Report: Ecological water quality assessment of the Mpanga catchment, Western Uganda

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Preface

This project was executed jointly by PROTOS and Ghent University, with the support of Mountains of the Moon University and collaboration with the Albert Water Management Zone under the Ministry of Water and Environment (MWE).

PROTOS is a Belgian NGO involved in the development and improvement of sustainable water resource management in currently nine developing countries across the world. The organisation is active in Uganda since 2000 and has, in partnership with the Directorate of Water Resources Management (DWRM, MWE), been working with relevant stakeholders within the Mpanga catchment area to develop strategies for conserving its natural resources. As a result, a Catchment Management Organisation (CMO) has been formed, spear-headed by a Catchment Management Committee, the task of which is to plan and monitor activities in the Mpanga Catchment under the Integrated Water Resources Management Framework.

The research group of Aquatic Ecology (AECO) of the Faculty of Bioscience Engineering at Ghent University, Belgium, has over 20 years of experience in water quality assessment of freshwater ecosystems. AECO is active in Belgium and different developing countries around the world, addressing contemporary issues related to aquatic ecosystems.

Mountains of the Moon University (MMU) was established in 2005 in Fort Portal, Western Uganda. The university has five schools, of which the School of Agriculture and Environmental Sciences has three laboratories for water, soil, and agriculture related research. It educates students in different aspects related to agriculture and environmental conservation.

The project was funded by the Flemish government through the Vlaams Partnerschap Water voor Ontwikkeling (VPWvO) and was executed by PROTOS and Ghent University. Additional co-funding was obtained through Music For Life, as a result of a beer-selling action in the Faculty of Bioscience Engineering. Moreover, co-funding was provided by AECO from Ghent University, in particular related to staff funding and sampling material provision. Local support during field work was provided though the PROTOS UGANDA office in Fort Portal, while the main executive field team consisted of five PhD students from the AECO research team from Ghent University, and the coordinator of the Natural Resources Defence Initiative. The Directorate of Water Resources Management (DWRM, MWE) and Mountains of the Moon University supported the project by providing work space in the water research laboratory of the School of Agriculture and Environment, and by letting staff regularly help with field and laboratory activities. Therefore, the team is also grateful for the support via the VLIR-UOS IUC Mountains of the Moon.

Credits

Please refer to this work as follows:

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The AECO team would also like to give special thanks to staff of the Y.E.S. Hostel, in particular to Florence and Phiona, for their good care and delicious meals during the team's stay in Fort Portal.

This report was submitted to PROTOS in March 2017.

List of abbreviations

Institutions / Organisations / Administration	
AECO	Aquatic Ecology Research Group (Ghent University)
AWMZ	Albert Water Management Zone
CMO	Catchment Management Organisation
DWRM	Directorate of Water Resources Management
GoU	Government of Uganda
IUC	Institutional University Cooperation
MMU	Mountains of the Moon University
MWE	Ministry of Water and Environment
NGO	Non-governmental organisation
NWSC	National Water and Sewerage Corporation
RM-CMP	River Mpanga - Catchment Management Plan
SAES	School of Agriculture and Environmental Sciences
VLIR-UOS	Flemish Interuniversity Council for University Development Cooperation (Vlaamse Interuniversitaire Raad - Universitaire Ontwikkelingssamenwerking)
VPWvO	Vlaams Partnerschap Water voor Ontwikkeling
WAC	Compendium for Water Analysis

Scientific	
BMWP	Biological Monitoring Working Party
BOD	biochemical oxygen demand
chl-a	chlorophyll a, pigment in algae and plants
COD	chemical oxygen demand
DFP	Sampling area 'downstream Fort Portal'
DO	dissolved oxygen
EC(25)	electric conductivity (standardised to 25°C)
GPS	Global Positioning System
IFP	Sampling area 'in Fort Portal'
KW	Sampling area 'Kamwenge'
m a.s.l.	metres above sea level
MMIF	Multimetric Macroinvertebrate Index Flanders
MW	megawatt
NH_4	ammonium
NO_2	nitrite
NO_3	nitrate
NTU	nephelometric turbidity units
o-PO_4	ortho-phosphate
SASS5	South African Scoring System version 5
TC	total carbon
TIC	total inorganic carbon
TOC	total organic carbon
TotN	total nitrogen
TotP	total phosphorus
UFP	Sampling area 'upstream Fort Portal'
µS	micro-Siemens

Summary

The present study was conducted to support management activities in the Mpanga catchment by providing an overview on the current ecological quality state of streams and rivers within the catchment. Good ecological quality is needed to maintain the integrity of a river system and depends on the preservation of natural (chemical and biological) conditions of the water and the surrounding environment. Unsustainable use and pollution through various human activities can impair the ecological state of a natural system by altering its chemical composition and the biological communities that naturally occur in it. To assess the ecological state of the Mpanga, chemical, biological and hydromorphological data were collected in the streams within its catchment area.

The study area includes the Mpanga's headwaters at the foothills of the Rwenzori Mountains, the urbanised area of Fort Portal, the tea estates area downstream of Fort Portal and the downstream area in Kamwenge district until shortly before the joint of Mpanga with Lake George. Knowledge on potential human pressures and impacts on the Mpanga river ecosystem allowed to set up a monitoring map including key locations where these pressures can be assessed.

Results from the upstream area confirm that river sediment extraction has a large influence on the physical and chemical water quality. River bed and bank erosion increase the transport of suspended solids and nutrients downstream, driving up the cost and treatment effort that the National Water and Sewerage Corporation has to invest for making the water drinkable. While the impact on the general biodiversity of macroinvertebrates (e.g. river insect larvae), is less pronounced at present, the continuation of these extraction activities threaten the habitat availability for macroinvertebrates that depend on natural river banks and unpolluted water. Chemical and biological water quality were further lowered by certain urban pressures, which can be mainly linked to improper waste and sewage disposal, as to the absence of natural bank environments. Downstream of the urban area, where human pressure is less intense and where banks are less modified and protected from surrounding land use practices by a protection zone of natural vegetation, both chemical and biological quality improve. The river system recovers further as it passes through Kibale Forest Natural Park, which leaves time for suspended solids (turbidity) to settle and allows chemical and biological processes to lower the water's mineral, salt and nutrient-load. Influence from agriculture in Kamwenge is reflected in the water chemistry, but seems to be sufficiently small-scale to not seriously impair macroinvertebrate biodiversity, with the exception of some locations. The Mpanga hydropower dam alters the hydrology of the river, but has little additional influence on the chemical and biological quality of the system. Downstream of the dam, at short distance of Lake George, a protected area was established along the river banks to prevent further decline of the last remaining population of an endangered species of cycad. With this location harbouring the highest number of macroinvertebrate taxa in the study, the importance is highlighted of not only maintaining good water quality, but also a natural surrounding environment to ensure the preservation of natural riverine systems.

1. Introduction

1.1 Project background

Regulatory context

PROTOS has been collaborating with the Directorate of Water Resources Management, one of the three directorates of Uganda's Ministry of Water and Environment, responsible for the sustainable and integrated development and management of water resources. Within Mpanga catchment, PROTOS has been spearheading the implementation of the activities and facilitating creation of a multi-stakeholder platform for integrated water resource management.

In 2010 a Catchment Management Organization (CMO) was set up for mobilising resources and coordinating of activities. Its tasks involve mapping and delineating the sub-catchment, assessments and studies, awareness raising, community level participatory planning and consultations amongst the local governments, the private sector, civil society organizations, local communities and the central government agencies. Initially there was a draft catchment management plan developed by PROTOS which was later in 2015 updated and finalized. The Catchment Management Plan has been driven by the overall goal to ensure a well-managed River Mpanga catchment providing equitable and wise use of social, ecological and environmental services to the local and international community.

The Government of Uganda (GoU), through the Ministry of Water and Environment (Directorate of Water Resources Management), has been working in close collaboration with PROTOS, the district Local Governments, Civil Society Organizations, the private sector and the communities in implementing the Mpanga River Catchment Management Plan.

The River Mpanga Catchment Management Plan (RM-CMP) identifies and proposes suggestions of the possible interventions using the integrated water resources management approach. The plan takes into consideration the natural resources in the basin, their economic potential and identifies conservation threats from catchment wide processes by participatory decision and consensus making. The plan proposes management strategies that take into account the natural ecological linkages, conservation objectives and needs in designated areas and highlights targeted research to guide natural resource management and overall conservation of the basin while ensuring sustainable livelihoods.

In this context, the present project aims to support management activities in the Mpanga catchment, as it provides a first source-to-mouth ecological assessment of the area.

The Mpanga catchment

The Mpanga catchment is situated in Western Uganda and encompasses rural and urban settlements, valuable nature parks and ecosystems that depend on its waters. The Mpanga River system is the main fresh water resource for the communities that live along its banks, who rely on clean water for consumption, agriculture and fishery. Since the river flows into Lake George, the state of Mpanga is also contributing to the quality of the lake and its fish stock. In recent years, water quality of the Mpanga has been getting affected by human activities. Forestry and river sediment extraction in the catchment area may be providing economic advantages, but affect the water quality, flora and fauna downstream. Complaints about dirty, turbid tap water and concerns about the increased risk of getting water-borne diseases are urging the Mpanga CMO, PROTOS and local stakeholders to take action. To

prevent the system from getting overexploited, it is essential to implement sustainable ways of rural and urban development, especially with regard to water resource management.

The relevance of ecological quality

The relevance of a water body for human use lies in the amount and quality of services it can provide, such as drinking and irrigation water provision, natural water purification, support of fishery and aquaculture, or recreational uses. The sustainable, long-term use of such services depends strongly on the health of the system and is linked to good management of the quantity and quality of the water and of the surrounding environment. Assessing the ecological state of the rivers is one way to measure the health of the system and is done by an integrated analysis of biological, chemical and structural quality elements.

1.2 Aim of the research

The aim of this study is to map the general ecological state of the Mpanga catchment and to investigate how the ecological quality changes from its source area in the Rwenzori Mountains to its mouth at Lake George. This is done by looking at how the ecological quality gradually evolves from source to mouth, by identifying relevant changes in chemical and/or biological composition between the areas upstream of Fort Portal, in Fort Portal, downstream of Fort Portal and in Kamwenge, close to Lake George.

Besides this general assessment, it is investigated how the impact of certain human activities is reflected in the chemical and biological data, by comparing the surface water condition upstream and downstream of such pressures.

The results help to locate areas under (high) pressure and allow to suggest focus areas and key impact factors and characteristics for future monitoring.

