Conceptualizing a research agenda for Water-Energy-Food security Nexus research in small-scale water sheds in Sub-Saharan Africa: the case of the Sio-Malaba-Malakisi River Basin

Graphical abstract

Figure 1: Word cloud of „Index-Keywords" (n=84) (Threshold = 1)

1 Introduction

With the increasing pressure on ecosystems and natural resources due to human exploitation of nature, the last years have shown an increase in the development of conceptual frameworks to overcome some of the consequences associated to this exploitation, like increasing rural poverty, environmental degradation, an water-, energy- and food insecurity. These problems are particularly severe in large parts of Sub-Saharan Africa, which is seen, together with South Asia, as a hot spot region when it comes to water-, energy- and food insecurity (Conway et al., 2015; Hoff, 2011; Wong and Pecora, 2015). Within Sub-Saharan Africa, densely populated areas with high growth in economic activity, consumption, and population are the most vulnerable towards the consequences of human exploitation of nature, as the societies in these areas largely depend on natural resources (i.e. land, soils, water, forests) (Conway et al., 2015; Hoff, 2011; Waughray, 2011). On a river basin scale, this counts, for instance, for the Kagera river in the Great Lakes region of East Africa, selected river basins in the Gulf of Guinea (i.e. Cross, Oueme, Tano and Bia rivers), and particularly for the Sio-Malaba-Malakisi River Basin (SMMRB) in the southern border region of Kenya and Uganda (Meigh et al., 1999; Roussel, 2012; UNEP and UNEP-DHI, **2015**).

*Table 1 Area, population, and population densities in selected small river basins <10,000 km^2 (bolt, black) and medium scale 10,000-100,000 km^2 (grey) in Sub-Saharan Africa. Sources: 1)(Kaindi, 2013); 2) (UNEP and UNEP-DHI, **2015**); 3) (LVBC, 2013); 4) (BRL, 2008)*

River basin	Countries	Area [km^2]	Population [capita]	Pop. density [capita/km2]	Source
SMM	**Kenya, Uganda**	5,230	2,073,000	**396**	**1**
Umbeluzi	**Mozambique, South Africa, Swaziland**	5,000	635,000	**127**	**2**
Umba	**Kenya, Tanzania**	7,000	500,000	**71**	**2**
Great Scarcies	**Guinea, Sierra Leone**	8,000	516,000	**65**	**2**
Akpa	**Nigeria, Cameroon**	3,000	132,000	**44**	**2**
Loffa	**Guinea, Liberia**	10,000	224,000	**22**	**2**
Utamboni	**Equatorial Guinea, Gabon**	8,000	67,000	**8**	**2**
Mbe	**Equatorial Guinea, Gabon**	7,000	24,000	**3**	**2**
Kagera	Burundi, Rwanda, Tanzania, Uganda	59,800	16,248,000	272	4
Cross	Cameroon, Nigeria	52,000	10,766,000	207	2
Oueme	Benin, Nigeria, Togo	59,000	8,483,000	144	2
Tano	Côte D'Ivoire, Ghana	17,000	1,750,000	103	2
Bia	Côte D'Ivoire; Ghana	12,000	1,199,000	100	2
Chiloango	Angola, Congo, DRC Congo	13,000	1,169,000	90	2
Moa	Guinea, Liberia, Sierra Leone	20,000	1,757,000	88	2
Gash	Eritrea, Ethiopia, Sudan	24,000	1,906,000	79	2
Mara	Kenya, Tanzania	13,750	981,000	71	3
Pangani	Kenya, Tanzania	41,000	2,902,000	71	2
Thukela	Lesotho, South Africa	29,000	1,975,000	68	2
Mono	Togo	21,000	1,425,000	68	2
Sassandra	Côte D'Ivoire, Guinea	68,000	4,143,000	61	2
Cestos	Côte D'Ivoire, Guinea, Liberia	12,000	711,000	59	2
Cavally	Côte D'Ivoire, Guinea, Liberia	29,000	1,524,000	53	2
St. Paul	Guinea, Liberia	20,000	1,027,000	51	2
Little Scarcies	Guinea, Sierra Leone	19,000	926,000	49	2
Buzi	Mozambique; Zimbabwe	29,000	1,319,000	45	2
Incomati	Mozambique, South Africa, Swaziland	47,000	2,104,000	45	2
St. John	Côte D'Ivoire, Guinea, Liberia	17,000	761,000	45	2
Maputo	Mozambique, South Africa, Swaziland	30,000	1,335,000	45	2
Komoe	Burkina Faso, Côte D'Ivoire, Ghana, Mali	84,000	3,673,000	44	2
Geba	Guinea, Guinea-Bissau, Senegal	12,000	498,000	42	2
Baraka	Eritrea, Sudan	64,000	2,261,000	35	2
Pungwe	Mozambique, Zimbabwe	31,000	950,000	31	2
Corubal	Guinea, Guinea-Bissau	25,000	662,000	26	2
Gambia	Gambia, Guinea, Senegal	72,000	1,793,000	25	2
Benito/Ntem	Cameroon, Equatorial Guinea, Gabon	44,000	657,000	15	2
Lotagipi Swamp	Ethiopia, Kenya, Uganda	29,000	324,000	11	2
Nyanga	Congo, Gabon	25,000	100,000	4	2
Atui	Mauritania	43,000	76,000	2	2

One concept that has recently gained a lot of attention amongst various stakeholders in dealing with the challenges associated to the increasing pressure on natural resources is the so-called Water-Energy-Food security (WEF) nexus. The WEF nexus is defined by the Food and Agriculture Organization (FAO) as a “concept to describe and address the complex and interrelated nature of our global resource systems, on which we depend to achieve different social economic and environmental goals” (Dubois et al., 2014), and researchers are particularly addressed when it comes to “sharing and developing knowledge among relevant stakeholders to access the best available data and developing common frames of reference on the need for solutions” (Waughray, 2011). The knowledge should be shared with stakeholders from local over national to international levels in order to facilitate governance and resource planning at all levels (Bizikova et al., 2013). In practice, however, some authors argue that large parts of the WEF nexus discussion focuses on macro-drivers and omits the complexity existing at the local scale (Biggs et al., 2015). This indicates that, while most research and activities focused on areas on a higher political and larger hydrological and geographical scale (e.g. macro scale river basins, countries, world regions), the local scale (e.g. meso and micro river basins, village communities) are still underrepresented (Endo et al., 2017). Furthermore, WEF nexus research involves a lot of “rhetoric but lacks nuanced and detailed research-based evidence on how to implement nexus research and deliver real world solutions at multiple scales and in different contexts” (Leck et al., 2015).

