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Assessment of water resources development impact and setting of minimum threshold in Uganda - River Nyamugasani Catchment

March 2022

Participation Project 2020-2021 BIENIUM

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Assessment of Water Resources Development Impact and setting of minimum thresholds in Uganda- River Nyamugasani

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EXECUTIVE SUMMARY

The Ministry of Water and Environment (MWE) through the Directorate of Water Resources Management (DWRM) obtained funding from the United Nations Educational, Scientific and Cultural Organization (UNESCO) through the participation programme arrangement for 2020/2021 to carry out a water resources development assessment to determine the threshold for environmental flow in the Nyamugasani catchment, in order to address some issues of water governance in terms of planning, management and allocation.

The main objective of the study was to assess the magnitude of downstream impacts of water resource development projects on flows and quality of water in Nyamugasani system and suggest probable ecological limits of water flows to minimise adverse or irreversible environmental effects while meeting the basic human social and economic requirements of both upstream and downstream communities

The study was carried through literature review, stakeholders' engagements, data collection and analysis, survey of the water systems profiles, discharge measurement, ecologic and water quality sampling as input to the models.

The study findings show river/lake are used by over half (52%) of the population and is the most dominant source of water. The borehole used by 24% of the population is the second most important source. The rest of the population depend on protected springs (15%), open wells (7%) and a limited number (2%) on pipe water. The majority (64%) access their water sources over distances greater than 500m and 86% on average use less than one jerry can per person per day, which further indicates the difficulty of accessing water sources. It is estimated that the average water demand for livestock in the Nyamugasani catchment is 6531.4 litres/day or 0.08l/s. Over half (54%) of the households discharge grey water into the open areas, 40% into household gazetted disposal areas, while 6% into the drainage system. The survey findings further indicate that 60% of households dispose of solid waste into garbage pits, 9% into gazetted collection points while 30% into open areas and the majority of the households (92%) have toilet facilities.

The physiochemical parameters of water quality were found to be within the acceptable standards (World Health Organisation Standards) however all the points along the river were found to have Microbial contamination with exception of only Kanyampara stream which had no contamination. The microbial contamination is mainly attributed to river bank encroachment by human settlements.

In the Environmental flow requirements, four methods were used for analysis as below: -

1- In IHA modelling output, the flow of 2.966 m^3/s and 2.844 m^3/s are environmental flow values during the dry month of February and July, while wet months of May, October and November, the flow of 4.081 m^3/s, 4.009 m^3/s and 4.635 m^3/s are environmental flows respectively. The average value for the dry and wet seasons is 2.905 m^3/s and 4.241 m^3/s respectively**.** The overall average flow value for the two season is 3.5 m^3/s

2-Indices based on flow-duration analysis curve, the flow at 90 % exceedance probability is 3.4 $m^3/$.

3-In Tenant Method, we applied the mean annual flow (MAF) for the period of 2002 to 2011 from which 10% of the MAF applies for the dry period and 30% for the wet seasons and the MAF is 5.233 m^3/s, therefore 0.5233 m^3/s is the environmental flow during dry months and 1.5699 m^3/s is for wet months

4-In Wetted Perimeter methods, the graph breaks at two points having discharge 5.963 m^3/s and 7.026 m^3/s. Therefore, the environmental flow is 6.4945 m^3/s as the average of all the break points discharges

The results of 1, 3,7,30 and 90-day minimum flows that occur during any common 1, 3,7,30 and 90-day period in all years of analysis, show significant increasing and decreasing trends in low-flows regimes in Nyamugasani River. Furthermore, the results indicate that changes seem to be more significant for the more recent time which could be attributed to the impacts of development activities along the river systems. However, the exact nature of causes of these trends and the interaction between climatic factors and low-flow is not verified. From the results of environment flow analysis for the various methods used, it is very clear that there is no single method which can conclusively give a single appropriate value that can be consider for environmental flow. However, Seasonality low flow exhibited by Tennant and indicators hydrologic alteration methods could be considered because of their influence on aquatic species at various life stages. The flow measurements also show drastic decline in discharge volumes as the river flows downstream, an indication of high-water abstractions from the river upstream

The study findings show that river waters are used by over half (52%) of the population hence the most dominant source of water. The pollution loads computed from the discharge measurements conducted on river Nyamugasani as shown in results table 15, depict an increase in pollutants as the water flows from upstream to downstream. This could be due to development activities along the river on the upstream and river bank encroachment. The physiochemical parameters of water quality were found to be within the acceptable standards (WHO Stds) however all the points along the river were found to have Microbial contamination with exception of only Kanyampara stream which had no contamination. The microbial contamination is mainly attributed to river bank encroachment by human settlements. The pH of the samples was in the range of 7.0–7.8 and complied with the recommended guidelines for human consumption. The anions (Cl^-, NO_3^-, PO_4^{3-}, and SO_4^{2-}) were within the permissible limit for domestic and agricultural water use. It should also be noted that quantification of sediment could not be done due to limited time and lack of discharge data during wet season as well.

Of all the Laws, policies and regulations reviewed the details and intricacies of how environmental flows should be conducted or how ecosystem water needs are to be conducted is salient. There is a missing gap on how ecosystem protection can be guaranteed

It should also be noted that quantification of sediment could not be done due to limited time and lack of discharge data during wet season as well.

Further investigations are needed during the dry and wet season for a longer period of time on the impact of development activities on river flows in order to comprehensively verify and quantify the environmental flows for all the major rivers in Uganda.

The details and intricacies of how environmental flows or how ecosystem water needs are to be conducted and should be developed and adopted by all stakeholders.

Table of Contents

List of Tables

List of figures

Acronyms and abbreviation

AWMZ	Albert Water Management Zone
BBM	Building Block Methodology
DEM	Digital Elevation Model
DMC	Double Mass Curves
DO	Dissolved Oxygen
DWRM	Directorate of Water Resources Management
EC	Electro Conductivity
EFA	Environment Flow Assessment
EFCs	Environmental Flow Components
FDC	Flow Duration Curve
GIS	Geographical Information Systems
GWP	Global Water Policy
HEC-HMS	Hydrologic Modeling System
HEC-RAS	River Analysis System
HPP	Hydropower Plant
HRU	Hydrologic Response Units
IHA	Indicators of Hydrologic Alteration
IUCN	International Union for Conservation of Nature
IWRM	Integrated Water Resources Management
LC	Least Concern
MAF	Mean Annual Flows
MW	Mega Watts
MWE	Ministry of Water and Environment
NEMA	National Environment Management Authority
NFA	National Forest Authority
NWP	National Water Policy
NWQRL	National Water Quality Reference Laboratory
UBOS	Uganda Bureau of Statistics

UNESCO	United Nations Educational, Scientific and Cultural Organization
UNMA	Uganda National Meteorological Authority
UNRA	Uganda National Roads Authority
VWW	Vehicle Waste Water
WQMD	Water Quality Management Department
IFIIM	Instream Incremental Method- EE Modelling
DRIFT	The Degradation of a model's prediction power due to change in the Environment
IWMI	International Water Management Institute
PHABSIM	Physical Habitat Simulation model

1.0. Introduction

The Ministry of Water and Environment (MWE) through the Directorate of Water Resources Management (DWRM) obtained funding from the United Nations Educational, Scientific and Cultural Organization (UNESCO) to carry out a water resources development assessment to determine the threshold for environmental flow in the Nyamugasani catchment, The study is seeking to addresses issues of water governance in terms of planning, management, allocation and efficient use of water resources (scarcity and quality management).

Due to the need for minimising adverse environmental and socio-economic impacts of projects, such as hydropower, water supply and irrigation development, this study aims to address issues related with water resources development along the river Nyamugasani and determine the environmental threshold in order to guide policy and legislative measures to ensure ecological harmony and social equity are being given priority in many nations/regions.

In the Ugandan context, environmental policy and legislation is still weak in terms of enforcement and requires much work. Inadequacy of existing legal provisions on environmental flows and lack of harmonization of relevant laws and regulations appears to be the norm in Uganda's environmental policy. This problem is further exacerbated by weak institutional collaboration among water use sectors, capacities across the board and inadequate financing for enforcement.

1.1. Objectives

Overall: To assess the magnitude of downstream impacts of water resource development projects on flows and quality of water in Nyamugasani system and suggest probable ecological limits of water flows to minimise adverse or irreversible environmental effects while meeting the basic human social and economic requirements of both upstream and downstream communities.

The specific objectives for the study include:

1. Evaluation of the hydrologic impact of water resource development projects on downstream flows, sediment loads and chemical quality.
2. Assessment of downstream impacts of water resource development projects on aquatic eco-hydrology and biological water quality using indicator species of aquatic organisms including macro-invertebrates and fish.
3. Investigation of the implication of water resource development projects on the supply/demand of water, impacts on livelihood and quality of life of downstream communities using economic and socio-cultural parameters.
4. Assessment of effect on water use practices and institutional arrangements for water resource management by downstream communities giving due consideration to issues

such as water rights, negotiation, compensation and related legal instruments in line with Water Act Cap 152 and its improvement.

The study was conducted with an integrated, collaborative approach with UNATCOM, pooling expertise from various institutions to address the above specific objectives.

1.2 Scope

The study was piloted in the catchment of Nyamugasani Sub Catchments in the Albert Water Management Zone (AWMZ). The river form part of the lake George catchment.

1.3 General Approach /Methodology

Data Collection

1.3.1 Primary data:

Historical data from river discharges was obtained from the Ministry of Water and Environment. Data on humidity, temperature, precipitation and rainfall was obtained from Uganda National Meteorological Authority (UNMA). The obtained data was processed to ensure gaps are appropriately fill and smoothened.

1.3.2 Secondary Data Collection

To study features associated to the water resources availability in the delineated catchment, the existing shapefiles and images of the following data sets were collected;

- Topography data (Digital Elevation Model) (DEM);
- Administrative boundaries (districts, villages, etc.);
- Natural resources (rivers, national parks, e.t.c);
- Land use and cover;
- Location of existing hydro-meteorological stations for rainfall, evaporation and stream flow measurements.

Through desk studies, review of existing literature and reports on the environmental flows at regional and international and, socio-economic aspects of the selected catchment. This also involved review of existing laws and policies so as to obtain information that might be useful in the tasks.

1.3.3 Field assessments

Field reconnaissance visits were undertaken to the Nyamugasani catchment area to verify information obtained in the desk studies, stakeholder identification, and mapping data collection on socio-economic aspects, and hydro-meteorological parameters for model inputs and appreciation of catchment dynamics, Field survey of the water systems profiles, discharge measurement, ecologic and water quality sampling as input to the models.

1.3.4 Stakeholder Engagement

Stakeholder engagements with key stakeholders in the selected study area were carried out to gather information and identify issues in the catchment. This was done through focused group discussions, and meetings among others.

Awareness raising was done for the local communities through meetings of communities, local government staffs and non-governmental organisations.

1.3.5 Analysis and Modelling

Analysis was carried using four difference methods of approach below

Range of variability approach (Indicators of Hydrologic Alteration, IHA)

Version 7.1 of the Indicators of Hydrologic Alteration (IHA) software developed by the Nature Conservancy (released in 2009) was used to quantify the environmental flow for Nyamugasani River. The software uses daily flow time series data to generate multiple sets of hydrologic statistics. The five principal attributes of flow data variability (magnitude, duration, amplitude, frequency, and timing) are programmed in IHA because of their influence on aquatic species at various life stages. IHA calculates two types of flow statistics; the first type includes 33 IHA statistics and the second type includes 34 flow statistics calculated for five different environmental flow components (EFCs). The 33 IHA statistics and 34 EFCs together describe flow attributes deemed to be ecologically relevant. This assessment considered monthly low flows. Analysis was carried out using non parametric statistics for a single period from 2002 to 2011. Advanced calibration parameters were used where all flows below 10% of daily flows were considered as low flows. The low flows are considered the environmental flow requirement for specific months.

Wetted perimeter - discharge method

We selected six representative cross-sections along the course of Nyamugasani River, with different geometrical shapes.

The revolutions and sounding at different distances along the river cross sections were measured. From this the discharge, wetted width and average depth were calculated using the rating curve method for the various cross sections.

The wetted perimeter is two times the average depth plus the wetted width.

Wetted Perimeter = Wetted Width + (2 * Average Depth)

Wetted perimeter was plotted against discharge in order to determine the breakpoint which discharge is the environmental flow requirement.

Indices based on flow-duration analysis

From the flow-duration curves at Nyamugasani, we calculated one typical flow index, specifically the Q90. Using the daily flow values from 2002 to 2011, they were arranged in descending order and given a rank. The frequency was calculated by dividing the total number of flows by their ranks.

Probability of exceedance = $\left(\frac{1}{f}\right)\ x\ 100\ \%$

Where f is the frequency

The flow duration curve is the plot of discharge against probability of exceedance.

The rating curve for Nyamugasani was plotted to show consistencies and hence suitable for analysis to determine the environmental flow

Tennant method

We applied the mean annual flow (MAF) for the period of 2002 to 2011 from which 10% of the MAF applies for the dry period and 30% for the wet seasons from which the environmental flow values was calculated for the dry and wet season respectively.

Rainfall Analysis; rainfall stations in the catchment were identified and data (as precipitation, evapotranspiration and Temperature) obtain from Uganda National Meteriological Authority (UNMA), processed to obtain the Areal rainfall for the catchment to be used in the model.

1.3.6 Water demand assessment; data on existing and proposed water uses in the catchment were collected through stakeholder engagement from the relevant local government. The instream water uses and the water requirement for the riverine ecosystem was assessed

1.3.7 Monitoring; Monitoring was carried where necessary to evaluate parameters such as ecological impacts (biological parameters; indicator species), water quality (chemical & physical parameters), and socio-economic impacts.

1.3.8 Water Quality Analysis

The sampling followed recognized and conventionally acceptable protocols of the laboratories of The National Water Quality Reference Laboratory (NWQRL). The physical parameters of pH, Electro Conductivity (EC), Dissolved Oxygen (DO) and Temperature were done in-situ in the field for the rivers and streams. A sample was drawn in a bucket and measurements taken on site.

Test for Microbial contamination of the sources were done following the standard procedures at the sampling sits (E-Coli and Total coliform used to determine microbial contamination). Collected Samples were delivered to Entebbe National Reference Laboratory (NWQRL), Water Quality Management Department (WQMD) in the Directorate of Water Resources Management (DWRM), Ministry of Water and Environment (MWE).

Special 50ml bottles were used to collect samples from the identified points for stable trace metal analysis at the reference Laboratory in Entebbe.

2.0 INFORMATION OF THE STUDY AREA

2.1 Bio-Physical Environment

2.1.1Topography

The highest study area elevation is at the intake site of Nyamugasani hydropower plant along the slopes of Mt. Rwenzori and the lowest elevation in the southern part, which lies in the western rift valley, which is 883m along the shores of L. Edward. The topography ranges from flat low lands in the south and rises through undulating hills towards the snow-capped Rwenzori Mountain in the northern part.

2.1.2Climate

The District experiences bimodal rainfall pattern. The first rains are short and occur during March-May and the longer rains from August-November. Annual rainfall ranges from 900mm-1600mm, and is greatly influenced by altitude. Alongside, there exists wide temperature variations influenced by altitude from rather high temperatures at the plains to as below as zero at the summit. The temperature ranges between 22 and 30°C. However, the rainfall partners have greatly changed.

2.1.3Geology

The geology consists of ancient (Precambrian) rocks which were extruded from the surrounding plains during the formation of the western rift valley.

2.1.4Soils

The soil in the study area is generally dominated by rift valley soils embracing two types of mainly sandy clay loams with alluvial parent rock of medium to high productivity.

2.1.5 Land use/cover types

The study area has 5 FAO soil types and 10 land use/cover classes as shown in the figures below; the upper catchment is predominantly forested land. There is high rate of degradation in the middle and lower catchment area with subsistence farmland covering most of the lower area as shown in the land use map below.

