (soluble) (µg/L)	n.d	n.d	n.d	41	6	17		
Al (part.) (µg/L)	n.d	n.d	n.d	781	21	53		
Al (total) mg/L	n.d	n.d	n.d	**0.797**	0.029	0.072		0.100
Fe (soluble) (µg/L)	n.d	n.d	n.d	80	5	45		
Fe (part.) (µg/L)	n.d	n.d	n.d	525	70	90		
Fe (total) (mg/L)	n.d	n.d	n.d	**0.555**	0.075	0.135		0.100/ 0.200

Table 13 Spearman's correlations between chemical variables at the sites in Cumbaza River. Only significant correlations are shown.

Variables	pH	EC	DO	PO4	NH4-N	Ch_A	Ca	Mg	K	Na	HCO3	SO4	Cl	E. coli	Total Coliforms
pH	1														
EC	0.7	1													
DO			1												
PO4		0.7	-0.6	1											
NH4-N				0.7	1										
Ch A						1									
Ca	0.8	0.9		0.7			1								
Mg	0.8	1.0		0.7			1.0	1							
K	0.8	0.9		0.7			0.9	0.9	1						
Na	0.7	0.9		0.7			0.9	1.0	0.9	1					
HCO3	0.8	0.9		0.6			1.0	1.0	1.0	0.9	1				
SO4				0.7								1			
Cl													1		
E. coli														1	
Total Coliforms														0.9	1

Table 14 Spearman's correlation coefficients between chemical variables themselves and with the discharge measured in the Shima River. Only significant correlations are shown.

Variables	Q	pH	EC	TSS	DO	PO_4	NH_4-N	NO_3-N	NO_2-N	DOC	Ch - A	Al soluble	Al part.	Fe soluble	Fe part.	Ca	Mg	K	Na	HCO_3	SO_4	Cl	E. coli	Total Coliform
Q	1																							
pH		1																						
EC			1																					
TSS				1																				
DO					1																			
PO_4						1																		
NH_4-N							1																	
NO_3-N				0.6	-0.7			1																
NO_2-N				0.6					1															
DOC								0.7		1														
Ch- A											1													
Al soluble		-0.6					0.9					1												
Al part.		-0.8											1											
Fe soluble			-0.6				0.7					0.8		1										
Fe part.		-0.8											0.8		1									
Ca	-0.6		0.6											-0.6		1								
Mg			0.8				-0.6					-0.7		-0.9		0.6	1							
K						-0.7												1						
Na			0.8			-0.8								-0.6		0.6	0.9	0.6	1					
HCO_3																				1				
SO_4																					1			
Cl			0.9			-0.7								-0.7			0.9	0.7	1.0			1		
E. coli																							1	
Total Coliform																								1

4.3 PHYSICAL ASSESSMENT COMPARED WITH WATER CHEMISTRY

In this section we present the results of analysed relations between chemical variables and 1) the physical habitat at the riparian scale and 2) with physical characteristics within the watershed such as percentage of forest in the sub-watersheds and other physical parameters. First the results for the Cumbaza basin are presented continuing with the Shima basin. All relations are based on Spearman´s correlation matrix and can be seen in Table 15, Table 16 and Table 17.

4.3.1 Cumbaza

Stream Reach Assessment

The habitat average index correlated with several chemical variables such as EC (k=-0.9) and pH (k=-0.8). The negative correlation showed that the conductivity and pH increased with decreasing average SVAP score. There were also strong negative correlations between the SVAP average score and the cations, (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}; k=-0.9) showing an increase in concentrations of cations in waters classified as poor according to the Stream Reach Assessment. The correlation test also indicated an increase in concentration of HCO_3^- (k=-0.9) for waters classified as poor. A negative and less strong correlation was found with PO_4^- (k=-0.7). A summary of the Spearman's correlations between SVAP parameters and chemical variables is shown in Table 15. Of the individual physical habitat parameters almost all showed a positive correlation with the SVAP average score, see Table 9. Positive correlation was also found between the average habitat index and site elevation showing that the average habitat index decreases downstream along the Cumbaza River (Figure 29).

The Riparian zone as well as the Structural intactness of the riparian zone correlated with site elevation (k=0.8 and k=0.9 respectively), supporting the results seen from the scores (see chapter 4.1). There were positive correlations between site elevation and all other SVAP parameters (k≥0.6) except barriers to fish movement, bank stability and manure presence. There was a trend with strong correlations between pH, EC and most ions and the Riparian zone and the Structural intactness (k≤-0.6). Thus the amounts of ions and the pH increased when these physical parameters decreased. It was interesting to note that both PO_4 and NH_4-N showed correlations with the structural intactness (k=-0.7 and k=-0.6) but no such correlation was seen for the riparian zone. A positive correlation between Riparian zone and Structural intactness (k=0.8) showed that a wide riparian zone may have increased the intactness.

The Canopy cover correlated with chlorophyll A (k=0.6), thus the chlorophyll content decreased when the canopy cover decreased (further downstream). It also correlated negatively with temperature (k=-0.7) and shading may have influenced the water temperature. A negative correlation was found with some ions (Mg, Ca, K, HCO_3^-, k≤-0.6) but no correlation was found with EC.

Water appearance, Nutrient enrichment and Riffle embeddedness all showed the similar negative correlations with pH, EC, several ions (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+} and HCO_3^-) and PO_4 (k≤-0.7). The water appearance and nutrient enrichment did not correlate with NH_4-N which was the case with Riffle embeddedness (k=-0.6).

Both human wastes and human activity correlated with EC and Ca^{2+}, Mg^{2+}, K^+, Na^+ and HCO_3^-, but the human activity generally had stronger correlations (k≤-0.9 compared to k≤-0.6). Human activity also correlated pH (k=-0.8) and Human wastes was found to correlate with phosphate (k=-0.7). Manure presence did not correlate with any of the chemical variables.

The Instream fish cover correlated negatively with both PO_4 (k=-0.7) and NH_4-N (k=-0.8), indicating that an increasing eutrophication may have a negative impact on the fish covers. Additionally there was a negative correlation with EC and several ions (k≤-0.7). These correlations, just stronger (k≤-0.8), were found for pools as well. Pools was also found to correlate with phosphate (k=-0.7).

Some chemical variables did not correlate with any physical parameter. These were; Total suspended solids, dissolved oxygen and sulphate and bacterial parameters.

Some examples of scatter-plots may be seen in Appendix 7. They show SVAP-parameters versus chemical variables.

Table 15 Spearman's correlation coefficients between the physical parameters and chemical variables for the sites along the Cumbaza River.

Variables	Q	T	pH	EC	TSS	DO	PO4	NH_4-N	Ch_A	Ca	Mg	K	Na	HCO_3	SO_4	Cl	Total Coliform	E. coli
SVAP		-0.9	-0.8	-0.9			-0.7			-0.9	-0.9	-0.9	-0.9	-0.9				
Rip.zone		-0.8	-0.9	-0.7						-0.8	-0.8	-0.7	-0.7	-0.8		-0.7		
Structural intactness		-0.9	-0.8	-0.9			-0.7	-0.6		-0.9	-0.9	-0.9	-0.9	-0.9				
Bank stability			-0.8															
Barriers to fish movement		-0.6	-0.8													-0.6		
Instream fish cover		-0.7		-0.8			-0.7	-0.8		-0.8	-0.7	-0.7	-0.8	-0.7				
Pools		-0.8	-0.7	-0.9			-0.7			-0.9	-0.9	-0.9	-0.9	-0.9				
Canopy cover	-0.6	-0.7	-0.7						0.6	-0.7	-0.7	-0.6		-0.7				
Riffle embededdness		-0.9	-0.8	-0.9			-0.7	-0.6		-0.9	-0.9	-0.9	-0.9	-0.9				
Water appearance		-0.9	-0.8	-0.9			-0.7			-1.0	-1.0	-0.9	-0.9	-1.0				
Nutrient enrichmen		-0.9	-0.8	-0.9			-0.7			-1.0	-1.0	-0.9	-0.9	-1.0				
Manure presence																		
Human waste				-0.6			-0.7			-0.6	-0.6	-0.7	-0.6	-0.6				
Human activity		-0.9	-0.8	-0.9						-0.9	-0.9	-0.9	-0.9	-0.9				

Drainage Area Assessment
In Table 17 the Spearman's correlations between site elevation, slope and forest cover are shown as well as the correlations between these and water chemical variables. The correlations between area and mean elevation of each sub-basin corresponded exactly to the correlations for site elevation. The percentage forest had strong correlations with site elevation (k=1.0), mean elevation (k=1.0) and the area of the sub-basins (k=-1.0). The latter showed that a smaller area was more likely to have a high percentage of forest.

The amount of forest was likely to affect some chemical variables as suggested by Spearman's correlations. This was shown by the strong negative correlations with percent forest, EC and all ions except SO_4^- and Cl^- ($k \geq -0.9$), thus these ions seemed to decrease in the water when the amount of forest increased up-streams. There was also a strong negative correlation with phosphate (k=-0.7), but no correlation was found with ammonium, chlorophyll A or dissolved oxygen. According to the Spearman's correlations the amount of forest up-stream the site also affected the pH (k=-0.8) and water temperature (k=-0.9), but the same correlations were found with sampling elevation and the mean elevation in the sub-basins. The latter results showed that the temperature increased going from C6 to C1. A trend in the correlations between the physical properties and chemical variables was seen; all the correlations between the percentage forest, elevation and mean elevation and the chemical variables were found to be the same. The area of the sub-basins correlated also equally but with reversed signs. None of the mentioned physical properties correlated with E. coli or Total Coliforms. The slope only correlated with phosphate (k=-0.7) among the chemical variables.

Appendix 8 shows examples of scatter-plots between percentages of forest upstream versus chemical variables. The plots we have chosen have significant correlations between the variables.

4.3.2 Shima

Stream Reach
The Spearman's correlation indicated that the average physical habitat (SVAP-index) for Shima was related to K^+ (k= -0.7) (Table 16). These results indicate that the concentration of potassium in the stream water increased with deteriorated physical environment at the finest scale (stream reach). With respect to the other water quality variables the SVAP-index showed no significant correlations. On the other hand the results for *individual* SVAP parameters for Shima indicated many correlations with water quality variables.

The width of the riparian zone showed relations with both PO_4 (k= 0.6) and Total Coliforms (k= 0.9) which indicate that the PO_4 concentration and the number of Total Coliform bacteria were higher in the stream water at sampling sites with wider buffer zones. Furthermore the concentrations of DOC and particulate Fe were negatively related to the intactness of the buffer zone (k= -0.6 resp. k= -0.7) meaning that these concentrations decreased with less percent fragmented riparian vegetation.

Bank stability was best associated with concentrations of SO_4 (k= 0.6) and K (k= -0.8). This result indicates that the SO_4 concentration in the stream water was increasing with more stable stream banks while the K concentration in the stream water was decreasing.

Barriers to fish movement (i.e. presence of dams, dikes and diversions) were best at predicting ion concentrations in the water. There were negative relations with Mg (k= -0.6), K (k= -0.9), Na (k= -0.8) and Cl (k= -0.7). Also PO_4 was strongly positively related to presence of barriers (k= 0.8) as well as particulate Al (k= 0.6).

Among the water variables NO_2-N was positively related to the parameter Instream fish cover (k= 0.6) whereas the chlorophyll A concentration was negatively related (k=-0.7), i.e. the NO_2-N concentration is increasing and the chlorophyll A concentration decreasing with the numbers of different cover types for fish.

Numbers of deep and shallow pools only correlated with the Ca concentration (k=-0.6), i.e. streams with deep and shallow pools abundant seemed to have higher Ca concentrations.

Strong correlations were found between the parameter Canopy cover and PO_4, NO_2-N, Na and Cl. The results indicated that PO_4 and NO_2-N concentrations increased in the stream water with increasing percent of shaded water surface (k=0.8 resp. k=0.6) and on the contrary, that Na and Cl concentrations decreased with increasing percent shaded water surface (k= -0.7 for both) .

Water appearance was strongest linked to the Ca concentration (k= 0.6) and K concentration (k= -0.6). This means that the Ca concentration was higher in clearer water with good visual depths while the K concentration was higher in stream water with a more muddy appearance. Ca was also strongly related to the parameter Nutrient enrichment (k= 0.7), i.e. the Ca concentration was also higher in waters with low quantities of macrophytes and less amounts of algal growth on stones.