In order to develop this research-based evidence and deliver real world solutions for areas on watershed level on local scale in Sub-Saharan Africa, the aim of the article at hand is to construct an agenda for research on WEF related challenges, taking the example of the SMMRB as a case study. The research questions are:

1. What are the main challenges for water, energy, and food security in the SMMRB?
2. With respect to data used and methods applied in earlier research, how can these challenges be investigated?
3. What can be learned from the example of the SMMRB to other regions?

After describing the case study area, scientific literature on the WEF nexus is reviewed, with respect to data used and methods applied. Furthermore, scientific and non-scientific literature on the three main aspects of the WEF nexus in the case study area SMMRB is reviewed. Based on that, nexus related challenges for the case study are elaborated (constructed), and methods for their investigation at local level are suggested.

2 Method and methodology

2.1 Description of the case study area SMMRB

The SMMRB is located at the southern border region between Kenya in the east and Uganda in the west. The area covers two river basins, namely Sio and Malaba-Malakisi. The two basins cover in total around 4,000 km², of which 2,880 km² are in Kenya and 1,220 km^2 are in Uganda (Roussel, 2012). The Sio river, which forms the border between the two countries in the southern part of the area, is mainly located in Kenya and origins from the Kaujai and Luucho hills in Bungoma, Kenya, from an altitude of around 1,800 meters above sea level (MASL) (Barasa et al., 2011). It has a length of 85 km, covers an area of around 1,500 km² and drains into the Lake Victoria (1,135 MASL) (Kaindi, 2013; Roussel, 2012). The Malaba-Malakisi or solely Malaba river basin lies in the northern part of the area, discharges to the Lake Kyoga in Uganda (950 MASL) and occupies around 2,500 km² (Barasa et al., 2013; Kaindi, 2013). The upper part of the Malaba basin is dominated by the river Lwakhakha, which originate from the Ugandan side of Mount Elgon (4,320 MASL). After joining the from the Kenyan side of Mount Elgon originating Malakisi river at the border town of Malaba, it is subsequently termed as Malaba river. Additionally to that, the Mpolongoma river basin (2,000 km²) in Uganda is sometimes included in SMMRB studies, but not in the one at hand (Roussel, 2012). Using the hydrological classification of (Becker and Nemec, 1987), the Sio and the Malaba-Malakisi would thus be meso scale river basin of between 1,000 and 10,000 km².

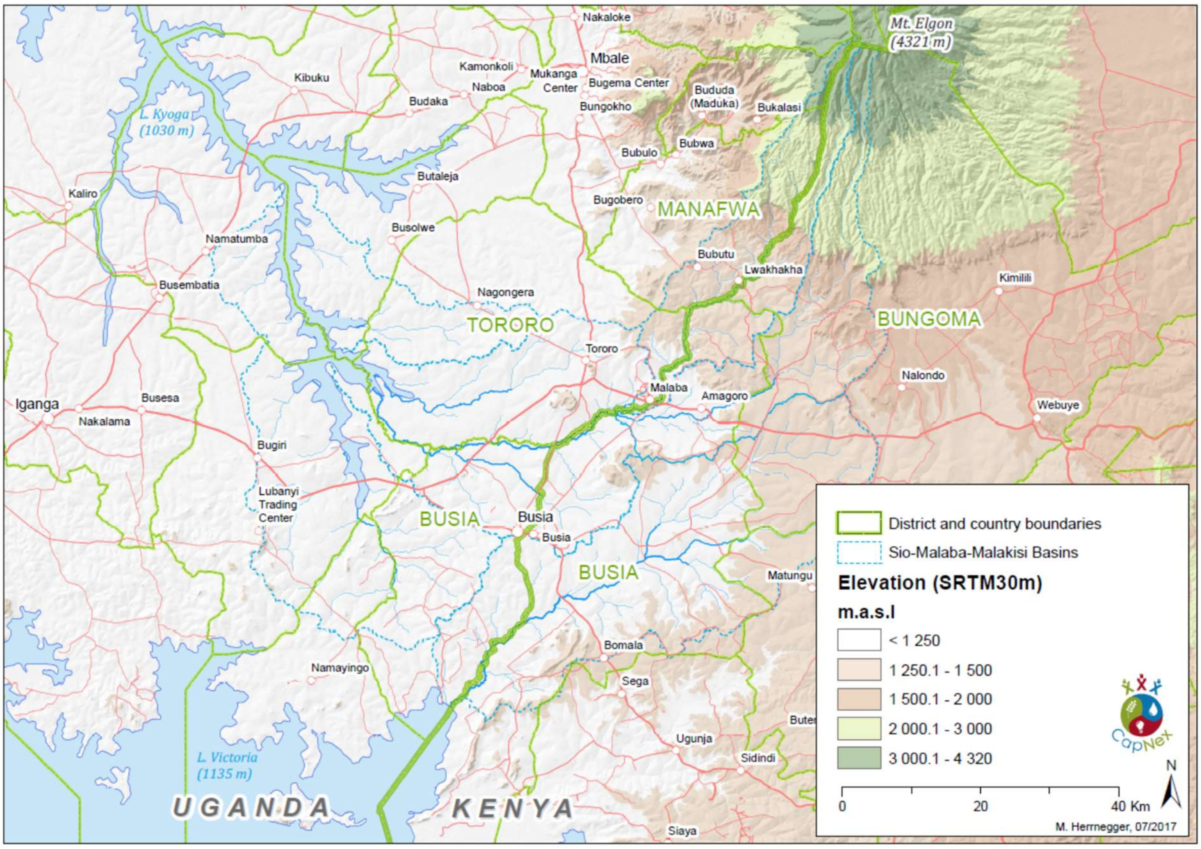


Figure 2 Location of and elevation distribution in the Sio-Malaba-Malakisi River Basin (SMMRB)

Table 2 gives an overview on the main area and population data of the SMMRB, excluding the Mpolongoma catchment.

Table 2 Area and population data of main districts and counties in the SMMRB; data from (KNBS, 2015a, b, c; UBoS, 2016a, b)

District/County	District / County Population 2014	Area [km²]	Area in SMMRB [km²]	Share of SMMRB [%]	Share of District / County in SMMRB [%]
Busia Uganda (U)	323,662	702	390	11%	56%
Manafwa (U)	353,825	603	240	7%	40%
Tororo (U)	517,082	1,671	590	17%	35%
Bungoma (K)	1,500,990	3,032	890	26%	29%
Busia Kenya (K)	812,036	1,695	1,270	36%	75%
Kakamega (K)	1,812,330	3,050	110	3%	4%
Total	**5,319,925**	**10,753**	**3,490**		

2.2 Literature review – WEF nexus

Under construction

3 WEF nexus related challenges in the SMMRB

3.1 Water security

3.1.1 Water quantity

The hydrological water balance, which describes the flows of water in and out of an area and thus also the quantitative water availability, constitutes of, precipitation, evapotranspiration, surface runoff, and percolation (change in groundwater storage).

