MAKERERE UNIVERSITY

Project title:

Water and Livelihood Resilience under Changing Climate(s) and Extremes: Groundwater Water and Agriculture Issues in the Lake Victoria Basin.

Deliverable MKU.M1:

Report and Database on hydrology and water uses by source and coupled with land use and cover

By

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1. Introduction

The Lake Victoria Basin (LVB) in East Africa, constituting a significant proportion of the Nile Basin is experiencing various environmental and biogeochemical processes, demographic transitions and development trajectories. These intricate processes experienced in the transboundary LVB have huge implications on the insitu and exsitu water resources and raise fundamental questions of sustainability of the ecosystems and thrivability of the 40 million inhabitants, the majority of whom derive their livelihoods from the lake and land resources. What are the challenges and opportunities related to these processes? A relatively poor region experiencing population growth of 3.5%/year ought to optimize the opportunities in order to realize the regional ambitious development aspirations but most importantly obviate the widespread challenges which are exemplified by increasing soil erosion, cases of stagnant or reducing crop yields, reducing forestry cover, poor water quality.

There is quite some urgency to address the above challenges in the LVB particularly from a scientific perspective in order to derive reasonable knowledge that can inform better practices and policy interventions. A fundamental and more meaningful notion is to holistic analysis that informs an improved knowledge generation as opposed to a compendium of previous isolated or thematic focussed studies. The Water-Energy-Food-Ecosystems (WEFE) Nexus provides a suitable and systematic approach to understanding and addressing the intricate processes in the LVB. The WEFE Nexus visualizes water, energy, food and ecosystems integrated, complex and inextricably entwined (Dondeynaz et al., 2018; Mishra et al., 2018; Palazzo et al., 2018). The utility of the WEFE approach is adopted in the broader project on "Water and Livelihood Resilience under Changing Climate(s) and Extremes: Groundwater Water and Agriculture Issues in the Lake Victoria Basin" under the auspices of the AU/NEPAD Central and Eastern African Network of Water Centres of Excellence (CEANWATCE), whose overall goal is to contribute to the sustainability and resilience of people and ecosystems in the LVB.

A key perquisite for addressing the intricate and complex environmental and livelihood related issues in LVB under the project domain with the WEFE approach is the availability of data. Identification and collating available data was therefore seen as the first stage for the project to realize its formulated goal and objectives. Data residing in national and regional institutions coupled with online/internet portals was gathered for WEFE analysis of the project. The datasets cover; soil, terrain (DEM), land use, water use, livestock, crop among others. The datasets were obtained in different formats i.e. tabular as well as digital files for geospatial utility and analysis. This report is an update on the deliverable MKU.M1, which tackles the database component of the overall deliverable of the project.

2. Datasets and their sources

As earlier noted, a compendium of datasets for specific uses in the project have been gathered and are shown in Table 1 and Table 2. Table 2 summaries the different datasets, their respective sources, purpose and the state of the action or use of the dataset. The datasets are available in tabular and digital formats that can be manipulated in a Geographical Information System (GIS). Some information is also available as visual graphics and static maps.

Table 1: Datasets gathered and their sources for WEFE analysis in the LVB

No.	Data	Source (s) and resolution	Purpose and action	Format	Remark
1	Ground water	Aqua stat (FAO)	ground water storage and recharge capacities assessment	Tabular	Indication of the resource and potential
2	Climate data (Rainfall, temperature, relative humidity, wind speed and solar radiation)	ICPAC, UNMA Uganda, CFSR Daily resolution	Trends analysis in climate change and variability; water resources modelling	Tabula, digital	Climate station data quite lacking for many points
3	Land use data	Sentinel-2 Imagery for East Africa, 10-meter resolution	Land use change analysis, Water resources modelling	Digital	Sentinel-2 for East Africa
	Land use	Landsat 30	Land use/cover	Digital	Change detection
4	Water use data	Internet search/agencies	ground water storage and recharge capacities assessment	Tabular	Data for East Africa
5	Topographic data	Regional DEM (30-meter resolution)	Water resources modelling with SWAT	Digital	Extractive parameters from the DEM
6	Population data	CIESEM Database	ground water storage and recharge capacities assessment	Digital imagery	Population distribution hotspots