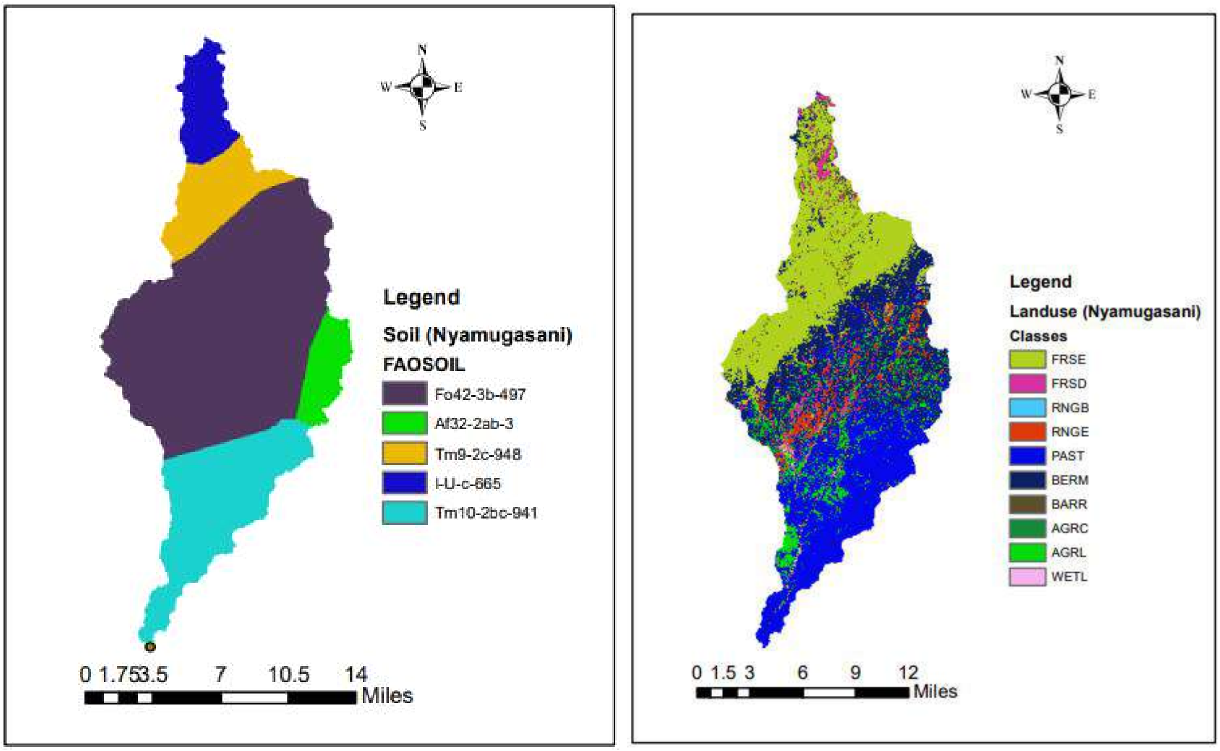


Figure 1. Soil types and Landuse in Nyamugasani catchment area

Land use around the study area is generally agriculture. The farming systems are dominated by Subsistence agro forestry practices.

The agriculture land use can be categorized in to two as indicated below;

The lower system

The area cultivated per capita are small, under one hectare. Banana and coffee are the main cash crops; root crops and several annual or biennial food crops are on the increase. Maize is a secondary cash crop and sweet potatoes a secondary food to bananas. The typical land holding is 2-4 hectares. The vegetation is mainly forest-savannah mosaic with pastures suitable for intensive livestock production.

The montane system

This is found at higher elevations between 1500-1750 amasl. The area receives high and effective rainfall and cloud cover. Banana is a major staple as well as sweet potatoes, cassava and Irish potatoes. Arabica coffee is prevalent at above 1600 meters. Some temperate crops like wheat and barley are grown. High population intensities and intensive agriculture are the norm because of small holdings of about 1.5 hectares.

2.2 Biodiversity

2.2.1 Vegetation

The study area comprises of montane grassland and modified woodland. The woodland has been mostly modified for agriculture. The Nyamugasani catchment is characterized by grass savannas with abundant Andropogon distachyus, Cenchrus Validus, Exotheca abyssinica and Hyparrhenia cymbaria have developed at altitudes of 2000-3000metres. The most productive grasses are Pennisetum clandestinum and P. purpureum followed by Setaria sphacelata on the foothills of the Ruwenzori Mountain. The P. clandestinum grasslands have a natural clover Trifolium semipilosum which is very compatible with the grass. During the vegetation survey, climbers, fern, grasses, sedges, herbs, shrubs and trees were sampled. Two species of climbers represented into two families and only one species of fern was recorded in the study area. The survey also recorded 11 species of grasses all belonging to the family Graminaea. The herb layer in different parts of the project area is covered by 53 species represented in 14 families. Only two species of sedges in one family was recorded. The recorded woody vegetation included 33 shrub species represented in 21 families as well as 31 tree species belonging to 15 families. All vegetation regard less of their habit groups are common and wide-spread specie s and are recorded by IUCN as Least Concern, meaning that the species are not endangered or threatened to extinction in the wild.

Figure 1: Vegetation cover in the Nyamugasani Catchment

2.2.2 Fish

Fish within the study area belongs to two genera *(Barbusand and Varicorhinus). Barbusapleurogramma* is more abundant (69.6 %) followed by B. alluaudi (15.2 %) and *Varicorhinusrwenzorii* (15.2 %). Two of three species recorded are of conservation interest. *Varicorhinusrwenzorii* and *Barbusalluaudiare* listed as Vulnerable D2 ver 3.1 and are endemic to the Rwenzori region. *Varicorhinusrwenzorii* lives in fast turbulent waters with many boulders behind which the fishes take shelter for feeding and spawning. Both fish species are listed as vulnerable species due to their limited extent of occurrence. According to the IUCN, Barbusalluaudi is restricted to only three locations; Rwimi, Mubuku and Sabwe rivers (Streams on the eastern flank of the Rwenzori Mountain). However, its specific habitat preference and ecology (feeding, spawning, breeding and migratory behaviour) are not known. According to Fish Base, *V. rwenzorii* is restricted to only two locations in Uganda; Mubuku and Sabwe Rivers. Its occurrence in the Nyamugasani River therefore provides the 3rd known habitat for this species. V.rwenzorii requires fast flowing water with numerous boulders but is not known to migrate upstream or downstream along riverbeds for either feeding or spawning.

The existence of the Nyamugasani 1 & 2 may affect the migration of these fish species

2.2.3Amphibians

Amphibians are ecologically important, being predators of insects, some of which are pests to crops or vectors of disease. Amphibians are also now recognized as sensitive environmental indicators: impact on their habitat is reflected by a change in abundance and diversity in a short time. Amphibians in the study area included;

Table 1: List of sampled amphibians

No.	Species	Common name	IUCN status
1.	Amietia angolensis	Angola River Frog	LC
2.	Bufo gutturalis	African Common Toad	LC
3.	Hemisus marmoratus	Marbled Snout-burrower	LC
4.	Hoplobatrachus occipitalis	Crowned Bullfrog	LC
5.	Hyperolius pusillus	Waterlily reed frog	LC
6.	Hyperolius viridiflavus	Common Reed Frog	LC
7.	Ptychadena	Porosissima	LC
8.	Xenopus victorianus	Mwanza Frog	LC

The IUCN conservation status of all the species is Least Concern (LC), meaning that the species are not endangered or threatened to extinction in the wild. However, the list of amphibians from the present study should be treated with care. Most amphibians are very active during the wet seasons. Therefore, since we sampled the amphibians during the dry season, the list might not be exhaustive.

2.3 Socio-Economic Setting

2.3.1 Administration

The study area is bordered by Nyakiyumbu Sub County to the west, Rwenzori Forest reserve to the north, Mahango and Kilembe sub counties to the northeast, Kasese town to the east and Rubirizi and Ibanda districts to the south.

2.3.2 Demographic Composition

Kasese district has a relatively high population density of 235.6 persons per square kilometre (NPHC 2014 provisional results). The district population has grown steadily over the years at a relatively high growth rate of 3.6% based on the 2002 census. At the recent census in 2014 the population growth rate had reduced to 2.4, but the district remains one of the most populated areas in the country. The 2014 UBOS population and housing census provisional results were obtained and employed in calculation of water demands and other data processing activities for this study. The 2014 census put the population in the study area at 213,611 and a total of 41,513 households as shown in the table 5-1 below;

Table 2: demographic composition

No.	Sub-county	Population Estimate	No. of Households
1.	Kyondo	25,005	4,438
2.	Muhokya	19,531	4,248
3.	Mukunu	42,195	7,574
4.	Kyarumba	31,854	6,125
5.	Kisinga	40,631	7,998
6.	Lake Katwe	23,559	5,237
7.	Nyakatonzi	30,836	5,893
Total		**262,343**	**213,611**

Source: 2014 National Population and Housing Census Provisional Results

As shown above, if this growth rate is not controlled, the population of the project area will increase, which will further put pressure on the available resources; especially land and water resources.

2.3.3 Economic activities

People in the study area are predominantly agriculturalists involved in both crop production as well as animal rearing. Household subsistence farm production still dominates. Other economic activities within the study area include: fishing; cattle keeping; service industry; trade in commodities; manufacturing industries, mining (lime, cobalt) as well as lumbering. Agriculture takes up the major economic activities employing over 80 percent of the total population. Most of farmers are small holders practicing subsistence agriculture. There is shortage of land implying the need for optimal utilisation of the available land. Households suffer from land fragmentation largely due to large family size.

2.3.4 Existing Water and Sanitation in the study area

Water

Majority of the population (59%) use open water sources for all their water needs. The study findings show river/lake used by over half (52%) of the population was the most dominant source of water. The borehole used by 24% is the second most important source. The rest of the people depend on protected spring (15%), open wells (7%) and a limited number (2%) on pipe water. The majority (64%) access their water sources over distances greater than 500m and 86% on average use less than one jerry can per person per day, which further indicates the difficulty of accessing water sources.

Sanitation

From the study findings, the majority of the households (92%) have toilet facilities however it was observed that the latrines were unhygienic, poorly constructed and maintained. Over half (54%) of the households discharge grey water into the open areas, 40% into household gazetted disposal areas, while 6% into the drainage system. The survey findings further indicate that 60% of households dispose of solid waste into garbage pits, 9% into gazetted collection points while 30% into open areas.

Observation of household practices revealed some undesirable practices, such as using very poor latrine and bathroom structures, and the habit of not washing hands after using the latrine. The communities are reluctant at participating in maintaining general cleanliness around their water sources. Proper disposal of waste water was still lacking with the majority of the households discharging wastewater into open areas. On the other hand, few households were disposing solid wastes into the open area. With the exception of Kyarumba, Kisinga-Kagando trading centres and Kasenyi and Katunguru landing sites, the rest of the trading centres and some sub-centres do not have public sanitation facilities despite there being weekly open space markets at most of them.

2.3.5 Settlement Patterns

The settlement patterns follow the different land use categorization in the study area. These categorizations include Lake communities/landing sites, roads, cattle keeping communities, cyclic farming communities, mountain homes, low lying villages and trading centres.

2.3.6 Housing

The study area comprises Semi permanent structures characterised by mud walls and iron sheets that the majority of families (about 73%) live. About 6% are sheltered in permanent structures of mostly brick walls, cement and iron roofs. However, a significant number of households (21%) dwell in temporary structures of mostly mud walls and grass thatched roofs.

2.3.7 Gender Analysis

Kasese district has made significant strides to promote gender equality and to empower women. However, despite the efforts made by the district to promote gender equality and empower women, some glaring gender gaps remain. Women's participation in decision-making at some levels is still low. Although women are responsible for over 80% of the agricultural production in the district, they own less than 7% of all productive land on which this production takes place. The level of literacy among adult women in the district is 42% as compared to that of men which is 52% (UBOS, 2002).

2.3.8 Energy resources

Over 90% of the human population use charcoal and firewood for energy save for a small percentage of the population that enjoys electricity and gas. This poses a threat on the forestry resources in the study areas.

2.3.9 Existing Infrastructure

Most of the areas are accessible by a network of gravel roads and the Kasese-Mpondwe and Kasese- Bushenyi/Mbarara highways. In addition, most of the places are covered by the satellite telecommunication network. The national electricity grid traverses the study area with the major towns/ town boards/ trading centres connected through step down transformers.

2.3.9.1 Major water users along the Nyamugasani River

Nyamugasani 1 hydropower plant

Nyamugasani 1 hydropower plant abstracts up to 0.45m^3/s to generate 15mw of electricity and releases environmental flows of 0.25m$^{3/}$s to sustain ecological life at the cut of section which is about 5.8 km with few communities living at the cut-off section. There is e-flow provision inform of a pipe. However, the e-flow is not monitored due to unavailability of flow measurement devices. The hydropower plant is up and running and is located at coordinates 0.654936N, 30.273824E. The Nyamugasani 1 HPP is the only project upstream of the River Nyamugasani.

Figure 2: Nyamugasani 1 Hydropower intake

2.3.9.2 Nyamugasani 2 Hydropower Plant

The Nyamugasani 2 HPP utilizes the tailrace water of the Nyamugasani HPP-1 to generate 5MW of electricity; the plant is located about 5m from the tailrace of Nyamugasani HPP-1. The project releases e-flow of 0.25m^3/s through a pipe fitted at the intake of the facility, however at the time of the study, e-flow measurement device was not incorporated at the facility, therefore the volume of environmental flow released at the cut of section is not known. This has an implication to ecological life and other water users downstream the hydropower plant.

Figure 3; Engagement with the Nyamugasani – 2 HPP staff

2.3.9.3 Uganda National Roads Authority;

UNRA abstracts water at the bridge for the rehabilitation of the Mpondwe road, the water is mainly used for construction and dust suppression. UNRA abstracts water from the river using a 15000 liters bowser.

Figure 4: Abstraction by UNRA

2.3.9.4 Katwe Water Works

The plant was constructed by National Water and Sewerage Corporation to supply water to the Water to the Katwe Kabatooro. The water supply scheme is located downstream the river Nyamugasani and is the most downstream water development project. At the time of this study, the water supply scheme was abandoned due to frequent siltation of the intake.

2.3.9.5 Artisan Sand miners;

Sand mining is a common activity long the banks of river Nyamugasani which has led to the destabilization of some section of the river leading to siltation and pollution of the water, this activity also renders the river vulnerable to floods. The youth are the major actors involved in the sand mining activities with no clear management. Following engagement with the community, it was noted that there are some people who claim to own plots in the river bed.

Figure 4: Sand mining activities along river Nyamugasani

2.3.9.6 Cattle rearing

Cattle grazing are one of the major activities carried out in the Nyamugasani catchment. The cattle are watered from river Nyamugasani and therefore depend on it. It is estimated that the average water demand for livestock in the Nyamugasani catchment is 6531.4 liters/day or 0.08l/s.

Plate 3: cattle drinking directly from the river

3.0 POLICY AND LEGAL FRAMEWORK FOR WATER AND ENVIRONMENT

Overview of provision of elements of E-Flows in the legislations

3.1 The Constitution of the Republic of Uganda (1995)

The Constitution of the Republic of Uganda (herein after referred to as the constitution) is the supreme ruling that lays the foundation for all laws that have a bearing on water and environment and provides for environmental protection and conservation. In particular, the constitution makes provision for management of natural resources of which water forms an integral part, clearly stating that it is the duty of the state unless otherwise decreed by parliament to manage water resources. Local and central governments hold natural resources in trust for the people of Uganda in accordance with the provisions of the constitution. As trustee, government only has powers to grant concessions, licenses or permits in respect of natural resources. The constitution (Article 39 and 17) further provides for the right to a clean and healthy environment, but states that it is the duty for every citizen of Uganda to create, protect and maintain the environment. To promote sustainable development and public awareness of the need to manage water resources in a balanced and sustainable manner and utilization of water resources in a way that would meet the development and environmental needs of present and future generations are also stipulated in the constitution.

In line with concepts of E- Flows the constitution (Article 245) requires Parliament to provide measures intended to protect and preserve ecosystems and the environment from abuse, pollution and degradation. Indeed, Parliament has ably done this through the enactment of the Water Act Cap 152, National Environment Act 2019 and other relevant laws and policies, in particular, to take all possible measures to prevent or minimize damages, pollution and destruction to water resources.

3.2 National Water Policy (1999)

The National Water Policy (NWP) provides for the overall framework for water resources management in Uganda. Among the key policy derivatives, it offers guidance on development and management of water resources in an integrated and sustainable manner. The aim is to secure water of adequate quantity and quality for all social and economic needs, with full participation of all stakeholders while being mindful of the needs of the future generations. Furthermore, the policy calls for regulation of water for all uses, that emphasizes the aspect of water allocation, in addition to promoting measures for controlling pollution of water resources to ensure good water quality which are within the concepts of E-Flows. However, other than the use of water permits in water allocation and control of the pollution of water resources no other water regulatory mechanisms was provided in the NWP. Moreover, the basis upon which minimum flows of water permits were developed did not incorporate ecosystem health, therefore increasing the threat on ecosystem integrity. The current NWP has a number of gaps and limitations that create a suitable environment or opportunities for E-Flow implementation so as to strengthen the processes of achieving policy objectives.

Opportunity for E-Flow implementation as a water allocation tool

E-Flows implementation may be used as a water allocation tool because it recognizes that a given catchment has a carrying capacity and as such not all water users may be granted permits *(Hirtji and Davis, 2009).* The concept calls for conducting an EFA of a given catchment to provide scientific basis upon which minimum flows maybe determined in addition to initiating guidelines for optimum water allocation plans for any given catchment. In this line the NWP calls for balancing social and economic benefits as well as determining the environmental objective of a given water resource in a participatory manner (societal judgement). The application of E-Flows concepts would support science and social choice in making effective decisions during water allocation (Dyson *et al.,* 2003).