Figure with meteorological and hydrological stations here

A number of meteorological stations in the SMMRB record the precipitation in the area. According to this data, the area receives an average of 1,500 mm of annual and bimodal rainfall (Barasa et al., 2013; Barasa et al., 2011), with values ranging between 1,200 mm/yr in the low lands and 2,000 mm/yr in the high lands of Mount Elgon. In selected micro climates, values down to 700 mm/yr have been measured (Roussel, 2012). Trends in precipitation have been analyzed by (Otim, 2008) for the District of Busia, Uganda, applying the Standardized Precipitation Index (SPI) to rainfall data between 1963 and 2005. Findings suggest that the highest drought and thus lowest rainfall magnitudes occurred in the 1970ies. (Barasa et al., 2013) analyzed data for the time period of 1983-2011 (rainfall) and 1992-2011 (streamflow) by SPI, Combined Precipitation Index (CPI), and the IHACRES model, in order to trace out extreme weather events (flood and drought) in the Malaba-Malakisi river basin.

Even though results were not uniform among the models applied, of the 28 years covered in the models, nine years were found to be dryer than average, of which one year was in the 1980ies, 3 years in the 1990ies, and the five years between 2005 and 2009. The authors concluded that the return time of extreme events, i.e. drought and floods, in the catchment has reduced during the observation time, dropping from 4-10 to 1-3 years. What both, (Barasa et al., 2013) and (Otim, 2008) point out are the meteorological data gaps existing for the years of political instability in Uganda in the 1970ies and 1980ies.

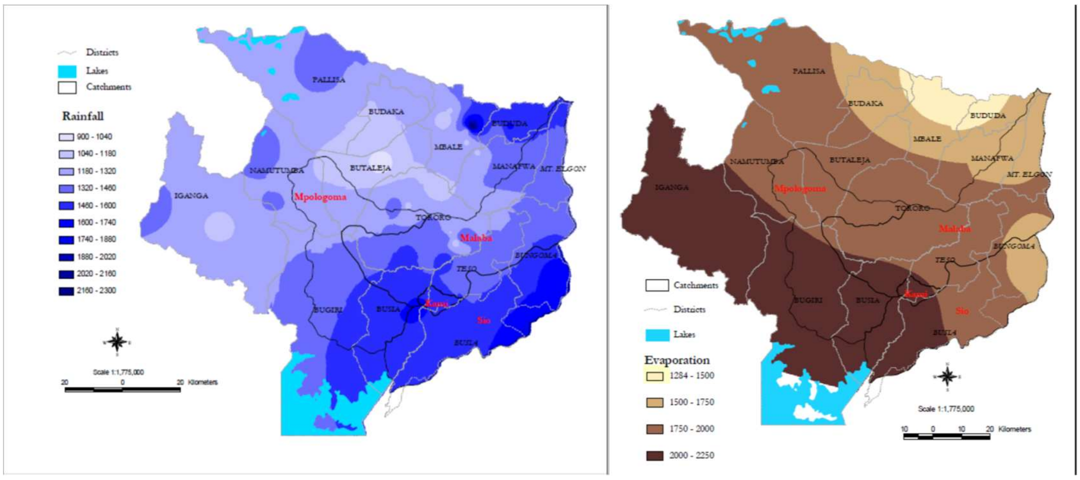


Figure 3 Precipitation and evaporation E0 in the SMMRB; data from(WREM, 2010) as cited in (Kaindi, 2013)

The evaporation E_0, which is also based on the data from meteorological stations, is highest in the southern end of the area that borders to Lake Victoria with values of up to 2,250 mm/yr and decreasing towards Mount Elgon to 1,500 mm/yr (Kaindi, 2013), reflecting the mean temperature at different sea levels. Land cover, which majorly effects transpiration, has been changed significantly during the last decades. (Mugagga et al., 2012b) investigated the impact of land use change on land slides in the Ugandan Manafwa District in the northern part of the area towards Mount Elgon, based on aerial photographs and satellite images. Results indicate that while there was little change between the years 1960 and 1995 in the distribution of land cover, a major change was recorded between 1995 and 2006. Thereafter, 80% of woodlands and forest cover reduced to only 40%, while agricultural land use increased from 20% to 60%, within only 10 years. These data, however, is in partial contradiction to the official statistics by the Ugandan Bureau of Statistics (UBoS) which shows that in the Districts of Busia, Tororo, and Mbale (which contains Manafwa District in its statistics), the agricultural land use was already high in 1995 with 72%-93%, and it further increase to 79%-93% of the whole district areas excluding water bodies in 2005 (UBoS, 2016a). Correspondingly, during the same time, the share of forests (0%-12% in 1995 and 0%-9% in 2005) and woodlands (4%-17% in 1995 and 3%-13% in 2005) decreased. Similar figures are given by the statistics of the Ugandan National Forestry Authority as stated in (Kaindi, 2013). However, land use transfers in the area are likely not only between natural ecosystems (i.e. forests) and agricultural land use. A study by (Ebanyat et al., 2010) carried out in three parishes in the neighboring district of Pallisa west of the area showed that the cultivated land increased between 1960 and 2001 from 24% to 46% of the land, while grassland earlier used as community grazing land reduced from 13% to 0%. For the Kenyan side of Mount Elgon, a survey by the Kenya Wildlife Service (KWS) and the Forest Department (KFD) showed that between 1960 and 1999, the forest and the moorland at the mountain decreased from 50% to 33% and from 23% to 17% respectively, while bamboo (from 15% to 20%), grass land (from 6% to 10%), plantations (from 1% to 4%), and agricultural land use (from 0% to 9%) increased (Kaindi, 2013). Also in detail, investigations on the land use and land use changes have been analyzed by (Makalle et al., 2008) and (Barasa et al., 2011) for the Sio river basin. (Makalle et al., 2008) who collected data by a questionnaire survey found that on the Kenyan side of River Sio, plots owned are larger and more land is used by farmers for grazing than in Uganda. (Barasa et al., 2011) showed by using landsat images a massive decrease in wetlands and a slight decrease in bushlands towards a steep increase in grasslands and agricultural land between the years 1986 and 2000. For the Solo river basin, the latter being a tributary of the Malaba river, all. (Barasa et al., 2017) furthermore investigated the influence of the land use along the river bank of River Solo on its morphology, finding much higher changes for agricultural land than for other land uses, such as forests, tree plantations, or bushlands.