7	Soils data	HWSD (FAO, ISRIC, 250-meter resolution)	Water resources modelling with SWAT		Limited to East Africa
8	Crop data	Internet	Sensitivity analysis of selected crops to water and climatic stressors with Aqua crop model		
9	Discharge data for Katonga and Bukoora sub catchments	Directorate of Water Resources Management	Calibration and Validation of the SWAT model		Limited to Uganda

Table 2: Summary on the ongoing utility of the data to address specific deliverables

No	Category	Issue	Progress	Remark
1	Spatial database	Hydrology		
		Water uses by source and sector	Secondary data obtained, inferences on the data	The data is at country level covering Uganda, Kenya, Tanzania, Burundi and Rwanda
		Land use and land cover	Land use data obtained and georeferenced (satellite imagery data), NDVI data obtained	Covers the extent of the Lake Victoria Basin. Time scope of the image is limited
		DEM- 30m from Shuttle Radar Topography Mission	Parameterized to extract specific terrain parameters	Input in the modelling protocols
2	(a) Water quality modelling	Arc SWAT	Preliminary results have been obtained, DEM Soil data encoded and customised to SWAT	Further refinement will be undertaken to improve the quality and validate the results where possible.
		Hydrus -1D	Not yet installed	Expected to facilitate analytics of water flow and solute transport in variably saturated porous media
	(b) Crop-climate sensitivity	Climate variability and change	Climate data obtained Climate data analysed Trajectories constructed Preliminary analysis	More station data
		Aqua crop model	Literature review undertaken Model downloaded and installed Priority Crops identified Climate data partially obtained Water use requirements defined	Crop response to climate change, model future productivity owing to climate change.
3	Dissemination materials	Presentation on theory, practise, baseline data, model design, implementation & analysis outcomes	Internal dissemination within the project TEAM	More activities will be conducted once concrete results on many of the objectives have been obtained

2.1. Description of the data and limitations

Climate

A pool of climate data was collected from three main sources and is available. The data consists of (1) satellite climate and temperature data processed under the CHIRPS arrangement (2) data obtained from meteorological stations, particularly from Uganda National Meteorological Authority (UNMA) and Kenya Meteorological Department (KMD) (3) Climate data obtained online. Statistical from the national meteorological services is understandably very limited owing to a range of constraining conditions. The observing functional stations are limited, not well geographically distributed and vivid gaps exist for the long-term data. Those notwithstanding, obtaining the existing data from the agencies is quite difficult due to the costs and other protocols involved.

Two observational products are used: Climate Research Unit (CRU TS4.02, 1901–2012, Harris et al. 2014) and Climate Hazards Group InfraRed Precipitation (CHIRPS) (Funk et al. 2015). CRU provides global 0.50 monthly data from January 1901 to the near present and covers all land areas except Antarctica. For this study, variables of precipitation, Potential Evapotranspiration, Minimum and Maximum temperature have been used. CHIRPS on the contrary provides monthly 0.050 rainfall data between 500 S-500 N since 1981.

The Climate Hazards Group Infra-Red Precipitation with Stations (CHIRPS) gridded rainfall data (Funk et al., 2015), at 0.05-degree resolution was used for the period 1981-2018. CHIRPS data is a blended satellite-station data presented in grid format and provides better estimates of precipitation over areas that have sparse ground station coverage. For temperature, gridded dataset was obtained from the Climatic Research Unit (CRU) at the University of East Anglia. This is a station-based gridded dataset (CRU TS4.02) available at 0.5-degree spatial and monthly temporal resolutions for the period 1901–2017. These two datasets represent the best available observational data for the region at the time this work has been undertaken. The method of bilinear interpolation has been applied to spatially interpolate precipitation and temperature observations, respectively, to obtain values at the desired 0.05-degree resolution. These datasets were then used as the observational data required for adjusting the climate model biases.