Opportunity for comprehensive ecosystem protection

The policy states the need to protect the environment and in-stream water uses however, the policy is silent on the details and intricacies of how this should be conducted and/or how ecosystems water needs are to be determined. The policy also provides for the overall strategy and principle of water allocation for consumptive water uses (industrial, agriculture, power generation. etc.), although it is not certain as to whether it did or did not include non-consumptive water needs (ecosystem water needs). Hirtji and Davis (2009) reported that ecosystems just like any other water users have water use needs that should be allocated. Whereas the policy provides for ecosystem protection there is a missing gap on how ecosystems protection can be guaranteed. The concept of E-Flows on the other hand provides a comprehensive water allocation mechanism through EFA that goes a great length in determining minimum flows based on scientific information thus fully protecting ecosystems (Poff *et al.*, 1997; Dyson *et al.,* 2003).

E-Flows to strengthening IWRM

The policy endorses IWRM approach however the challenge of IWRM is the practice to allocate water for both consumptive and non-consumptive purposes. Often times the well-placed consumers (economically, socially or politically) that can advocate for water and justify their use are allocated water while compromising ecosystems that are silent user (Korsgraard, 2006). The policy is cognisant of the need to protect ecosystems, however, the details and elaborate ways of what (natural flow regimes, minimum/in-stream flows maintenance) and how (water allocation mechanism, societal choice) water resources can be managed and conserved to support ecological goods and service that enhance economic performance were not provided. An argument by Bisaws (2004), is that much as the definition of IWRM was very attractively

packaged it leaves a lot to be desired. The concept does not spell out which aspects need to be integrated, by whom, how and also the feasibility of the integration still remains wanting. Much as IWRM addresses all other social and economic water needs, ecosystem water needs are not often given priority or due consideration in water allocation mechanism. Therefore, taking a wider picture of ecosystems protection and conservation approach into IWRM is the concept of E-Flows (Bisaws, 2004; Korsgraad, 2006).
Currently Uganda is implementing IWRM approaches at catchment levels, considering that E-Flows are within the settings of IWRM, with elaborate ways on ecosystem conservation and protection, its implementation will greatly contribute towards a holistic integrated and improved water resources management (Tharme, 2003). In addition, Dyson *et al.,* (2003) argues that the concept of E-Flow is a very important element of IWRM because it maximises the resultant economic and social welfare in an equitable manner without comprising the sustainability of vital ecosystems.

Opportunity for full provision of the Reserve

The policy gives an unconditional first priority of water allocation for domestic use and not for ecosystem water needs. The South African Act (1998) defines the *'Reserve*' as given quantity and quality of water that is excluded from any other water use, other than for supplying basic human needs and ecosystem health needs. Basic human need reserve refers to the water that is used to satisfy and preserve human needs like drinking, washing, bathing, cleaning, cooking. While ecological health reserve refers to the water needed for aquatic ecosystem conservation and protection. In the Ugandan contexts the *"Reserve*" is partially implemented with a focus on only domestic water use. Accordingly, by law ecosystem water needs compete with other water uses (Industry, hydropower generation, recreation, commercial agriculture etc) and its prioritization is dependent on other factors and subject to tradeoffs between social and economic water needs.

The concepts of E-Flows require that the *"Reserve"* (domestic and ecological water needs) be given first priority in water allocation and then using societal judgment other water users may be allocated available water through mutual negotiations and tradeoffs (Korsgraard, 2006; O`Keeffe and Le Quesne, 2009). Although the *Reserve* is mentioned and the importance of ecological water needs emphasized in the policy, it is apparent that ecological water needs have not been prioritized by not providing for full implementation of the *"Reserve"*. In a broad sense implying that ecological conservation has not been sufficiently accorded the necessary protection, thereby risking ecosystem health and/or in-stream water needs which E-Flow implementation would negate.

Opportunity for sustainable water resources use and management

The policy provides for sustainable use of water resources. Although this may be achieved through IWRM, implementation of E-flows will add a more holistic, practical and attainable version of sustainable water resources use and management. In Uganda today, there are no clear guidelines on setting flow requirement for rivers or catchments given their uniqueness and different uses. Most river systems already have altered flow regimes due to modifications or management of flows to meet economic developments (Rosenberg *et al*., 2000; Tharme, 2003). Implementation of E-Flow concepts would allow for a wide range of methods, approaches and framework guided by science and societal judgement in determining minimum flows thus contributing towards sustainable water use (Tharme, 2003; Korsgraard 2006).

Considering that there are no clear procedures and harmony over the amount of minimum flows (low and high) in Uganda to provide guidelines on optimum abstraction or released at hydropower dams that ought to mimic natural flow paradigms there is need to implement the concepts of E-Flow. Moreover, it`s implementation will facilitate the exercise of water allocation and/or provide a platform for negotiations and trade-offs among water users that is lacking in IWRM. Thus, enhancing conservation and protection of water resource, maintenance of natural flow paradigms and subsequently contributing towards sustainable use and management of the water resource (GWP, 2000; Dyson *et al.,* 2003).

E-Flow to facilitate water resources quantification before allocation

The policy is silent on prior quantification of water resource before allocation and yet it promotes allocation of water for agricultural production (crops, livestock and fish) in order to modernizes agriculture and mitigate effects of climatic change variations on rainfed agriculture. Water resources quantification before allocation is very essential in protecting in-stream flow especially where massive abstractions or hydropower generations may be ongoing in low yield or small water resource particularly in water scare areas. In view of the escalating Ugandan population (growth rate of 3.2% per annum (UBOS, 2002), climate change, temporal and spatial distribution of water resources there is indeed a need for quantification of water resources prior to planning and allocation. Although water allocation is more of a social political activity scientific information and analysis of the initial quantity are very vital as a basis for equitable and sustainable conclusion (Dyson *et al*., 2003). The concept of E-Flow is a suitable option considering that it calls for prior water quantification before and incorporates population and ecosystem water demands, environmental objectives, social economic development, scientific information and societal choices in determining minimum flows and finally development of catchment water allocation plans.

Policy provision regarding water allocation principles

The law (Water Policy, 1998; Water Act, Cap 152, Section 5; The Constitution of Uganda, 1995) places all rights to use, control, protect, and manage water resources under the control of the Minister of Water and Environment and Director, Directorate of Water Resources Management. Whereas no permanent water rights exist, temporary rights may periodically be obtained through allocation of water using water permits that are renewed on expiry. In exercising water allocation, the NWP provides for the following options during the processes;

Principle I: First priority for domestic water needs

The first priority for water allocation is to meet domestic water demand, implying that community water allocation is to be considered, committed and excluded from other water uses. Thereafter, depending on the total available water in the resource other users among which industrial, agricultural, and ecosystems may be considered. This does not necessarily mean that societal choice is considered during water allocation although it does imply that a water allocation mechanism that is not yet in place ought to be considered in computing communal domestic water needs.

Principle II: Provision for resource management and environment

The second provision in water allocation is to reserve in-stream water to ensure continuous viability and conservation of the environment. In particular the NWP states that minimum flows shall be provided for maintenance of water quality and aquatic ecosystem. Currently, there are about four informal approaches of allocating water for ecosystem needs these include leaving;

i). About 10-15% of the MAR,
ii). 30-40% of the minimum flows,
iii). 1% of the minimum flows and
iv). Q 95% reserved for ecosystem water needs.

There is therefore a need for a scientifically based water allocation mechanism to harmonize the above practices and determine the amount of flows that ought to be regarded as minimum to maintain water quality and aquatic ecosystems of a given water resource, therefore calling for E-Flow implementation (Poff *et al.,*1997*).*

Principle III: Provision for Water for production

Policy requirements for allocating water for production calls for consideration of social economic value of the water use, optimum development of the water potential and the impact on water resources. Indeed, in alliance with concepts of E-Flows the physical limit or carrying capacity beyond which a water resource suffers irreversible damages to its ecosystem function ought to be considered before undertaking social economic activities (Hirji and Davis, 2009). In addition, the concept recognizes social choices in determining environmental objectives and provides for a water allocation plan that will result to sustainable utilization of the water resource which is in line with the concept of E-Flow (Korsgraad, 2006).

Principle IV: Market based allocation principle

Over a period of time the policy requires that "Market-based Allocation" that is supported by the principle of *"water as a social and economic good"* be applied. This principle promotes water allocation basing on the understanding of the available yield less the allocation for a *"Reserve"* (domestic and ecosystem water needs). Thus, prior assessments of yields or quantities of each water resource at the prevailing level of development before committing the *"Reserve"* is required so as to facilitate resource management. In addition, involvement of stakeholder is a prerequisite for the continuity of the established of water allocation plans bringing in societal choices in determining the environmental objective of the given resources which are all within the concepts of E-Flows.

In view of the onset of effects of climate change, dwindling water quantity and availability, increasing demand for social economic development and population growth, Uganda has reached this point in time that entails the establishment of the Market-based Allocation. An inventory of water resources to establish availability against demands ought to be conducted to offer effective guidance during water allocation. Whereas the law provides for these principles which are in fact components of E-Flows, currently the main focus is on full implementation of Principle I and partially II. Implementation of E-Flows requires full activation of Principle IV (Market-based Allocation) as a contribution towards sustainable water resources management (Water Policy, 1999).

3.3 The National Environmental Management Policy, (1994)

The overall goal of the National Environment Management Policy is to promote sustainable economic and social development that will meet the needs of the present generation while being mindful of the needs of future generations. The specific policy objectives are to introduce:

- Sound environmental management,
- Environmental planning,
- Ecosystem conservation,
- Sustainable resource consumption, and
- Environmental awareness and community participation.

Within the policy, EIA is recognized as an important environmental planning tool in preserving and enhancing environmental quality and ecosystem productivity which are in line with concepts of E-Flow. E-Flow concepts are key to sustainable development, enhancing ecosystem integrity, sharing of benefits and poverty alleviation, nevertheless, water allocation for environmental uses is still lacking among water resources practitioners (Dyson *et al.,* 2003) even in Uganda as well.

The Policy is recognizant of the low cost of preventing environmental damage compared to high costs of repairing them thus establishing a sound economic justification for instituting and carrying out EIA. In advocating for the use and application of EIA, the policy seeks to integrate environmental concerns early enough in the development planning process for all activities and projects at national, district and local levels with full public participation. Thus, the policy requires that eligible projects or policies likely to have significant adverse ecological or social impacts undertake EIAs before implementation. It has now been proven that the world`s biodiversity and alleviation of poverty among the rural communities that greatly depend upon ecosystems can only be achieved by maintaining a sound ecological system (Naimen *et al.*, 1995; Dyson *et al.,* 2003).

3.4 The National Forestry Policy (2001)

Over the years the Forest Policy (1929), underwent considerable transformations due to the need for less strict conservation and more liberal economic use of forest resources. The new policy instituted the National Forest Authority (NFA) and provided alteration following increasing deterioration of forests; receding ecological goods and services; declining natural forest cover; increasing pressure on forest land and demand for forest products in the country. The policy now provides direction towards conservation of ecosystems and sustainable development, with guiding principles built on government national development priorities of poverty eradication and good governance. The major sectoral goal in alliance with concepts of E-Flow is to contribute towards poverty alleviation by safeguarding biodiversity, ecosystems and environmental goods and services through effective conservation strategies. As supported by Naimen *et al.*, (1995) it is now evidenced that maintaining a sound ecological system is the answer for maintaining the world's biodiversity and poverty alleviation for the rural communities.

3.5 National Policy for Conservation and Management of Wetland Resources (1995)

Wetlands cover about 13% of the area of Uganda providing direct and non-direct goods and services to its population. Until the early 1990s wetlands were considered as "Wastelands", subsequently, heavily reclaimed for agricultural purposes in rural area and drained as a measure of controlling malaria in urban settings. Through the mid-1990s, a realization to conserve and protect wetlands culminated into the process of institutional the Wetland Inspectorate Department (Directorate of Environment Affairs) and formulating the National Wetland Policy. The policy seeks to promote wetland conservation in order to sustain ecological and socio-economic functions for the present and future wellbeing of the people. In Uganda today wetlands are considered as water resources in form of "green water" their conservation culminates to conserving flows in water courses. In line with E-Flows the policy calls for sustainable management and protection of wetland ecosystems, in addition to ensuring that all negative impacts that could degrade ecosystems are negated through EIA processes.

3.6 The National Energy Policy for Uganda (2003)

The main policy goal of the energy sector is to meet energy needs of the Ugandan population for social and economic developments in an environmentally sustainable manner. In alliance with E-Flow concepts, the policy recognizes potential environmental impacts of hydropower related investments on water resources and ecosystems thus calling for EIA undertakings. The Energy sector is also entrusted to ensure that environmental guidelines that enhances protection of ecosystems and establishes monitoring mechanism to evaluate compliances are established. Indeed, this was provided through DWRM that issues water permits for hydropower generation stipulating minimum flow and agreed curve requirement. E-Flows do not prevent the use of water resources for economic developmental purposes like hydropower generation, rather it calls for proper planning, designing, operations and practices that would not modify or transform natural flow regimes of rivers especially where releases are concerned (Dyson *et al.,* 2003).

3.7 The Water Act, Cap 152

Following the Water Policy (1998), the principal law for water resources management is the Water Act Cap, 152. The act provides the basic foundation of most provisions to reconcile environmental protection while ensuring availability of water of adequate quantity and acceptable quality. The objectives of which are to enable equitable and sustainable management; use and protection of water resources through supervision; and coordination of public and private activities that may negatively impact water resources (quantity and quality). Within the act there exist limitations and gaps that provide an opportunity and/or could be strengthened through implementation of E-Flow concepts thereby contributing towards effective management of water resources.

E- Flows as alternative regulatory tool

Allocations of permanent water rights are prohibited (section 18) but temporal rights could be attainable through time-bound permits to abstract water, construct hydraulic works and discharge waste. Persons requiring to use water, construct (construct herein defined as alteration, improvement, maintenance and repairs of water systems) or operate any works or cause or allow waste to come into contact directly or indirectly with water resources (section 6, 28 and 31) are obliged to obtain permits from the Director. Albeit, the act gives general rights to persons that are residents on land or adjacent land with water resources to collect water and use it to meet domestic water needs (firefighting or irrigation a subsistence garden). However, limiting water quantities not to exceed 400 m^3/day and prohibits motorized water use whether for domestic or not without authorization.

Currently, the water permit system is the only available regulatory tool of which minimum flows were informally determined basing only on hydrological parameters not mindful of dynamics of different catchments and ecosystem water needs. Implementation of E-Flows as a regulatory tool that applies a multidisciplinary criterion and allows application of diverse measures in determining minimum flows (high and low) towards a more holistic regulatory strategy is now a necessity in fostering contributions towards sustainable management of the water resources in Uganda.

E-Flows as a water resource planning tool

Notwithstanding, general rights to use water resources may be limited by the Minister, in times of shortage and/or anticipated shortage thus granting use for only specific purposes an aspect of water allocation within concepts of E-Flow (Section 8). Furthermore, the act calls for orderly development and use of water resources (animals, irrigation, industrial, commercial and mining uses, energy, navigation, fisheries, preservation of flora and fauna and recreation) in ways which minimize harmful effects to the environment and ecosystems. Still in alliance with concepts of E-Flow the act (section 28 and 31) provides for controls of pollution by promoting safe storage, treatment, discharge and disposal of waste which may pollute water or otherwise harm the environment and human health. Thereby ensuring that clean, safe and sufficient supply of water for domestic use are availed as a right to every citizen of Uganda (Constitution of Uganda, 1995) In performing his function, the Minister is required to regulate, restrict and prohibit some activities and allow others in relation to water availability and societal choice. At this moment the Minister`s ability to perform functions pertaining to water resources planning and allocation are inadequate. E-flow implementation will enhance performance of these functions given that it will call for conducting an inventory of all water resources, determination of the *Reserve* and available water (uncommitted) as well as establishing carrying capacity of given water resources. In addition, catchment water allocation plans with optimum numbers of permits would be developed. With this in place the Minister will then be able to determine the state of the resources and forecast anticipated water shortages against known water quantities and demands then initiate appropriate water resources sustainable actions.

E-flows as a decision-making tool

In executing his duties, the Water Act, allows the Director to vary granting permits if in his opinion the water resources are likely to become insufficient in quantity or quality for the needs of the persons/public using the resource or seeking to utilize it (section 22). This duty requires prior knowledge of the state of water resources (quantification and classes), environment objective of resources, societal choices and development of catchment water allocation plans. The Director would then be informed of the optimum number of abstraction and waste discharge permits and hydropower generation plants within a given catchment being mindful of the resource carrying capacity (Hirii and Davis, 2009). Considering that in Uganda today there is no quantification of a resources before water allocation, no classification of resources, the Director ability to perform duties and provide authentic decisions on the state of any water resources is limited and E-Flow implementation would bridge this gap.