The evidence of animals having access to the riparian reach was strongly negatively related to the electric conductivity (k= -0.7), i.e. there was a relation between more evidence of manure within the reach and higher EC. Evidence of human waste within the riparian reach was related positively to concentrations of PO_4 and particulate Al (k= 0.7 resp. k= 0.8) and negatively to pH and concentrations of K and Na (k=-0.7, k= -0.7 and k= -0.6). This indicates that pH and concentrations of K and Na tended to be higher at places with extensive evidence of human waste within the reach whereas concentrations of PO_4 and particulate Al were lower under such conditions. There was no significant relation between any of the water variables and different kinds of human activities as bathing and washing within the riparian reach.

For the rest of the parameters, i.e. Channel condition, Riffle embeddedness and Human activity no significant correlations with water variables were found, i.e. the parameters did not seem to influence the water chemistry. Also, due to the lack of score, no statistical analysis was done between water variables and the parameter Frequency of flooding whereupon no conclusions could be made about how flooding frequency may affect the concentrations of water variables in stream water. Water variables that did not correlate with any physical parameter were; water temperature, TSS, DO, NH_4-N, NO_3-N, Al soluble, Fe soluble, HCO_3 and E. coli bacteria. Table 16 shows all significant Spearman's correlation coefficients. Scatter-plots for the correlations between water variables versus physical parameters are shown in Appendix 7.

The discharge was negatively related to both Water appearance and Nutrient enrichment (k=-0.8 resp. k=-0.9), i.e. clearer water with less amounts of algal growth on stones was associated with a lower discharge.

Table 16 Spearman's correlation coefficients between the physical parameters and chemical variables and discharge for the sites along the Shima River. Only significant correlations are shown.

Variables	Q	pH	EC	TSS	DO	PO_4	NO_2-N	DOC	Ch. A	Al part.	Fe part.	Ca	Mg	K	Na	SO_4	Cl	E. coli	Total Coliforms
SVAP-index														-0.7					
Channel condition																			
Rip.zone						0.6													0.9
Structural intactness								-0.6			-0.7								
Bank stability														-0.8		0.6			
Barriers to fish movement						0.8				0.6			-0.6	-0.9	-0.8		-0.7		
Instream fish cover							0.6		- 0.7										
Pools												-0.6							
Canopy cover						0.8	0.6								-0.7		-0.7		
Riffle embeddedness																			
Water appearance	-0.8											0.6		-0.6					
Nutrient enrichment	-0.9											0.7							
Manure presence			-0.7																
Human waste		-0.7				0.7				0.8				-0.7	-0.6				
Human activity																			

Drainage Area

Spearman's correlations showed that there was a very strong negative correlation between percentage forest cover at the watershed scale and the concentration of K^+ in the stream water in Shima (k=-0.9), i.e. the concentration of potassium in stream water was increasing with decreasing percent of forest in the sub-watersheds (Table 17). There were no significant correlations with forest cover and other chemical variables.

Among all the measured water variable concentrations there were only the PO_4 and K concentrations that were linearly related to the distance from the outflow. PO_4 was positively related to sampling elevation (k=0.6) (Table 17) and mean elevation (k=0.6) and negatively related to area (k=-0.6) and thus decreased downstream the river whereas K was negatively related to sampling elevation (k=-0.9) (Table 17) and mean elevation (k=-0.9) and positively related to area (k= 0.9), i.e. increased downstream the river.

Scatterplots for the correlations between water variables versus percent forest in the sub-watersheds and sample elevations are shown in Appendix 8.

Table 17 Chemical assessment compared with site elevation, slope and forest cover in the Cumbaza and Shima basins. Spearman's correlations; only significant correlations are shown.

	Cumbaza			**Shima**		
Variables	**Sampling Elevation [m a.s.l.]**	**Slope [°]**	**Percentage Forest [%]**	**Sampling Elevation [m a.s.l.]**	**Slope [°]**	**Percentage Forest [%]**
Site Elevation	1			1		
Slope		1			1	
Percent forest	1.0		1	0.9		1
Q						
T	-0.9		-0.9			
pH	-0.8		-0.8			
EC	-0.9		-0.9			
TSS						
DO						
PO4	-0.7	-0.7	-0.7	0.6		
NH4-N						
Ch A						
Ca	-1.0		-1.0			
Mg	-1.0		-1.0			
K	-0.9		-0.9	-0.9		-0.9
Na	-0.9		-0.9			
HCO3	-1.0		-1.0			
SO4						
Cl						
E. coli						
Total Coliforms						
DOC						
Al part.						
Al soluble						
Fe part.						
Fe soluble						

5 DISCUSSION

5.1 CUMBAZA

Physical assessment

SVAP

The highest SVAP-index was found at the uppermost site (C6), which therefore was used as a reference site. For C4 the score was a bit higher than for C5 which likely depended on the adjacent fields and that more people pass (also with animals) or rest at this site. This was shown by the lower scores for the parameters for Human wastes, Human activity and Manure presence. Apart from this exception the SVAP-index decreased going downstream the Cumbaza River. This depended mainly on the increasing population downstream. The increasing population means more fields close to the river and more people using the water and cutting down forest nearby which may be a reason for the lower scores in the Stream reach assessment. This may also be seen by the parameters Riparian zone and Structural intactness, which were scored 10 at the site C4 to C6 but showed lower scores at the sites C1-C3. The highest score of shading was found only at site C6. The shading is higher due to the much narrower river and a denser riparian zone compared to other sites. A narrower river at site C6 probably offered less possible fish covers than further downstream, shown by the scores for Instream fish cover. As expected there was more sediment in the river going downstream the river, thus the scores for the parameter Riffle embeddedness was lower further downstream as well as the Water appearance.

Drainage area assessment

The deforestation was more extensive in the lower parts where the population density was higher. It was therefore likely that a small sub-basin (found at the higher parts) would have a higher percentage of forest. The correlations were also found to be very strong between area and forest cover and mean elevation and forest cover. Forest cover was also expected to correlate with slope as the fields are more often found in less steep areas, but no such result was found. The deforestation to open up land for cultivations and pasture seemed to depend mostly on where people chose to live. Both the percentage of forest and the SVAP-index pointed at degradation downstream and a positive correlation was found. This shows that the amount of forest at the riparian scale may indicate the degree of deforestation in the whole catchment.

Chemical assessment

The site C1 received the chemicals from all the sites upstream, which may accumulate in the river. It is also the only site located downstream the city of Tarapoto. In Tarapoto the water is used for car-washing, cars passing and urban storm water may enter the river without any treatment. A lot of chemicals found in a city are thus washed down into the Cumbaza River. This was seen by the results as the values of chemical variables were much higher at C1 than at other sites. The individual ions generally showed much higher values here than at other sites, but did not exceed the recommendations made by NFA. The lower value for chloride found at C1 at one sampling event seemed not to depend on lower flow but may be the result of error in the sample analysis. The EC-value at both sampling events (55 and 52 mS/m, respectively) was much higher than at the sites up-streams (e.g. 11 and 16 mS/m at C2), which indicates elevated amounts of ions at site C1 compared to the other sites in Cumbaza. Previous studies showed EC-values of 2.4 at Puente San Pedro de Cumbaza, which is located a bit up-stream site C3, and 18.6 mS/m at Casiero Juan Guerra, which is located downstream site C1 (IIAO, 2004). These values were lower than our values (4 and 6 mS/m at C3 and 55 and 52 mS/m at C1). Another study has reported calcium values around Tarapoto in the Cumbaza River of 36.5 mg/l (IIAP, 1994). We found concentrations downstream Tarapoto (at site C1) to be 57.3 mg/l and 67.1 mg/l for each sampling event. Comparison with these previous studies showed an increase in calcium concentration since 1994 and an increase in ion content in general since 2004.

The nutrients also showed high values compared to the other sites and the ammonium concentration was much higher than the recommended value for drinking water, both compared to Swedish and Peruvian recommendations. In the classification of eutrophication of fresh water made by the Swedish Environmental Protection Agency the site C1 would be classified as having an extremely high eutrophication degree, since the phosphate by itself exceeded the limit value for total phosphate (Section 2.2.2). This could indicate high eutrophication around Tarapoto and/or high eutrophication around the tributary entering the Cumbaza River between sites C1 and C2. Figure 33 shows that there are many fields around this tributary. At all other sites the values were too low to detect and according to the Swedish Environmental Protection Agency classified as no eutrophication. Important to note is that the classification is based on total phosphorus and in this study only phosphate has been investigated. The total phosphorus would be higher and might have indicated some eutrophication at other sites as well.

According to the nutrient concentrations measured at C1 the dissolved oxygen could then be expected to be consumed at a higher rate at site C1 than at the other sites and the results showed that this was the case. No other site had lower concentration of DO in the water. The values of DO corresponded to those seen in previous studies (except for site C1), where concentrations of 6.8 mg/L and 8.1 mg/L have been observed earlier (IIAP, 2004). At the first occasion the DO was lower than the Peruvian recommendations at site C1. The chlorophyll A was also higher at site C1 than at other sites, but a high value was also found at one occasion at C6. This could be explained by matter containing chlorophyll that entered the water sample from other sources than the water, before filtration. It might also have been an error during analysis.

The pH at site C1 was a little lower than the pH measured at C2 and C3. On the other hand, at the three uppermost sites the pH was lower than at C1 and also much lower than recommended values from NFA (pH>7.5). Also according to the Peruvian guidelines the pH was too low at these sites, at least for the first set. At C1 the pH exceeded these recommendations at one occasion.

At sites C5 and C4 pH was also below recommended values (according to the National Food Administration). At these sites the calcium concentration was also low, especially at site C6. This site was located in an area where the bedrock consists only of *Grupo Oriente* which has been described to contain limestone (Section 3.2.3). However, it was also one of the oldest formations in the region and the weathering process might already have dissolved the parts of the calcite that have been exposed to water. By this followed that little calcium was dissolved in the soil and thus not end up in the water. There were also indicators that the calcite content may vary a lot in different areas of the bedrock. This led to uncertainties that the bedrock really contained calcite in the discussed areas[26]. At the site C4 the water was also effected by *Formación Sarayaquillo* and *Formación Chonta*. Both contain calcium and might be the reason why the calcium values were higher here than at C6. The *Formación Sarayaquillo* is though much older (the oldest formation in Cumbaza) and might be more weathered than the *Formación Chonta*. The human activities around C4 and C5 may also have an effect, e.g. deforestations may increase the transport of ions into the streams. This may also explain the increase in calcium at every site when going downstream. The correlations showed an increase in pH going downstream. Natural water with low human influences in the Cumbaza River is therefore expected to have a pH of about 5-6 according to this study. Previous studies showed, however, that the pH in some parts of the Cumbaza River were around 8-9 at the time of sampling (IIAP, 2004) and around Tarapoto pH 6 has earlier been observed (IIAP, 1994).

The amount of suspended particles was not following the above mentioned trend of increasing concentration when going downstream, but fluctuated along the river. The variations in values between the sampling events at the same site (this can be seen for all sites except C1) showed that the increase in runoff due to rainfall previous to sampling probably increased the TSS value. Both before the first occasion at C6 and C4 intense rainfalls were observed. The TSS values were higher at these sampling events than at the second event for both sites. Almost all results exceeded the Peruvian limit values.

According to the recommendation of the National Food Administration of Sweden the water was not suitable as drinking water at any of the investigated sites as the bacteriological analysis showed that both E. coli and Total Coliforms were found at all sites. No or little faecal bacteria was expected at C6 due to extremely little human activities in the area but the result showed that both E. coli and Total Coliforms were present even at this site. Neither could the water be recommended as drinking water according to the Peruvian guidelines; only the site C2 had a value of Total Coliforms that did not exceed the Peruvian guidelines. It was expected that increased surface runoff would increase the presence of bacteria in the water as well as increased particles but no correlation with flow or TSS was seen. Few samples could be collected due to logistics and that might be the reason for the absence of correlations with other variables. More samples would be necessary for certain conclusions about the water quality.

During our analysis we also noted that the water at the sites C1 and C3 to C5 could not be recommended as bathing water. According to the Swedish standards the presence of E. coli bacteria should be less than 1000 (which was the case only at C2 and C6). All sites in Cumbaza had more than 1000 ufc/100 ml of Coliform bacteria why the water at no site could be classified as good to use for bathing according to the Swedish recommendations. (Bydén et al., 2003).