Some climate data was also obtained from The National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR). Details of the scientific basis of the CFSR data are given by Dile and Srinivasan (2014) and Fuka et al. (2014). The data from CFSR was specifically obtained for SWAT modelling owing to the paucity of directly observed data form the Meteorological agencies in the region. We selected five climate elements covering rainfall, temperature, solar radiation, wind speed and relative humidity all within the boundaries of the Lake Victoria Basin. The data is freely and readily available at the CFSR online portal (https://globalweather.tamu.edu/) and can be downloaded on a daily scale. For the Lake Victoria Basin, data for seven (7) georeferenced stations was obtained.

Land use and land cover data for the LVB

Land use and land cover data of different scales and from diverse sources was collected. Firstly, processed data collapsed to the LVB boundaries was obtained from the Regional Center for Mapping of Resources for development (RCMRD). These maps were developed for the Lake Victoria basin for the years 1985, 1990, 2000, 2010 and 2014 to create a water quality and ecosystems geospatial database. The land cover data provided information on the ecosystem degradation in the aforementioned area. These classifications were created using Landsat images such that the final products had a spatial resolution of 30m. These land cover maps were developed by RCMRD - SERVIR Eastern and Southern Africa. SERVIR is a joint USAID-NASA project. Available in a digital format, detailed quantitative and qualitative change detection in spatial and temporal terms can be undertaken in a GIS environment as exemplified in Figure 1. The data is readily available on the RCMRD data portal.

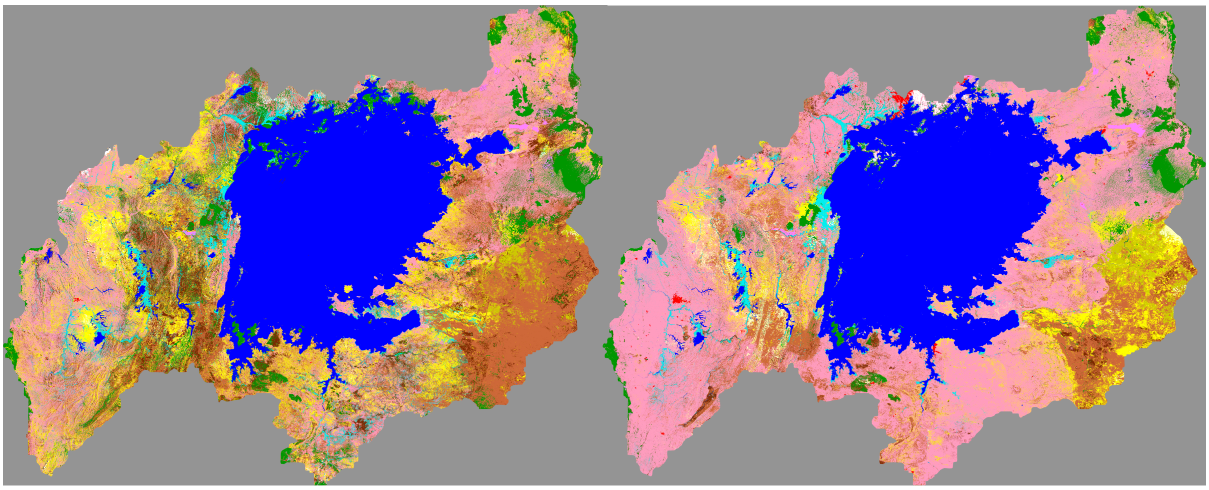

Figure 1: Spatial configuration of Land use and land cover in 1985 (left) and 2014 (right) derived from Landsat images.