E-Flows as a tool for equitable sharing of water resources

The Director is required to (section 23) offer guidance on ample amount of water quantities in his view that the permit holder may need if quantities are not specified. The major aim is to ensure equitable sharing of water resources among different societal users so as to prevent water wastage, promote tradeoffs and negotiations towards sustainable development of water resources. E-Flows is about equitable distribution (down and upstream; among different sectors; etc) and accessibility of water and services that aquatic ecosystems provide (Dyson *et al*., 2003). In executing his duties, the Director requires knowledge of the available water resources (quality and quantity), the *Reserve* (to ascertain uncommitted water) and water allocation plan to facilitate equitably sharing of the water resource. In addition to establishing what the society wants for the given water resources (societal choice) which are enveloped
within concepts of E-Flows.

3.8 The Water Resources Regulations (1998)

The overall objective of water resources management is *"to manage and develop the water resources of Uganda in an integrated and sustainable manner, so as to secure and provide water of adequate quantity and quality for all social and economic needs of the present and future generations with the full participation of stakeholders"*.

From the onset elements of E-flows are identifiable in the Water Resources Regulation (1998). The need to protect the environment and government policy related to conservation, water allocation and use of water resources are provided. Prior to water (surface or ground) abstraction, authorization from the Director-DWRM (section 3), through acquisition of water abstraction permit is a pre-requisite. In alliance with concepts of E-Flows, the regulation (section 6 and 7) coerces the Director to assess projected effects of abstractions on water availability and quality and determine likely impacts of water allocation on the following;

i) the existing water uses
ii) protection of water and of surrounding
iii) maintenance of flow in the waterway
iv) protection or control of in-stream uses of water
v) aquifer or water way including effects on land which forms the waterway or its surrounding,
vi) Maintenance of drainage regime including the riverine and riparian environment.

Furthermore, construction of any works on water ways without undertaking measures to protect in-stream water uses, maintenance of flows in waterways and the drainage regime are prohibited. The regulation calls for steps and measure that will maintain in-stream water availability to satisfy other water users in cases of water shortage in waterways, this is none other than implementation of concepts of E-Flows. Indeed Poff *et al.,* (1997) states that a new ecological thinking and management style among water managers is urgently needed if societies are to continue depending on river ecosystems for food production, power generation, waste assimilation, fisheries, and flood control. Sadly, though the importance of the variability of natural in-stream flows that exits in rivers have not been linked to ecosystems health or societal welfare and therefore not received attention of water managers.

In alliances with E-Flow concepts, the regulation provides for a requirement to maintain drainage regimes (natural flow paradigms) and releases that will not negatively impact on downstream water users. The requirement to consider the existing water users before issuance of permit brings in an element of carrying capacity, development of water allocation plan and attempts to prevent over allocation of water resources thus sustaining minimum flows (Hirji and Davis, 2009). The challenge however, is that the policy and legal framework in Uganda do not provide for full implementation of the *Reserve* and thus compromises ecological water needs. Prioritising of only domestic water needs subjects ecological water need to competition with other more powerful socio-economic water users thus compromising ecosystem health and integrity (Korsgraard, 2006).

3.9 The Water (Waste Discharge) Regulations (1998)

The Wastewater Discharge Permit (1998) was established with the aim of regulating and controlling wastewater discharges into the environment and subsequent water quality and ecosystem protection. Prohibiting discharge of untreated effluents or waste into aquatic environment or land unless in conformity with specified minimum permissible limits provided by law. Water quality is a fundamental element of water resources management that is the primary consideration of all options for reconciling water requirement and availability (DWAF, 2008). In line with concepts of E-Flows, the Director is obliged to ensure that no negative impacts from the permit affect in-stream and downstream water quality so as to enhance protection and conservation of water resources and ecosystems health. Palmer (1999), reported that there is now a realisation that supplying adequate water resources quantities in time and space would not necessarily result to ecosystem health if the water quality is impaired. Thus, the water quality reserve (environmental water quality requirement and ecological water needs) which is the description of water quality that is required to maintain aquatic ecosystems in a predetermined state (DWAF, 2003).

3.10 The National Forestry and Tree Planting Act, 2003

The National Forest and Tree Planning Act (2003) provided for the establishment of the National Forest Authority (NFA). NFA is charged with protection, conservation, productivity enhancement, sustainable use, management and development of forests for the benefit of the people of Uganda. The act promotes strategies and actions that aid promotion and improvement of livelihood so as to contribute towards poverty alleviation which is in line with E-Flow concepts. Dyson *et al.,* (2003) appraise E-Flows as a major contributor to sustainable development, enhancing ecosystem integrity, sharing of benefits and poverty alleviation. The act (Section 6) is recognisant of the linkage between forestry and environment and the need to protect streams, rivers, lakes, lake shores, river banks, wetland and ecosystems which are in support of concepts of E-Flow. The act grants protection against likely adverse effect on habitats and environment due to detrimental changes in temperature or erosion, pollution, degradation, deposits of sediments and desertification. In addition to ensuring that environmental benefits, costs and values are reflected in the strategies and activities related to forest.

The Act prohibits actions that are likely to negatively impact on forests, and/or environment and requires that the responsible persons or bodies be brought to action and an EIA carried out to mitigate such impact. In line with concepts of E-Flows, the act authorises the Minister of Water and Environment (Section 7) to declare an area as a forest reserve (strict natural reserve) for conservation purposes. Streams, rivers, lakes, lake shores, river banks, wetland and ecosystems are to be conserved and forest reserves protected for ecological and tourism purposes for the common good of the citizen. In addition, the Act (Section 13) calls for management of forest reserves in a manner that will conserve biological biodiversity, ecosystems and habitat while sustaining economic yields and promote fair distribution of economic, social, health and environmental benefits. It's now evidenced that maintaining a sound ecological system is the answer for maintaining the world's biodiversity and poverty alleviation for the rural communities (Dyson *et al.,* 2003).

E-Flow implementation to address gaps within the act

In as much as the act emphasises on protection of in-stream flows, rivers, lakes and wetlands the act is silent on tree planting in relation to water availability. The aspect of uneven distribution of water resources in time and space was not incorporated in the act probably due to the assumption that Uganda is well endowed with freshwater resources
(Water Policy, 1999).

Currently NFA has embarked on nationwide tree planting activities that are likely to impact on water resources quantities thus in-stream flows. The fact that some tree species require enormous quantities of water while others thrive in water scares areas were not captured in the act. Water demand information of the different tree species ought to be availed to the public as a guideline on tree planting activities based on suitability, water resources availability and wise use. It should be noted that changes in river flows are not only due to over abstraction, storage or regulation through dams but also upstream land use activities like forestry, urbanisation and agriculture (Dyson *et. al.,* 2003). EFA will clearly show water stress and water abundant areas within the different catchments. This with environmental objectives of a given catchment developed through societal choices will guide the authority on the kind of tree in relation to water demand to promote in the given catchments. Once implemented E-Flow will enhance NFA`s ability to improve livelihood and alleviate poverty among communities as well as contribute towards sustainable use and management of forest and water resources in Uganda.

3.11 The National Environment Act No. 5 of 2019

The National Environment Act No. 5 of 2019 provides for sustainable management of the environment, calling for wise use, conservation and management of natural resources in an equitable manner for the benefits of both the present and future generations. In line with E-Flow concepts the act requires that the rate of population growth and productivity of the available resources be taken into account to enhance sustainable utilisation. The Act (section 52) also prevents contamination of water resources restricting the use of lakes and rivers stating that no person shall, in relation to a river or lake use, erect, reconstruct, alter, extend, remove or demolish any structure or part of any structure in, on, under or over the bed or excavate or drill (section 53). By preventing modification, transformation or alteration along the water course, natural flow regimes that promote and sustain ecosystem health and integrity will be maintained (de Groot, 1987; Naimen *et al.,* 1995; Coastanza *et al.* 1997).

Also, in line with E-Flow concepts the act provides for (Section 60 and 61) in-situ and ex-situ conservation of biological fauna and flora resources on land or in water and reclamation of lost ecosystems. The requirements to maintain a stable functioning relationship between living and non-living parts of the environment through preservation of biodiversity and respecting the principles of optimum sustainable yield of natural resources are in line with E-Flow concepts. The concept recognizes that there is a physical limit or a carrying capacity beyond which a water resource suffers irreversible damages to its ecosystem function, therefore calling for an allocation of water for ecosystem needs (Hirji and Davis, 2009).

3.12 The National Environmental (Environmental and Social Assessment) Regulations, 2020

Environmental Impact Assessment (EIA) regulations followed a requirement from the National Environment Act No. 5 of 2019 that calls for mitigation of negative environmental impacts for developments and projects with potential effects on the environment. It ensures that environmental impacts are incorporated early in the project life cycle (conception, design, pre- and post-implementation stages) as well as their financial and technical aspects. Thereby ensuring that important environmental resources are recognized and protected early in the planning and decision-making process. In Uganda, the requirement for undertaking EIAs are supported by a number of sectoral laws (Forestry, Mining, Fisheries, Energy, Petroleum explorations etc) that were enacted in 1995, and continues to be endorsed in other environment related sectors.

In alliance with E-Flow concepts, implementation of EIA is based on active participation and involvement of stakeholders whose collective contribution is considered in the final decision, an aspect of societal judgement in environmental aspects (Dyson *et al.,* (2008). Furthermore, EIAs are based on the appreciation and realization of the cheap costs of having to prevent environmental damages than repair which are also in support of E-Flows concepts. Moore (2004) said the link between social economic costs and benefits of E-Flows ought to be well explained to stakeholders so that they can make informed choices, recommending sensitisation and awareness rising. Poff *et al.,* (1997), expounded on this and said it's very important that societies understand the underlying scientific principles behind natural flow regimes of rivers and their link to supplying the vital goods and services that contribute to their welfare. In this way not only will they appreciate but also be willing to contribute to river conservation and restoration.

Hirji and Davis (2009) stated that EIA policies of many countries have not matured to the point of effectively integrating EFA. As is the case in Uganda where little or no emphasis on water allocation and/or minimum flows or ecological water needs are provided in the EIA policy. Therefore, in this current Ugandan EIA policy the requirement to protect water resources and wetlands of significant importance so as to maintain equitable, sustainable use and conservation of ecological functions will inadequately be attained. Moreover, the second schedule of the National Environmental (Environmental and Social Assessment) Regulations, 2020 demands that sufficient understanding of ecological considerations, physical environment and social consideration are catered for during the EIA process. Specific regards were accorded to ecological factors, calling for sustainability of fish breeding populations, wise use of wetland, maintenance of fragile ecosystems and negating effects of proposal on food chains.

E-Flows as a measure of strengthening ecosystem protection

Implementation of E-Flow concepts and/or its incorporation in the EIA process in Uganda would go a further step in ensuring full ecosystem protection, management and sustainable use of water resources. The natural flow variation that may be in terms of hours, days, seasons, years or even longer are obtained through very long observation from stream flow gauges or though extrapolation from streams with gauges provided they are within the same geographical areas (Poff *et al.* 1997). Natural flows of a river that regulate ecological process are determined by five components that include magnitude, duration, frequencies, timing and rate of change (Poff and Ward 1989; Poff *et al.,* 1997). These components act together in intricate ways to regulate geomorphic and ecological processes. Closure of fisheries, groundwater depletion, water quality decline, water availability, intense flooding and river bank erosion and sedimentation are symptoms of the present river management and economic development policies (Naiman *et al.,* 1995; Poff *et al.,* 1997). It is therefore very important that societies, environmental practitioners, water and environmental resources managers, politicians and other stakeholders understand the underlying scientific principles behind natural flow regimes of rivers. And their link to supplying the vital goods and services that contribute to their welfare thus alleviating poverty and improvement of human health. In this way not only will they appreciate maintenance of natural flows but also be willing to contribute to river conservation and restoration (Poff *et al.,* 1997).

Table 3: Key Stakeholders involved in the EIA process in Uganda

- **Developers;** charged with the responsibility of conduct EIAs as a function of their planning process.
- **NEMA;** authorization by law to co-ordinate, supervise and monitor the processes and requirements of implementing EIA.
- **Lead agencies;** Sectoral government departments and local governments are charge with a significant role of reviewing Environmental Impact Statements on developments and projects activities whose implementation may have potential impact on components of the environment under their jurisdiction.
- **EIA Practitioners;** Provide technical expertise in conducting environmental assessments of impacts of developments and projects thereby providing useful information to both developers and decision makers,
- **Members of the general public;** Beneficiary Communities likely to be affected by development activities and whose input is critical at various stages of the planning and development process. This also includes NGOs and civil society groups whose advocacy role provides pressure for effective adoption of EIA as a planning and decision-making tool.

E-Flow concepts to address gaps in EIAs for hydropower generation

The Energy Policy (2002) provides for EIA undertakings however there is no clear requirement to maintain natural flow paradigms. It may be urged that water permits that provide for minimum flows are obtained from DWRM, but the current minimum flow conditions provided in water permits are not harmonised, besides its basis is not upon proven scientific finding. In addition, only the requirements to maintain low minimum flows are provided in the permits. Having to maintain high minimum flows (wet season) will ensure flooding of wetlands and recharging of groundwater, facilitate movement of fish to their breeding ground, flash rivers thereby improving water quality, maintenance of biodiversity and fragile ecosystems which are often very vulnerable to low flows. On the other hand, low minimum flows (dry seasons) will ensure that the low flow biodiversity are maintained and food chains of the different species breed at the different phases of the river cycle.

Key informant interviews revealed that the practise at hydropower dams is to maintain releases according to recommended permit low minimum flows and/or withhold water in the nights releasing during the day because of the differences in power demand it was also observed that both Nyamugasani HPP 1 & 2 do not have measuring devices to measure the amount of e-flow released at the cut-off section. This practise alters natural flow paradigms and in-stream flows. In-stream flow quantity is one of the most crucial aspects of river systems its timing plays a central role in determining water quality, water supply and ecosystem integrity. In addition, it is responsible for establishing physicochemical characteristic (water temperature, channel geomorphology, habitat diversity) that determines abundance and distribution of riverine species and control ecological integrity of flowing rivers (Poff *et al*., 1997). The importance of the variability of natural stream flow that exits in rivers had not been linked to social economic development and ecosystems health and therefore not received attention of water managers even of Uganda as well.

Poff *et al.,* (1997) reported that water managers often face difficulties in management of rivers due to fragmentation of responsibilities among different agencies. This is the case in Uganda, where water permits to operate hydropower dams are issued by DWRM (Ministry of Water and Environment) and yet implementation of releases is carried out by Ministry of Energy and Mineral Resources and Electricity Regulatory Authority and enforced by NEMA. It was also reported that the Ministry of Energy and Mineral Resources is also involved in issuance of related water permits. These discrepancies will be minimised in the event that concepts of E-Flows are implemented, because DWRM would avail E-flow guidelines based on scientific knowledge, technocrats in hydropower generation would be sensitised on importance of maintaining natural flow paradigms thus contributing towards sustainable management of water resources and ecosystem health.

Literature review international context EFRs

THREE SCHEMES FOR CLASSIFYING ENVIRONMENTAL ASSESSMENT METHODS

Table 4: classification of environmental assessment methods

Organization	Categorization methods	Sub-category	Examples
IUCN Dyson el, al 2003	Methods		
		Look up tables	Hydrological (e.g. Q95 Index Method)
			Ecological (e.g Tenant Method)
		Desk top Analyses	Hydraulic (e.g. Wetted perimeter)
			Hydrological (e.g Richter Method
			Ecological
		Functional Analysis	BBM, Expert Panel Assessment Method,
			Benchmarking Methodology
		Habitat Modeling	PHABSIM
	Approaches		Expert Approach
			Stakeholder Approach (Expert and non-Expert)
	Framework		IFIM, DRIFT
Word bank (King and Brown 2003	Prescriptive Approaches	Hydrological Index Method	Tenant Method
		Hydraulic Rating Method	Wetted perimeter
		Panel of Expert	
		Holistic Approaches	BBM
	Interactive approaches		IFIM, DRIFT
IWMI	Hydrological approaches		Tenant Method
	Hydraulic rating methods		Wetted Perimeter
	Habitat simulation approaches		IFIM
	Holistic methodologies		BMM, DRIFT, Expert Panel Benchmarking Methodologies

4.0 ASSESSMENT OF ENVIRONMENT FLOW REQUIREMENTS

4.1 Methodology on Determination of Environmental Flow

This section explains the hydrologic characteristics and environmental flow requirements of Nyamugasani River.

Study area

Nyamugansani River is located in Kasese District, traverse through many sub counties and Villages. The river drains from Rwenzori Mountains flowing through the borders of Bukonjo and Kyondo to Kisinga, Nyakatonzi and L. Katwe sub counties. The river has a catchment area of 501km2 and drain to Lake George.