Physical assessment vs Chemistry

SVAP

The SVAP-index was found to correlate with several chemical variables but lacked correlation with others. This indicates that the water quality may be investigated with

[26] Personal communication with Lina Lindell.

the Stream Reach Assessment to some extent. It was shown e.g. by the increase of EC, HCO_3^- and the analysed cations, when the habitat index decreased (for water classified as poor, Table 10). However, there was no correlation with e.g. phosphate and DO which both are important indicators of eutrophication. High eutrophication may lead to bad water quality which preferably should be mirrored in the SVAP scores.

When it comes to individual SVAP parameters, phosphate, as well as ammonium, correlated with Structural intactness but only phosphate correlated with Riparian zone. This indicates that when it comes to controlling nutrients in the stream an intact riparian zone may be more important than its width. However, a positive correlation between Riparian zone and Structural intactness shows that the intactness increased when the width of the riparian zone increased. It also shows that studying individual parameters when estimating the water quality with the stream reach assessment may be as important as just studying the SVAP-index.

Nutrient enrichment, Water appearance and Riffle embeddedness were expected to correlate with chemical variables such as phosphate, ammonium and DO, indicating an increased eutrophication. Only the correlation with phosphate was found with these three SVAP parameters. Ammonium only correlated with Riffle embeddedness, while no correlation with DO was found. This shows that increasing eutrophication may be reflected in physical conditions along the stream. But it also shows that e.g. the ammonium concentration may increase without affecting the water appearance or the nutrient enrichment parameters. Other SVAP parameters of interest when estimating the eutrophication in the Stream Reach Assessment are Manure presence, Human activity and Human wastes. The only correlation with the above mentioned chemical variables was found between Human wastes and phosphate, but as it was negative it indicates an increase in phosphate when the human wastes decreases. This may show some of the difficulties when estimating the SVAP parameters rather than a plausible result.

Another chemical parameter connected to eutrophication is chlorophyll which was expected to correlate with e.g. Nutrient enrichment and Water appearance. The only correlation found with chlorophyll A is however with Canopy cover. An increased canopy cover seems to increase the chlorophyll concentration in the water. The expected correlation would be the reverse– that increased sun light (decreased Canopy cover) would increase the chlorophyll content.

Some SVAP-parameters could be expected to influence the chemical variable. Above is discussed the Riparian zone and the Structural intactness which were expected to affect not only nutrients but also the concentration of ions (Section 2.1.2). Correlations were found with EC and several ions (except SO_4^- and Cl^-) which support this theory. Even stronger correlations were found with Structural intactness. This indicates again that the Intactness of the riparian zone is important to minimise the flow of chemicals into the water.

The classification of the water quality in the Stream Reach Assessment was not adequate to determine the suitability of the water as drinking water. This is shown by the lack of correlation between the SVAP-index and some chemical variables such as E. coli, Total Coliforms, TSS, ammonium where especially bacteria are important to eliminate to obtain a healthy drinking water. The few samples used in the analysis of bacteria might be the cause to the lack of correlations with these variables. As the presence of particles in the water is known to increase the amounts of bacteria, the correlations with TSS were also interesting to study. There is no correlation with SVAP-index and TSS why there is nothing in the classification of the water that may indicate the presence of bacteria.

The Stream Reach Assessment in the Cumbaza basin showed that some information may be obtained with this investigation. It was however not possible to do any certain estimation of the water quality using this assessment alone. Some correlations showed on non-expected results which indicated that the Stream Reach Assessment was not reliable, at least not without complementary chemical assessment. The Stream Reach Assessment was, however, found to be a useful tool to learn more about the environment in and around the stream and about the variations of the environment along a stream. It is probably effective to detect changes in the environment in the stream reach during a period of time.

Drainage area assessment

The hypothesis presented in Section 1.2 was that the amount of forest upstream a study site affects the water quality. The results showed that many chemical variables have a negative correlation with the percentage forest upstream the study site. This indicates that more forest upstream results in lower values of variables such as phosphate, EC and several ions in the stream. However, no correlation was found with ammonium which is often found in fertilizers. Through nitrification ammonium may be transformed to NO_3^- which is known to often pass the riparian zone (Section 2.1.2) without being taken up by plants which in turn may be the cause of the lack of correlation.

The pH seems to decrease with increasing forest cover but this decrease may coincide with other parameters not present in this statistical analysis such as the soil chemistry. The ions with a strong correlation with forest cover may have derived from natural sources such as weathering of minerals in the soil and were thus easily taken up by plants.

The lack of correlations with some important parameters, e.g. bacteria, indicates that it is not enough to study only the forest cover to draw any conclusions about the drinking water quality. It seems though to affect some chemical variables.

A trend is seen in the correlations with the chemical variables; they are exactly the same for mean elevation, site elevation and area parameters such as for forest cover. This was explained by the strong correlations between the forest cover and these physical parameters. The percentage of forest was highest upstream and the area smallest (k=-1) and the mean elevation naturally highest (k=1). Steeper slopes often lead to an increase in the surface runoff why correlations between the slope and some chemical variables could be expected, e.g. TSS. However, no such result was however found. The slope adjacent to the river may be low even though the mean slope is high. A high surface runoff close to the river probably has a higher impact on the water variables than does the surface runoff further away.

5.2 SHIMA

Stream Reach

The SVAP-method turned out to be a good tool to evaluate the physical riparian habitat at the sites along Shima. The results on the SVAP-index show quite a wide range indicating that there were sites classified next to be “reference” sites with minimally impaired physical structures (upper reaches) while there also were those that were classified as being “poor” (lower reaches), i.e. had a predominantly impaired physical habitat. Furthermore the SVAP-index decreased downstream, indicating that the physical habitat was deteriorated downstream.

Individual physical parameters that account for impairments of the average physical habitat downstream are fragmentations of the riparian vegetation, instable and low stream banks, high amount of gravel or cobble particles embedded in the bottom sediment, muddy water appearance and extensive amounts of algal growth on stones. Many of these were related to concentrations of water quality variables in the stream which indicate that physical structures at the finest scale (stream reach) and water quality are linked.

The strong correlations between decreasing bank stability and increasing slope at the sample sites are not surprising as increasing slope tend to put more pressure on the banks and increases the risks for landslips.

Drainage Area

The results showed that the percent of forest in the watershed decreases downstream Shima. The explanation seems to be an increasing deforestation which is more extensive in parts where most people are settled, i.e. downstream. Furthermore the percent forest in the watershed was positively related to the physical habitat at the finest scale which means that deforestation at the watershed scale also put pressure on riparian land causing impaired physical habitats.

Water quality along the river

Spearman’s correlations matrix indicated that the physical habitat for Shima was related to sampling elevation (k= 0.8). This indicates that the physical environment within the riparian reach deteriorates downstream along the river. As a consequence the water quality was deteriorates downstream changing from “good” quality to “poor” quality. As the K concentration in the stream increases downstream with increasing deteriorated physical habitat the result may indicate that high concentrations of K can be associated with poor water quality downstream at the finest scale.

Percent forest at the watershed scale is also related to sampling elevation (k= 0.9), i.e. the proportion of forest in the sub-watersheds decreases downstream. As the K concentration increased in the stream with decreasing percent of forest in the sub-watersheds the result may indicate that high concentrations of potassium can be associated with increasing deforestation downstream at the watershed scale.

Water quality at the sites

Among those water variables that have limit values in drinking water concentrations of EC, Mg^{2+}, Ca^{2+}, Na^{+}, SO_4^{2-}, dissolved oxygen, NH_4-N and NO_3-N all were *within* acceptable levels for drinking water quality set by the NFA at all sites whereas pH was below limit values at some of the sites and water variable concentrations of Cl^-, NO_2-N, total Al and total Fe, E. coli and Total Coliform bacteria exceeded limit values for drinking water quality. Comparing with the Peruvian limits for drinking water the amount of Total Coliforms exceeded the limit value at site S5 and concentrations of TSS exceeded recommendations at four sites. Among the water variables mentioned pH, EC and concentrations of Ca^{2+}, Na^{+}, SO_4^{2-}, NO_2-N and particulate Fe correlated with individual SVAP-parameters indicating that physical habitat at the finest scale and drinking water quality are linked.

EC was, as expected, positively related to Ca^{2+}, Mg^{2+}, Na^{+} and Cl^-. All these ions come from decomposition of compounds and are being charged when dissolved in water. The electric conductivity is an indirect measure of the presence of these (among other) ions in the water (Section 2.2.5). In this study the electric conductivity was below limit values for drinking water (< 250 mS/m) at all of the sites (Section 2.3) and increased with more evidence of manure within the site. As manure contains many ions the explanation can be that elevated concentrations of ions in the stream come from manure runoff.

The Mg concentration was low for fresh waters in general whereas the Ca concentrations exceeded values common for fresh water (> 15 mg/L) at all sites (Section 2.2.1). Elevated Ca concentrations are likely to have come from weathering of carbonate rocks (Section 2.2.1) and were associated with clearer water appearance and less nutrient enrichment on stones in the streams. We have not been able to find in the literature if this result has been seen elsewhere. In general the median concentrations of Ca and Mg correspond well to the median values for the whole Saposoa basin (Nagel, 2005). The Na concentration increased with more human waste within the site which is not surprising as there is extensive evidence of human waste often being associated with many people using washing powder and soaps containing Na for washing and laundering at the site. The median Na concentration was much lower in Shima than median values for the whole Saposoa basin (Nagel, 2005). The SO_4 concentrations in Shima were below values for natural fresh waters at all of the sites (< 2 mg/L) (Section 2.2.1) with exception at S6 were concentrations were elevated and showed more natural values. Weathering processes are the most common source for elevated SO_4 concentrations (Section 2.2.1). Also, one cannot exclude precipitation as a source. Dissolved oxygen concentrations varied across sites but were adequate for aquatic life at all sampling sites (DO> 2 mg/L) (Section 2.2.5). The evidence for a negative relation between the dissolved oxygen concentration and concentrations of NO_3-N has also been found by others and indicates that an increased eutrophication based on nitrate consumes oxygen.

The low NH_4-N-concentrations along Shima may indicate good plant uptake in the riparian zone even though no significant correlation was shown with the width of the riparian zone or the intactness of it. The low values may also indicate that influences from outflows from industries or from drains are not appreciably high or /and that the nitrification in the soils in which ammonium is consumed is high. The association between the NH_4-N concentrations in the water and higher Fe concentrations has also been shown in prior studies (Section 2.2.2).

Others have found relations between lower concentrations of NO_3-N in tropical stream waters with wider riparian buffers (Section 2.2.2) but the results along Shima indicate no such relations. Instead it is, in comparison to what Neill and others found in small pasture streams in the Brazilian Amazon (Neill et. al., 2001), possible that enhanced oxygen concentrations increases the nitrate concentration in Shima. However, one cannot exclude that factors such as plant uptake and denitrification as well as runoff from agricultural lands influence the movement of NO_3-N. Contrary to others the results show increasing concentrations of NO_3-N at places located close to cultivated land. An example is S3, which has the second highest measured concentration, and is located close to a big plantation and a smaller habitation. As the riparian zone here is very thin, scored only 1 in the SVAP-assessment protocol, there is a possibility that the plant uptake in the riparian zone is insignificant and NO_3-N is entering the water through runoff. Another example is S6, located just close to a slash and burn field and where the concentrations of NO_3-N are the highest measured for all sites along Shima. Also as NO_3-N in fertilizer has a tendency to leak and bypass the root zone in the riparian zone and through groundwater reach the stream (Section 2.2.2), this can explain the high concentrations where the riparian zone is dense and wider but concentrations in stream water are still high. However, the majority of the farmers in the study area are not using fertilizers thus other explanations are also plausible. Furthermore, the association between increasing NO_3-N concentrations and increasing DOC concentrations can be explained by more organic matter providing for more nitrates through increased nitrification (Section 2.2.2).

The pH values were within the normal interval for natural fresh waters (Section 2.2.5) but low values below the limit values for drinking water quality (< 7.5) were measured at three sites (S2, S3, S4). pH increased with more evidence of human waste within the reach which is not surprisingly as much evidence shows that human waste often is associated with more human activities such as bathing and washing in the stream where people used washing powder and soap containing basic compounds.

Among the ions only Cl was detected in a concentration that exceeded the limit value for drinking water quality (S1) (Section 2.3). The elevated concentration can be toxic to plants but will not affect the human health. It can have reached the stream through weathering of rocks, atmospheric deposition or leakage from agriculture or sewage effluents. It might also indicate fecal contamination at S1 (Section 2.2.1). Compared to the whole Saposoa basin the Cl median concentration in Shima was very low (WWF, Peru).