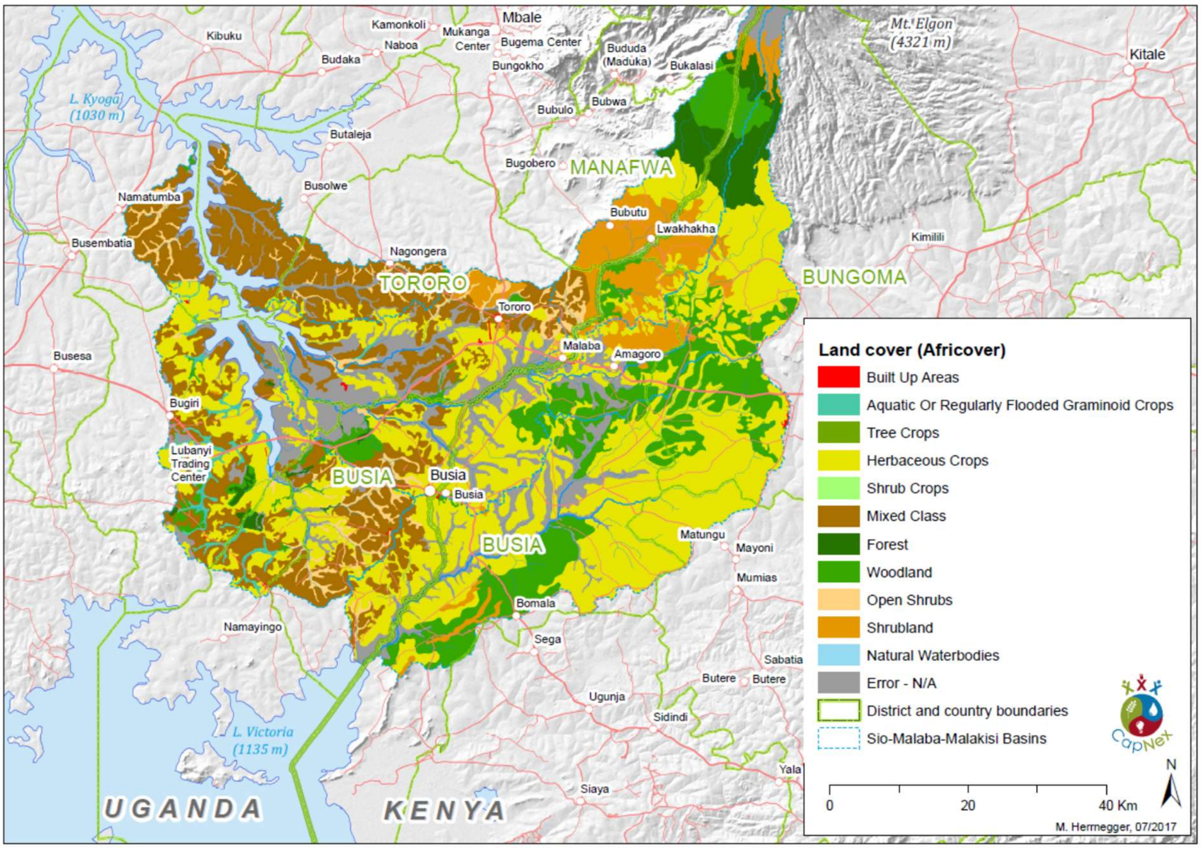


Figure 4 Land cover information on the SMMRB taken from Africover

Given a certain rainfall and land cover, surface runoff as well as groundwater formation is mainly influenced by the slope and the soils of an area. In the SMMRB, slopes are steep close to the Mount Elgon in the Malaba-Malakisi part of the catchment, while the rest of the area is generally flat, resulting in slopes of more than 20% gradient covering 7% of the area, slopes of 5%-20% gradient covering 7% of the area, and flat land of slopes lower than 5% of gradient covering the remaining 85% of land (Roussel, 2012).

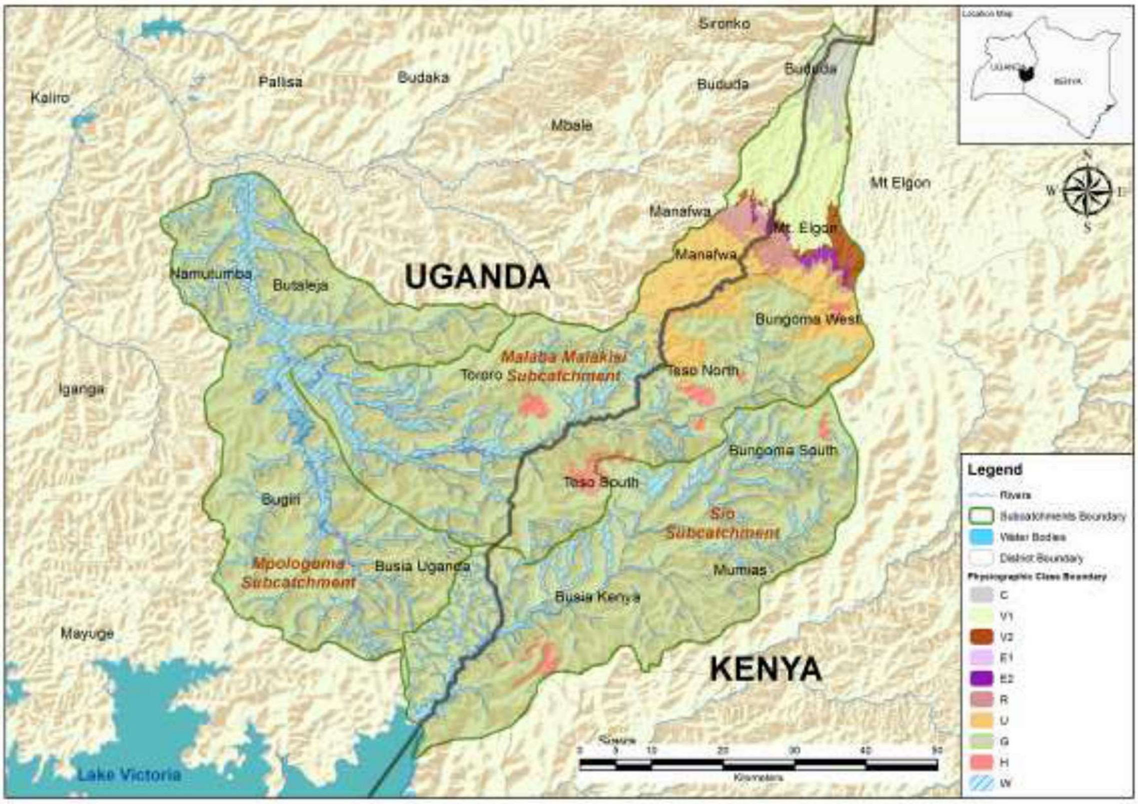


Figure 5 Physiographic map of the SMMRB illustrating the distribution of slope gradients, with land classes C, V1, V2, E1, E2 are gradients higher than 20%, R and U are gradients between 5% and 20%, and G and W are gradients below 5%. The details on the classification can be found in (Roussel, 2012)