Apart from the Landsat image derived datasets, low spatial resolution data, particularly Normalized Difference Vegetation Index (NDVI) for the region is also available. This data is available at a country level from the USDA data portal under the Foreign Agricultural Service, FAS (https://www.fas.usda.gov). Because of its finer temporal resolution, derived information on seasonal crop performance is available. The online NDVI maps are coupled with graphic data as illustrated in Figure 2. The maps and graphs can be extracted for each of the five countries which are par of the LVB.

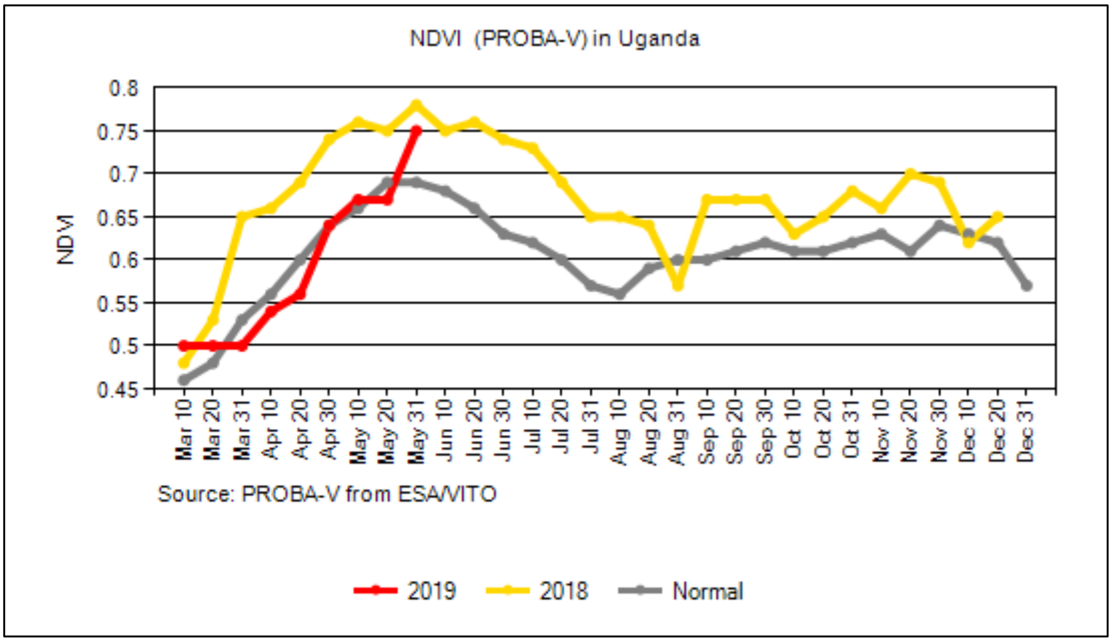

Figure 2: Seasonal trajectories of NDVI for Uganda: Source: USDA

More finer resolution land use and land cover data from Sentinel (10-meter resolution) was also obtained. The Sentinel-2 semi processed data is available at the RCMRD geospatial portal (http://geoportal.rcmrd.org/maps/680#more). To our knowledge, this data represents the most recent finer resolution on land use and land cover for the LVB and was derived from sentinel images of 2016. A total of nine (9) land use and land cover classes were classified, including agriculture characterized by small scale and commercial farming, shrubs, grasslands, grazing land as pasture, tropical forests, built up areas and the lake. The major land use/cover classes include agriculture (cropland) with a coverage of 37% of the total basin area, predominantly observed in the Eastern part of the basin (Kenya). The lake (25% of the basin area), Grassland (16%), Pasture/grazing land (10%) and tropical rainforest (9.5%) of the total basin area. The spatial pattern of land use is very spotty and shows agriculture use, pasture/shrub, and grasslands next to one another, as a result of dominant cultivation by small scale farmers.