2. Study area and background: the Mpanga catchment

2.1 General information

The Mpanga catchment is located in the south-west of Uganda along the border with Democratic Republic of the Congo and is part of the Lake George and Lake Albert sub-basin, situated within the Nile basin. It covers a surface of approximately 4700 km², with its waters flowing over a distance of approximately 200 km through the districts of Kabarole, Kyenjojo and Kamwenge, before discharging into Lake George (Figure 1). River Mpanga's headwaters originate from the slopes of the northern part of the Rwenzori Mountain range (around 1700 m a.s.l.) and join at the eastern foothills to form the River Mpanga. The river then flows east, crossing the city of Fort Portal and an area of tea estates before entering Kibale Forest National Park and turning south-east. In the downstream area of Kamwenge, Rushagwe River joins Mpanga as an important tributary from the east, and the river continues west to discharge into Lake George (920 m a.s.l.).

Despite its relatively small size, the catchment comprises a variety of climatologically and ecologically different regions, ranging from a year-round wet climate in the source area of the steep Rwenzori mountains (2000-3000 mm annual rainfall), over a wet climate with two short dry seasons per year (1400 mm annual rainfall) in the mid-range regions of the system, to the drier downstream region (1000 mm annual rainfall) with pronounced dry and wet seasons. Depending on altitude and season, mean temperatures from source to mouth areas may vary from below 10 °C to over 22 °C.

2.2 Human activities along the Mpanga

River Mpanga runs through several areas of high ecological value that need appropriate protection if they are to be preserved for the future. The Rwenzori Mountains National Park (998 km²) protects the highest part of the mountains and has been declared a World Heritage site in 1994 and Ramsar site[1] in 2008. The lower slopes and foothills of the mountains, however, have been modified to serve as agricultural land. Deforestation of the steep slopes, and since lately sand, gravel and stone extraction from river beds, are enhancing soil and bank erosion. An increasing risk of landslides and lower river bank stability do not only pose a threat to people living in the area, but also increase turbidity of the water and sediment transportation downstream.

Fort Portal Town is situated roughly 15-20 km downstream of the source area. With a growing population size of nearly 55000 in 2014, the Mpanga is exposed to typical local urban impacts. Due to its proximity to several attractive national parks (a.o. Rwenzori, Semuliki, Kibale, Queen Elizabeth), Fort Portal is taken up in Uganda's Vision 2040 planning to develop into a tourist city, which will put additional pressure on the surrounding environment. At present, the National Water and Sewerage Corporation (NWSC) operates a drinking water plant that abstracts water from the Mpanga and after physical and chemical treatment distributes it to 7000 households, covering 95% of the population's water need. In contrast, only 0.3% of household sewage water is collected and treated in sedimentation ponds (lagoons). Thus, the river still receives important inputs of household discharges containing detergents and organic waste, both from washing (e.g. laundry, car washing bays) as from controlled and uncontrolled waste disposal. Rinsing water from the local slaughter house and waste disposal from Mpanga Market are additional sources of organic and inorganic (plastic) waste. In the most urbanised parts, the removal of all natural bank vegetation not only makes the banks vulnerable for erosion, but it also takes away the buffering and barrier capacity for city and waste runoff during rainfall.

Downstream of Fort Portal Mpanga flows through an agricultural area first and then continues through vast areas of tea plantations. Tea production is an important economic activity in Fort Portal as it accounts for 40% of the municipality's employment. Like most croplands, tea plantations are rain-fed, putting them at risk from droughts. While irrigation infrastructure is to be developed in the future, tea factories at present use groundwater for processing and machine maintenance in times of rainwater scarcity. Waste water from tea factories is treated in a chain of waste stabilisation ponds before it dissipates into the soil. It was communicated to us by a factory director that for growing tea no fertilisers nor pesticides are used, but a herbicide is applied year-round on a three-monthly basis. It is stipulated in the National Environment Act Cap. 153 that river banks and lake shores are to be surrounded by a natural protection zone. In this zone no human activity is tolerated (unless permission is granted) within a zone of 30 m, or for certain rivers, amongst which Mpanga, for 100 m from the highest water line. In practice, however, this regulation is not always respected. The absence of a protection zone at the border of a tea plantation could thus result in the herbicide affecting the local bank or water vegetation if it washes into the river.

[1] A Ramsar Site is a wetland site designated of international importance under the Ramsar Convention. The Convention on Wetlands, known as the Ramsar Convention, is an intergovernmental environmental treaty established in 1971 by UNESCO, and coming into force in 1975. It provides for national action and international cooperation regarding the conservation of wetlands, and wise sustainable use of their resources. Source: http://www.ramsar.org

Shortly downstream of the tea plantations, the Mpanga enters Kibale Forest, a national park of 795 km² protecting one of Uganda's most biodiverse tropical forests. East and south of Kibale Forest, shrubs and grassland with only few rural habitations and agriculture dominate the landscape around Mpanga, gradually turning into a more densely populated, deforested area with intense agricultural activity until shortly upstream of Lake George. Just a few kilometres upstream of Lake George, the Mpanga Hydroelectric Power Station and its dam are built across the river. Construction of the small hydropower plant started in 2007 and ended in 2011, and it is presently working at a capacity of 18 MW. Another point of interest is that it is located in the area of Mpanga Falls, which harbours a critically endangered species of cycad tree, *Encephalartos whitelockii*. The plant is endemic to the Mpanga Gorge and was the focus of one of PROTOS' conservation projects (IUCN (2016), SOS (2016)). Due to their efforts, there is now a protected area of 8 km x 100 m for the cycads along the river and a hydraulic pump that transports water up the gorge. This way, farmers no longer need to lead their cattle down to the water through the cycad area. In addition, the pump supplies water for small scale irrigation so that crops no longer need to be planted close to the river banks. Ultimately, Lake George receives the water from Mpanga, which continues further to Lake Edward, Lake Albert and from there on enters the Nile system.

3. Approach

This section describes the working approach of the study, covering sampling site selection and description, and the strategies and methodologies used to collect and report the physico-chemical, biological and hydromorphological data.

3.1 Site selection

The aim of the study was to provide an overview of the ecological state of the surface waters within the Mpanga catchment. Sampling locations were chosen to include both the diversity of the catchment's environment as well as potentially relevant impact areas. 43 sampling sites were selected, spread over four areas further referred to as 'upstream Fort Portal' (UFP), 'in Fort Portal' (IFP), 'downstream Fort Portal' (DFP) and 'Kamwenge' (KW) (Table 1, Figure 1). Table 1 contains information on the main surrounding land use and of particular impact factors in proximity of the sampling sites. The number of reference sites (sites with minimal human impact) is limited to few locations at the mountains' foothills upstream of Fort Portal. Access to pristine (source) sites was limited because rural habitations, agricultural activity and sand/stone mining continue until high up on the Rwenzori mountains' slopes, where no driveable paths lead to. The most upstream samples included in the study area lie at the Rwenzori foothills (> 1700 m a.s.l.) and the most downstream site is located at the powerhouse of the Mpanga Hydropower Station (Kamwenge), downstream of the dam (950 m a.s.l.), at short distance from Lake George.

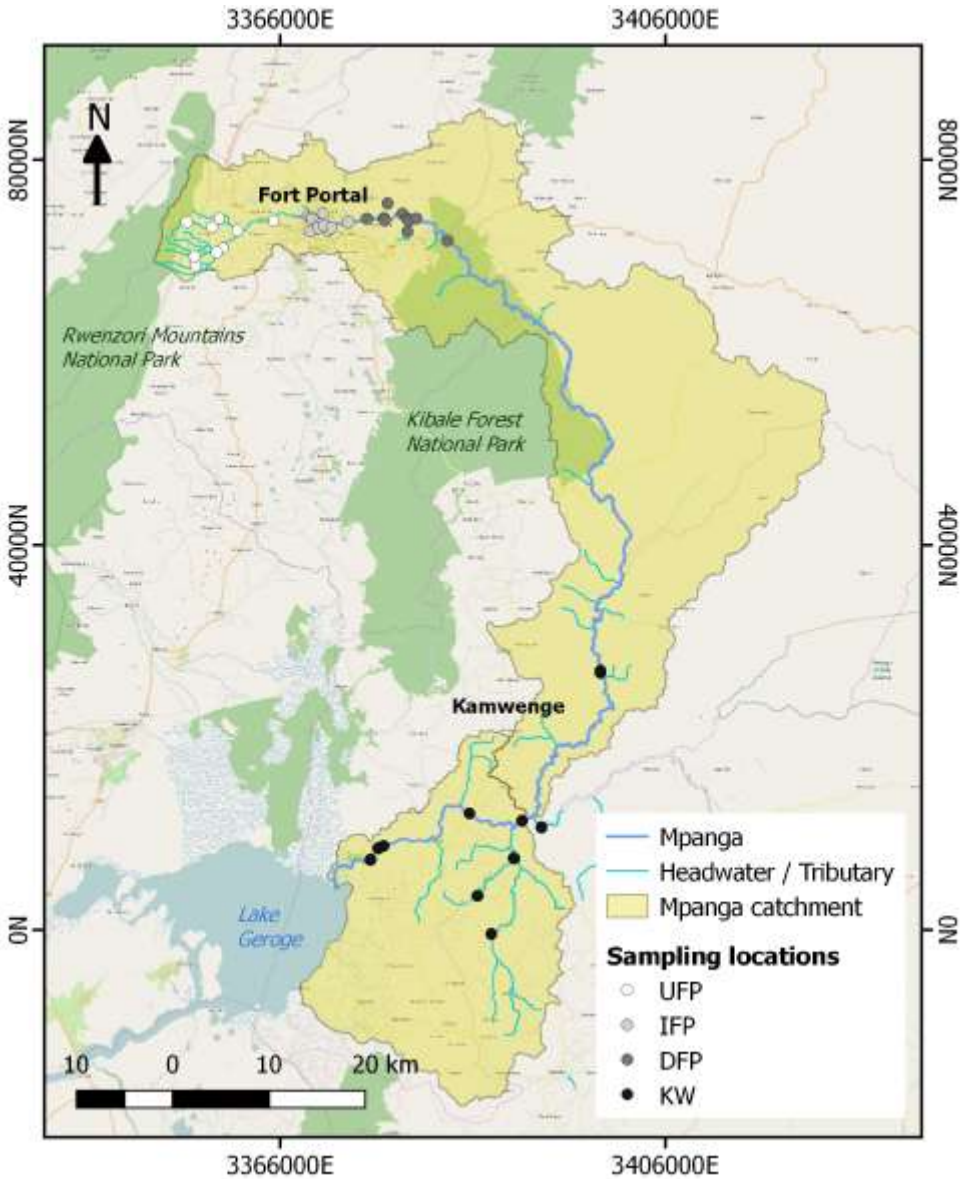


Figure 1. Map of the Mpanga catchment with indication of sampling locations per area (UFP = upstream Fort Portal; IFP = in Fort Portal; DFP = downstream Fort Portal; KW = Kamwenge).