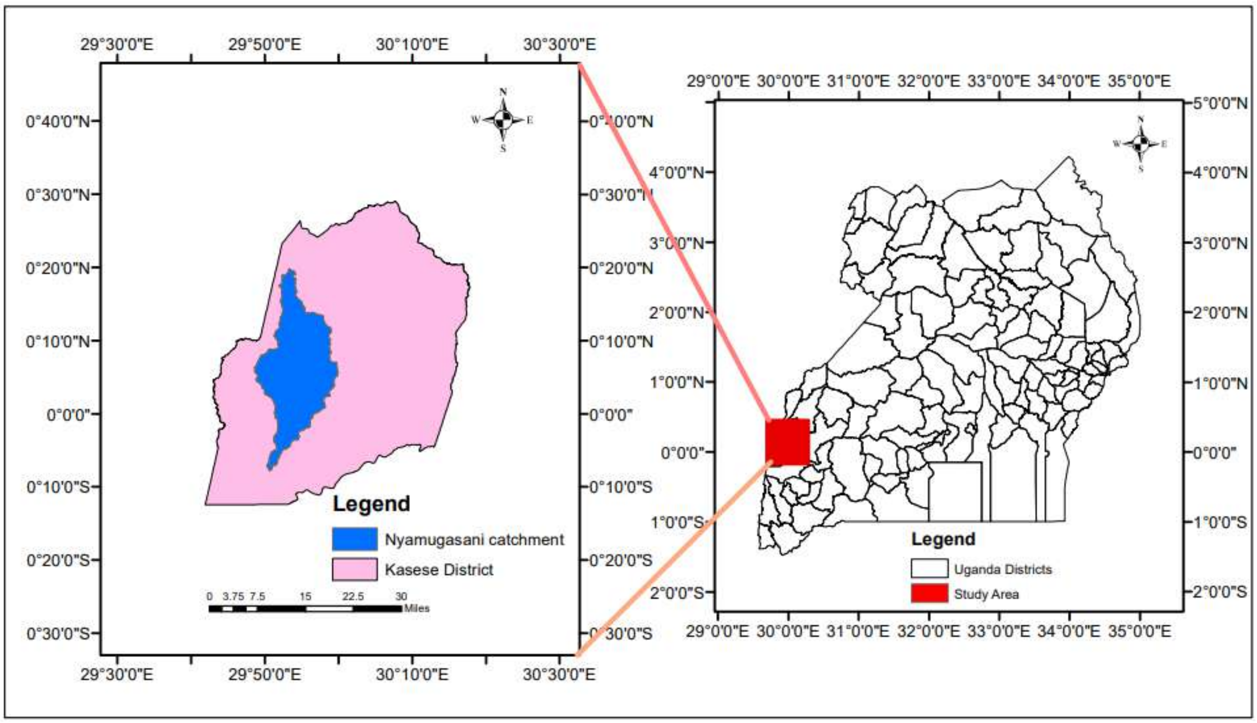


Figure 5. Nyamugasani catchment area

Data Collection.

The data used in this analysis was collected from different sources as shown below.

Data	Sources	Period
Rainfall data	UNMA	1990-2020
Temperature	UNMA	1990-2020
Flow data	DWRM	2002-2015

4.2 Rainfall characteristics

Rainfall characteristics

Daily rainfall.

The rainfall over the catchment ranges between 1000mm to 2300mm annually. The figure shown below shows the daily rainfall characteristics over a period of 30 years from 1990 to 2020.

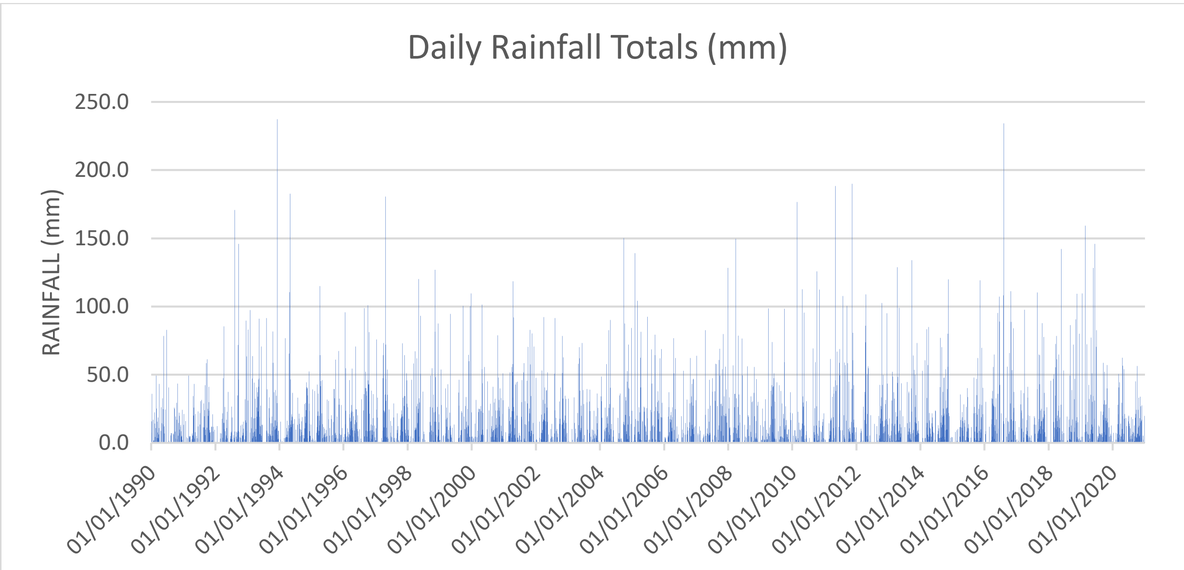


Figure 6. Daily rainfall totals

Nyamugasani catchment experiences two wet seasons of March to May and September to November and low rainfall periods of December to February and June to July as shown in the figure below. Due to this, low flows are expected within the low rainfall seasons and high flows during wet seasons.

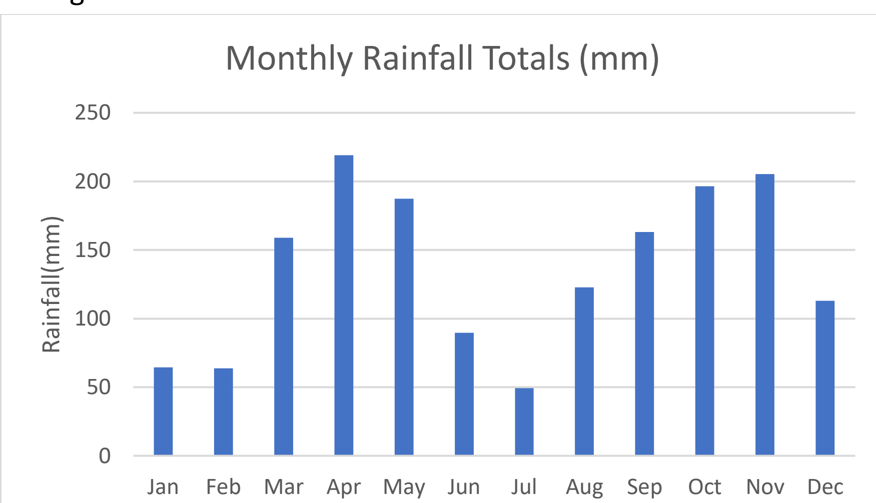


Figure 7: Monthly average rainfall

Temperature

The average temperatures within the project area range between 17.68 to 30.63°C. Minimum temperatures occur in May and October while the highest occur between December through March every year. Generally, the average temperatures are around 24.15°C. The average. Figure shows the temperature variation over a period of 30 years for Kasese District

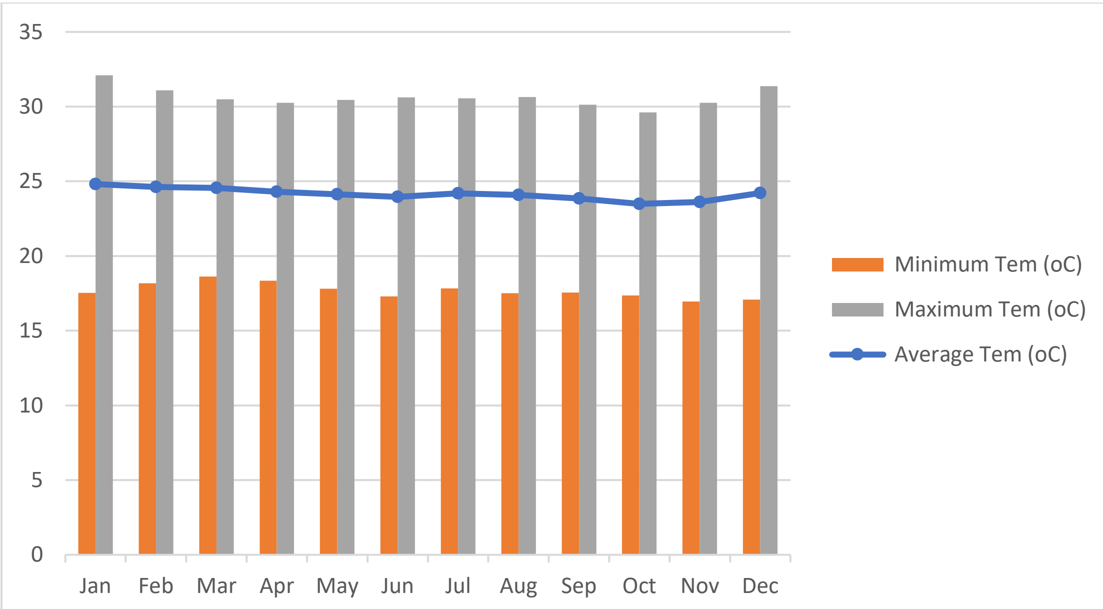


Figure 8: Average temperature

4.3 Flow data

Nyamugasani catchment has a flow gauge downstream of the river with flow data from 2002 to 2015.

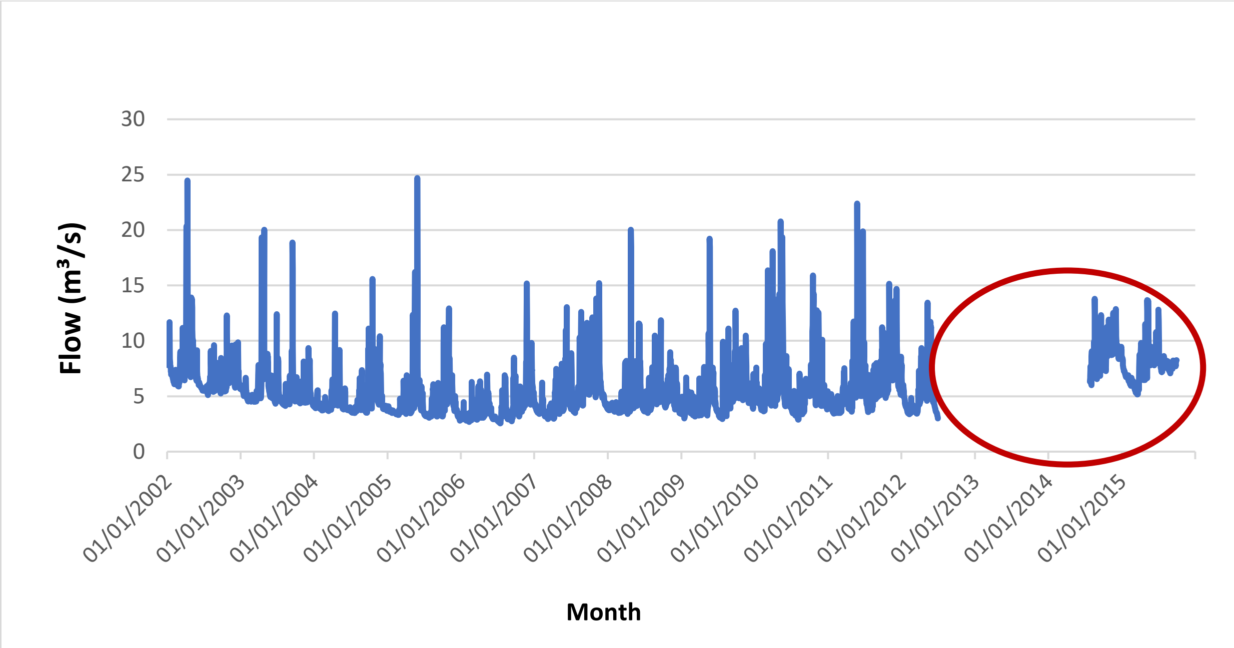


Figure 9. Daily flow of Nyamugasani River

Due to missing flow data in some years from 2013 to 2014 and low peaks and slightly high base flow from 2015 to 2016, analysis was carried out from 2002 to 2011 during which complete flow data series was available.

Rating Curve

The rating curve for Nyamugasani was plotted from 2002 to 2011 as shown in the graph below, the data shows consistencies hence suitable for analysis to determine the environmental flow.

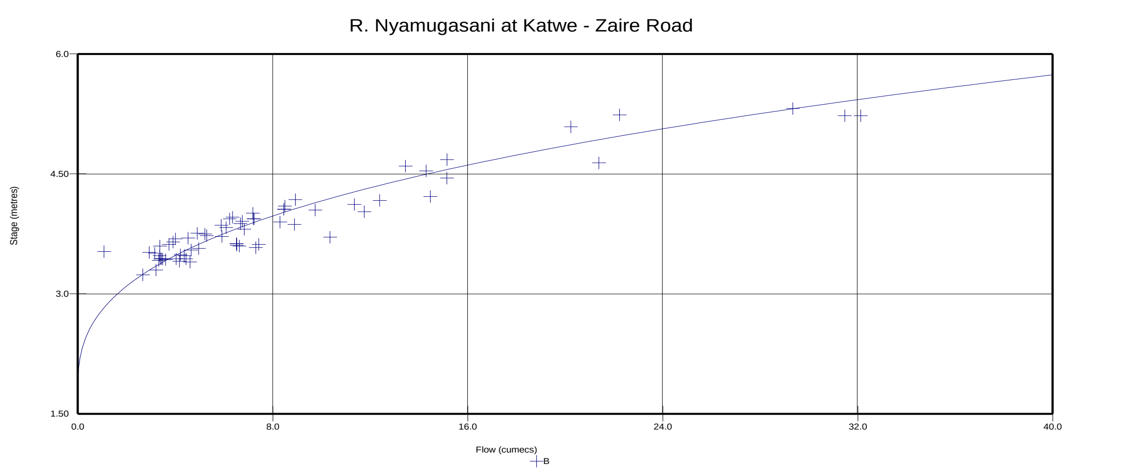


Figure 10: Rating Curve

4.4 Environmental Flow Requirement

The environmental flow is the amount of water that should be kept flowing down a river in order to maintain the river in a "desirable" environmental condition. Environmental flows are all about using the water resources sustainably to maintain the river in a predefined ecological state. The relation between the human need and the ecological need must be decided, and the recognition that there is a limit when a water resource suffers irreversible damage to its ecosystem functions. There are mainly four categories of environmental flow determination methodologies, which are being considered here:

1. *Hydrological (Desktop Estimates, Look up Table)*

This is a simple and rapid method that uses hydrological data to derive the environmental flow requirement. A "minimum flow" often represents the flow intended to maintain the recommended river condition. Hydrological methodologies are generally used for the planning level and have been applied widely, both in developed and developing countries. The Tennant Method is the most widely used hydrological method.

2. *Hydraulic Rating (Rapid Determinations)*

These types of methodologies measure changes in various single river hydraulic variables (e.g. depth and velocity) to develop a simple relationship between biota habitat availability and river flow. A common methodology is the Wetted Perimeter Method, developed in Australia.

3. *Holistic (Holistic Approaches, Frameworks, Comprehensive)*

In a holistic approach all important flow characteristics (high floods, base flows etc.) are identified. These methodologies incorporate hydrological, hydraulic and habitat simulation models. The Building Block Methodology (BBM) is a holistic methodology and was developed in South Africa.

4.4 Environmental flow methodology

This assessment was carried out using the Range of variability approach (Indicators of Hydrologic Approach, IHA), Wetted perimeter–discharge method and hydrological method, in particular the Tennant method and Indices based on flow-duration analysis.

4.4.1 Range of variability approach (Indicators of Hydrologic Alteration, IHA)

Range of variability approach (Indicators of Hydrologic Alteration, IHA)

Version 7.1 of the Indicators of Hydrologic Alteration (IHA) software developed by the Nature Conservancy (released in 2009) was used to quantify the environmental flow for Nyamugasani River. The software uses daily flow time series data to generate multiple sets of hydrologic statistics. The five principal attributes of flow data variability (magnitude, duration, amplitude, frequency, and timing) are programmed in IHA because of their influence on aquatic species at various life stages. IHA calculates two types of flow statistics; the first type includes 33 IHA statistics and the second type includes 34 flow statistics calculated for five different environmental flow components (EFCs). The 33 IHA statistics and 34 EFCs together describe flow attributes deemed to be ecologically relevant. This assessment considered monthly low flows. Analysis was carried out using non parametric statistics for a single period from 2002 to 2011. Advanced calibration parameters were used where all flows below 10% of daily flows were considered as low flows. The low flows are considered the environmental flow requirement for specific months. Refer appendix table … shows the 33 IHA statistics prescribing the IHA parameters. Hydrologic parameters and ecosystem influences and appendix table... on environment flows component, Hydrologic parameters and Ecosystem influences

4.4.2 Wetted perimeter - discharge method

We selected six representative cross-sections along the course of Nyamugasani River, with different geometrical shapes.