Hydrological data

Hydrological data is collected by a range of national agencies in the five countries of the Lake Victoria Basin. Some discharge data obtained from the Directorate of Water Resources management in Entebbe Uganda. the data is on a daily scale. The stations include Katonga and Bukoora on the Ugandan side of Lake Victoria. The United States Department of Agriculture (USDA), possesses online data on Lake Victoria altimetry which is periodically updated (Figure 3). The data is however only given in a graphical format.

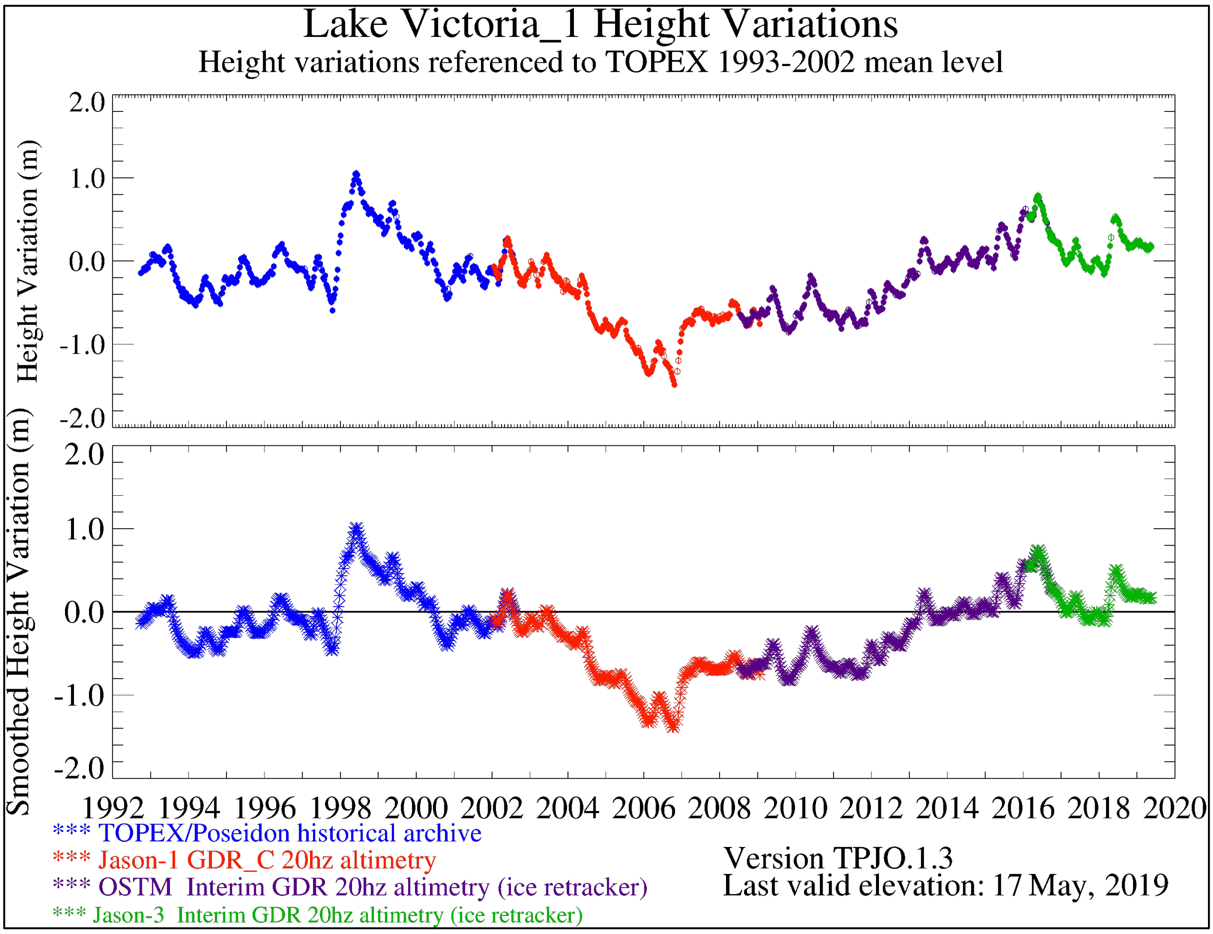

Figure 3: Lake Victoria Height Variations from TOPEX/POSEIDON and Jason series Altimetry. Source: USDA: (https://ipad.fas.usda.gov/cropexplorer/global_reservoir/gr_regional_chart.aspx?regionid=eafrica&reservoir_name=Victoria). Accessed May 2019