Table 1. Sampling site information. Code = sampling site label; Name = name of the stream or river; Type = functional role of the stream/river with regard to Mpanga; Land use = main land use in a cone of 500 m upstream of the sampling location; Description = additional information on the location or stream.

Code	Name	Type	Land use	Description
UFP1	Mpanga	Main channel	Grassland	Mpanga, downstream of joint with Dunga
UFP2	Mpanga	Headwater	Grassland	Mpanga, upstream of joint with Dunga
UFP3	Dunga	Headwater	Agriculture	Dunga, upstream of joint with Mpanga
UFP4	Muhirre	Headwater	Agriculture	Joint of Kakuke, Muhirre and Nywankoba, pours into Dunga
UFP5	Nyaruswo	Headwater	Agriculture	Pours into Dunga
UFP7	Kitobo	Tributary	Agriculture	Pours into Mpanga
UFP8	Mpanga	Headwater	Natural	Upstream of river sediment mining
UFP9	Mpanga	Headwater	Natural	Downstream of river sediment mining
UFP10	Dunga	Headwater	Agriculture	Most upstream Dunga location
IFP1	Mpanga	Main channel	Agriculture	Upstream of urban area
IFP2	Kahama	Tributary	Agriculture	Pours into Mpanga

IFP3	Mpanga	Main channel	Agriculture	Upstream NWSC drinking water plant
IFP4	Mpanga	Main channel	Urban	Downstream NWSC drinking water plant
IFP5	Mugunu	Tributary	Wetland	Upstream effluent of sewage treatment ponds (lagoons)
IFP6	Mugunu	Tributary	Urban	Downstream effluent of sewage treatment ponds (lagoons), pours into Mpanga
IFP7	Nyakimya	Tributary	Urban	Downstream controlled car wash bay, pours into Mpanga
IFP8	Karamaga	Tributary	Rural/ Grassland	Pours into Mpanga
IFP9	Mpanga	Main channel	Grassland	Downstream uncontrolled car wash bay, 2 km downstream Fort Portal town border
IFP10	Mpanga	Main channel	Urban	Downstream joint of Mugunu (lagoons), at slaughter house, upstream Mpanga market
IFP11	Mpanga	Main channel	Urban	Downstream Mpanga Market
IFP12	Mpanga	Tributary	Rural/ Grassland	Effluent from area behind hospital complex, sediment dumping pit
IFP13	Nyakimya	Tributary	Wetland/ Grassland	Upstream controlled car wash bay (UFP7)
DFP1	Mpanga	Main channel	Grassland	4 km downstream of Fort Portal town border
DFP2	Kibonwa	Tributary	Agriculture/ Wetland	Kibonwa after passing through agricultural wetland area, pours into Mpanga
DFP3	Kibonwa	Tributary	Agriculture/ Wetland	Stream formed by collective wetland waters upstream
DFP4	Mpanga	Main channel	Grassland	Downstream joint of Kibonwa, upstream of tea plantations
DFP5	Mpanga	Main channel	Grassland/ Tea	Broad forested protection zone
DFP6	Mpanga	Main channel	Tea	Narrow grass/reed protection zone
DFP7	Nyakunuka	Tributary	Tea/Wetland	Broad reed protection zone
DFP8	Nyakunuka	Tributary	Tea/Wetland	Medium reed protection zone
DFP9	Mpanga	Main channel	Tea	Narrow forested/shrubs protection zone
DFP10	Mpanga	Main channel	Natural/ Forest	Entrance of Kibale Forest at Kibale bridge
KW1	Mpanga	Main channel	Agriculture	Downstream of joint with Rushagwe
KW2	Mpanga	Main channel	Natural	Downstream of joint with Kiburara
KW3	Mpanga	Main channel	Grassland	Mpanga hydropower dam reservoir
KW4	Mpanga	Main channel	Natural	Downstream of dam reservoir, in cycad protection zone, at PROTOS ram pump
KW5	Mpanga	Main channel	Natural	Downstream of Mpanga hydropower powerhouse, pours into lake George
KW6	Bigera	Tributary	Agriculture	Downstream of joint with Kyebonekeere, pours into Mpanga
KW7	Mpanga	Main channel	Agriculture	Karambi/Nyakahama upstream of effluent from PROTOS protected wetland area
KW8	Kyebonekeere	Tributary	Agriculture	Receives collective water from upstream wetland, joins Bigera
KW9	Rushagwe	Tributary	Agriculture	Large river, pouring into Mpanga
KW10	Bigera	Tributary	Agriculture/ Grassland	Receives water from several streams in agricultural area
KW11	Mpanga	Main channel	Agriculture	Karambi/Nyakahama downstream of effluent from PROTOS protected wetland area

3.2 Data collection

In ecological or environmental monitoring, information from chemical, biological and physical characteristics is used to evaluate the quality of an environment. The water's chemical composition plays a fundamental role for the biota living in it. In turn, it is influenced by other factors and tends to fluctuate or vary within different temporal and spatial scales. Hydromorphological characteristics are also included to evaluate an aquatic environment's condition. The width and depth of a river, water velocity, bank shape and substrate composition all influence the local ecology and contribute to shaping the biological community.

3.2.1 Schedule

Sample collection took place between November and December 2016 and was preceded by a week of preparative work during which all locations were visited to check accessibility. Coordinates of the sampling locations were registered with a GPS device. Field work was alternated with laboratory work to ensure that both chemical and biological samples could be processed within maximum one day after sampling. This is important to prevent samples from degrading, i.e. chemical concentrations to change from true field concentrations, and macroinvertebrates to die and decompose. Within a same day, and when at short distance from each other (< 3 km), downstream locations were sampled before upstream locations to prevent that downstream measurements get influenced by prior sampling activities upstream (i.e. by whirling up sediment and nutrients and dislodging macroinvertebrates that flush downstream). Likewise, chemical samples were taken a moment before or shortly upstream of where macroinvertebrates were collected to avoid interference from whirled up material.

3.2.2 Chemical analyses

Sample collection and preservation procedures are based on the Belgian standard procedures specified in the Compendium for Water Analysis (WAC/I/A/003 and WAC/I/A/010), with slight adaptations (e.g. pooling certain variables in one recipient) for practical reasons.

On-site measurements were done with YSI multiparameter probes (YSI 6600 and YSI 6920), equipped with sensors for temperature, electric conductivity (EC), pH, dissolved oxygen (DO), turbidity and in-vivo chlorophyll a (chl-a). The sensors were calibrated weekly with commercially available standard solutions. On site, the measurements were done in a sample collected in a large bucket (Figure 2).

Figure 2. Measuring variables in the field and collecting water samples for analysis in the laboratory.

For variables that could not be measured in the field, water samples were collected for analysis in the laboratory at Mountains of the Moon University (Figure 2). This was done for ammonium (NH_4), nitrite (NO_2), nitrate (NO_3), total nitrogen (TotN), total phosphorus (TotP), dissolved orthophosphates (o-PO4), chemical oxygen demand (COD), biochemical oxygen demand (BOD) and total, inorganic and

organic carbon (TC, TIC, TOC)[2]. Stream water was collected in a well-rinsed bucket (10 l), from an undisturbed spot (no upwelling sediment or floating debris), where water is flowing (not stagnant) and well homogenised (e.g. not immediately downstream of an effluent discharge point). From this general sample, separate sampling recipients were filled by means of a measuring jug and stored in a cooling box containing sufficient frozen cooling elements to keep samples cool until the return to the laboratory. The samples were analysed spectrophotometrically, using Hach Lange® cuvette tests within 24h of sampling. Due to unstable power supply, BOD samples were frozen and transported to Belgium for analysis.

3.2.3 Biological assessment

The biological entity that was considered in this study are stream macroinvertebrates. In freshwater systems, macroinvertebrates are small animals (> 0.5 mm) including water insects and their larvae, molluscs, worms, crustaceans, mites and leeches that live in close association with the stream bed or the aquatic (bank) vegetation. In contrast to a 'snapshot' of rather variable water chemistry, the macroinvertebrate community integrates the environmental quality over a longer time period and is therefore commonly used as an ecological quality indicator, forming the basis of biotic indices like the Biological Monitoring Working Party (BMWP, Hawkes, 1998), the Multimetric Macroinvertebrate Index of Flanders (MMIF, Gabriels et al., 2010) or the South African Scoring System (SASS5, Dickens and Graham, 2002).

Macroinvertebrate samples were collected using the hand net and kick-sampling method (WAC/I/A/006). Hereby, macroinvertebrates are dislodged and collected in a hand net (mesh size 0.5 mm) by kicking the stream bed substrate while the net is held directly downstream of the whirled up sediment (Figure 3). Per sampling location, a stretch of 10-20 m, not necessarily continuous, was selected to cover as many microhabitats as possible (bank vegetation, submerged roots and branches, large boulders and different substrate types, …). Kick-sampling was limited to 5 minutes of active sampling, and where applicable, large boulders or particular structures were swiped by hand to collect attached animals that would be missed by only kicking. The sample was then transferred to a large bucket filled about 1/3 with stream water, closed by lid and transported to the laboratory for fresh processing. Keeping macroinvertebrates alive (unpreserved) helps in the sorting process because animals are more visible as they move and they retain their original body shape and colour. In the laboratory, samples were rinsed over 10 mm, 1 mm and 0.5 mm mesh size sieves. The different fractions were then transferred to white sorting trays and carefully checked for animals. Animals were sorted into taxonomic groups, stored in small recipients with 95% ethanol within 24h after sampling and transported to Belgium for identification to family level.

[2] The analysis results of TC, TIC and TOC were not further used in this study because of performance issues of the chemical analysis (cuvette test kit).

Figure 3. Macroinvertebrate collection by kick-sampling using a hand net (left), and transfer of the sample into buckets for transportation to the laboratory (right).

The biological data was further used to calculate a biotic index, which is a way to express the biological (ecological) quality in a summarized, comprehensive way. Uganda does currently not have its own biotic index, and therefore the scores from the South African Scoring System version 5 (SASS5) (Dickens and Graham, 2002) are used. Each macroinvertebrate family is assigned a tolerance score, indicating its tolerance towards pollution. The scores range from 1 (high tolerance, low sensitivity) to 15 (low tolerance, highly sensitive). Per sample, the scores of all present taxa are summed up and divided by the number of taxa found in the sample. This gives the average score per taxon (ASPT) and represents the average tolerance of the biological community at a certain location. By lack of region-specific tuning to reference conditions, default quality classes adopted from Rossouw (2004) are assigned to values of the ASPT (Table 2).

Table 2. Biological quality classes based on default class boundaries of the ASPT (Rossouw, 2004).

ASPT score boundary	Quality class	Color code
7	Natural	
6	Good	
5	Fair	
< 5	Poor	

3.2.4 Hydromorphological characteristics

Hydromorphological characteristics like stream velocity, stream and sampling depth, substrate composition and presence of aquatic vegetation were recorded on site (Figure 4), using the field protocol used by the AECO research group (see Appendix), complemented by the standard form from the Belgian Compendium for Water Analysis (WAC/I/A/006).