The revolutions and sounding at different distances along the river cross sections were measured. From this the discharge, wetted width and average depth were calculated using the rating curve method for the various cross sections.

The wetted perimeter is two times the average depth plus the wetted width.

Wetted Perimeter = Wetted Width + (2 * Average Depth)

Wetted perimeter was plotted against discharge in order to determine the breakpoint which discharge is the environmental flow requirement.

The table below shows the calculated parameters along the cross sections in Nyamugasani Rivers.

4.4.3 Indices based on flow-duration analysis

From the flow-duration curves at Nyamugasani, we calculated one typical flow index, specifically the Q90. Using the daily flow values from 2002 to 2011, they were arranged in descending order and given a rank. The frequency was calculated by dividing the total number of flows by their ranks.

Probability of exceedance = $\left(\frac{1}{f}\right) x\, 100$ %

Where f is the frequency

The flow duration curve is the plot of discharge against probability of exceedance.

4.4.4 Tennant method

We applied the mean annual flow (MAF) for the period of 2002 to 2011 from which 10% of the MAF applies for the dry period and 30% for the wet seasons were considered.

Results and Discussions

1. **Range of variability approach (Indicators of Hydrologic Alteration, IHA)**

The values in the table below summary of the annual statistics for Nyamugasani data.

Table 5: IHA Annual Summary Statistics

Year	January	February	March	April	May	June	July	August	September	October	November	December
2002	7.795	6.162	7.294	8.129	8.125	5.889	5.552	5.757	6.004	6.349	7.649	6.287
2003	5.572	4.621	4.724	6.513	7.242	4.938	4.759	4.49	5.555	4.892	4.979	4.724
2004	4.079	3.888	3.936	4.7	4.349	3.818	3.563	4.283	3.855	5.354	5.317	3.873
2005	3.617	3.424	3.879	3.726	6.037	4.532	3.19	4.118	3.954	4.731	5.148	3.218
2006	2.947	2.915	3.293	3.396	4.069	2.97	2.805	3.346	3.442	3.929	4.597	5.593
2007	3.739	3.644	3.209	3.953	4.186	5.458	3.956	4.949	6.196	6.854	6.729	4.507
2008	3.999	3.759	3.904	4.711	4.451	4.794	3.79	5.147	5.427	4.759	5.913	3.925
2009	3.771	3.902	3.584	3.987	5.314	4.618	3.223	4.177	5.543	5.592	5.966	4.631
2010	5.063	4.386	5.282	5.553	9.041	4.384	3.553	3.62	5.34	6.445	5.001	4.451
2011	3.967	3.625	4.753	4.319	7.02	5.735	4.442	5.074	6.213	6.408	7.771	6.94

Non-Parametric IHA scorecard

The header panel contains a number of parameters that apply only to the period of analysis as a whole. Length of flood-free season is the length in days of the longest period common to all years where flows are at or below the high pulse threshold. The rest of the table shows different IHA parameter medians and coefficient of dispersion values. 3-day minimum or maximum stated in parameter group 2 indicates the minimum or maximum flow that occur during any common 3-day period in all years of analysis. Refer to table below for Non- Parametric IHA scorecard.

Table 6: Non- Parametric IHA scorecard

Non-Parametric IHA Scorecard		Nyamugasani		Period of Analysis: 2002-2011 (10 years)	Normalization Factor	Mean annual flow	Non-Normalized Mean Flow	Annual C. V.	Flow predictability	Constancy/predictability	% of floods in 60d period	Flood-free season
					1	5.23	5.23	0.41	0.75	0.93	0.32	13

		Parameter Group #1	January	February	March	April	May	June	July	August	September	October	November	December
Medians			3.983	3.824	3.92	4.51	5.676	4.706	3.677	4.387	5.485	5.473	5.615	4.569
Coeff. of Disp.			0.372	0.2275	0.3505	0.4206	0.5558	0.273	0.3554	0.2505	0.3871	0.3043	0.3497	0.4059

Parameter Group #2	1-day minimum	3-day minimum	7-day minimum	30-day minimum	90-day minimum	1-day maximum	3-day maximum	7-day maximum	30-day maximum	90-day maximum
	3.177	3.232	3.272	3.55	3.969	20.03	15.07	10.84	7.802	6.546
	0.2424	0.2172	0.2276	0.202	0.1868	0.3703	0.2793	0.235	0.3405	0.3273

EFC Low flows	January Low Flow	February Low Flow	March Low Flow	April Low Flow	May Low Flow	June Low Flow	July Low Flow	August Low Flow	September Low Flow	October Low Flow	November Low Flow	December Low Flow
	3.967	3.778	3.845	4.175	4.273	4.267	3.786	4.205	4.86	4.774	4.827	4.515
	0.2013	0.1609	0.2087	0.231	0.2063	0.2256	0.2151	0.1675	0.2481	0.1809	0.1638	0.3133

Flow duration curves.

The flow-duration curve is a cumulative frequency curve that show the percent of time specified discharges were equaled or exceeded during a given period. The annual flow duration curve for Nyamugasani is presented below.

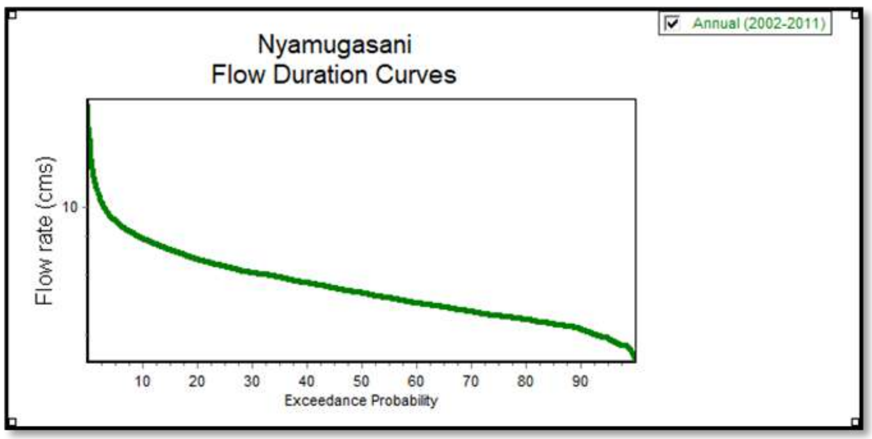


Figure 11. Annual Flow Duration Curve

Monthly flow duration curves.

The figure below shows the flow duration curve for the month of January to June. December through to March exhibit the lowest flow rate with 100% exceedances reaching zero flows.

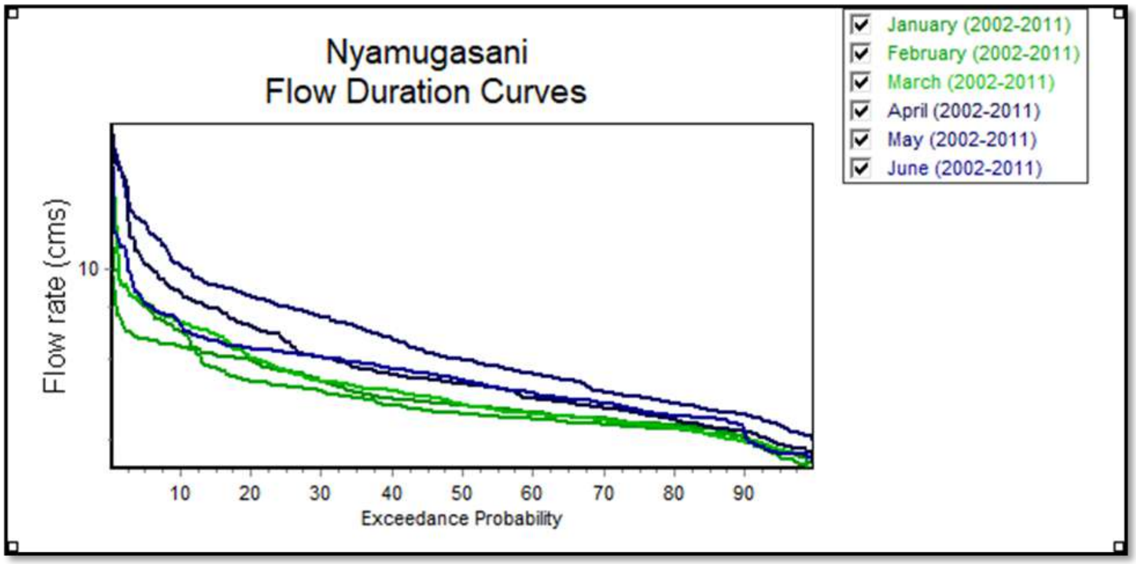


Figure 12. Monthly Flow Duration Curve (January to June)

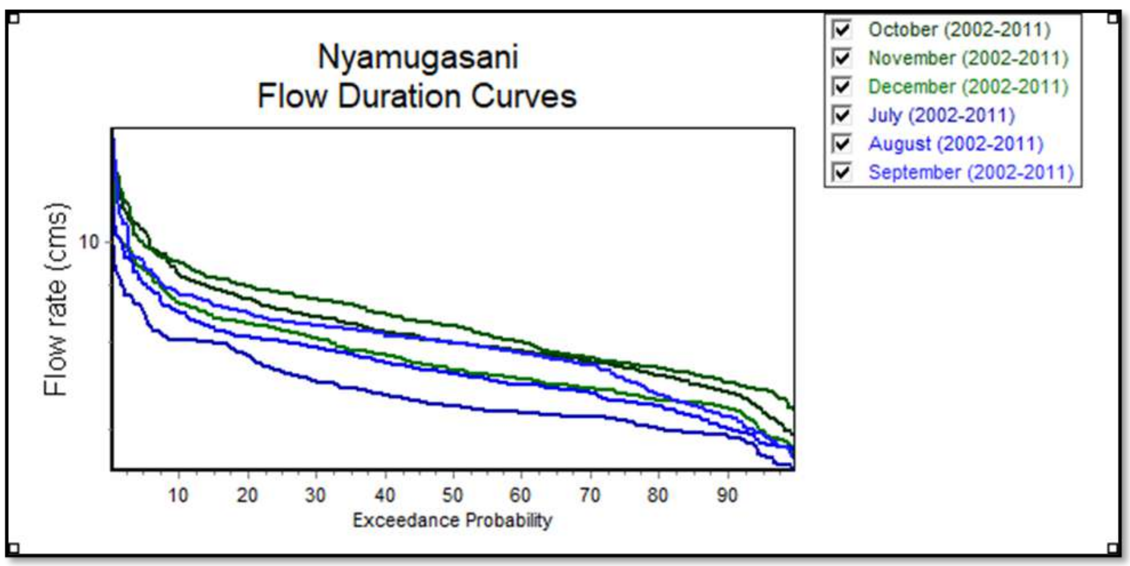
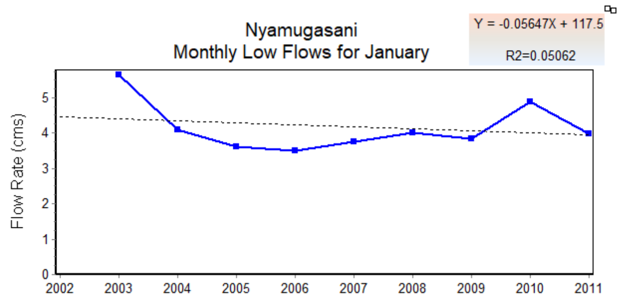
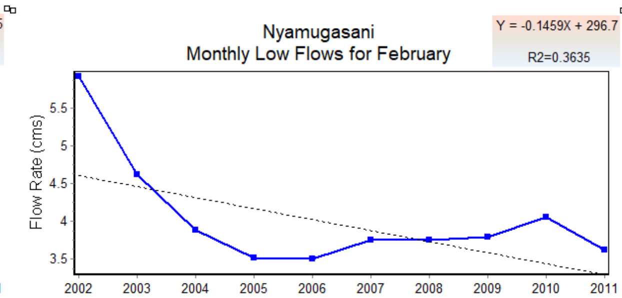
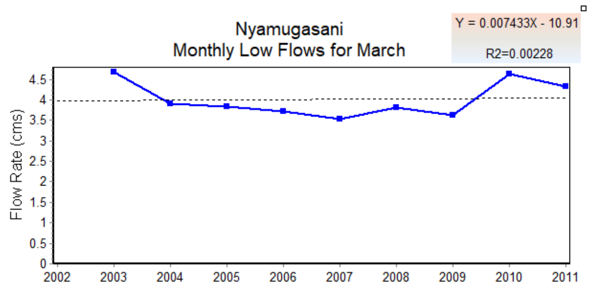


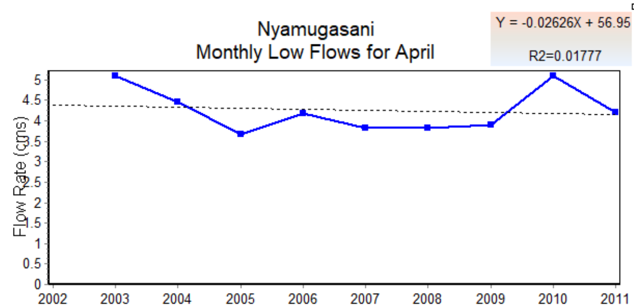
Figure 13. Monthly Flow Duration Curve (July to December)

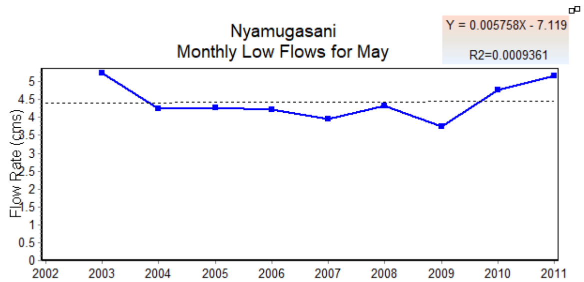
Figures 10 to 21 show the monthly low flows for each year and month from January to December. These flows represent 10% of the daily flows in each year.

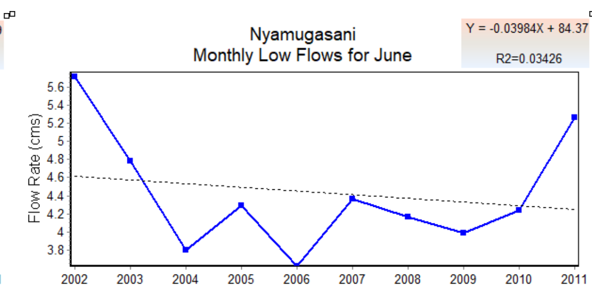

Nyamugasani
Monthly Low Flows for January
Y = -0.05647X + 117.5
R2=0.05062
Flow Rate (cms)
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011

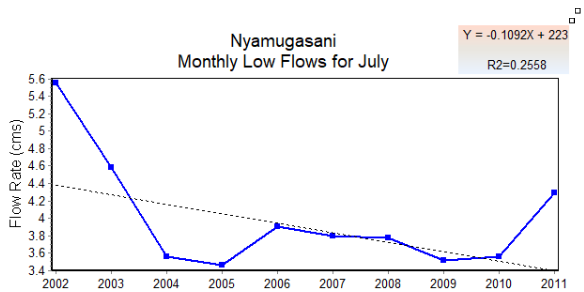

Nyamugasani
Monthly Low Flows for February
Y = -0.1459X + 296.7
R2=0.3635
Flow Rate (cms)
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011

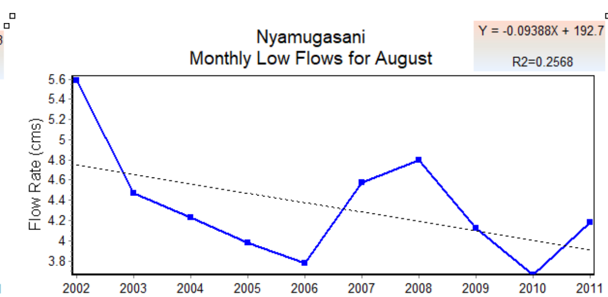

Nyamugasani
Monthly Low Flows for March
Y = 0.007433X - 10.91
R2=0.00228
Flow Rate (cms)
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011

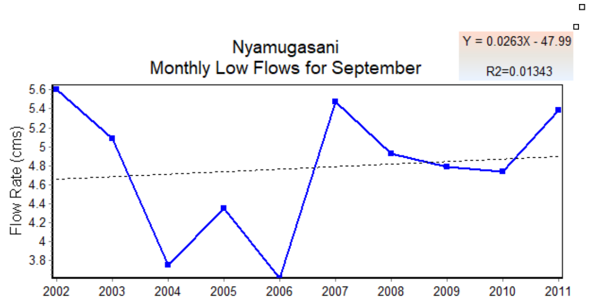

Nyamugasani
Monthly Low Flows for April
Y = -0.02626X + 56.95
R2=0.01777
Flow Rate (cms)
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011