Two of the sites (S2, S4) had concentrations of NO_2-N that can result in an increased risk for waterborne diseases (> 0.03 mg/L) if the water is consumed without treatment (Section 2.3). The concentration at S3 was equal to the limit value ($= 0.03$ mg/L). NO_2-N was predicted with Canopy cover showing elevated concentrations at places with a higher percent of water shaded by canopy. As shade from vegetation contributes to lower water temperatures and thus increases the oxygen holding capacity of the waters (see Section 2.2.5), the result may indicate higher NO_2-N concentrations in waters with higher oxygen content. Others have found (Section 2.2.2) that nitrite converts into nitrate if the oxygen concentration is high and that the concentration of nitrite in the stream therefore decreases. As the concentrations of dissolved oxygen in Shima ranged from 7.3 to 9.0, which according to the Swedish environmental protection agency is high (> 7 mg/L), we expected lower NO_2-N concentrations. We have not been able to find in the literature if this result here has been seen elsewhere. Furthermore, NO_2-N was positively related to Instream fish cover. Increasing numbers of woody debris, macrophytes and roots under water increase the ammonification due to increasing activity by decomposers. By this follows an increasing degradation of the increasing ammonium concentration into nitrite which can explain the result here.

Three of the sites (S3, S4, S6) had concentrations of total Al that can affect the human nervous system (> 0.100 mg/L) if the water is being consumed without treatment and all of the sites had concentrations of total Fe that may give the water a bad taste (Section 2.3). Concentrations of total Fe exceeded the limit value (0.100 mg/L) for water from a purification plant *before* distribution for all sites and also for "water by user"[27] (0.200 mg/L) at two of the sites. Nagel found even higher median concentration for iron for the whole Saposoa basin (0.41 mg/L), far above acceptable levels (Nagel, 2005). Particulate Fe concentrations increased with more fragmented riparian vegetation which in turn is associated with deteriorated water quality according to the SVAP-method. An explanation may be that iron bound to humus more easily can reach the streams through increasing runoff at places with less ground vegetation to prevent the movement. Al was predominately found in its particulate form which is not surprising as Al is mainly bound in different complexes when 4< pH < 9 (Section 2.2.4) which is within the range for Shima. Soluble Al concentrations increased with lower pH which has also been found by others (Section 2.2.4) and strengthens the fact that the toxicity of aluminium is increasing with lower pH.

E. coli bacteria and Total Coliform bacteria were present at all five sites where samples were taken. Their presence indicates a faecal impact from humans and animals from outlets or manure (Section 2.2.3). However, no significant correlation was found with manure presence or human wastes or activities. The explanation can be that the impact probably derived from outlets outside the investigated areas and may have reached the stream through runoff or with groundwater. On the contrary this study showed that the amount of Total Coliform bacteria increased with the width of the riparian zone. Total Coliforms are naturally present in soil and plants and a wider riparian zone can provide for more organic material and therefore also for more decomposed material containing coliforms. This means that runoff of such decomposed material is another possible source for Total Coliforms along Shima.

A possible explanation for the elevated concentration (far above the Peruvian limit value) of suspended particles (TSS) at site S4, during the first set, can be the increase in runoff due to an intense rainfall before the sampling. The increased runoff was also shown in the elevated discharge at this site. Similar results were found at sites along Cumbaza (see Section 5.1 above).

Chlorophyll A has no limit value in drinking water but may indicate presence of nutrients. In this study, however, the results for chlorophyll A were very doubtful due to low concentrations and error sources for the measurement equipment but overall the

[27] The notion includes drinking water from a distribution plant, water tank or food business or for drinking water tapped on bottles for sale.

concentrations lie within the same range as those measured by others in smaller pasture streams in the Brazilian Amazon (Neill et. al., 2001).

Eutrophication / acidification
There are no limit values for PO_4, K or DOC in drinking water but as high concentrations of these in streams can indicate eutrophication or acidification it is important that concentrations do not become elevated (Section 2.2.1 and Section 2.2.2). Furthermore they were all related to individual SVAP- parameters and K was also, as the only parameter, related to SVAP-index and forest cover. PO_4 and K also showed relations with the geomorphology in the watershed.

The result in this study showed an extremely high level of eutrophication based on the concentrations of PO_4 according to the criterions set by the Swedish environmental protection agency at all sites along the Shima River (Section 2.3) and further that the PO_4 concentration is decreasing downstream. Others have found relations between concentrations of PO_4 in stream water and the width of the buffer zone (Section 2.2.2). The result in this study shows increasing PO_4 concentrations with increasing width of the buffer zone. This indicates that a wider buffer zone, i.e. more forest cover, causes more PO_4 to enter the stream. Similar result has also been found by Waggoner who showed that elevated concentrations of PO_4 in stream water were more likely to occur at sites with higher proportions of forest cover compared to grass cover (Waggoner, 2006). The explanation can be that more vegetation in a wider buffer has a greater ability to reduce water velocity in the buffer zone which increases the waters travel paths creating deposits of sediment and attached phosphorus in the buffer (Section 2.1.2). PO_4 from such deposits is unavailable for plants and can reach the stream through runoff.

This study showed that more impaired physical structures provide for increasing concentrations of K in the stream which indicates that elevated concentrations of K point at a poorer water quality status according to the SVAP-method. Here elevated concentrations can indicate deterioration in water quality since it might cause a certain grade of eutrophication. Individual physical parameters that were linked to K were Bank stability and Water appearance. When the bank stability decreases the banks have a greater sensitivity for erosion and the risk of landslides increases. As a result K, which normally should have been taken up by plants, can have reached the streams through increasing runoff from cultivations. The muddy water appearance at sites with elevated concentrations can indicate a certain degree of eutrophication (Section 2.2.1). Furthermore high K concentrations were associated with extensive human wastes within the reach which can be explained by that dish-washing and laundering with soaps containing K quite often were associated with extensive evidence of human wastes within the reaches. The fact that the K concentrations were increasing with decreasing percent of forest cover in the watershed downstream along Shima strengthens our hypothesis that when trees and plants have been cut down the buffer zone loses its ability to bind K which can be released and may enter the water through runoff or leaching. Compared to the upper parts of the Shima basin the lower parts are dominated by more recent geological formations. This can also explain elevated K concentrations in the lower reaches. More recent formations may still undergo certain weathering and elevated concentrations of K in the lower reaches can be the result of weathering of such formations, such as Subrecent Alluvial deposits and Sarayaquillo.

In this study the DOC concentrations increased with a more fragmented buffer zone which proves that runoff of organic matter increases with less forest ground cover. This result can indicate that a more fragmented riparian buffer increases concentration of DOC in the water which can result in deterioration in water quality because it may cause acidification.

5.3 COMPARISON CUMBAZA – SHIMA

The water chemistry assessment showed that the variations in water quality along the Cumbaza River were larger than along the Shima River. This may be explained by the higher population density variation along the Cumbaza River compared to Shima. In sub-basin C6 almost none was living permanently but site C1 was located downstream the most populated city in the department of San Martín. Another explanation may be the larger variation in deforestation along the Cumbaza River. The highest amount of forest upstream the site was found in C6, but the lowest in C1. Along the Shima River the forest cover upstream the sites decreased downstream but not as much as in the Cumbaza basin. The deforestation is also linked to the population density. The higher deforestation in C1 compared to S1 shows that in the Cumbaza basin the total deforestation was higher than in the Shima basin where larger extents of untouched forest was found. However, differences in water chemistry between the basins may also be caused by differences in lithology.

Few correlations were found in the Shima basin between chemical variables and the percentage of forest. This could be compared to the Cumbaza basin where many chemical variables correlated with the amount of forest. It might depend on the location of the forest compared to the streams in the area, e.g. if the deforestation is high adjacent to the river it should have, at least in theory, lead to more chemicals being transported to the streams. This study shows that there is more deforestation in areas along Cumbaza than along Shima which can explain the result.

A great part of the geology was similar in the Shima basin and in the Cumbaza basin. Generally the high content of calcium rich soils in both basins would give naturally high calcium content in the streams. The chemical assessment showed generally higher calcium content in the Shima River than in the Cumbaza River. Also other ions, both negatively and positively charged, were generally found in higher concentrations in the Shima River than in the Cumbaza River as well as a higher EC value at almost all sites. Some values, e.g. EC, even exceed the values at the site that seem to be the most contaminated site, C1. This indicated a possible higher weathering process in the Shima basin and/or more lime stone and evaporite, leading to more salts being transported to the river. As the deforestation in Shima was much lower compared to Cumbaza the results in this study indicate that concentrations of ions are related to geology rather than deforestation.

Comparison of phosphate showed that higher concentrations of phosphate were generally found in the water in Shima than in Cumbaza. This can be linked to the fact of more phosphate in areas drained by more forest in Shima together with higher percentage of forest in the Shima basin. Site C1 was extremely high in ammonia which was likely due to contamination from Tarapoto and surrounding farming land. The extremely high eutrophication at C1 was shown both by the lowest SVAP-index, lowest score of the parameters Riparian zone and Structural intactness of the riparian zone as well as having the lowest percentage of forest upstream. Except for site C1 the ammonium concentrations were similar in the two rivers. This would indicate a general higher eutrophication degree in Shima than in Cumbaza. As the deforestation generally was higher in Cumbaza we expected higher values than in Shima, especially for sites C2 and C3. The Stream Reach Assessment showed low average scores compared to other SVAP indices in Cumbaza and Shima for these two sites. The scores for individual parameters such as Riparian zone and Structural intactness were also low to regular. This shows the difficulty in using only one of the methods when estimating e.g. the eutrophication grade.

In general the SVAP-index in the two rivers follows the trend seen in the chemistry assessment; the highest score was found at the uppermost sites (C6 and S6) and the lowest at the site near the outlet (C1 and S1). The variation in SVAP index along the Shima River was much less than along the Cumbaza River, i.e. the physical environment at the finest scale is impaired more slowly downstream along Shima compared to Cumbaza. The correlations test also showed that among the water variables only potassium correlated with the SVAP-index in Shima whereas in Cumbaza many correlations with water variables and SVAP-index were found. As an indication on water quality status according to the SVAP template, this result showed a closer relation between physical structures within the riparian zone and water quality for Cumbaza than for Shima.

For individual SVAP-parameters versus water variables there were also more correlations found in the Cumbaza River compared to the Shima River. Few of the correlations between SVAP parameters and chemical parameters were found in both basins. Human wastes correlates with phosphate, potassium and sodium for both basins; pools correlates with calcium; Water appearance correlates with calcium and potassium; Nutrient enrichment correlates with calcium; and Barriers to fish movement correlate with chloride for both watersheds.

The Stream Reach Assessment seems to be a good method for estimating the general physical conditions of a stream. The efficiency of working with this method when studying individual chemical parameters is, however, less clear.

There is also a difference in mean elevation and in slope between the two catchments. The Cumbaza basin has a bigger variation in mean slope and mean elevation in the sub-basins than the Shima basin. The effect of the mean slope seems to be little in both catchments as the only correlation found is with phosphate in the Cumbaza River.

In summary, even if the concentrations of ions and phosphate and also EC were generally higher in Shima compared with Cumbaza the variation of the water variable concentrations along the stream were bigger in Cumbaza. The Stream Reach Assessment as well as the Drainage Area Assessment was to a bigger extent linked to the water variables in Cumbaza compared to Shima.

5.4 CONSIDERATIONS

If one includes all the factors associated with performing a riparian habitat assessment (time, cost and resources) the SVAP-method turned out to be very effective.
The average score appeared to be a good predictor of impairments of the environment at the finest scale. Overall it was easy to use under the specific conditions within the study area. However some notions need to be done.

Some parameters were practically more difficult to estimate than others. For example, in order to be able to do an optimal and consistent estimation some practise is needed about the scorings of those parameters that involve percentage estimation. Another example is the measurement of the width of the riparian zone which in some cases was extra difficult in areas with dense vegetation and difficult terrain. The rough terrain at some sites also caused some problems in the scoring of the intactness of the riparian zone as it was quite hard to walk in some areas. The conclusion of this is simply to allow the estimation to take time.