Figure 4. Recording stream velocity and completing the sampling site description form.

4. Results and discussion

4.1 Chemical water quality

Water composition was found to change substantially for some variables in the Mpanga main channel as it flows from headwaters to Lake George. The panels in Figure 5 show the evolution of some of these variables in the Mpanga main channel per sampling area.

Physical variables

A key variable in aquatic environments is dissolved oxygen because like most other organisms, aquatic organisms need oxygen for respiration. Algae and plants produce oxygen through photosynthesis during the day and consume oxygen at night and on cloudy days, while all other organisms (fish, macroinvertebrates, microorganisms, …) only consume oxygen. This can lead to large day-night fluctuations in the dissolved oxygen content of a water body, and result in the disappearance of organisms that are sensitive to periodic or permanent oxygen depletion. Dissolved oxygen can be expressed as the absolute concentration (in milligrams of oxygen per litre water) or as percent saturation (%), indicating how much oxygen the water contains compared to its maximum oxygen dissolving capacity. The dissolved oxygen (DO) content in the Mpanga main channel remains above 85% saturation in most locations. It is lowest in the urban area (IFP), while it is at full saturation in the headwaters and gradually increases again downstream of Fort Portal.

The pH is a measure for the acidity of the water. It is a key variable because it influences other characteristics like the capacity to dissolve oxygen, electric conductivity, and many chemical processes. Water of neutral acidity has a pH of 7, while lower pH values indicate more acid water. While the pH remains fairly neutral overall in the main channel (pH 7-8), it shows a slight drop in the urban area and stabilises again in the downstream area. The greatest variation is observed in Kamwenge due to a steady increase of nearly an entire pH unit (7.1 to 8) from upstream to downstream locations. Just like

DO, the pH in natural waters tends to fluctuate on a diurnal basis, but strong deviations from its natural average usually point to an external cause.

Electric conductivity is an indirect measure for the load of dissolved mineral salts in the water. As conductivity strongly varies with temperature, measurements are reported as the standardised conductivity at 25°C (EC25). A stream's natural conductivity is determined mainly by its hydrology and the mineral composition of the underlying geology and watershed soil. Sudden strong deviations are therefore unlikely to reflect a natural gradient, but can rather be ascribed to an external influence. The (natural) conductivity in most of the headwaters remains under 200 µS/cm, but rises to the double in Fort Portal, with the highest values of around 450 µS/cm in the downstream tea estates area. In Kamwenge, conductivity in the main channel is quite stable around 250 µS/cm.

Turbidity is an indirect measure for the content of suspended solids and light permeability of water. Despite the high variability, the headwaters carry the most turbid water (> 50 NTU), while from there on, turbidity decreases gradually along the river course, to a minimum of less than 10 NTU in Kamwenge. As a rule of thumb, turbidity values can be interpreted as proposed by Weiner (2012):

Turbidity < 0.1 NTU is required for effective disinfection.
Turbidity ≈ 5 NTU in drinking water is visible, but generally acceptable to consumers.
Turbidity < 10 NTU is generally regarded as low turbidity.
Turbidity > 10 NTU is generally regarded as turbid.
Turbidity > 50 NTU is generally regarded as high turbidity.

The chemical oxygen demand (COD) is the amount of oxygen that is chemically needed to break down all organic compounds in a water sample. While this measure is usually used for assessing the effluent of sewage treatment plants, it here also gives an indication of the organic enrichment in the water, albeit in a much lower order of magnitude. Higher COD values in the headwaters indicate organic enrichment, which appears to be lower in the urban area, but increasing again downstream, and reaching the highest levels in Kamwenge.

The biochemical oxygen demand is the amount of oxygen consumed (typically in 5 days) by microorganisms to decompose the organic material in a water sample. If BOD is high (much oxygen consumed), this is indicative for organic pollution that can lower the oxygen content within the water body. Like COD, BOD is also typically measured to control the quality of sewage treatment plant effluents. In the Mpanga main channel (and the entire catchment in general) BOD levels were low (<3 mg O2/L), with the highest level found in the tributary Nyakimya in Fort Portal (IFP7).

Chemical compounds and nutrients

Ammonium (NH_4) is the ionised form of ammonia (NH_3), which is an extremely toxic compound to aquatic life. The ratio between ammonium and ammonia depends on temperature and the pH of the water and can be calculated. Low concentrations are present by nature, while elevated levels generally indicate pollution from sewage or manure.

Nitrite is naturally only present in very low concentrations, as it is quickly oxidised to nitrate from ammonium in presence of sufficient oxygen. Its presence thus indicates recent pollution. In Mpanga's main channel, it was only detected in Fort Portal, at the same locations where also elevated levels of ammonium were detected.

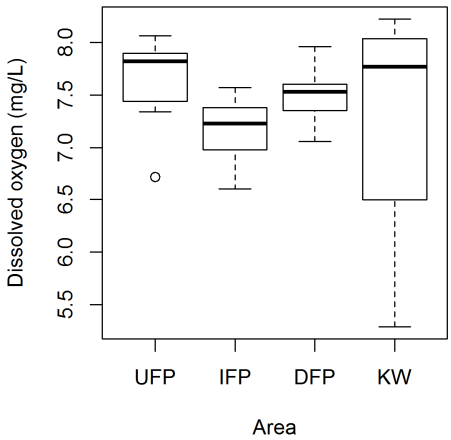
Nitrate (NO_3) is the oxidised form of nitrogen that can be taken up as nutrient by microorganisms and plants. Natural nitrate concentrations in aquatic systems are usually very low, with elevated values mostly being the consequence of waste discharge or agricultural runoff from fertilisers and manure. Nitrate concentrations are elevated in the headwaters, decline sharply in the urban area and rise again downstream until Kamwenge.

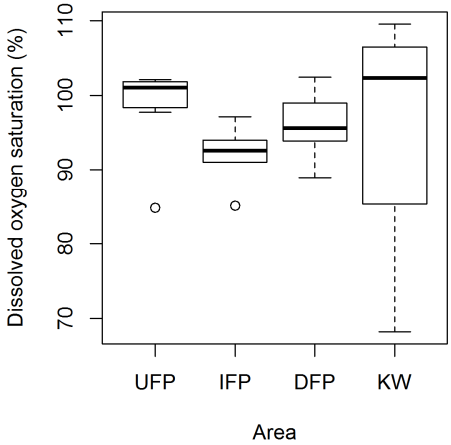
(Ortho-)Phosphates (oPO_4) are important phosphorous-compounds that are used by microorganisms and algae and can, together with nitrates, lead to eutrophication and excessive growth of algae if present in high concentrations. Like nitrate, its concentrations are usually limited in natural systems. Phosphates are commonly found in fertilisers and domestic detergents, and thus elevated concentrations usually point to agricultural runoff or (domestic) waste water discharge. Orthophosphates are highest in the upstream and urban area, then decrease and remain constant downstream of Fort Portal and throughout Kamwenge.

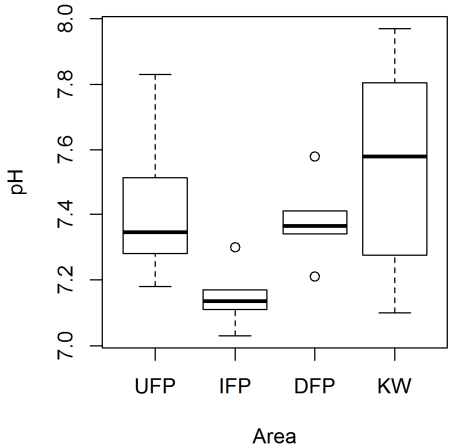
Interpretation

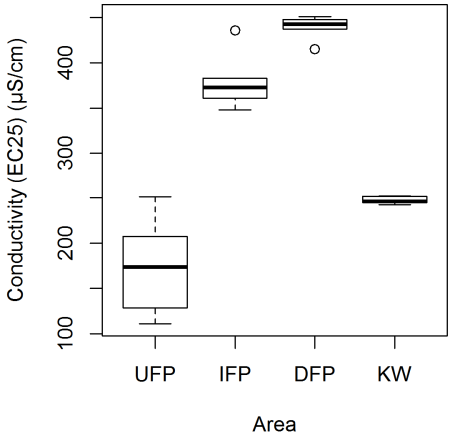
The trends observed in the different physical and chemical variables are linked to each other and result from different impact sources along the Mpanga. The most drastic direct disturbance in the headwaters is the sediment extraction from the streams. As the river bed and banks are destabilised, fine particles and soil containing minerals, nutrients and organic matter are flushed downstream, the input of which is further enhanced by runoff from the deforested agricultural mountain slopes. As a consequence, the accumulating minerals and salts alter the pH of the water and cause conductivity to rise already before the river enters Fort Portal. This is also possibly the cause for the decline in DO, nutrients and COD in Fort Portal: microorganisms use oxygen for respiration during the breakdown of the organic matter, thereby using and retaining the nutrients that are supplied from the headwaters. Minerals and salts, in contrast, are taken up in much smaller amounts, thus a similar decline in conductivity was not observed. In fact, conductivity keeps rising until far downstream of Fort Portal due to accumulating effects of sewage, household waste and washing water being discharged into the Mpanga. This is also reflected in the concentration of phosphates which, unlike nitrates, does not decline, because there is additional input from household waste water (detergents) in the city. The concentration drops only downstream of Fort Portal, where the waste water input is less intense.

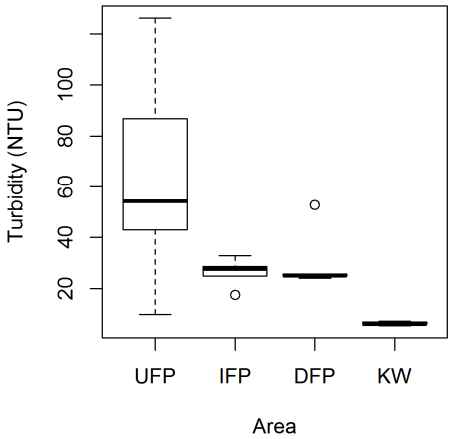
The nutrient levels in Kamwenge are not particularly high, while the COD values indicate slight organic enrichment. The yellowish colour of the water and the absence of a particular COD gradient within these KW-locations, would suggest that the organic matter originates from humic substances released into the water by Kibale Forest. Humic substances are the major organic constituents of soils in many natural streams and are formed by microbial biodegradation of dead plant matter, but are themselves quite resistant to further biodegradation. The lower conductivity downstream of Kibale Forest could result from substances like humic acids forming complexes (colloids) in which ions like calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), and metals like iron (Fe^{2+}) and copper (Cu^{2+}). But to elucidate the exact processes that alter the water composition throughout Kibale Forest more specific monitoring and analyses are needed.