The soils in the area are quite heterogenic, reflecting the geological activity. Around Mount Elgon in the North of the area, soil types are present as concentric circles, with the upper slopes of the massive dominated by young soils rich in organic matter, i.e. Sapric Histosols and Cambric Umbrisols. The lower slopes are dominated by Umbric, Rhodic and various other Nitisols, both on top of alkali volcanic base rock. Further south, the base of the generally deep and well drained soils is Precambrian gneiss-granulite, granite, and to a lesser extent the metamorphic rocks of the so-called Nyanza System. Soil types change and also divide between the Kenyan and the Ugandan side. The Kenyan side which is in this part of the area more or less identical to the sub-catchment of the river Sio, the shallow hills and ridges are different types of Acrisoils, while the valleys Eutric Gleysoils saturated with groundwater for long periods of the year. On the Ugandan sites, Haplic Ferralsols can be found along the border, changing to Albic Plinthosols towards North-West and Plinthic Lixisols towards South-West. Poorly drained soils of high heterogeneity can be found in river beds (JICA and MWE, 2011; Jones et al., 2013; Roussel, 2012; Westerhof et al., 2014).

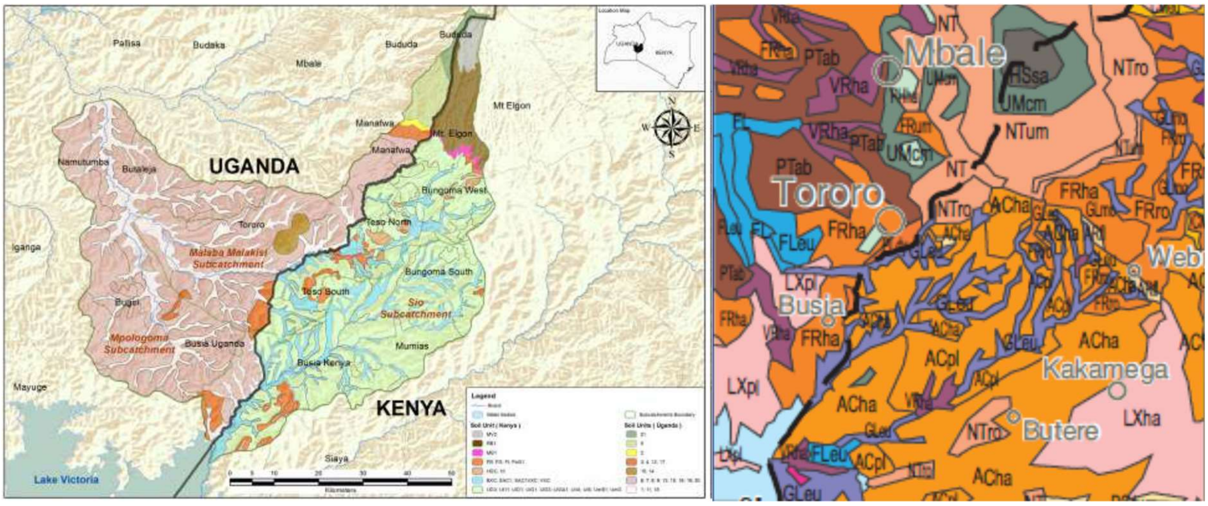


Figure 6 Soil types in the SMMRB after (Roussel, 2012) and (Jones et al., 2013)

For the formation of groundwater, these properties mean that a relatively large amount of water is subject to surface run-off in the upper part of the area towards Mount Elgon. Based on a study by (Bamutaze et al., 2010) carried out in the Mount Elgon region of the SMMRB neighboring Manfwa river catchment, slope gradient was a more significant factor decreasing the in general high infiltration rate of the volcanic soils than other factors, i.e. soil texture and carbon content. Despite that, the higher amount of rainfall in these parts may also lead to higher infiltration of up to 600 mm per year (JICA and MWE, 2011) (see Figure 8). The infiltrated water is stored in both, the weathered bed rock as well as in the granulite, and the static groundwater level in the area is between 5 and 15 meters (Kaindi, 2013).