The scoring of Riparian zone also faced another difficulty when the active channel width is very narrow and at the same time as wide as the length of the riparian zone. If this is the case the score for the parameter Riparian zone in SVAP becomes high and one has to be careful when drawing conclusions regarding the removing benefits of the buffer zone. If, for example, there is slash- and burn agriculture bordering the riparian zone and an increase in discharge leads to increasing runoff from this field, resulting in increasing concentrations of water variables in the stream, the removing benefits of the buffer cannot have been as sufficient as the high SVAP score may indicate.

Closer consideration should also to be taken to paths leading down from pasture land and cultivations to the streams as these enable free passage for transports within the riparian zone. The presence of any types of paths would lower the score for intactness of the riparian zone considerably.

In the unstructured interview the respondents were mainly adults and elderly, and usually men, whereupon the answers given to the questions about activities within the area exclusively were based on their experiences. Women, younger people and children can have complementing important information about the activities within the area and the interviews should therefore even include this group of responders.

To do a full comparison between SVAP and chemical variables more samples would have been necessary. Some samples, e.g. phosphate, would preferably been analysed sooner after the sampling collection for more accurate results. Logistics and the rough terrain made that difficult.

6 CONCLUSIONS

The physical habitat on both the stream reach scale (SVAP) and drainage area scale (forest cover) is increasingly degraded downstream both rivers. The total forest cover in year 2005 was 46% in the Cumbaza basin and 78% in Shima. The fragmentation was however high, especially in Cumbaza. The percentage of forest in the watershed was positively related to the physical habitat at the finest scale which means that deforestation at the watershed scale also put pressure on the riparian zone causing impaired physical habitats.

Adverse aquatic conditions (high nutrient, low oxygen) were measured at the site south of Tarapoto which shows the large impact the city has on the stream quality. Other chemical elements (anions and cations) were also higher at the lowermost sites in both Cumbaza and Shima and most likely the result of the geology (limestone and evaporitic deposits). The influence from deforestation cannot be ruled out especially in the case of potassium.

The Stream Reach Assessment turned out to be a method easy to use and useful in order to evaluate the physical riparian habitat at the sites along the rivers Cumbaza and Shima. SVAP-parameters could also be related to concentrations of some water quality variables which indicated that riparian structures and water quality may be linked. Although, lack of correlations, especially in Shima, indicated that more investigations are necessary before this method could be thoroughly evaluated and the efficiency of working with this method when studying individual chemical parameters is less clear. To only use this method for evaluating the water for drinking water could therefore not be recommended at this state and a chemical analysis would be necessary as a complement. However, we consider the method useful in order to educate people about their local environment and their effect on it as well as how physical characteristics within a riparian area can affect both water quality for aquatic life and drinking water quality.

The Drainage Assessment is much more technically difficult and resource demanding. It is though a good complement, in order to eliminate human source of error, for organizations and others with the sufficient education and resources, and to give an overview of a catchment. However, it is not possible to make any recommendations about the drinking water quality in neither of the rivers exclusively based on the drainage assessment. Instead a chemical analysis would be necessary as a complement. Also, instead of just analysing the amount of forest a complete land use classification is preferable.

Comparing the two methods and the rivers, this study shows that a drainage area assessment based on forest cover can be a better predictor of the water quality in the Cumbaza River as compared with the Stream Reach Assessment. On the contrary, for Shima, the Stream Reach Assessment is to a greater extend linked to water quality and thus seems to be the better predictor. Neither the percentage of forest nor the SVAP index and SVAP individual parameters could be related to Total Coliforms or E. coli (except Riparian zone in Shima), which shows that neither of the methods is adequate to determine if the water is suitable as drinking water.

The stream water at the investigated sites can not be recommended as drinking water without treatment, for neither of the streams. This is due to the presence of bacteria at all sites. For one site, S4, the result is unknown as it could not be analysed for bacteria. No relation between bacteria and chemical variables was found why bacteria analyses are recommended to classify the drinking water. High concentrations of nitrite and total aluminium for sites along Shima also lead to bad drinking water quality. Many sites in the Cumbaza River have very high levels of bacteria and are not even suitable for bathing. We would highly recommend boiling the water at all sites in both basins before any consumption.

In summary, for investigation of water quality, we recommend that a chemical analysis is done. To evaluate the environment and its impact on the stream water both a classification in GIS and a Stream Reach Assessment could be recommended for Cumbaza. Based on our results especially a Stream Reach Assessment could be recommended for Shima. For both rivers supplement of physical and also biological parameters are recommended in order to receive more information about the streams. More investigations are also recommended for both streams to further evaluate the suitability of these to physical assessments in Cumbaza and Shima basins.

Finally we can conclude that the water chemistry in surface waters is very complex and depend on many parameters which lead to difficulties when evaluating the water quality. There is still a lot to learn about the complexity of the watersheds as well as the stream reach to learn how we may save the fresh water in this area.

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APPENDICES

APPENDIX 1

STREAM VISUAL ASSESSMENT PROTOCOL

River:____

Site nr: _________**Site coordinates:**_________________ **Date and time:**_______________

Landowner's name (if applicable):____

Evaluator's name:____

Weather conditions:

Active channel width: __________**(m) Size of the reach:** _____________ **(m)**

Applicable reference site:____

<table>
<tr><th>Parameters</th><th>Score</th><th>Comments</th></tr>
<tr><td>Stream physical structure and changes</td><td></td><td></td></tr>
<tr><td>1. Channel condition</td><td></td><td></td></tr>
<tr><td>2. Frequency of flooding (time/year)</td><td></td><td></td></tr>
<tr><td>Stream stability and integrity</td><td></td><td></td></tr>
<tr><td>3. Riparian zones (to fill in: lowest score)
<table>
<tr><td>Transect:</td><td>1</td><td>2</td><td>3</td><td>Average</td><td>Score</td></tr>
<tr><td>Left width:</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Right width:</td><td></td><td></td><td></td><td></td><td></td></tr>
</table></td><td></td><td></td></tr>
<tr><td>4. Structural intactness of the riparian zone (to fill in: lowest score)
<table>
<tr><td>Side:</td><td>%</td><td>Score</td></tr>
<tr><td>Left side</td><td></td><td></td></tr>
<tr><td>Right side</td><td></td><td></td></tr>
</table></td><td></td><td>Grass or bare ground?</td></tr>
<tr><td>5. Bank stability (to fill in: lowest score)
<table>
<tr><td>Side:</td><td>%</td><td>Score</td></tr>
<tr><td>Left side</td><td></td><td></td></tr>
<tr><td>Right side</td><td></td><td></td></tr>
</table></td><td></td><td></td></tr>
<tr><td>Suitability of the streams for fish</td><td></td><td></td></tr>
<tr><td>6. Barriers to fish movement</td><td></td><td>Dams within 3.2 – 4.8 km upstream or downstream?</td></tr>
<tr><td>7. Instream fish cover (number of habitat-types)</td><td></td><td></td></tr>
<tr><td>8. Pools</td><td></td><td></td></tr>
<tr><td>9. Canopy cover (%)</td><td></td><td></td></tr>
</table>

10. Riffle embeddedness		
Other factors to assess		
11. Water appearance		
12. Nutrient enrichment		
13. Manure presence		
14. Human waste		
15. Human activity		
Total score		
Average score (Total score divided by numbers of parameters)		

APPENDIX 2

SCORING DESCRIPTIONS

1. Channel condition

Score	10	7	3	1
Condition	Natural conditions. No evidence on straightening or channelization of the stream.	Evidence of past channel alterations but natural bottom and banks.	Channel stabilisation through riprap and/or sediment.	Bank stabilisation of both banks and bottom.

2. Frequency of flooding

Score	10	7	3	1
Condition	Flooding every 1.5 to 2 years. No dams or dikes limiting the streams access to the flood plain.	Flooding only once every 3 to 5 years.	Flooding once every 6 to 10 years.	No flooding.

3. Riparian zones

Score	9-10	7-8	5-6	3-4	1-2
Condition	Natural vegetation extends at least two active channel widths on each side.	Natural vegetation extends one active channel width on each side. *or* If less than one width, covers the entire flood plain.	Natural vegetation extends half of the active channel width on each side.	Natural vegetation extends a third of the active channel width on each side	Natural vegetation extends less than a third of the active channel width on each side.

4. Structural intactness of the riparian zone.

Score	9-10	7-8	5-6	3-4	1-2
Condition	< 20 % of the natural vegetation is fragmented.	20-40 % of the natural vegetation is fragmented.	40-60 % of the natural vegetation is fragmented.	60-80 % of the natural vegetation is fragmented.	> 80% of the natural vegetation is fragmented.

5. Bank stability

Score	10	7	3	1
Condition	Banks are stable and low. > 33 % of the stream bank is protected by roots that extend to the base-flow elevation. 0-25 % risk of erosion.	Moderately stable and low banks. < 33% of the stream bank is protected by roots that extend to the base-flow elevation. 25-50 % risk of erosion.	Moderately stable banks.Typically high. Overhanging vegetation at top of the bank. Some mature trees falling into stream annually. 50-75 % risk of erosion.	Unstable and high banks. Overhanging vegetation at top of the bank. Mature trees falling into stream annually. >75 % risk of erosion

6. Barriers to fish movement

Score	10	7	3	1
Condition	No barriers.	Seasonal water withdrawals inhibit movement within the reach.	Dams, dikes and diversions, < 0,3 m drop.	Dams, dikes and diversions, > 0,3 m drop.

An interview can give answers regarding the presence of dams at a distance of 3.2 to 4.8 km (2-3 miles) upstream or downstream the reach.

7. Instream fish cover

Score	9-10	7-8	5-6	3-4	1-2
Condition	>7 cover types available.	6-7 cover types available.	4-5 cover types available.	2-3 cover types available.	None to one cover type available.

Cover types: pools, boulders/cobble, riffles, woody debris, overhanging vegetation, dense macrophyte beds, undercut banks, isolated pools (places that not connect with the main stream) and root mats under the water.

8. Pools

Score	10	7	3	1
Condition	Deep and shallow pools abundant. > 30 % of the pool bottom is obscure due to depth.	Pools present, but not abundant. 10-30 % of the pool bottom is obscure due to depth.	Pools present, but shallow. 5-10 % of the pool bottom is obscure due to depth.	Pools absent or the entire bottom is discernible.

Generally only one to two pools are present within an area of 12 times the active channel width. Therefore it is a good idea to look within a larger reach. <u>Definitions:</u> deep pool = the pool is about 1.5 times deeper than average stream depth, shallow pool = the pool is < 1.5 times of the average stream depth.

9. Canopy cover

Score	10	7	3	1
Condition	>75 % of water surface shaded of vegetation	50-75 % of water surface shaded of vegetation	25-50 % of water surface shaded of vegetation	< 25 % of water surface shaded of vegetation

10. Riffle embeddedness

Score	10	8	5	3	1
Condition	Gravel or cobble particles are < 20% embedded in bottom sediment.	Gravel or cobble particles are 20-30 % embedded in bottom sediment.	Gravel or cobble particles are 30-40 % embedded in bottom sediment.	Gravel or cobble particles are > 40 % embedded in bottom sediment.	Riffle is completely embedded in sediment.

11. Water appearance

Score	10	7	3	1
Condition	Very clear, or clear but tea coloured. No oil sheen on surface. No oil film, submerged objects or rocks.	Occasionally cloudy. No oil sheen on surface. Submerged objects or rocks can have slightly green colour.	Considerable cloudiness most of the time. Submerged objects or rocks covered with heavy green or olive-green film. *or* Moderate odour of ammonia or rotten eggs.	Very turbid or muddy appearance most of the time. Skum Floating algal mats, surface scum, sheen or heavy coat of foam on surface. *or* Strong odour of chemicals, oil, sewage, other pollutants.
	Visible depth on 1-2 m.	Visible depth on 0.5-1 m.	Visible depth on 1.5 dm to 0.5 m.	Visible depth < 1.5 dm

For shallow waters the estimation can be based on the visual criterions whereas for deeper waters the estimation can be based on visible depth criterions.

12. Nutrient enrichment

Score	10	7	3	1
Condition	Clear water along the entire reach. Low quantities of many species of macrophytes. Little algal growth on stones and debris present.	Fairly clear or slightly greenish water along the entire reach. Moderate algal growth on stream substrates.	Greenish water along the entire reach. Overabundance of lush green macrophytes. Abundant algal growth especially during warmer months.	Pea green, gray or brown water along entire reach. Dense stands of macrophytes clog streams. Severe algal blooms create thick algal mats in stream.