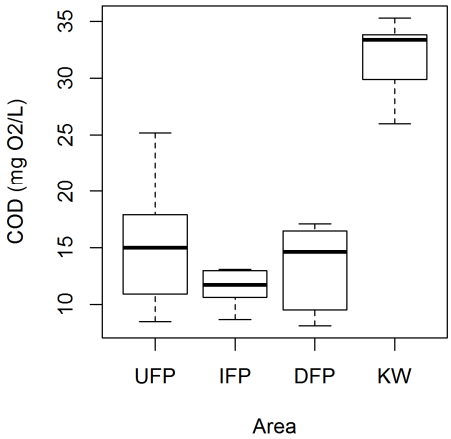

Dissolved oxygen (mg/L)
5.5
6.0
6.5
7.0
7.5
8.0
UFP
IFP
DFP
KW
Area


Dissolved oxygen saturation (%)
70
80
90
100
110
UFP
IFP
DFP
KW
Area


pH
7.0
7.2
7.4
7.6
7.8
8.0
UFP
IFP
DFP
KW
Area


Conductivity (EC25) (µS/cm)
100
200
300
400
UFP
IFP
DFP
KW
Area


Turbidity (NTU)
20
40
60
80
100
UFP
IFP
DFP
KW
Area


COD (mg O2/L)
10
15
20
25
30
35
UFP
IFP
DFP
KW
Area

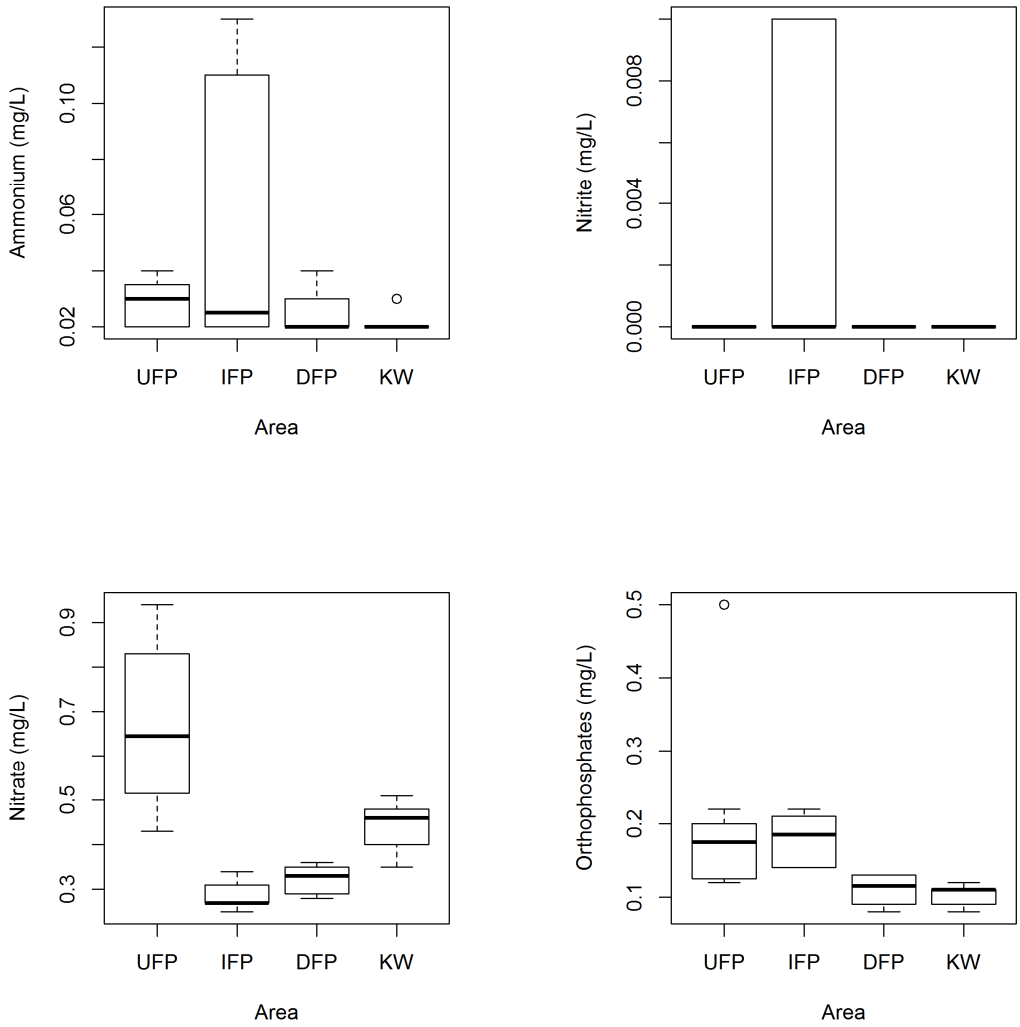


Figure 5. Box-Whisker plots of environmental variables measured in the headwaters and Mpanga main channel (excluding tributaries), grouped per areas UFP, IFP, DFP and KW. The black line gives the sample median and the surrounding box the 25 and 75% percentiles. Whiskers give the 95% percentiles, whereas single points are outliers. The number of samples *n* per area is: n_{UFP}=8, n_{IFP}=6, n_{DFP}=6, n_{KW}=7.

4.2 Biological water quality

Indicators

A simple indicator of biodiversity is the sum of taxa (#taxa), in this case families, that are present at a location. The average score per taxon (ASPT) in a sample gives an indication of how adapted the local macroinvertebrate community is to disturbances. Typically, undisturbed natural locations can harbour more (higher #taxa) and more sensitive (higher ASPT) taxa (families) than polluted or otherwise disturbed habitats. The panels in Figure 6 show the median number of taxa and the ASPT in the main channel in the different sampling areas, and Figures 7 A-D give detailed views on the biological quality indices in the four sampling areas. The headwaters are in general the most taxon-rich and also harbour the most sensitive communities. In Fort Portal, only about half as many taxa are found and some of the communities are reduced to only a few resistant taxa as indicated by the low ASPT. But biodiversity

recovers again and some sensitive species return downstream of the urban area. In Kamwenge biodiversity has nearly fully recovered, with a record of 28 taxa found at site KW4, in the cycad protection zone. The ASPT remains somewhat lower than in the UFP and DFP areas, suggesting that there is a lower share of very sensitive species compared to slightly more resistant taxa.

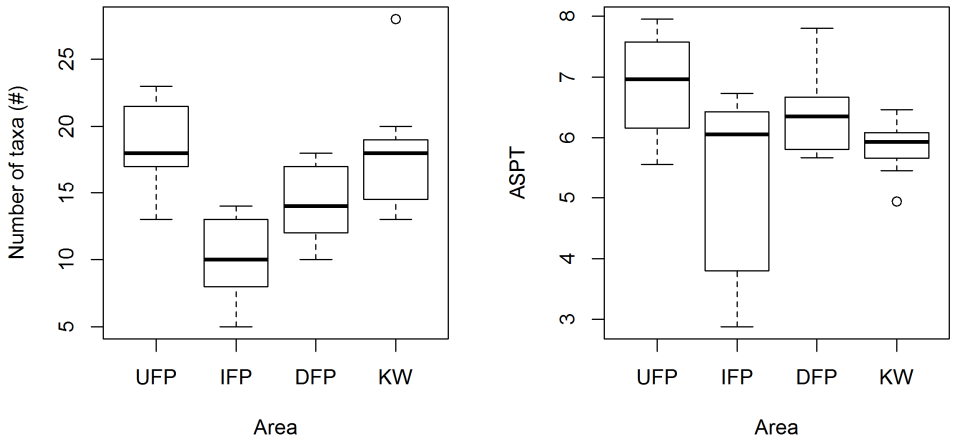


Figure 6. Box-Whisker plot of the number of taxa and of the average score per taxon (ASPT) in the headwaters and Mpanga main channel (excluding tributaries), grouped per areas UFP, IFP, DFP and KW. The black line gives the sample median and the surrounding box the 25 and 75% percentiles. Whiskers give the 95% percentiles, whereas single points are outliers. The number of samples *n* per area is: n_{UFP}=8, n_{IFP}=6, n_{DFP}=6, n_{KW}=7.

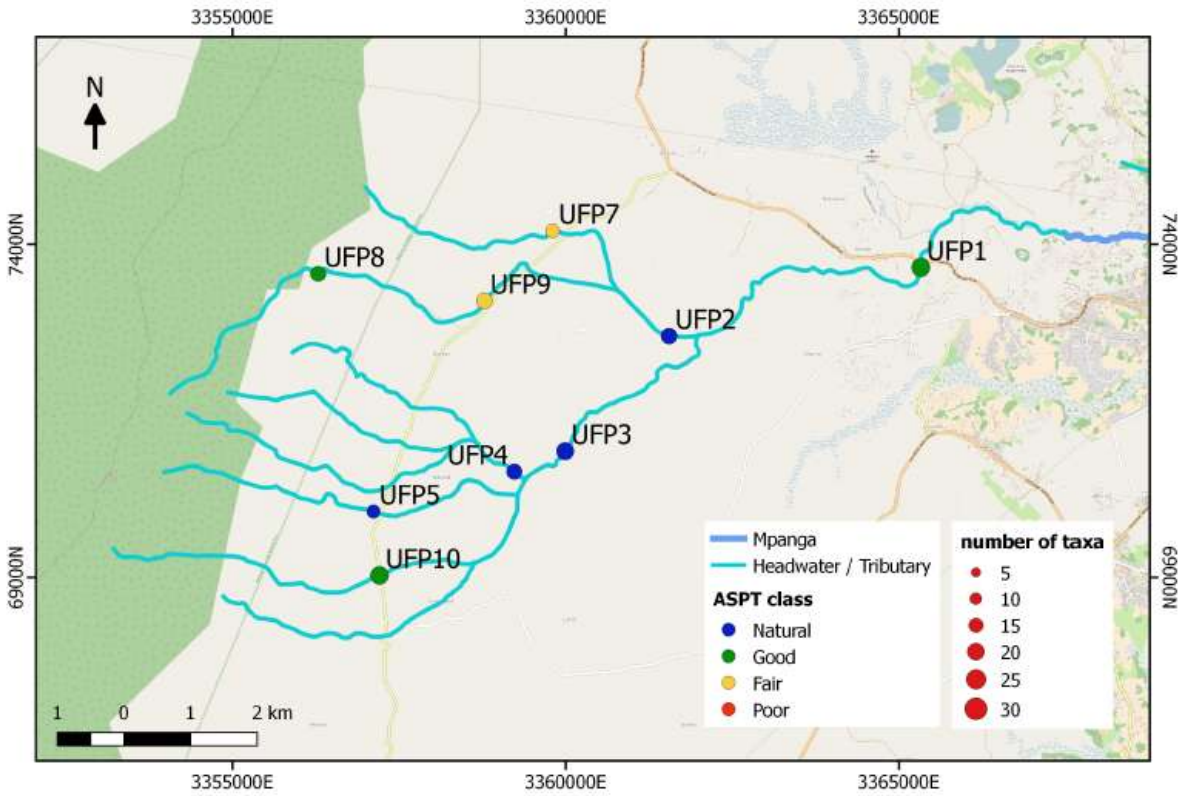


Figure 7 A. Detailed view on the biological quality indices for the Mpanga source area, upstream of Fort Portal.