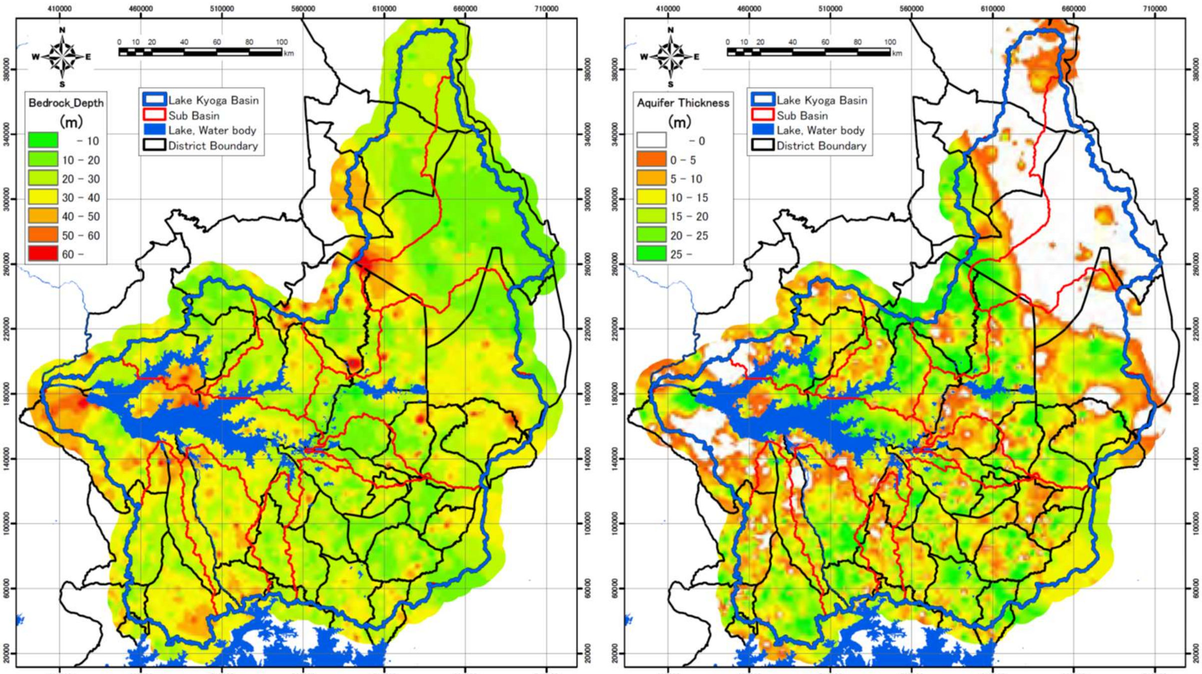


Figure 7 Estimated bedrock depth (left) and aquifer thickness (right) after (JICA and MWE, 2011)

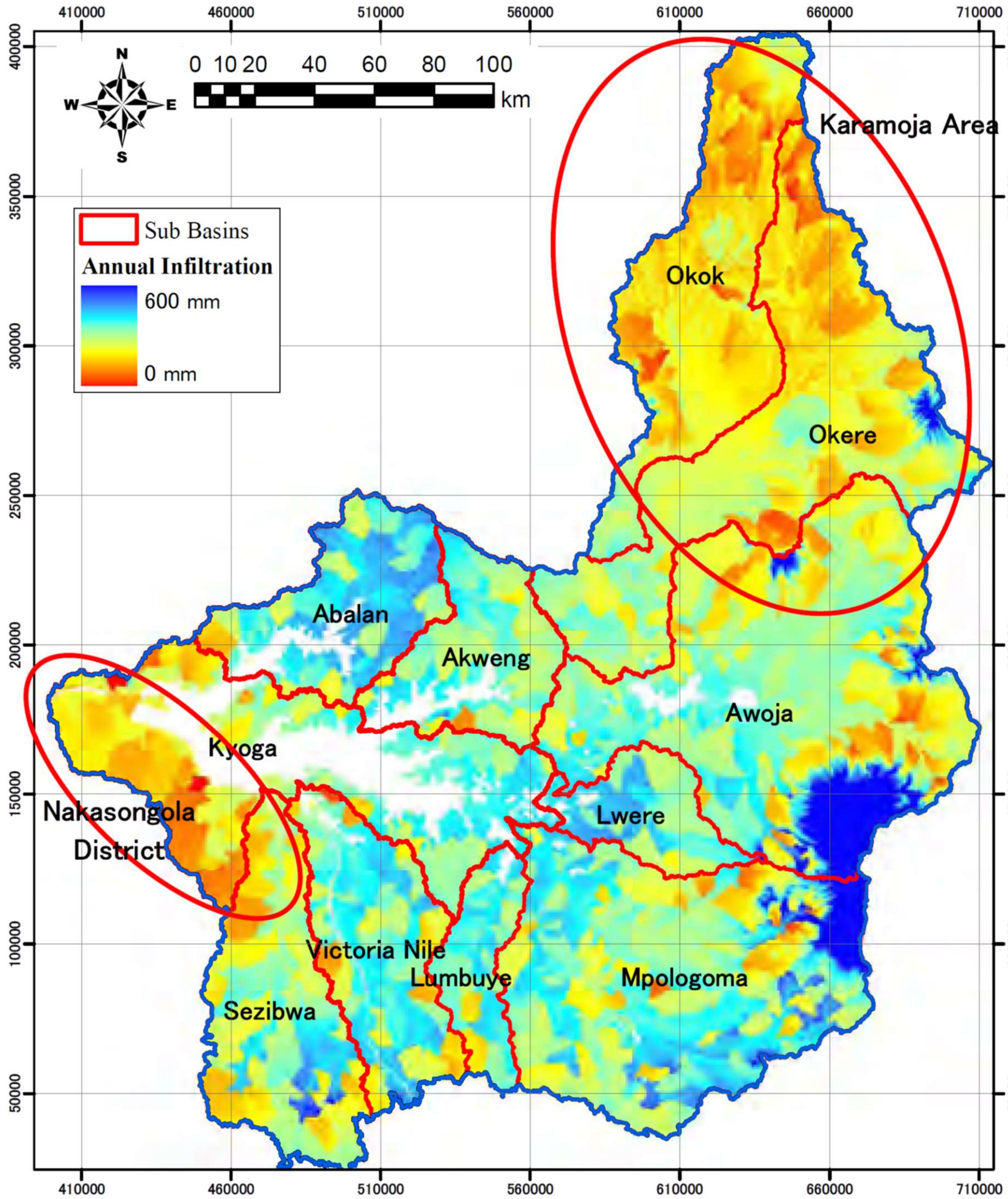


Figure 8 Estimated annual water infiltration after (JICA and MWE, 2011)

All of these features form the water balance, which has been determined for the SMMRB by Newplan (2010) as cited in (Kaindi, 2013), applying the Soil Water Assessment Tool (SWAT). The result of this calculation, expressed as the water yield, shows that it is highest in the slopes towards Mount Elgon with over 1,000 mm/yr, which can be mainly explained by higher rainfall and lower precipitation in this part of the area. Water yields of between 700 and 1,000 mm/yr can be found in the Eastern part of the Sio catchment, while the area in between is characterized by water yields of between 500 and 700 mm/yr. Lower water yields can only be found in the Western part of the SMMRB (see Figure 9).