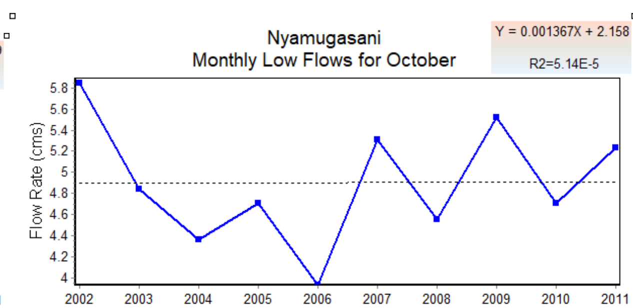

Nyamugasani
Monthly Low Flows for May
Y = 0.005758X - 7.119
R2=0.0009361
Flow Rate (cms)
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011


Nyamugasani
Monthly Low Flows for June
Y = -0.03984X + 84.37
R2=0.03426
Flow Rate (cms)
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011


Nyamugasani
Monthly Low Flows for July
Y = -0.1092X + 223
R2=0.2558
Flow Rate (cms)
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011


Nyamugasani
Monthly Low Flows for August
Y = -0.09388X + 192.7
R2=0.2568
Flow Rate (cms)
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011


Nyamugasani
Monthly Low Flows for September
Y = 0.0263X - 47.99
R2=0.01343
Flow Rate (cms)
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011


Nyamugasani
Monthly Low Flows for October
Y = 0.001367X + 2.158
R2=5.14E-5
Flow Rate (cms)
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011

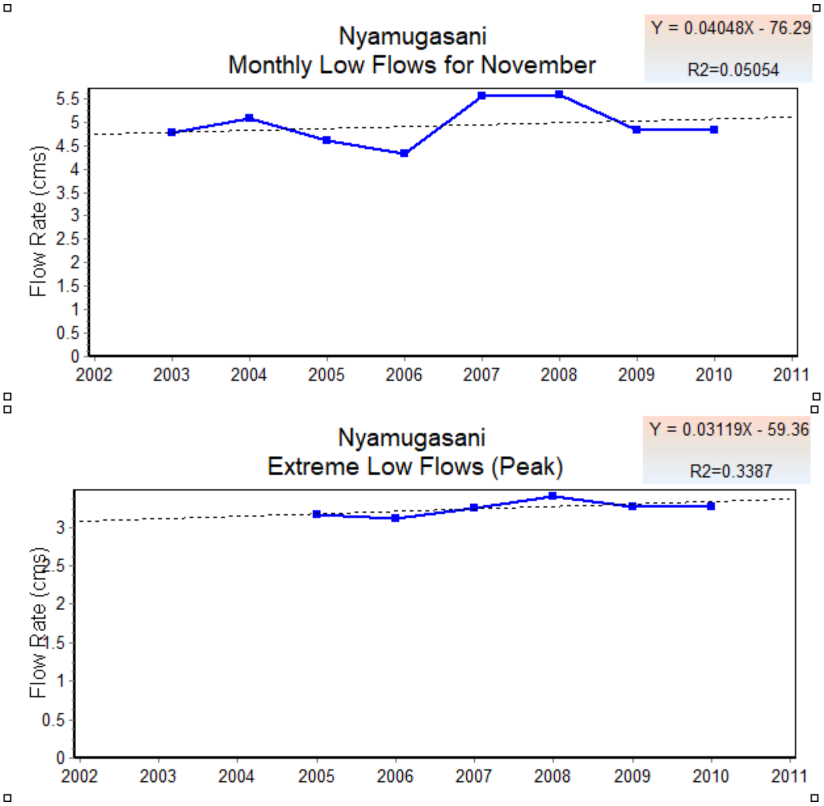
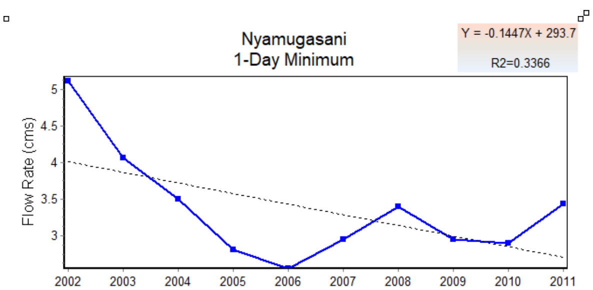


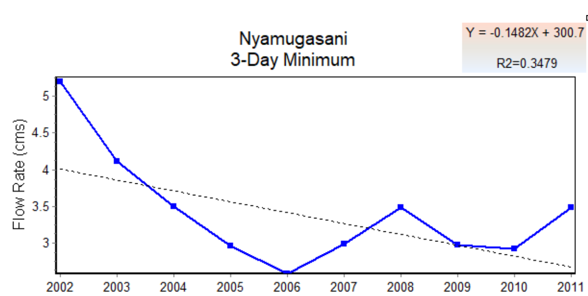
Figure 2. Extreme low flows

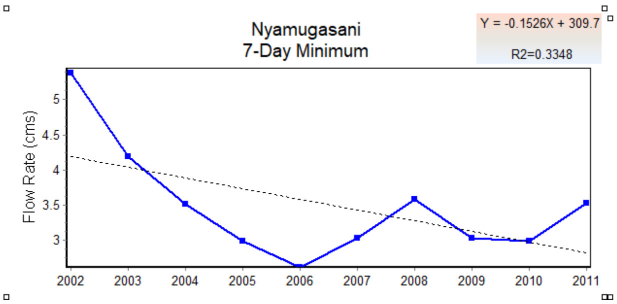
Extreme value low flows analysis is a predictive statistical tool commonly used in hydrology to make inference concerning the probability of occurrence of extreme events such as floods and low flows. In the above figure 22 demonstrated that there is very minimal changes in the extreme low flows except around 2008 for the period analyzed.

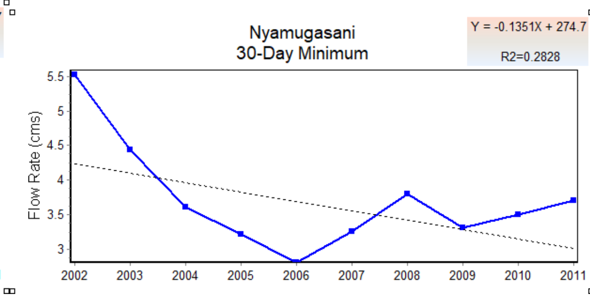
Minimum Flows

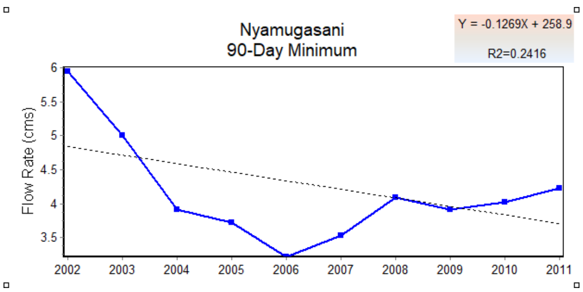
The figures below show the 1, 3,7,30 and 90-day minimum flow that occur during any common 1, 3,7,30 and 90-day period in all years of analysis.











The results of1, 3,7,30 and 90-day minimum flow that occur during any common 1, 3,7,30 and 90-day period in all years of analysis the graphs above show significant increasing and decreasing trends in low-flows regimes in Nyamugasani River. Furthermore, the results indicate that changes seem to be more significant for the more recent time. However, the exact nature of causes of these trends and the interaction between climatic factors and low-flow is not verified.

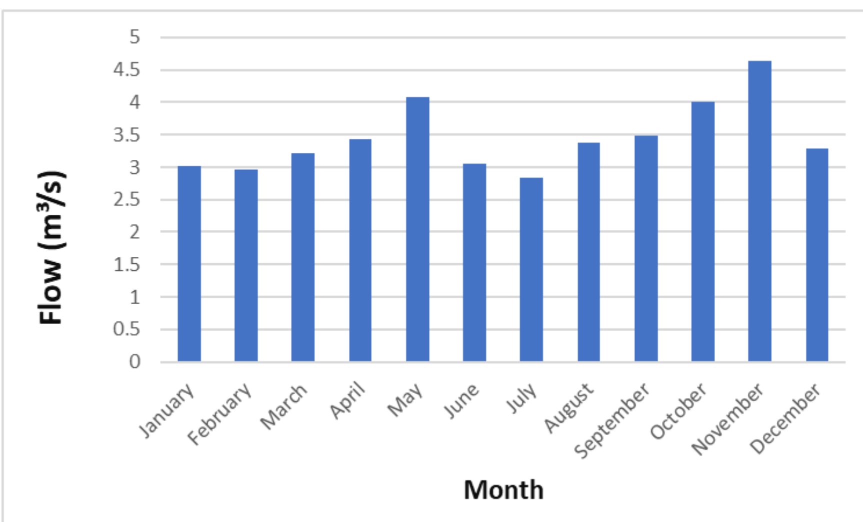


Figure 13. Low monthly flow extracted from IHA software

Table 7. *Low monthly flow extracted from IHA software*

January	February	*March*	April	May	*June*	*July*	*August*	*September*	*October*	*November*	*December*
3.014	*2.966*	*3.217*	3.429	4.081	3.054	2.844	3.373	3.483	4.009	4.635	3.284

The flows below are taken as environmental flow values for each month. During the dry month of February and July, the recommended environmental flow is 2.966 m^3/s and 2.844 m^3/s respectively. With the average of 2.905 m^3/s

For the wet months of May, October and November, environmental flow is 4.081 m^3/s, 4.009 m^3/s and 4.635 m^3/s respectively. With the average of 4.241 m^3/s

The overall average flow value is 3.5 m^3/s for the two seasons.

2. Indices based on flow-duration analysis

From the flow-duration curves at Nyamugasani is as shown below based on flow from 2002 to 2011.

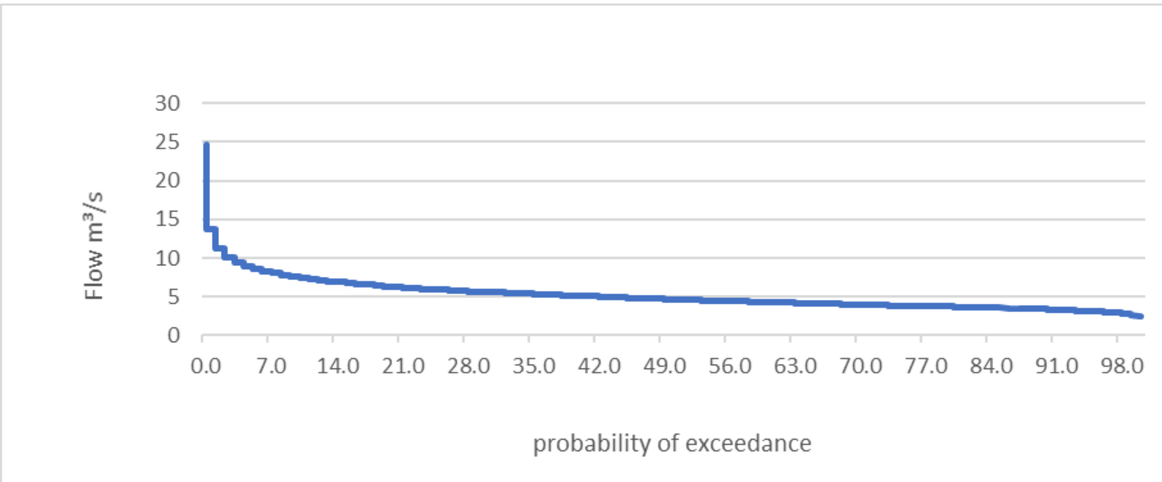


Figure 14. Probability of exceedance

Based on the flow duration curve, the flow at 90 % exceedance probability is 3.4 m^3/s.

3. Tennant method

Mean annual flows from 2002 to 2011 are as shown below;

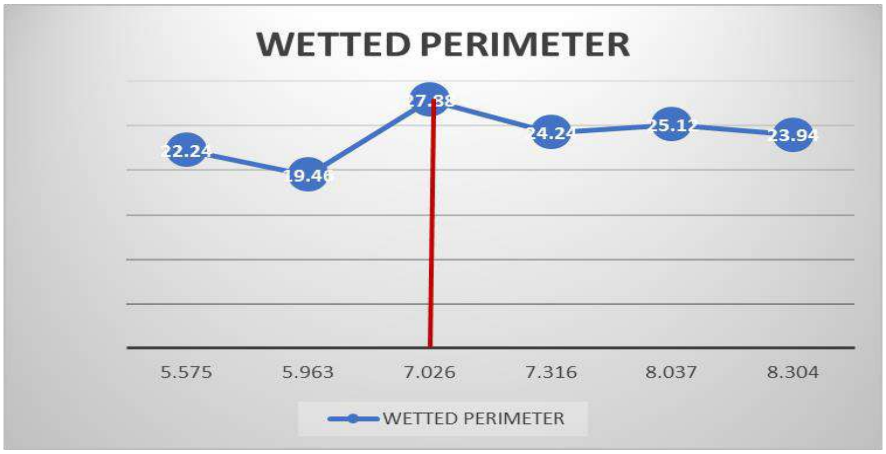
Table 8*. Mean Annual Flow*

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Mean
Average of flow (m^3/s)	7.069	5.643	4.562	4.48	3.989	5.105	4.926	4.87	5.738	5.949	**5.233**

The MAF is 5.233 m^3/s, therefore 0.5233 m^3/s is the environmental flow during dry months and 1.5699 m^3/s is for wet months.

4. Wetted perimeter methods

WETTED PERIMETER	22.24	19.46	27.88	24.24	25.12	23.94
DISCHARGE	5.575	5.963	7.026	7.316	8.037	8.304



The graph breaks at two points having discharge 5.963 m³/s and 7.026 m³/s. Therefore, the environmental flow is 6.4945 m³/s as the average of all the break points discharges.

Table Summary comparison results

FDC	WETTED PERIMETER	TENANT METHOD		IHA	
		Dry season	Wet season	Dry season	Wet season
3.4 m³/s	6.4945 m³/s	0.5233 m³/s	1.5699 m³/s	2.905 m³/s	4.241 m³/s

5.0 WATER QUALITY ASSESSMENT ON RIVER NYAMUGASANI

5.1 Introduction

Water is a vital commodity, both to sustain life and for the global economy. However, the quality of global water has rapidly declined for decades due to the impact of both natural and anthropogenic factors. Assessing water quality for different water use purposes, such as domestic use, irrigation, conservation and industrial usage, are an important strategy for food safety and human health. Water quality evaluation aims to identify the sources of water pollution and develop a strategy for sustainable water source management, maintaining and promoting human health and other social and economic growth.

Water quality often determines the fitness of water use for a variety of purposes. The assessment of water quality is thus important to evaluate the water use potential of any water resource. Water is usually abstracted from rivers, lakes, and dams and used without any form of treatment. The ease of access to surface water is one of the controlling factors contributing to its wide use, though it is often prone to higher chances of contamination and serves as one of the major sinks for environmental pollution. Water quality is of a great concern globally because the decline in its quality due to contamination has great economic and public health burden.

Activities such as human settlements, industrialization, and agriculture (crop and livestock farming) have adversely affected the quality of most rivers, streams, and dams.

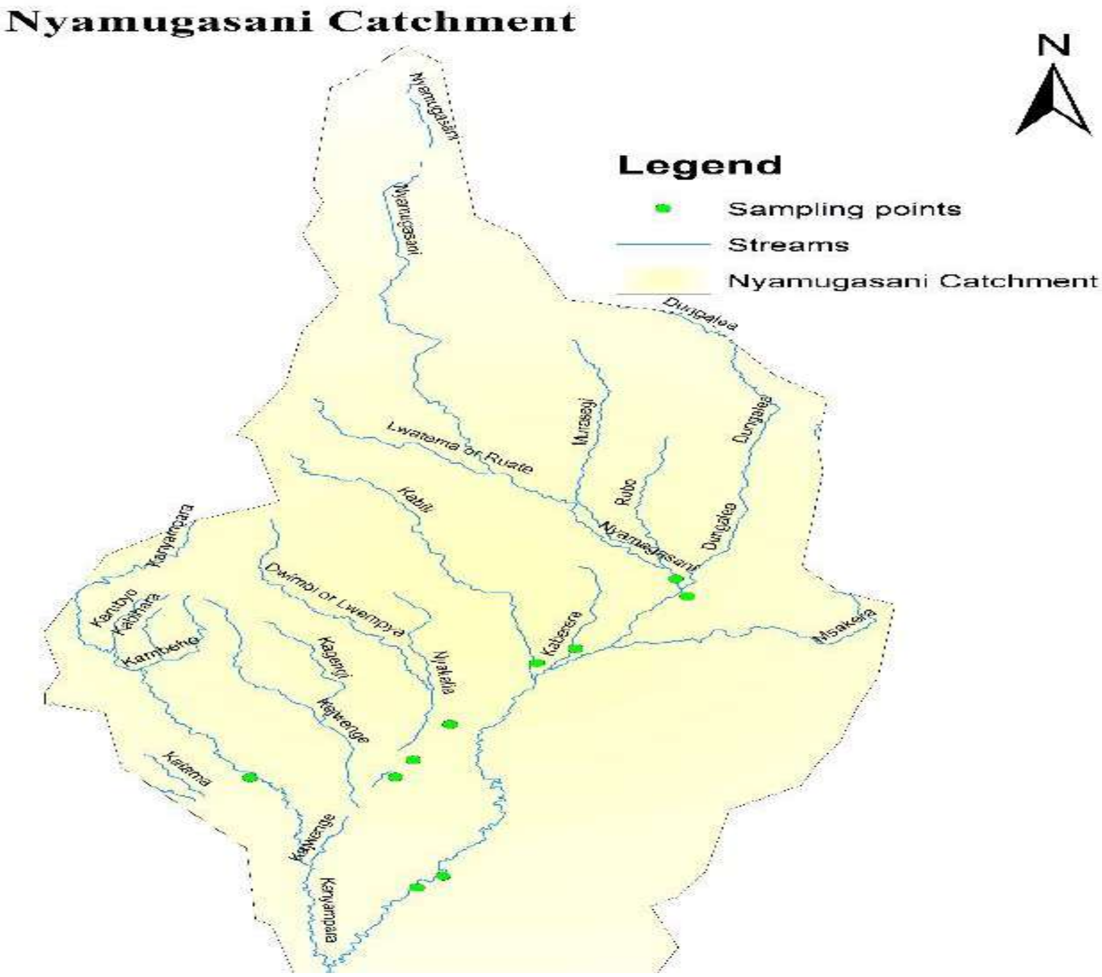
Nyamugasani River is widely used for domestic, recreational, and agricultural purposes (irrigation and animal watering). Moreover, small-scale businesses such as car washes abstract water from the river. Small-scale fishing also occurs within the river course.