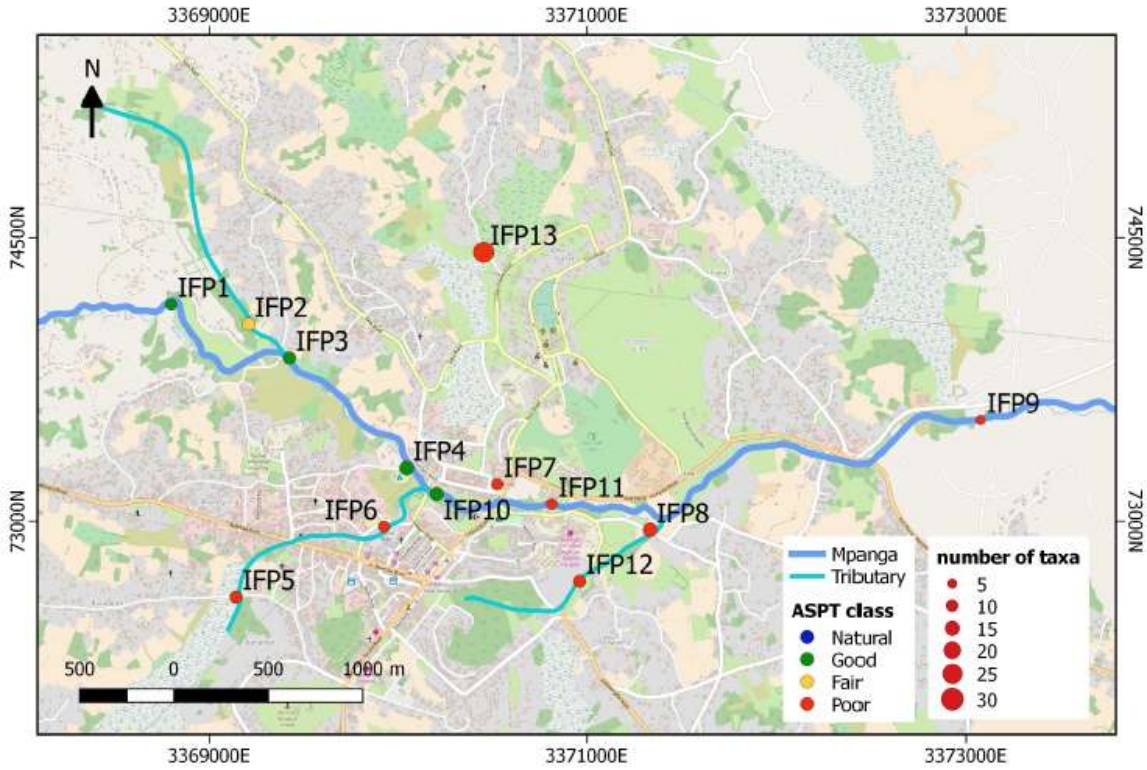


Figure 7 B. Detailed view on the biological quality indices for the sampling area in Fort Portal.

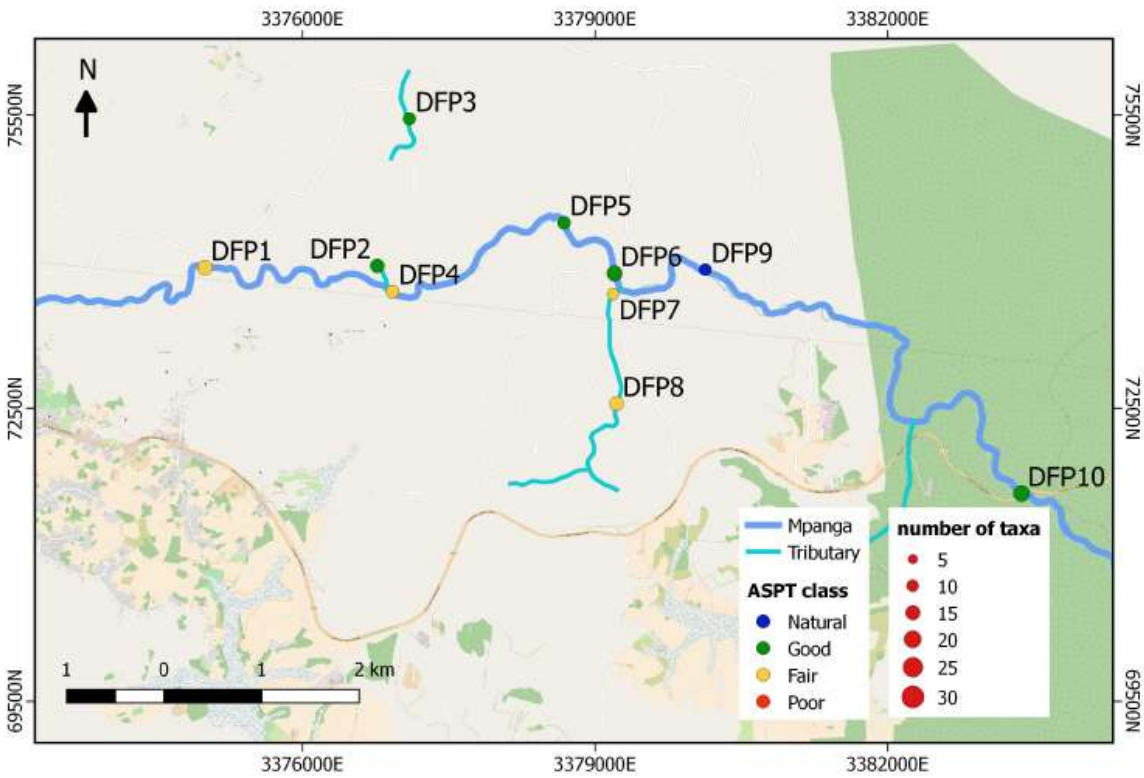


Figure 7 C. Detailed view on the biological quality indices for the sampling area downstream of Fort Portal.

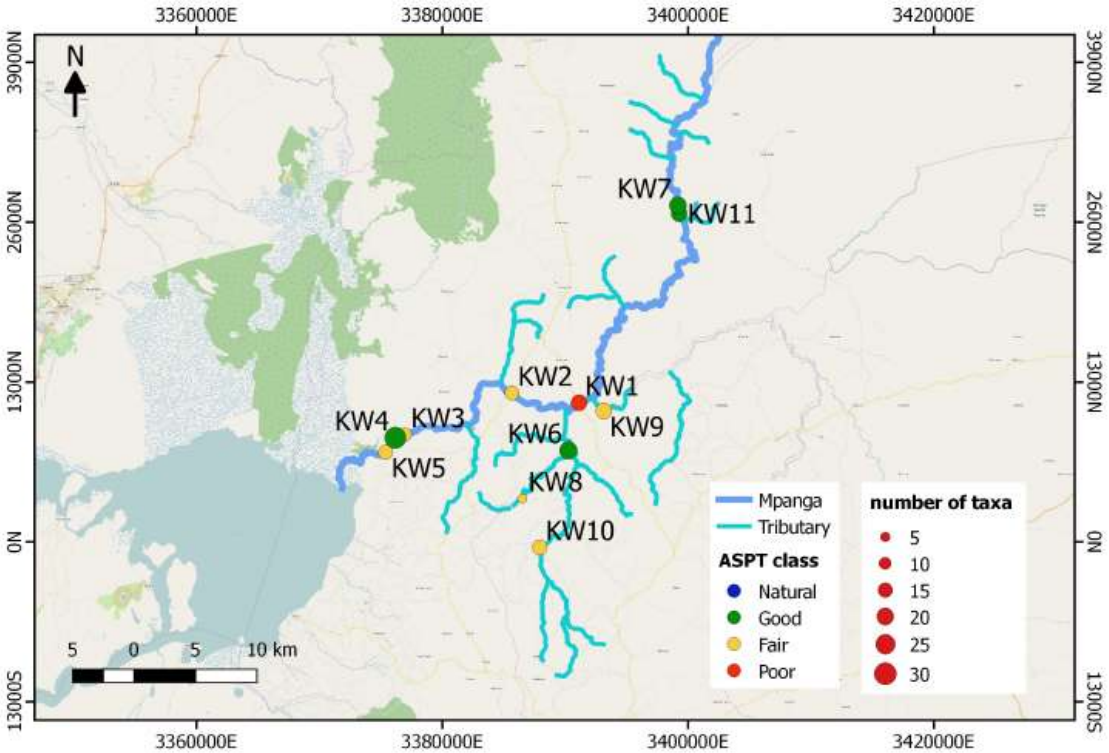


Figure 7 D. Detailed view on the biological quality indices for the sampling area in Kamwenge.

Interpretation

The observed pattern in biological quality is similar to that of DO, pH and the reverse of Conductivity. Except at KW7 and KW11, where DO saturation drops just below 60%, oxygen saturation in the main channel remains above 80% local saturation or 6.5 mg O_2/L, which is considered a safe threshold for most local aquatic life. DO is thus unlikely to be the direct cause of the decline in number of taxa, although it may affect the most sensitive ones on the long term. Conductivity and the pollution sources that cause its rise are thus more probably the variables that make the habitat unsuitable for many macroinvertebrate species. Another relevant quality issue is the river bank modification in the urban area that prevents natural bank vegetation to develop and provide a suitable habitat for those species that depend on it. Both water and river bank quality improve downstream of Fort Portal as buffer zones and vegetation reappear around the river banks and allow biodiversity to recover to some extent before entering Kibale Forest. In the main channel in Kamwenge almost equal amounts of taxa are present as in the headwaters. The fact that the ASPT did not recover to the same extent may be due to the surrounding agricultural land use, as is also reflected in the more elevated concentration of nitrates in this area (Figure 5), which might prevent some sensitive taxa from settling there.