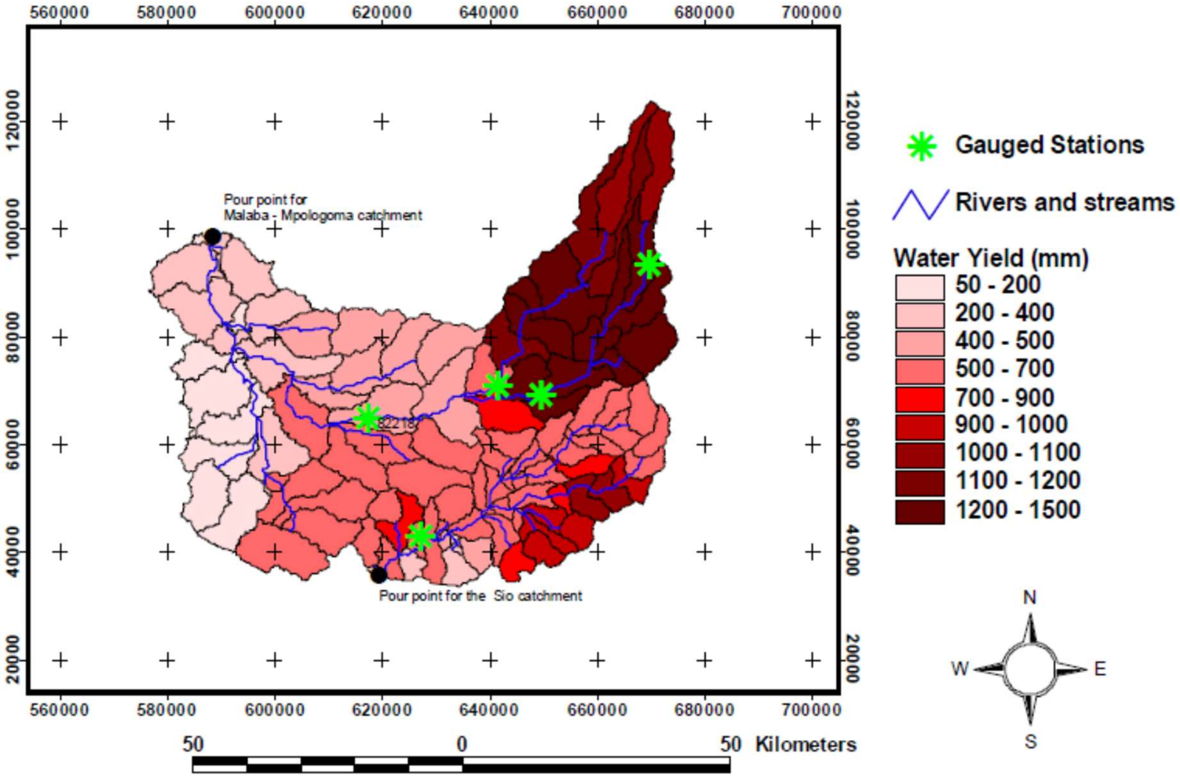
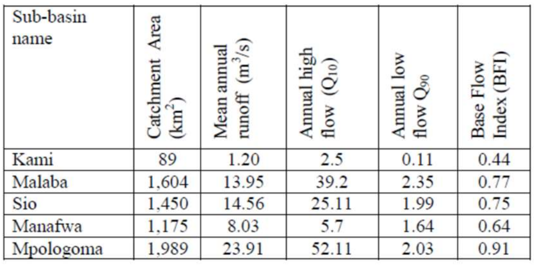


Figure 9 Estimated water yield using SWAT after Newplan (2012), cited in (Kaindi, 2013)

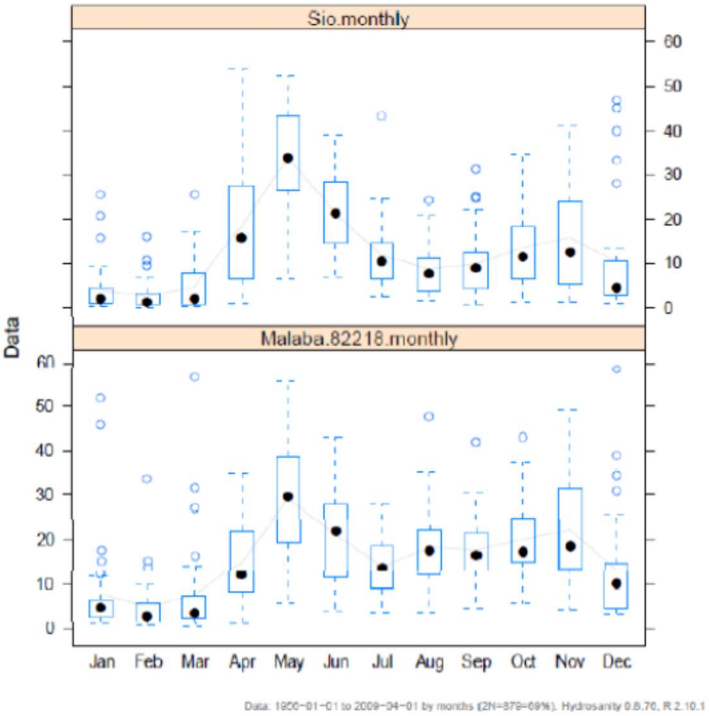
Part of the water yield is the surface runoff through rivers, which marks the last important and hitherto covered term in the water balance of the area. Like for meteorology, hydrological stations exist measuring the discharge of the rivers in the area, but not as many as for the aforementioned (Verweis: Literatur über die Stationen; (MWE, 2016)). A selection of some runoff data was presented by (Kaindi, 2013). This data shown in Table 3, however, did include neither the reference period, nor the exact position of the hydrological station or the reference document in detail. Nevertheless, the same source also stated that according to WREM (2008), floods in the area were recorded in the years 1961, 1988, 1994, 1997, 1998, 2000, 2002, 2003, 2007. Even though this indicates an increase, one should bear in mind that for a long time period in the 1970ies and 1980ies, it is likely that no measurements were conducted, for the aforementioned political instability during that time. More data should be available for the Kenyan side of the SMMRB, which is also indicated by Figure 10.

Table 3 Selected runoff data from the SMMRB, taken from WREM (2008) or Newplan (2012) as cited in (Kaindi, 2013)



Sub-basin name	Catchment Area (km^2)	Mean annual runoff (m^3/s)	Annual high flow (Q_{10})	Annual low flow Q_{90}	Base Flow Index (BFI)
Kami	89	1.20	2.5	0.11	0.44
Malaba	1,604	13.95	39.2	2.35	0.77
Sio	1,450	14.56	25.11	1.99	0.75
Manafwa	1,175	8.03	5.7	1.64	0.64
Mpologoma	1,989	23.91	52.11	2.03	0.91

Runoff data is also presented by (JICA 2011) for 4 stations on the Ugandan site, of which one is at River Malaba (82218), one at the border at the Kami river, a tributary to the River Malaba (82226), and two are at the River Mpologoma.