13. Manure presence

Score	10	7	3	1
Condition	No evidence of livestock having access to riparian zone.	Evidence of livestock having access to riparian zone	Occasional manure in stream or waste storage structure located on the flood plain.	Extensive amount of manure on banks or in stream *or* Untreated human waste discharged to the stream.

14. Human waste

Score	10	7	3	1
Condition	No evidence on human waste within the reach.	Occasionally evidence on human waste within the reach.	Considerable amount of waste material within the reach.	Extensive amounts of waste material within the reach. *and/or* Stationary refuse dumps on the bank.

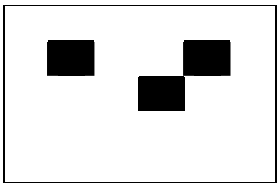
15. Human activity

Score	10	7	3	1
Condition	No activity	Partly activities.	Moderate activities.	Extensive activities.

Activities: doing laundry, bathing, washing-up etc.

APPENDIX 3

Example of percent distibution.



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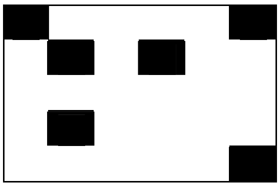

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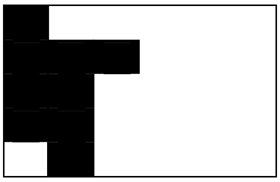

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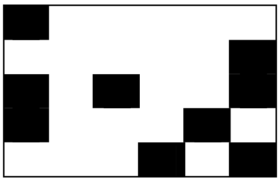

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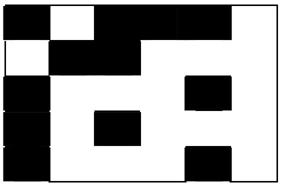

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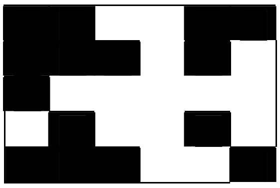

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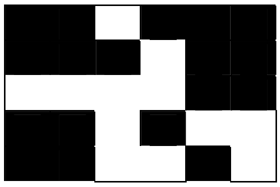

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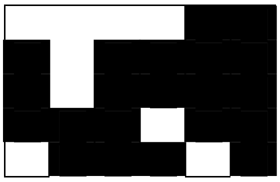

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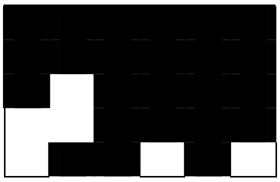

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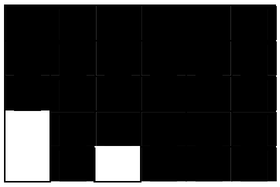


90%

APPENDIX 4 The coordinates for each site.

The coordinate system used was: UTM WGS 84 zone 18S

Cumbaza	Coordinates
C1	0348024/9279094
C2	0348076/9284882
C3	0347244/9287988
C4	0342474/9294758
C5	0337024/9297400
C6	0338611/9300579

Shima	Coordinates
S1	0299680/9237359
S2	0297847/9237198
S3	0296098/9236018
S4	0292950/9240160
S5	0291193/9245891
S6	0287420/9248936

APPENDIX 5 The results of chemical analysis and hydrological measurements, Cumbaza basin.

Site	Q M3/s	T º C	pH	EC mS/m	TSS ppm	DO mg/L	PO4 mg/L	NH4-N mg/L	Ch_A µg/L
C11	0.95	26.7	7.4	52	62	3	2.098	4.78	2.6
C12	0.758	32	9.3	11	51	9	0.0035	0.07	1.6
C13	2.104	24	8.2	4	65	8.8	0.0035	0.04	1.4
C14	2.044	24	5.5	4	42	8.8	0.0035	0.04	1.3
C15	1.076	21.9	5.9	4	28	8.2	0.0035	0.04	1.1
C16	0.032	18.6	4.3	0.1	31	8.1	0.0035	0.25	3.1
C21	0.98	29	7.5	55	67	5.3	2.424	3.35	1.2
C22	0.747	26.8	8.6	16	18	7.6	0.0035	0.05	0.8
C23	1.197	26.2	8	6	21	7.8	0.0035	0.02	1.9
C24	2.838	23.6	7.1	0.4	26	6.9	0.0035	0.03	1.2
C25	1.3	20	6.4	0.1	48	7.5	0.0035	0.02	0.4
C26	0.054	18.1	4.6	0.9	11	8.1	0.0035	0.04	2.4

* The phosphate values for C2-C6 were too low to be detected; half the detection limit (0.007 mg/L) was used in the Spearman´s correlations matrix.

Site	Ca Mg/L	Mg mg/L	K mg/L	Na mg/L	HCO3 mg/L	SO4 mg/L	Cl mg/L
C11	57.31	9.97	7.04	27.36	213.56	12.99	28.36
C12	17.23	2.31	1.56	5.06	67.12	0.32	10.64
C13	9.22	1.7	1.56	3.22	32.95	0.48	7.09
C14	6.01	0.97	0.78	0.92	18.31	0.16	7.09
C15	5.61	0.85	1.17	0.92	18.31	0.16	7.09
C16	1.8	0.36	0.78	0.46	7.32	0.48	3.55
C21	67.13	11.3	7.82	34.94	197.7	23.25	2.13
C22	22.65	2.43	1.96	4.83	68.95	0.48	8.51
C23	10.22	1.46	1.17	0.92	34.78	0.64	8.51
C24	7.01	0.85	1.17	0.69	25.02	0.48	6.38
C25	4.41	0.49	0.78	0.23	12.2	1.92	1.77
C26	3.01	0.36	0.39	0.23	4.88	0.48	3.55

** The sulphate values for C4 and C5 (second set) were to low to be detected; half the detection limit (0.32 mg/L) was used in the Spearman´s correlation matrix.

APPENDIX 6 The results of chemical analysis and hydrological measurements, Shima basin (n.d. =no data).

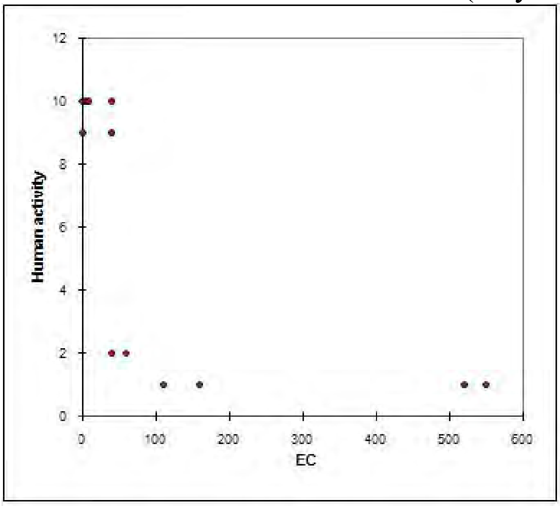
Site	Q	T	pH	EC	TSS	DO	PO4	NH4-N	NO3-N	NO2-N	DOC	Ch_A	Al soluble
	m3/s	º C		mS/m	ppm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L
S11	0.851	26.8	8.34	70	34	9	0.0117	0.01	0.05	0.015	2.31	2.9	8
S12	0.543	24.7	7.83	34	22.5	8.4	0.133	0.01	0.125	0.0515	2.735	1.3	6
S13	0.906	24	7.24	26	64	7.5	0.181	0.02	0.35	0.028	5.38	2.0	17
S14	2.035	23.4	7.1	58	139.5	7.6	0.344	0.015	0.25	0.0625	4.3	0.9	16
S15	0.462	24	7.73	31	16	7.6	0.195	0.005	0.05	0.009	2.33	1.7	7
S16	0.102	23.3	7.71	42	19.5	7.7	0.135	0.03	0.05	0.0065	1.155	1.1	9
S21	0.661	25.4	7.68	64	16	8.5	0.099	0.04	0.13	0.008	5.11	1.8	19
S22	0.452	24.8	7.44	31	24	7.5	0.12	0.03	0.2	0.011	2.38	0.7	17
S23	1.121	24.3	7.15	29	32	7.4	0.142	0.04	0.13	0.03	3	1.4	41
S24	0.463	26.7	7.22	30	26	8.8	0.202	0.04	0.11	0.062	2.43	0.9	22
S25	0.569	27	7.78	28	28	8.1	0.172	0.04	0.13	0.021	1.9	1.4	17
S26	0.378	24.6	7.47	31	56	7.3	0.148	0.03	0.37	0.028	3.07	1.7	18

* The NH_4-N value for S15 was too low to be detected; half the detection limit (0.005 mg/L) was used in the Spearman's correlations matrix.
** The NO_3-N values for S11, S15 and S16 were too low to be detected; half the detection limit (0.05 mg/L) was used in the Spearman's correlations matrix

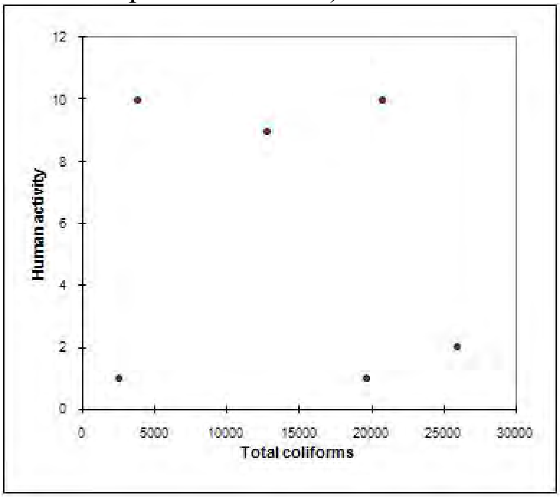
Site	Al part.	Fe soluble	Fe part.	Ca	Mg	K	Na	HCO3	SO4	Cl	E. coli	Total Coliforms
	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	ufc/100 mL	ufc/100 mL
S11	21	5	70	49.1	4.5	2.74	89.89	97.63	0.8	177.25	130	900
S12	27.5	15	70	50.3	4.13	1.96	18.28	186.71	0.08	23.04	80	2000
S13	207	40	180	39.68	2.67	1.56	9.89	145.22	1.28	10.64	90	900
S14	780.5	30	525	45.28	3.16	1.76	11.15	151.93	0.4	19.5	n.d	n.d
S15	34	30	70	52.71	3.28	1.17	13.33	186.1	3.05	14.18	190	5600
S16	109	5	100	61.82	3.83	1.17	18.16	146.44	16.51	28.36	90	1200
S21	41	50	100	46.69	3.65	2.74	68.97	142.17	0.16	96.42	n.d	n.d
S22	50	60	100	44.89	3.04	1.96	13.79	141.56	0.48	19.85	n.d	n.d
S23	73	80	110	43.29	2.55	1.56	10.12	137.29	0.16	10.64	n.d	n.d
S24	55	60	80	45.49	2.55	1.17	9.66	140.34	0.16	9.22	n.d	n.d
S25	41	60	70	44.09	2.31	1.17	9.2	129.36	0.16	9.22	n.d	n.d
S26	62	60	70	49.3	2.55	1.17	12.87	136.07	7.38	12.05	n.d	n.d

APPENDIX 7 Scatterplots showing correlations between SVAP-parameters and chemical variables in Cumbaza and Shima basins.

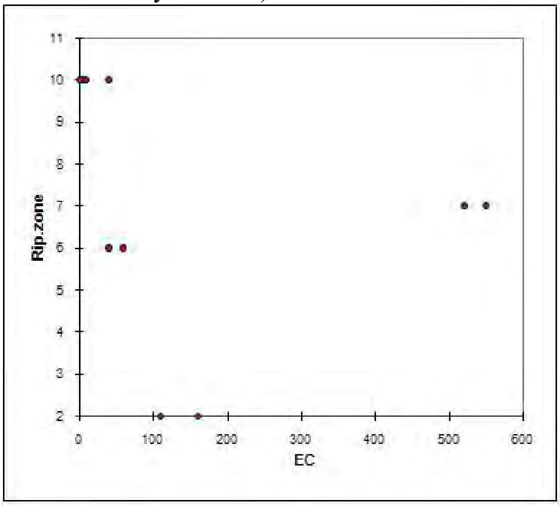
Correlations in the Cumbaza River (only a selection of plots are shown).