4.3 Effects from particular pressures

River sediment extraction

The effects of sediment mining are most visible in the elevated turbidity in the headwaters compared to further downstream areas and to the most upstream location UFP8, with only 10 NTU. The location is situated at Mount Gessi Primary School, upstream of all sand mining activity, hence the 3-12 times

lower turbidity compared to other UFP locations (Figure 5). The contrast is largest when compared to location UFP9, which is situated just 3 km downstream of UFP8, but showing the cumulative effect of the numerous extraction spots upstream. Sediment in the southern headwaters is being removed by workers of the Karangura Stone Quarry, which is reflected in the high turbidity in locations UFP5 and UFP10. At the moment of sampling these two locations, it had started to rain, which likely caused the turbidity to be even higher than usual, while at the same time it illustrates how the flushing of fine matter can suddenly peak within a short time. Compared to UFP8, sites after sand mining areas (UFP5, UFP7, UFP9 and UFP10) show higher levels of nutrients and conductivity, which is due to the combined effect of the sediment extraction activities (Figure 8), as well as runoff from the agricultural land on the mountain slopes (Figure 9).

Figure 8. Turbid water and river bed and bank modification due to sediment extraction activities.

Figure 9. Agricultural land on a deforested Rwenzori mountain slope.

The water entering Fort Portal (UFP1) had a five times higher turbidity than the unaffected stream in UFP8, and this may render the water undrinkable and increase the necessary treatment effort in the NWSC drinking water plant in Fort Portal. Macroinvertebrates in the headwaters do, however, not seem to be too severely affected by the sediment extractions. The ASPT drops slightly from UFP8 to UFP9, whereas the number of taxa remains the same, indicating an equally diverse, but slightly more tolerant community in UFP9. Yet, the presence in nearly all upstream samples, including UFP9, of sensitive taxa with tolerance scores of up to 13 (maximum is 15) and the recovery towards a good biological state in the further downstream locations UFP1-3 are reassuring that the water quality is still suitable to maintain a good ecological state in the upstream area. This does not mean that river bed destruction leaves macroinvertebrate communities unaffected at the extraction sites. Also, an increase in extraction areas would further reduce the availability of undisturbed habitats for macroinvertebrates and could have an impact on their persistence in the future.

National Water and Sewerage Corporation (NWSC)

Treatment water from the NWSC drinking water plant at Kabundaire enters into the Mpanga between locations IFP3 and IFP4. During the sampling period, this had no visible effect on Mpanga's water chemistry, nor on the ecological state of the river, as indicated by a good state in both locations according to the ASPT of 6.4-6.7.

Sources of pollution in Fort Portal

Ammonium and nitrite, two indicators of sewage discharge, are detected in notable concentrations only in a few locations in Fort Portal. According to the EU Freshwater Fish Directive [2006/44/EC] the imperative threshold for total ammonium is 1 mg/L for waters containing cyprinid fish (commonly referred to as carp or minnow fish families), with the actual guideline being 0.2 mg/L and for drinking water 0.5 mg/L according to the EU Drinking Water Directive [98/83/EC]. The measured ammonium concentrations in the Mpanga at IFP10 and IFP11 were 0.17 and 0.14 mg/L, respectively, and in the side streams Mugunu at IFP6, and Nyakimya at IFP7 they were 0.29 and 0.28 mg/L, respectively. The latter thus surpass the safety guideline for cyprinid fish water and come close to the imperative threshold for drinking water. If during peak discharge moments or overflow due to heavy rainfall ammonium concentrations rise even higher, they can pose a considerable threat to aquatic life.

In the Mpanga main channel, IFP10 is situated at the slaughterhouse, and while the place itself may give rise to input peaks from washing and flushing in the morning after slaughtering, the NH_4 and NO_2 concentrations measured at the moment of sampling originate mainly from the side stream Mugunu, which receives the effluent from the sewage treatment ponds. Except for NH_4, NO_2 and NO_3, however, none of the other measured variables showed deviating values. Shortly downstream of Mpanga Market, at IFP11, the river likely receives additional sewage from the market latrines located directly on the banks and from the extremely polluted side stream Nyakimya. Only 8 taxa were found at the market site, with a very low ASPT of 2.8, indicating that only a few resistant taxa manage to survive here. Quality remains poor until downstream of the uncontrolled car washing bay outside town (IFP9), where only 5 taxa were caught.

IFP7 is located on Nyakimya, downstream of a controlled car washing bay, and was sampled during rainfall. Therefore, the sample may have contained overflow water from the car washing bay's sedimentation pit. The water composition at the moment of sampling was characterised by an extremely high turbidity of 345 NTU, a high conductivity of 559 µS/cm, and an oxygen saturation of

66%. In addition, the highest total phosphorus concentration (>2 mg/L) and a poor biological community of merely 9 taxa, with an ASPT of 4.1 were determined.

The highest conductivity (673 µS/cm), along with the highest measured nitrate concentration (> 5 mg/L), was measured at location IFP2, in the side stream Kahama at the entrance of Fort Portal. The resulting low biodiversity of 12 taxa, with a moderate ASPT of 5.8, can be ascribed to the dominance of agricultural land use in its upstream area.

Moreover, unlike the main channel, some locations in tributary streams are characterised by relatively low oxygen saturation. Oxygen saturations of 40-60% were recorded in the nearly stagnant waters in locations IFP5, IFP12 and IFP13. The lower oxygen content is probably natural since the sites are situated upstream of identified impact factors (see Table 1), and could, for example, result from receiving wetland water from upstream which can be naturally low in oxygen. These sites do not all present a particularly low number of taxa (11, 11 and 26 taxa, respectively), but the ASPT is low, indicating that they harbour adapted, tolerant macroinvertebrate communities. At the same time this means that the streams may be more vulnerable to organic pollution, which could further decrease oxygen levels and thus put macroinvertebrate communities under additional stress.

Tea plantations and protection zones

The biological quality in Mpanga gradually recovers downstream of Fort Portal, while it crosses the tea estates on its way to Kibale Forest. Even though conductivity and turbidity remain unaltered from where the river left Fort Portal (>430 µS/cm, ≈25 NTU), phosphate and nitrate levels remain low, with no indication of contamination by ammonium, nitrite or elevated COD levels. Respecting protection zones and allowing bank vegetation to develop more naturally does certainly benefit the river. This is also reflected in the side stream Kibonwa, which, despite running through agricultural area, is kept in a moderate to good state by the wetland surrounding the stream, allowing for a community of 11-14 taxa with an ASPT of ≥ 6. A particular stream is Nyakunuka (DFP7 and DFP8), which is characterised by oxygen depleted water (9-19 % local DO-saturation), low conductivity and acidic water of a pH around 6. The yellow water is draining from a wetland and is completely covered by plant detritus from the thick reed vegetation emerging from it, hence a high COD (>50 mg/L). An ASPT of 5 indicates that the 9-14 taxa present are adapted to these particular conditions, but no negative impact on the Mpanga river was observed, as indicated by the high biological quality state in location DFP9 (10 taxa, ASPT of 7.8). Thus, from the present observations, it seems that as long as the protection zone between tea plantations and stream is respected, water quality is not further impaired by runoff from the plantations and tea factories (Figure 10).

Figure 10. Narrow buffer zone between a tea plantation and the Mpanga main channel (location DFP6).

Agriculture in Kamwenge

The land in Kamwenge is characterised by intense small scale agricultural activity. This is mostly reflected in the elevated concentrations of nitrate, compared to the DFP area (Figure 5) and the many places along the river where banks are trampled by cattle. The effects on chemical and biological quality, however, differ strongly per location. The lowest biodiversity was found in the Kyebonekeere tributary (KW8), marked by strong oxygen depletion, and likewise, the Bigera tributary (KW10) had a low ASPT, likely due to its low oxygen content. In contrast, at the downstream confluence of these tributaries (KW6), water quality is much better, indicating that the pressure sources that impair Ruambo and Bigera act only locally and on a limited stretch of the stream with no relevant impact on the quality in the Mpanga main channel.

Hydropower dam

The hydropower dam does, apart from altering Mpanga's hydrology, have little influence on the chemical quality of the water, as no relevant differences in the measured variables were found between upstream (KW3) and downstream (KW4, KW5) locations of the dam. Striking is that the highest number of taxa (28) and a good ASPT of 6.5 were found downstream of the hydropower dam in the cycad protection zone. Indeed, the surrounding environment is practically undisturbed and the location is marked by a large diversity of habitat patches that promote biodiversity.

5. Advice for future monitoring

5.1 Additional and alternative strategies

In the present study the water and ecological quality of Mpanga catchment were analysed based on common chemical and biological water quality indicator variables. For future studies, the inclusion of more specific variables could be considered to give deeper insight into the pressure sources and the natural processes that influence the chemistry and ecology in the Mpanga.

A relevant additional analysis would be the determination of microorganisms in the water column, especially fecal coliforms (can cause diarrhoea and vomiting when taken in by drinking water), to identify the main input sources of sewage in urban and rural areas, and to map the general spread along the Mpanga.

Oxygen depletion in certain locations and variable pH levels, both in the main channel and side streams, suggest that additional information on their diurnal fluctuations should be collected. This would help to find the minimum and maximum ranges that biota are exposed to and identify whether the pressure sources can be remedied. In addition, the alkalinity, or buffering capacity of the water should be measured. This measure indicates how resistant the water is to changes of pH following input of acidic or alkaline substances. Such information could help understand the higher variability in pH in the upstream and Kamwenge areas, compared to the IFP and DFP areas.

With regard to biological sampling, we would advise to work with artificial substrates in locations where access by handnet is difficult (e.g. Mpanga main channel) and can lead to an underestimation of the present taxa. The principle of this method is to attach an artificial substrate sampler (e.g. a net filled with stones or pieces of bricks) by means of a rope onto a fixed structure on the bank (e.g. a tree trunk, root or branch) and leaving it in place on the stream bed until it is colonised by macroinvertebrates (± 4 weeks). Typically, per location, three samplers are placed in different spots on the river bed. After colonisation, the samplers are retrieved in buckets and animals are collected by rinsing the substrate over a macroinvertebrate sieve (0.5 mm mesh size). The main advantages are access to the bottom of deep river channels and uniformity of the substrate being sampled, while disadvantages include the potential loss of the samplers through detachment by natural forces or by unaware passengers, and the waiting time for colonisation. More practical information can be found in De Pauw et al. 1986.

5.2 Advised key locations

This first screening study helped to identify some of the important 'key locations' on which future monitoring effort could focus. In the upstream area, these would be UFP3 to represent the conditions in stream Dunga, UFP2 to monitor the sediment extraction impact on the upstream Mpanga area and UFP1 to control-check the water before it enters the urban area.

In Fort Portal, key locations in the main channel are IFP4, IFP10 and IFP11 to monitor the visible influence of sewage that is being discharged into the main channel by side streams Mugunu and Nyakimya, which could be monitored complementarily. Apart from the car washing bay, other major sources of pollution on these side streams should be identified (e.g. petrol station, waste disposal along the sidewalks) and managed.

To check how far outside of Fort Portal the effect of pollution remains visible, either IFP9 and/or DFP1 should be monitored. DFP10 should be included for the same reason, for its easy access to the stream, for it also being a local hydrology monitoring point, and for being the last easily accessible point before the Mpanga flows into Kibale Forest.