Terrain data

A Digital Elevation Model (DEM) of 30-meter resolution is available at the United States Geological Survey, USGS website (www.earthexplorer.usgs.gov). The DEM was downloaded from the site and is being processed to extract a range of terrain parameters using standard procedures.

Soil data

Digital Soil data is available on some flagship portals. The soil map was downloaded from the Harmonized World Soil Database of ISRIC (https://www.isric.org/explore/soilgrids). Climate data (precipitation, temperature, solar radiation, wind speed and relative humidity) for the period 1998-2013 was acquired from the Climate Forecast System Reanalysis. The USDA also has soil moisture data for the respective countries (see example in Figure 4 below) and seasonal to annual variations can be obtained. The African Soil Information Service, AFSIS (http://africasoils.net) is a repository with some data on soil properties downloadable in a TIFF or other formats. This data is being used in the modelling components of the project.

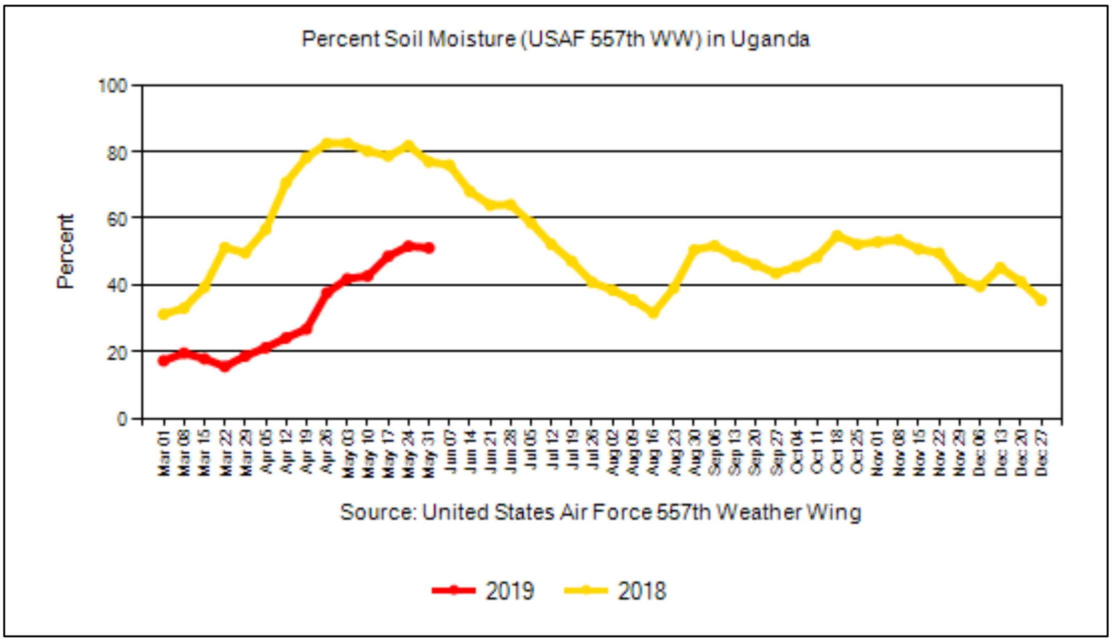

Figure 4: Monthly percent soil moisture for Uganda for 2018 and 2019. Source: USDA

Water demand data

Water demand data was obtained from the FAO Aquastat portal. The data is given at a country level as summarized in Tables 3,4,5 and 6.