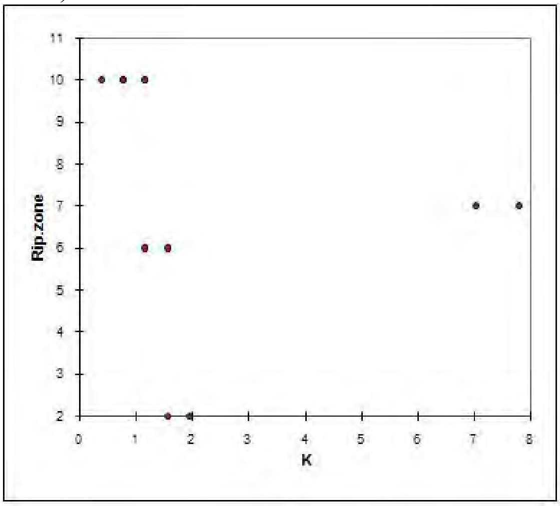
Human activity versus a) EC



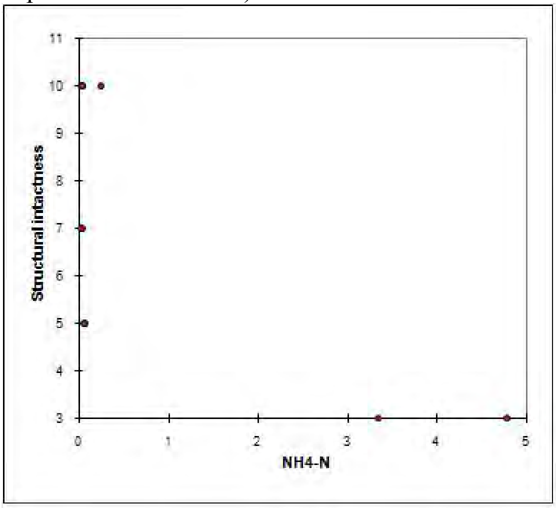
and b) Total Coliforms



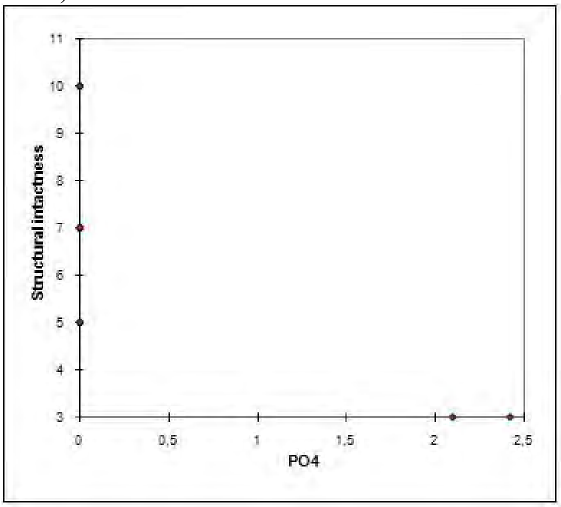
Riparian zone versus a) EC



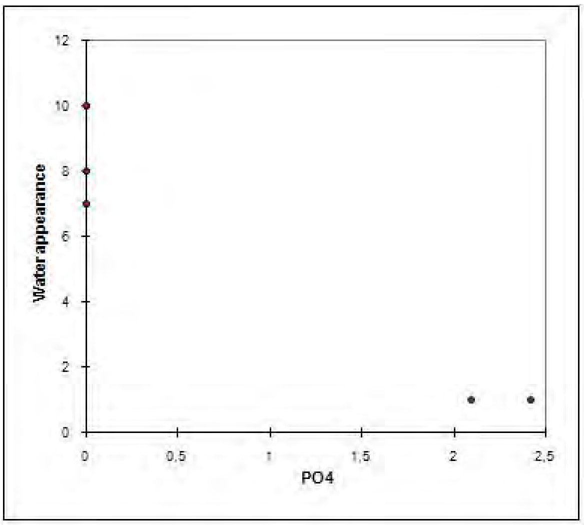
and b) K



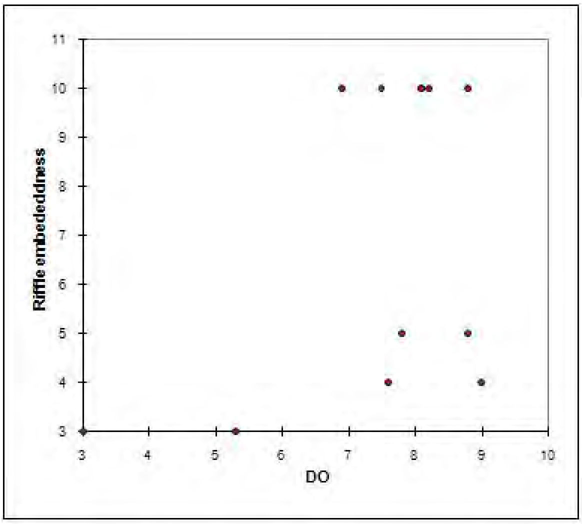
Structural intactness versus a) NH4-N



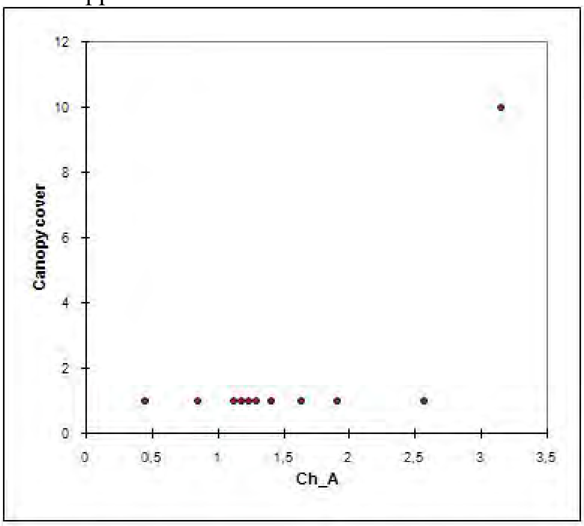
and b) PO4



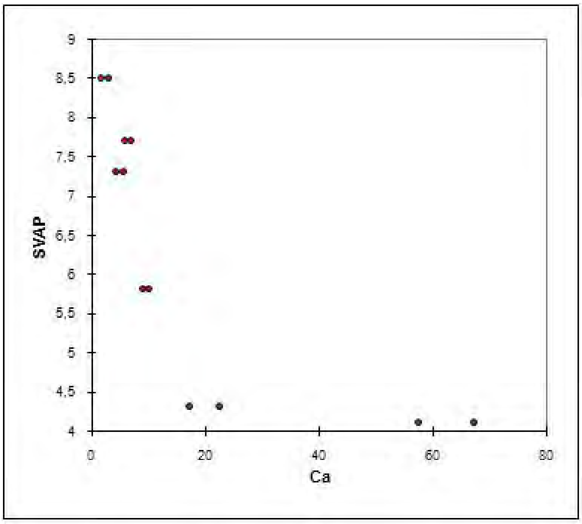
Water appearance versus PO4



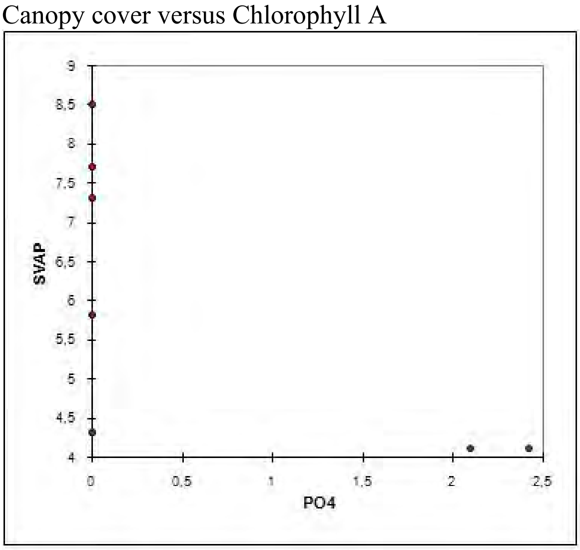
Riffle embededdness versus DO



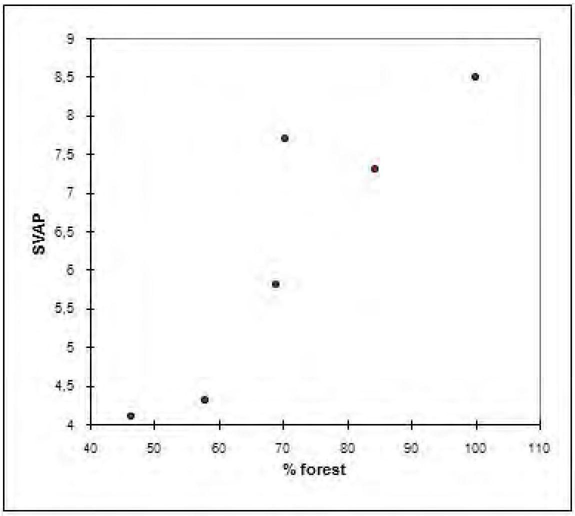
Canopy cover versus Chlorophyll A



SVAP versus Ca

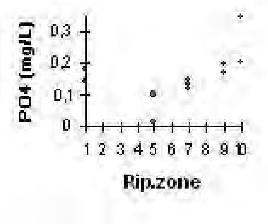


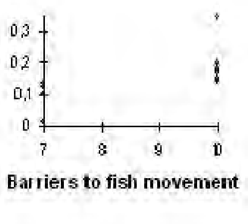
SVAP versus PO4

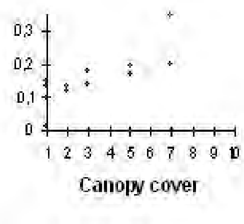


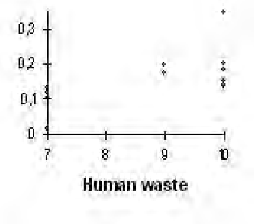
SVAP versus percentage forest

Correlations in the Shima River.



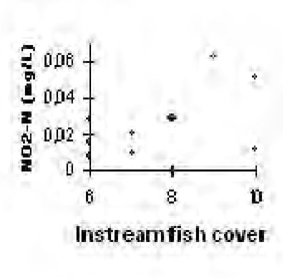


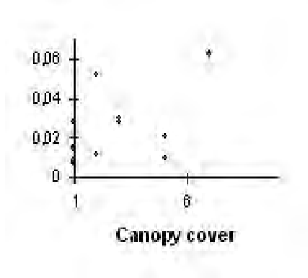




a b c d

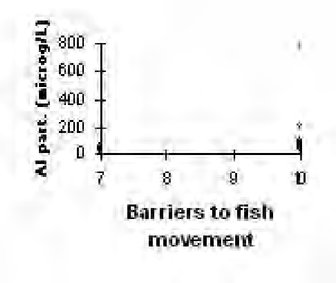
Phosphorus versus a) Riparian zone b) Barriers to fish movement c) Canopy cover and d) Human waste.

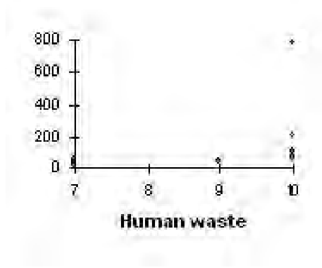




a b

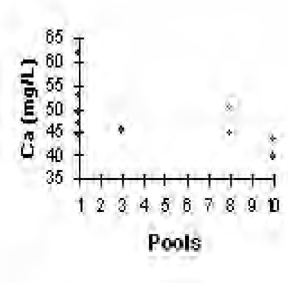
Nitrite versus a) Instream fish cover and b) Canopy cover.

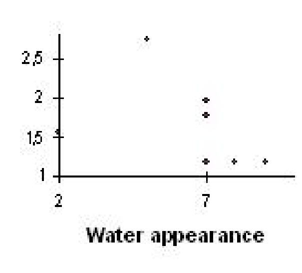


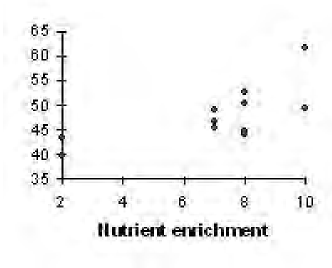


a b

Particulate aluminium versus a) Barriers to fish movement and b) Human waste.