Other potential sources of pollution to the river system include open dumping of solid wastes, open grazing of free-ranging animals, and surface runoff from various farmlands within its course.

Water quality sampling points

NO-	**Site**	**GPS Cordinates**		**Village**	**SUBCOUNT**
1	R. Nyamugarasi	E822760	N922	KIBULALU	KISINGU
2	R. Nyamugarasi downstream	E822129	N423	KIDODO	KISINGA
3	R. Rwembeya	0.046437	29.888926		
4	Rwembeya - Kilembe GFS	E822027	N5886	KIREMBE	KISINGI
5	KAGANDA - GFS	E822921	N7395	KAGANDA	KISINGI
6	R. Kabiri	E825038	N10034	KYONGO	KYONDO
7	R. Kabere	E825975	N10643	KABEREE	KYONDO
8	R. Nyamugarasami Upstream	E828407	N13630	KYARUMB	KYARUMB
9	R. DungURUHA	E828683	N12887	KYARUMB	KYARUMB
10	R. KanYapara	E818065	N5115	KAMUWO	KISINGA

Water quality sampling map



5.2 *Water Quality issues*

- The potential pollution sources include sanitation, car wash, and dumping of refuse on open spaces and on the riverbank.
- Land use activities vary in the upper, middle and lower parts of Nyamugasani River. The river is covered by agricultural activities and there is hydropower station in the upper stream.
- Agriculture affects water quality through the release of nutrients (as a result of soil management and fertilizer application) and other chemicals (e.g. pesticides) into the water environment, through biological contamination (e.g. from microbiological organisms in manure), and via soil being eroded and washed off.
- River and streams within the catchment are the major source of domestic water in the catchment. The communities collect water from the streams, however there are gravity flows water systems which also use river water as the source of water.

5.2.1 Grazing animals

Animal grazing on rivers contributes to pollution through nutrients from urine and feces dropped by the animals. Nitrogen from the urine and feces of grazing animals can negatively affect water quality

5.2.2 Settlements on river banks

Pollution from these settlements has severe water quality implications for downstream water users, and for community health. Pollution from these settlements also impacts on the natural functioning of river ecosystems, which affects the sustainable use of the resource

These communities are characterized by lack of basic services and as a result, resort to environmental degradation where the removal of vegetative cover, waste disposal and water pollution are evident. Furthermore, many of the informal settlements are situated in close proximity to water source, especially rivers.

Living in informal settlements leads to the exposure and vulnerability to environmental hazards to people and the land which they occupy. Informal settlements are characterized by a lack of basic services, pollution, overcrowding and poor waste management.

5.2.3 Sand mining

- The effect of sand mining is not only degrading the water quality of the river but also changing the physical quality of the river, such as river bank erosion, river bank slump, changes in the river flow, and decreasing the river flow
- All of these cause soil erosion and sedimentation in the water bodies, which reduce water quality. The physical disturbance of the sediment while dredging the sand affects the suspended solids and increases the turbidity of the water.

- Excessive sand mining can alter the river bed, force the river to change course, erode banks and lead to flooding. It also destroys the habitat of aquatic animals and micro-organisms besides affecting groundwater recharge
- Vehicle wash wastewater (VWW) contains a wide range of contaminants and discharge of such contaminated wastewater into the surface water bodies degrade water quality

Vehicle waste water contains a wide range of contaminants such as petroleum hydrocarbon wastes (petrol, diesel, and motor oil), nutrients (phosphorous and nitrogen), surfactants, asphalt, salts, organic matter, and heavy metals (Discharge of such contaminants into the surface water bodies degrade water quality which in turn affect aquatic ecosystems and also impair the use of water for household, industrial, agricultural, and recreational purposes.

5.3 Sampling

Nyamugasani River was divided into three sections, which are the upstream, midstream, and downstream, for samples collection. Nine water samples were collected using plastics bottles and field parameters were measured on site using Horiba microbiology samples were incubated and read after 24 hours.

Table 10: Physical and microbial results

Site	GPS Position		Village	SUBCOUNT	District	TEMP	pH	Turbidity (N	EC (us/cm)	TDS (mg/l)	E-Coli (CFU/00ml)
R. Nyamugarasi	E822760	N922	KIBULALU	KISINGU	KASESE	22.58	7.8	44	32	22	90
R. Nyamugarasi downstrea	E822129	N423	KIDODO	KISINGA	KASESE		7.7	30.2	31	22	760
R. Rwembeya	0.046437	29.88893			KASESE	20.65	7.6	58.2	31	20	290
Rwembeya - Kilembe GFS	E822027	N5886	KIREMBE	KISINGI	KASESE	24.22	7.9	23	23	15	40
KAGANDA - GFS	E822921	N7395	KAGANDA	KISINGI	KASESE	22.85	7.2	5.8	23	15	30
R. Kabiri	E825038	N10034	KYONGO	KYONDO	KASESE	18.8	7.2	25	28	18	70
R. Kabere	E825975	N10643	KABEREE	KYONDO	KASESE	21.69	7.0	32.5	58	37	420
R. Nyamugarasami Upstrea	E828407	N13630	KYARUMB	KYARUMB	KASESE	20.29	7.2	59.9	35	23	380
R. DungURUHA	E828683	N12887	KYARUMB	KYARUMB	KASESE	19.67	7.3	36.7	38	24	50
R. KanYapara	E818065	N5115	KAMUWO	KISINGA	KASESE	19.32	7.4	21	22	14	0
National Portable Water Standards							6-8.5	15	2500	1500	0

Table 11: Chemical results

5.4.2 Chemical Results

Site	GPS Position		Village	SUBCOUNT	District	Na (mg/l)	K (mg/l)	T.Alkalinity	Bicarbonate	T.Hardness	Ca.Hardnes	Mg.Hardne	Calcium (m	Magnesium	NO_3-N (mg	NO_2-N (mg	NH_4-N (mg	PO_4 (mg/l)	BOD (mg/l)	TSS (mg/l)
R. Nyamugarasi	E822760	N922	KIBULALU	KISINGU	KASESE	6.9	2.3	37	45	33	20	13	8	3	0.52	<0.002	0.06	0.199	0.91	46
R. Nyamugarasi downstrea	E822129	N423	KIDODO	KISINGA	KASESE	7.6	3.5	35	42	37	22	15	9	4	0.56	0.01	0.21	0.241	2.3	180
R. Rwembeya	0.046437	29.88893			KASESE	8.8	2.4	44	54	41	14	27	6	6	1.02	0.01	0.19	0.189	1.5	52
Rwembeya - Kilembe GFS	E822027	N5886	KIREMBE	KISINGI	KASESE	5.6	2.4	27	33	32	13	19	5	5	1.04	<0.002	0.04	0.096	0.9	12
KAGANDA - GFS	E822921	N7395	KAGANDA	KISINGI	KASESE	5	1.9	27	32	20	16	4	6	1	0.78	<0.002	0.06	0.061	1.1	4
R. Kabiri	E825038	N10034	KYONGO	KYONDO	KASESE	7.8	1.9	30	37	41	34	7	14	2	0.84	<0.002	0.09	0.075	0.9	54
R. Kabere	E825975	N10643	KABEREE	KYONDO	KASESE	19	5.3	62	76	69	27	42	11	10	1.21	0.02	0.14	0.174	0.7	220
R. Nyamugarasami Upstrea	E828407	N13630	KYARUMB	KYARUMB	KASESE	6.8	2.4	49	60	62	24	38	10	9	0.54	<0.002	0.09	0.182	1	70
R. DungURUHA	E828683	N12887	KYARUMB	KYARUMB	KASESE	9	2.6	49	60	46	13	33	5	8	0.64	<0.002	0.17	0.073	1.4	56
R. KanYapara	E818065	N5115	KAMUWO	KISINGA	KASESE	4.3	1.8	31	37	44	22	22	9	5	0.87	<0.002	0.15	0.121	1	34
National Portable Water Standards						250	100	600							20	2	0.5	0.2	50	100

Table 12; Pollution Loading in R-Nyamugasani

Sampling date	Site	GPS Position		Village	SUBCOUNT	District	Flow rate (m3/s)	TSS Load (g/s)	Calcium Load (g/s)	Mg Load (g/s)	NO3 Load (g/s)	NO2 Load (g/s)	NH4 Load (g/s)	PO4 Load (g/s)	BOD Load (g/s)
11/10/2021	R. Nyamugarasami Upstream	E828407	N13630	KYARUMB	KYARUMB	KASESE	7.316	512.12	21.4095424	122.9088	3.95064	0	0.65844	1.331512	7.316
11/10/2021	R. Nyamugarasi Midstream	E822760	N922	KIBULALU	KISINGU	KASESE	8.037	369.702	25.8373476	88.72848	4.17924	0	0.48222	1.599363	7.31367
11/10/2021	R. Nyamugarasi downstream	E822129	N423	KIDODO	KISINGA	KASESE	5.575	1003.5	12.43225	240.84	3.122	0.05575	1.17075	1.343575	12.8225

5.5. DISCUSSION OF RESULTS

5.5.1 Physical and Chemicals results

The Electro Conductivity (EC) values ranged from 22-58µS/cm. The values recorded complied with the standard guideline of <2500µS/cm.

The pH which is a measure of the acid balance of a solution and is defined as the negative of the logarithm to the base 10 of the hydrogen ion concentration runs from 0 to 14 (i.e. very acidic to very alkaline), with pH 7 representing a neutral condition. The pH for untreated water should range between 5.5-8.5. In this study, the pH of the samples was in the range of 7.0–7.8 which complied with the recommended guidelines for human consumption.

The anions (Cl^-, NO_3^-, PO_4^{3-}, and SO_4^{2-}) were within the permissible limit for domestic and agricultural water use.

5.5.2. Microbial results/Biological water quality

Microbial contamination refers to the presence of disease-causing (or pathogenic) microbes, which are generally introduced to water sources by contact with fecal material. All the samples collected for microbial contamination showed high level of contamination which was an indication that all the water sources are polluted with human fecal matter. The World Health Organization (WHO) considers microbial pathogens the highest priority in water treatment given their ability to cause infectious disease. (WHO GUIDILINE STANDARD, ECOLI>1). Only River Kanyampara was found to be free from microbial contamination.

The pollution loads computed from the discharge measurements conducted on river Nyamugasani as shown in results table 15, depict an increase in pollutants as the water flows from upstream to downstream. The flow measurements also show drastic decline in discharge volumes as the river flows downs tream, an indication of highwater abstractions from the river upstream.

5.5.3. Aquatic Ecohydrology

Fish within the study area belongs to two genera *(Barbusand Varicorhinus). Barbusapleurogramma* is more abundant (69.6 %) followed by *B. alluaudi* (15.2 %) and *Varicorhinusrwenzorii* (15.2 %). Two of three species recorded are of conservation interest. *Varicorhinusrwenzorii* and *Barbusalluaudiare* listed as Vulnerable D2 ver 3.1 and are endemic to the Rwenzori region. *Varicorhinusrwenzorii* lives in fast turbulent waters with many boulders behind which the fishes take shelter for feeding and spawning. Both fish species are listed as vulnerable species due to their limited extent of occurrence. Its occurrence in the Nyamugasani River therefore provides the 3rd known habitat for this species.

Aquatic ecolohydrology has been affected due to soil erosion and sedimentation in the water bodies, which reduce water quality. Also, the physical disturbance of the sediment while dredging the sand affects the suspended solids and increases the turbidity of the water. It also affected the habitat of aquatic animals and micro-organisms

5.5.4. Effects of development on water use practices and Institutional arrangements for water by downstream community

Pollution from development activities and settlements of the community's close to the river bank has severely affected water quality for downstream water users, and for community health. Pollution from these settlements has also impacts on the natural functioning of river ecosystems, which affects the sustainable use of the resource. Catchment water use plan and catchment investment measures is being developed by Ministry of water and Environment to address the issues of catchment degradation and water resources use for sustainability

5.5.5. Implications of the projects on supply/ demand and impacts on livelihood and quality of life of downstream communities

Majority of the population (59%) use open water sources for all their water needs. The study findings show river/lake used by over half (52%) of the population was the most dominant source of water. Therefore, development activities such as hydropower project which divert/ impound water for power generation from a section of the river system has impacted directly on the downstream community's livelihood in terms of water quantity/ quality. Excessive sand mining and farming on the river bank has altered the river bed, forced the river to change course, erode banks and occasionally lead to flooding which destroys people's farms, animal and properties.

6.0 Conclusions and Recommendations.

6.1 Conclusion

The results of 1, 3,7,30 and 90-day minimum flows that occur during any common 1, 3,7,30 and 90-day period in all years of analysis, show significant increasing and decreasing trends in low-flows regimes in Nyamugasani River. Furthermore, the results indicate that changes seem to be more significant for the more recent time which could be attributed to the impacts of development activates along the river systems. However, the exact nature of causes of these trends and the interaction between climatic factors and low-flow is not verified The flow measurements also show drastic decline in discharge volumes as the river flows downstream, an indication of high-water abstractions from the river upstream The study findings show river waters is used by over half (52%) of the population was the most dominant source of water From the results of environment flow analysis for the various method used, it is very clear that there is no single method which can conclusively give a single appropriate value that can be consider for environmental flow. However, Seasonality low flow exhibited by Tennant and indicators hydrologic alteration methods could be considered because of their influence on aquatic species at various life stages

The pollution loads computed from the discharge measurements conducted on river Nyamugasani as shown in results table 15, depict an increase in pollutants as the water flows from upstream to downstream. This could be due to development activities along the river on the upstream and river bank encroachment. The physiochemical parameters of water quality were found to be within the acceptable standards (WHO Standards) however all the points along the river were found to have Microbial contamination with exception of only Kanyampara stream which had no contamination. The microbial contamination is mainly attributed to river bank encroachment by human settlements. The pH of the samples was in the range of 7.0–7.8 and complied with the recommended guidelines for human consumption. The anions (Cl^-, NO_3^-, PO_4^{3-}, and SO_4^{2-}) were within the permissible limit for domestic and agricultural water use.

Of all the Laws, policies and regulations reviewed the details and intricacies of how environmental flows or how ecosystem water needs are to be conducted is salient. There is a missing gap on how ecosystem protection can be guaranteed. It should also be noted that quantification of sediment could not be done due to limited time and lack of discharge data during wet season as well.

6.2 Recommendations

Recommendation	Action By
1- The exact nature of causes of the trends and the interaction between climatic factors and low-flows of river Nyamugasani need to be further verified	Ministry of Water and Environment (MWE) Ministry of Energy and Mineral Development (MEMD) and National Environment Management Authority
2- Further investigations are needed during the dry and wet season for a longer period of time on the impact of development activities on river flows in order to comprehensively verify and quantify the environmental flows for all the major rivers in Uganda	Ministry of Water and Environment (MWE) and Ministry of Energy and Mineral Development (MEMD).
3- Market based allocation principle IV is good for implementation of eflows because it promotes water allocation basing on the understanding of the available yield less the allocation for a "Reserve" (domestic and ecosystem water needs). This principle should be promoted	MWE and MEMD

4- Permit systems should not be based only on the hydrological parameters but also on the dynamics of difference catchment and ecosystem water needs	MWE
5- The details and intricacies of how environmental flows or how ecosystem water needs are to be conducted should be developed and adopted by all stakeholders	MWE, MEND and NEMA

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