In Kamwenge, an additional monitoring point should be added closer to the southern border of Kibale Forest to get an indication on the Mpanga's quality before running through agricultural area after the forest. Further, KW11 can be included at intermediate distance through Kamwenge and KW2 as a control point for potential impact from the discharges of Rushagwe River (KW9) and Bigera (KW6), which could be monitored complementarily. An additional sampling location could be included shortly downstream of the NWSC drinking water treatment plant near Kamwenge town. Even though this plant is equipped with sedimentation tanks that capture chemically treated waste water, periodic and occasional overflows from storm water and maintenance (cleaning) could potentially affect the biota downstream of the plant on the long term. At last, KW4 should be included as most downstream location to represent the ecological quality of Mpanga shortly before it pours into Lake George.

6. Conclusion

In each of the studied areas, different factors contribute to the chemical and biological quality of the Mpanga. Both chemical and biological quality show decreases and recovery along the course from source to mouth following local pressures and conditions. In the upstream area, the main issue is sediment mining from the river. If these practices are not managed in a sustainable way, they are likely to lead to further deterioration not only of the chemical, but also the biological integrity of the river. In Fort Portal, some major sources of pollution including the discharge of sewage and other waste waters must be addressed to prevent the resilience and recovering capacity of Mpanga's ecosystem to get impaired downstream. While the effect of tea plantations is low, the presence at many places of a vegetated protection zone around stream and river banks seems to play a role in helping the river recover from urban pressures. In Kamwenge, only certain locations have been found to be severely impaired, potentially by agricultural practices, but likely also by other unidentified causes. Shortly upstream of Lake George, the environmentally good state of the cycad protection zone and the chemical water quality in the Mpanga are sufficiently high to maintain a diverse aquatic community.

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Appendix

SAMPLING PROTOCOL: SITE DESCRIPTION

- Site Name:
- Time and date:
- Sample ID:
- Investigator:

Stream name/lake	
Type of watercourse	River Lake
Coordinates	
Altitude of sampling sites [m.a.s.l]	
Photos of the sampling location (numbering the photos) - Downstream - Upstream - Left bank - Right bank - Substrate	
Description of sites (exceptional, weather conditions, main interruption, …)	

Land use of the bank top (Estimate at both banks for the stretch of 100m * 10m)

Type of land use	% on left bank	% on right bank	Dominant
forests			
arable land			
residential areas			
road, paths			
urban area			
quarrying or mining			
orchard			
other			

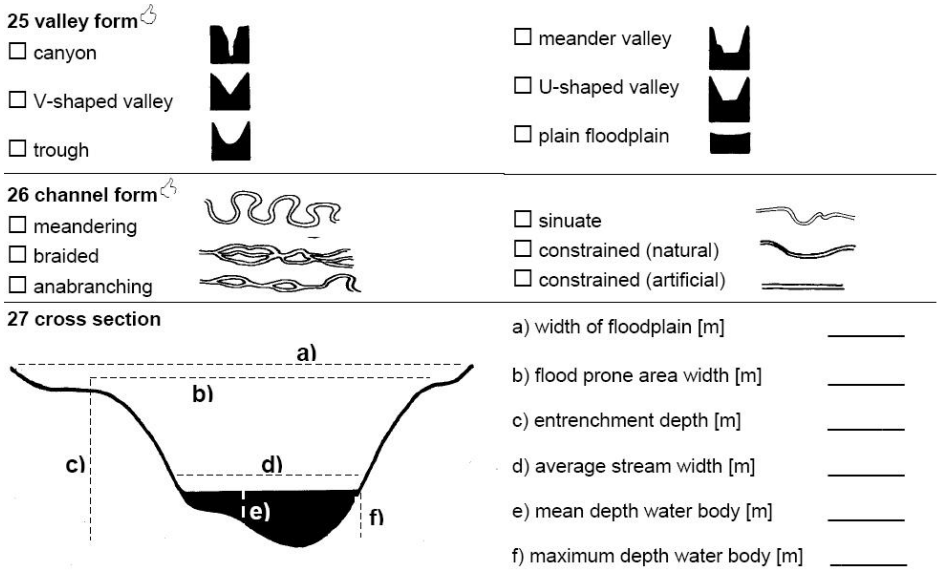
Shading

partly shaded, limited stretch <33%	
partly shaded, longer stretch 33-90%	
partly shaded, whole stretch >90%	
completely shaded, limited stretch >33%	
completely shaded, longer stretch 33-90%	
completely shaded, whole stretch >90%	

Presence of macrophytes (% of the bed covered by Macrophytes) (Estimate area cover at the littoral zone of 100m * 10m)

	Submerged aquatic macrophytes	Emerged aquatic macrophytes	Floating aquatic macrophytes
Contigous/Interrupted			
Abundant = 75-100%			
Common = 50-75%			
Frequent = 25-50%			
Occasional = 5-25%			
Rare = 1-5%			
Invisible			

River morphology

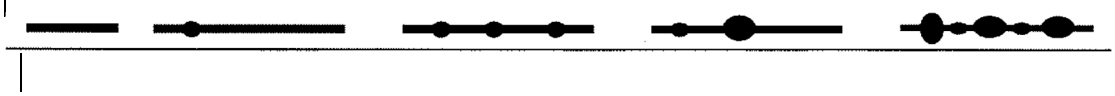


Dominant

Free drawing (as seen from above: draw stream and indicate flow direction, draw nearby roads, bridges, discharge pipes, bank vegetation and trees, large stones, sand banks, and any other particular observations, and mark the locations where samples were taken (chemical, biological, …)

variation in width

Dominant



Bank

erosion	Absent/Limited/Abundant
curvature erosion	Absent/Limited/Abundant
width-erosion	Absent/Limited/Abundant

Profile of the bank (indicate left and right bank, facing downstream)

Vertical steep (>45°) gradually not trampled composite not trampled

Variation in flow
absent
at human constructions
low
moderate
high

Sludge layer

invisible	absent	<5cm	5 - 20 cm	> 20 cm

Dead wood

twigs d<3cm	branches 3-30 cm	branch >30 cm
Absent	Absent	Absent
Limited	Limited	Limited
Abundant	Abundant	Abundant

Current Velocity

(Should be measured at the same location where the depth measurements were taken)

S1	S2	S3	S4	S5
B1	B2	B3	B4	B5

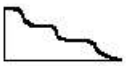
Mineral substrates (% of the bed covering)

%	0	0-20	20-40	40-60	60-80	>80	Dominant
Invisible							
Boulder (D>256mm)							
Cobble (D=64-256mm)							
Gravel (D=2-64mm)							
Sand (D=0.062-2mm)							
Silt (D=4-62 um)							
Clay (D=0.24-4um)							

Bank material Assess % composition for each bank

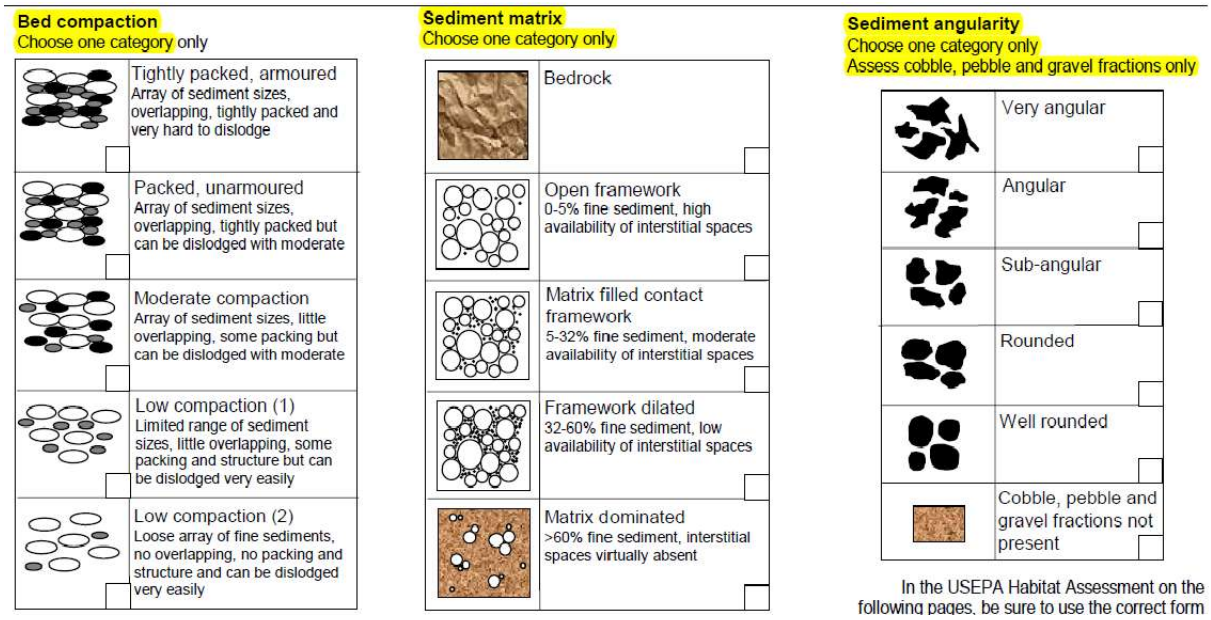
	Left bank	Right bank	Dominant
Bedrock	____	____	
Boulder (>256mm)	____	____	
Cobble (64-256mm)	____	____	
Pebble (16-64mm)	____	____	
Gravel (2-16mm)	____	____	
Sand (0.06-2mm)	____	____	
Fines (silt and clay, <0.06mm)	____	____	
	Total 100% each		

Bank shape
Choose one category for each bank

		Left bank	Right bank	Dominant
	Concave	☐	☐	
	Convex	☐	☐	
	Stepped	☐	☐	
	Wide lower bench	☐	☐	
	Undercut	☐	☐	

Bank slope
Choose one category for each bank

		Left bank	Right bank	Dominant
	Vertical 80 - 90°	☐	☐	
	Steep 60 - 80°	☐	☐	
	Moderate 30 - 60°	☐	☐	
	Low 10 - 30°	☐	☐	
	Flat <10°	☐	☐	



Pool/Riffle class

Class 1 Pool-riffle pattern is (nearly) pristine: extensive sequences of pools and riffles.	**Class 2** Pool-riffle pattern is well developed: high variety in pools and riffles.
Class 3 Pool-riffle pattern is moderately developed: variety in pools and riffles but locally.	**Class 4** Pool-riffle pattern is poorly developed: low variety in pools and riffles.
Class 5 Pool-riffle pattern is absent: uniform pool-riffle pattern.	**Class 6** Pool-riffle pattern is absent due to structural changes: uniform pool-riffle pattern due to reinforced bank and bed structures.