Table 3: Country level Water and hydrological related aspects

No.	Parameter	Uganda	Kenya	Tanzania	Rwanda	Burundi
1	Long-term average annual precipitation in depth (mm/year)	1180	630	1071	1212	1274
2	Long-term average annual precipitation in volume (10^9 m3/year)	285	366	1015	32	36
3	Surface water produced internally (10^9 m3/year)	39	20	80	10	10
4	Groundwater produced internally (10^9 m3/year)	29	4	30	7	8
5	Total internal renewable water resources (IRWR) (10^9 m3/year)	39	20.7	84	9.5	10.06
6	Total internal renewable water resources per capita (m3/inhab/year	999	450	1571	818	900
7	Surface water: entering the country (total) (10^9 m3/year)	21.1	10	12.3	3.8	0.13
8	Surface water: total flow of border rivers (10^9 m3/year)	-	-	-	-	5
9	Surface water: accounted flow of border rivers (10^9 m3/year)	-	-	-	-	2
10	Surface water: accounted inflow (10^9 m3/year)	21	10	12	4	3
11	Surface water: leaving to other countries (total) (10^9 m3/year)	37	9	16	6	8
12	Groundwater: entering the country (total) (10^9 m3/year)	-	-	-	-	-
13	Groundwater: accounted inflow (10^9 m3/year)	-	-	-	-	-
14	Groundwater: leaving to other countries (total) (10^9 m3/year)	-	-	-	-	-
15	Groundwater: accounted outflow to other countries (10^9 m3/year)	-	-	-	-	-
16	Water resources: total external renewable (10^9 m3/year)	21.1	10	12.27	3.8	2.48
17	Total renewable surface water (10^9 m3/year)	60.1	30.2	92.27	13.3	12.54
18	Total renewable groundwater (10^9 m3/year)	29	3.5	30	7	7.47
19	Total renewable water resources (10^9 m3/year)	60.1	30.7	96.27	13.3	12.54
20	Dependency Ratio (%)	35.11	32.57	12.75	28.57	19.75
21	Total renewable water resources per capita (m3/inhab/year)	1540	666.7	1800	1146	1122

Source: Aquastat

Table 4: Water withdraw of the LVB countries for the period 1988-1992

No.	Parameter	Uganda	Kenya	Tanzania	Rwanda	Burundi
1	Agricultural water withdrawal (10^9 m3/year)	-	1.57	-	-	-
2	Industrial water withdrawal (10^9 m3/year)	-	0.08	-	-	-
3	Municipal water withdrawal (10^9 m3/year)	-	0.40	-	-	-
4	Total water withdrawal (10^9 m3/year)	-	2.01	-	-	-
5	Irrigation water withdrawal (10^9 m3/year)	-	-	-	-	-
6	Irrigation water requirement (10^9 m3/year)	-	-	-	-	-
7	Agricultural water withdrawal as % of total water withdrawal (%)	-	76.43	-	-	-
8	Industrial water withdrawal as % of total water withdrawal (%)	-	3.90	-	-	-
9	Municipal water withdrawal as % of total withdrawal (%)	-	19.67	-	-	-
10	Total water withdrawal per capita (m3/inhab/year)	-	81.86	-	-	
11	Environmental Flow Requirements (10^9 m3/year)	12.26	8.22	26.66	2.91	3.215
12	Fresh surface water withdrawal (primary and secondary) (10^9 m3/year)	-	-	-	-	-
13	Fresh groundwater withdrawal (primary and secondary) (10^9 m3/year)	-	-	-	-	-
14	Total freshwater withdrawal (primary and secondary) (10^9 m3/year)	-	2.05	-	-	-
15	Desalinated water produced (10^9 m3/year)	-	-	-	-	
16	Direct use of treated municipal wastewater (10^9 m3/year)	-	-	-	-	-
17	Direct use of agricultural drainage water (10^9 m3/year)	-	-	-	-	-