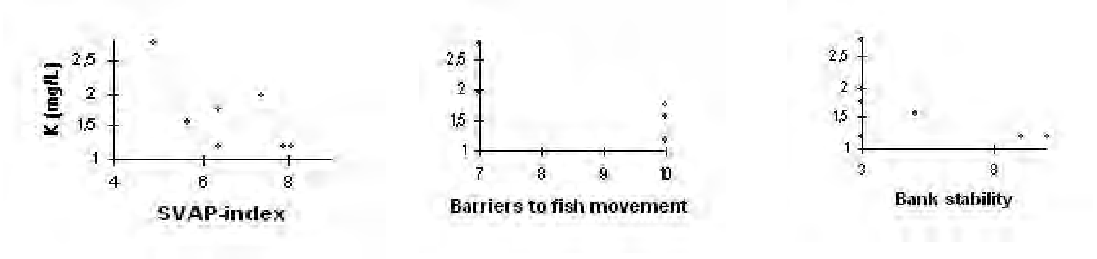




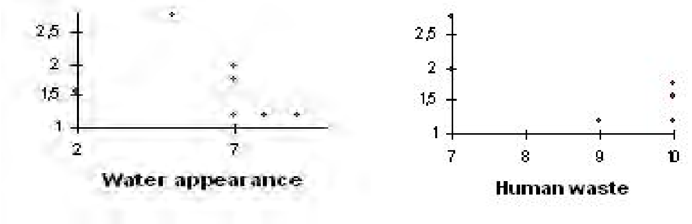


a b c

Calcium versus a) Pools b) Water appearance and c) Nutrient enrichment.

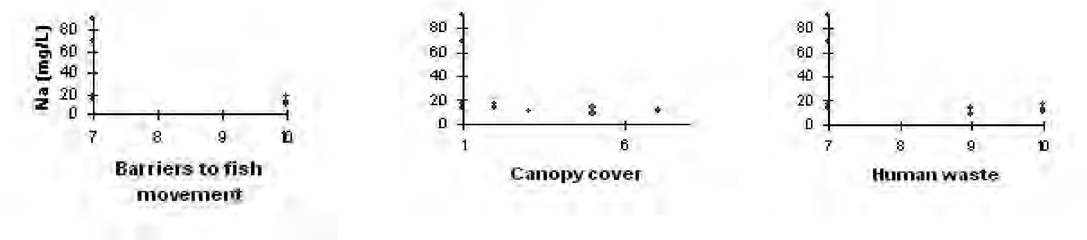


a b c



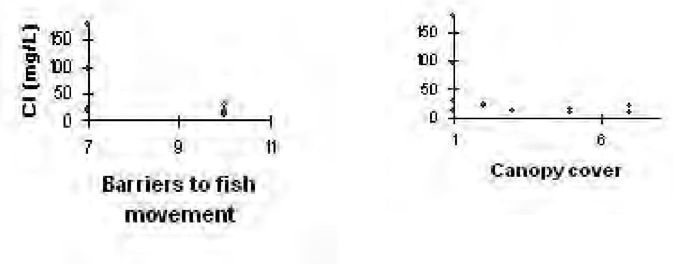
d e

Potassium versus a) SVAP-index b) Barriers to fish movement c) Bank stability d) Water appearance and e) Human waste.



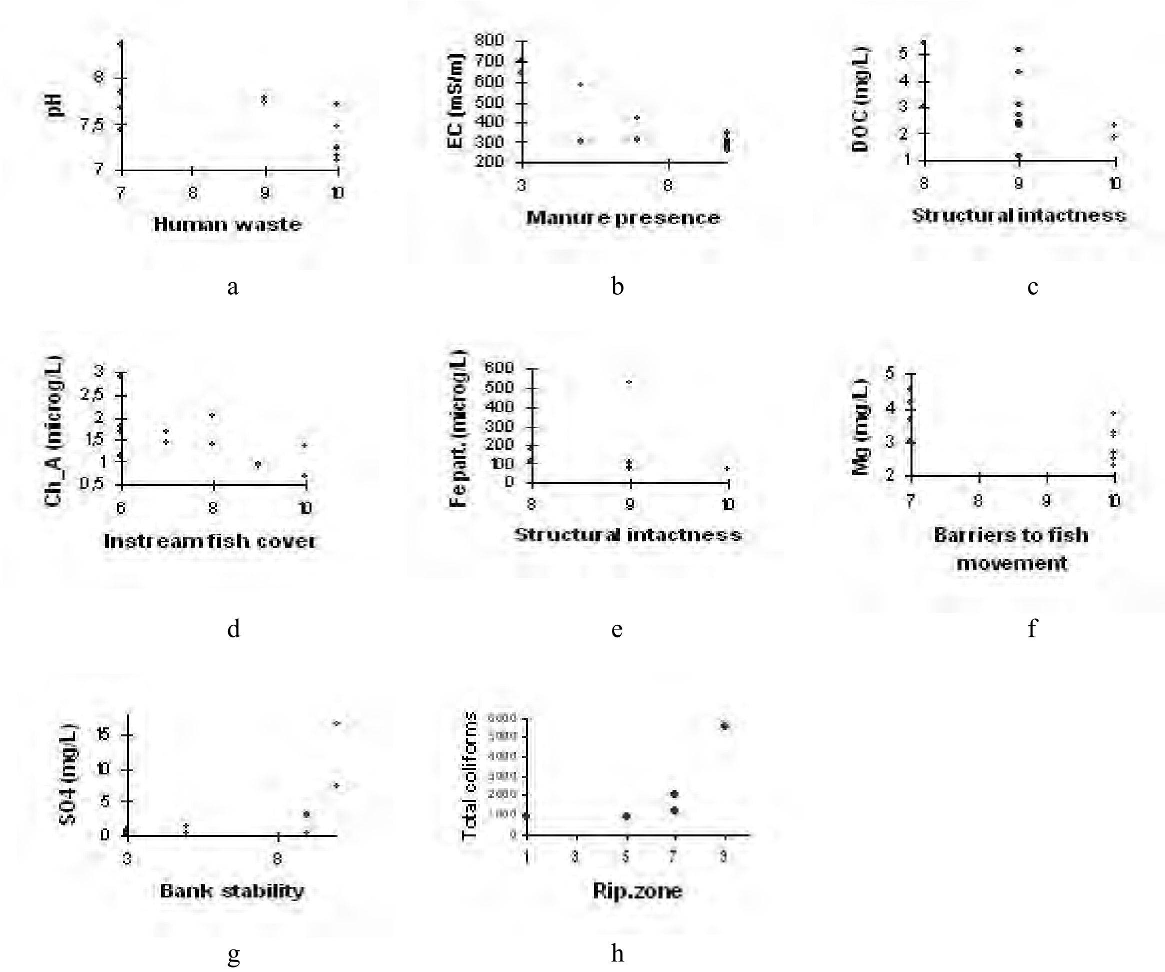
a b c

Sodium versus a) Barriers to fish movement b) Canopy cover and c) Human waste.



a b

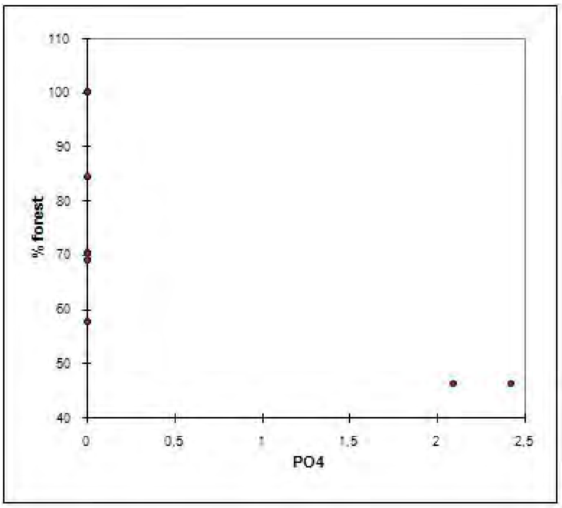
Chloride versus a) Barriers to fish movement and b) Canopy cover.



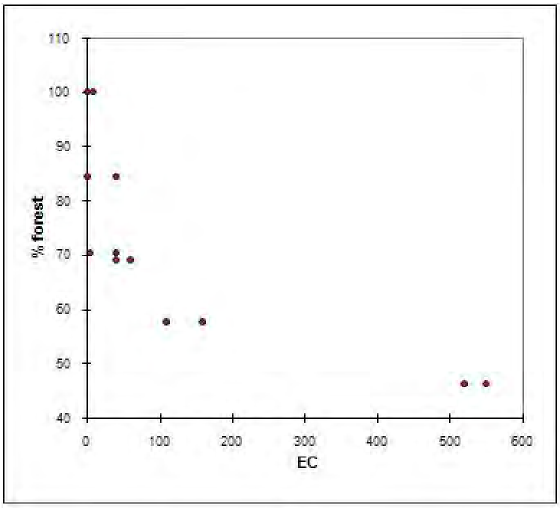
Individual water variables versus SVAP-parameters a) pH vs. Human waste b) EC vs. Manure presence c) DOC vs. Structural intactness d) Chlorophyll A vs. Instream fish cover e) Particulate iron vs. Structural intactness f) Magnesium vs. Barriers to fish movement g) Sulphate vs. Bank stability and h) Total Coliforms vs. Riparian zone.

APPENDIX 8 Scatterplots showing correltaions between chemical variables versus i) forest cover and ii) metres above sea level in the Cumbaza and Shima basins.

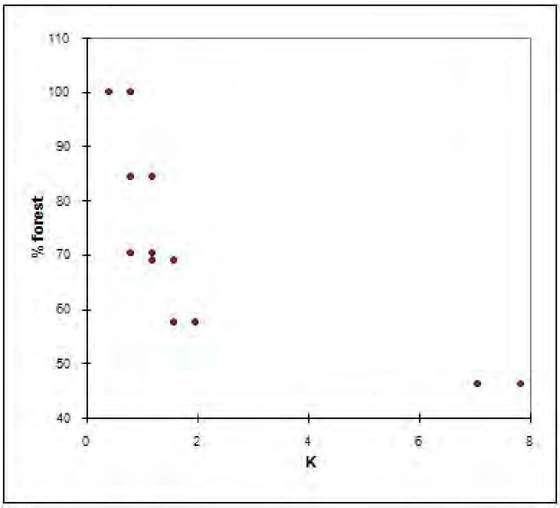
Correlations in the Cumbaza River.



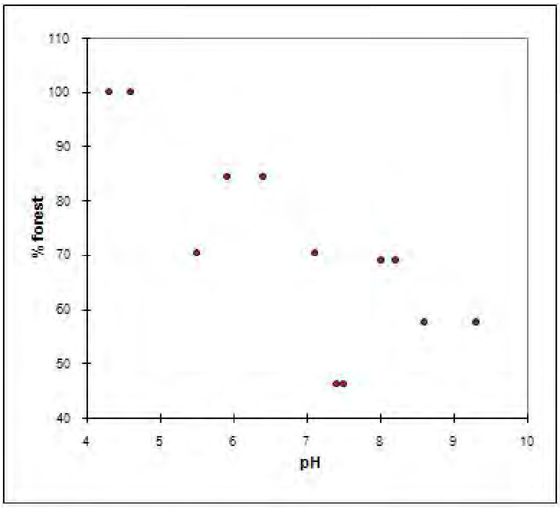
Amount forest vs PO4



Amount forest vs EC

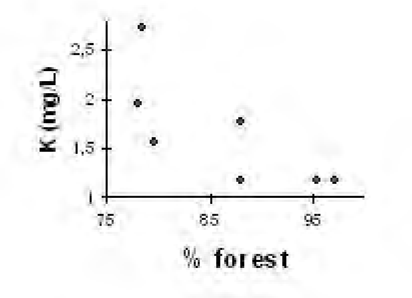


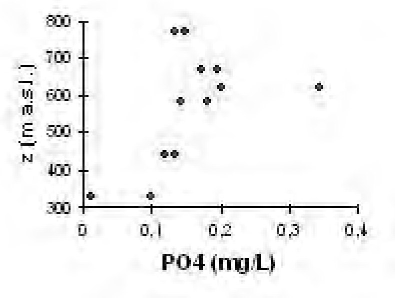
Amount forest vs K

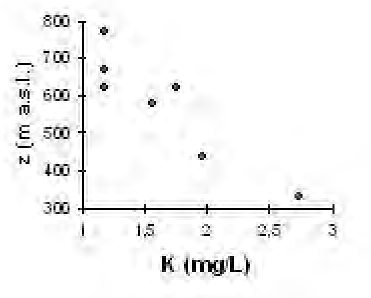


Amount forest vs pH

Correlations in the Shima River.







a b c

a) Potassium versus percentage forest cover and m a.s.l. versus b) Phosphorus and c) Potassium