Source: Aquastat

Table 5: Water withdraw of the LVB countries for the period 1998-2002

No.	Parameter	Uganda	Kenya	Tanzania	Rwanda	Burundi
1	Agricultural water withdrawal (10^9 m3/year)	0.12	1.01	4.63	0.10	0.22
2	Industrial water withdrawal (10^9 m3/year)	0.05	-	0.01	0.01	0.02
3	Municipal water withdrawal (10^9 m3/year)	0.15	-	0.53	0.04	0.05
4	Total water withdrawal (10^9 m3/year)	0.32	-	5.18	0.15	0.29
5	Irrigation water withdrawal (10^9 m3/year)	-	-	4.43	-	0.2
6	Irrigation water requirement (10^9 m3/year)	-	-	0.97	-	0.03
7	Agricultural water withdrawal as % of total water withdrawal (%)	37.81	-	89.35	68	77.08
8	Industrial water withdrawal as % of total water withdrawal (%)	14.49	-	0.48	8	5.90
9	Municipal water withdrawal as % of total withdrawal (%)	47.7	-	10.17	24	17.01
10	Total water withdrawal per capita (m3/inhab/year)	12.52	-	144.6	17.57	40.22
11	Environmental Flow Requirements (10^9 m3/year)	12.26	8.22	26.66	2.91	3.215
12	Fresh surface water withdrawal (primary and secondary) (10^9 m3/year)	-	-	-	-	-
13	Fresh groundwater withdrawal (primary and secondary) (10^9 m3/year)	-	-	-	-	-
14	Total freshwater withdrawal (primary and secondary) (10^9 m3/year)	0.32	-	5.18	0.15	0.29
15	Desalinated water produced (10^9 m3/year)	-	-	-	-	-
16	Direct use of treated municipal wastewater (10^9 m3/year)	-	-	-	-	-
17	Direct use of agricultural drainage water (10^9 m3/year)	-	-	-	-	-

Source: Aquastat

Table 6: Water withdraw of the LVB countries for the period 2003-2007

No.	Parameter	Uganda	Kenya	Tanzania	Rwanda	Burundi
1	Agricultural water withdrawal (10^9 m3/year)	-	1.91	-	-	-
2	Industrial water withdrawal (10^9 m3/year)	-	0.13	-	0.02	0.02
3	Municipal water withdrawal (10^9 m3/year)	-	1.19	-	0.061	0.04
4	Total water withdrawal (10^9 m3/year)	-	3.22	-	-	-
5	Irrigation water withdrawal (10^9 m3/year)	-	1.60	-	-	-
6	Irrigation water requirement (10^9 m3/year)	-	-	-	-	-
7	Agricultural water withdrawal as % of total water withdrawal (%)	-	59.26	-	-	-
8	Industrial water withdrawal as % of total water withdrawal (%)	-	3.88	-	-	-
9	Municipal water withdrawal as % of total withdrawal (%)	-	36.86	-	-	-
10	Total water withdrawal per capita (m3/inhab/year)	12.3	75.64	-	-	-
11	Environmental Flow Requirements (10^9 m3/year)	-	8.22	26.66	2.91	3.22
12	Fresh surface water withdrawal (primary and secondary) (10^9 m3/year)	-	-	-	-	-
13	Fresh groundwater withdrawal (primary and secondary) (10^9 m3/year)	-	-	-	-	-
14	Total freshwater withdrawal (primary and secondary) (10^9 m3/year)	-	3.22	-	-	-
15	Desalinated water produced (10^9 m3/year)	-	-	-	-	-
16	Direct use of treated municipal wastewater (10^9 m3/year)	-	-	-	-	-
17	Direct use of agricultural drainage water (10^9 m3/year)	-	-	-	-	-

Source: Aquastat

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