Data: 1950-01-01 to 2009-04-01 by months (2N=879=69%). Hydrosanity 0.8.76, R 2.10.1

Figure 10 Average monthly runoff data for rivers Sio and Malaba after Newplan (2012) as cited in (Kaindi, 2013)

Forecast model by Strzepek et al. (2011), cited in (Kaindi, 2013)

3.1.2 Water quality (supply side)

Even though the quality of water sources in the SMMRB is considered in a number of documents, it can hardly be dealt with straight forward in a review, as the definition of quality unlike quantity lies very much in the demand of the users. Thus, water for production or hydropower generally requires a lower quality with respect to most parameters usually measured (i.e. biological and chemical parameters) than drinking water or water as a habitat. Due to the higher requirements for drinking water, the parameters relevant for this water used are the baseline for this review, while likely effects of water quality properties on other water uses are highlighted where applicable.

According to (JICA and MWE, 2011) and (Kaindi, 2013), surface water quality of rivers in the SMMRB is measured at three stations in Kenya and three stations in Uganda. However, for one of the latter (SWR009 at River Manafwa NWSC treatment works), it is not clear if this one is within the SMMRB. Water quality measurement is carried out every three months at Kenya stations and with a lower and less regular frequency at the Ugandan stations. The results, which are only published for the three Kenyan stations for the years of 2002-2007, shows that of the few parameters measured, Nitrates, pH value and electric conductivity are below selected standard guidelines for drinking water, while turbidity and color are way above these standards particularly during the rainy season, which indicates a large transport of sediments by erosion (Kaindi, 2013). These sediments are not only a problem for utilization of drinking water, but also for hydropower and multipurpose dams for water for production, as they may settle and thus may lead to an early siltation of the reservoirs (Quelle). For the three stations in Uganda, unfortunately, only highly aggregated data is presented in (JICA and MWE, 2011) which counts for both, historical data between the years 1998 and 2008, as well as data collected by the authors themselves in the year 2009. This data, which considered more parameters than just the ones aforementioned (e.g. total suspended solids TSS, total dissolved solids TDS, etc.), confirm the same high values of turbidity and color, but in addition to that, other parameters like E-coli, total P and N proofed to be too high too. This on the first hand effects persons using the water directly without pre-treatment. With respect to groundwater, the quality is generally better than for surface water, however, the study by to (JICA and MWE, 2011) for Uganda and (Kaindi, 2013), for the Sio basin in Kenya show that also here, drinking water parameters do not meet the standards. For the river Sio, which seems to be the best investigated with respect to water quality, Ngirigaca (2010) as cited in (Kaindi, 2013) found that along the river, turbidity, total suspended solids and the sediment load significantly increases. Contrary to that, total P and N decreased significantly along the river.

Examples for sources for water pollution and low water quality are point sources like waste water from pit latrines and cesspits (for nutrients and Ecoli) (Kaindi, 2013; Roussel, 2012). However, (Scheren et al., 2000) who roughly estimated the sources of Biological Oxygen Demand (BOD), Nitrogen and Phosphorus as nitrification agents in Lake Victoria, found that domestic BOD sources overweigh industrial ones, while erosion from agricultural land and particularly deposition were the main sources of N and P. For N, (Minghua et al., 2014) estimates support these finding. Erosion from agricultural land ((Jiang et al., 2014); Newplan 2010 as cited in (Kaindi, 2013)) and riverbank erosion (Barasa et al., 2016) were also identified by other authors as major sources for particulate matter pollution. Furthermore, (Barasa et al., 2016) found not only higher riverbank erosion rate in areas with artisanal gold mining activities at River Okame, a tributary to River Malaba in Busia District, Uganda, but also suspected that these activities may lead to a notable pollution with Mercury.

3.1.3 Water use (demand)

As highlighted in the database of the Directorate of Water Development (DWD) of the Ministry of Water and Environment (MWE), drinking water demand on the Ugandan side is meet by several technologies, supply and operating schemes (DWD, 2011). In the Districts of Busia, Tororo and Manafwa whose area is almost entirely part of the SMMRB, the population of the rural areas that has access to drinking water largely depends on groundwater point sources through boreholes and shallow wells, while urban areas like Busia Municipality, Tororo Municipality, Malaba and Lwakhakha Towns in Uganda rely on a piped network. Of these urban areas, Tororo, Malaba and Lwakhakha retrieve their drinking water from the Malaba river. The data base further shows that around 80% of the population has access to safe drinking water (DWD, 2011). On the Kenyan side, the situation is quite similar, even though not as much information was possible to retrieve. Like in Uganda, the largest cities on the Kenyan side of the SMMRB, namely Busia Kenya and Malakisi are supplied by surface water from the Rivers Sio and Malakisi. The town of Nambale, which is the second largest on the Kenyan side of the area, plans to meet its water demand in future by River Sio as well (Quellen). Like on the Ugandan side, rural water supply is dominated by shallow wells and deep boreholes in the lower and flat parts of the SMMRB, while protected springs can be found towards Mount Elgon in the North and the Kaujai and Luucho hills in the East (Kaindi, 2013). For the entire SMMRB, Newplan (2010) projected the future domestic water demand to more than double within the next 25 years (Kaindi, 2013). This increase is assumed to be largely based on the population growth.

With respect to water for production (industry, animal husbandry, irrigation), irrigation is currently the only relevant water for production user, and the irrigated area in the SMMRB is relatively small compared to the total cropland. According to data by the Irrigation Subsector Review 1999 of the FAO and the Kenyan Western Province Irrigation Office in Kakamega, more irrigated area is in the Ugandan part of the SMMRB (393 km²) than on the Kenyan side (7.5 km²). Contrary to these figures, the data by Newplan (2010) which is also cited in (Kaindi, 2013), shows more than that (450 km² in Uganda and 117 km² in Kenya). According to the same source, the anticipated irrigated area in the year 2035 should increase to 917 km² on the Uganda side and 956 km² on the Kenyan side of the area, leading to a large increase in the water demand to 690 million m³/yr (Kaindi, 2013). This is much higher than the anticipated water demand for animal husbandry (18 Million m³/yr), industry (23 million m³/yr) and fisheries (90 Million m³/yr). Regarding the crops irrigated and the regarding irrigation schemes, it turns out that almost all the irrigated land in Uganda are rice fields located in former wetlands along the rivers (Kaindi, 2013), part of it in the so-called Doho rice scheme (DRS). The DRS dates back to the 1940s and received Chinese government aid in the 1970ies. Around 10 km² of rice paddies are cultivated by 4,320 farmers in this scheme (Angella et al., 2014; Nakano and Otsuka, 2011). On the Kenyan side, where no data on crops irrigated is given, lies also the only constructed reservoir for irrigation, the Munana dam. For the future, however, both countries' governments plan to increase the number of reservoirs in the SMMRB, usually in a multipurpose design (water for production and drinking water) (NBI, 2011a, b). The sites of these dams are shown in Figure 11.

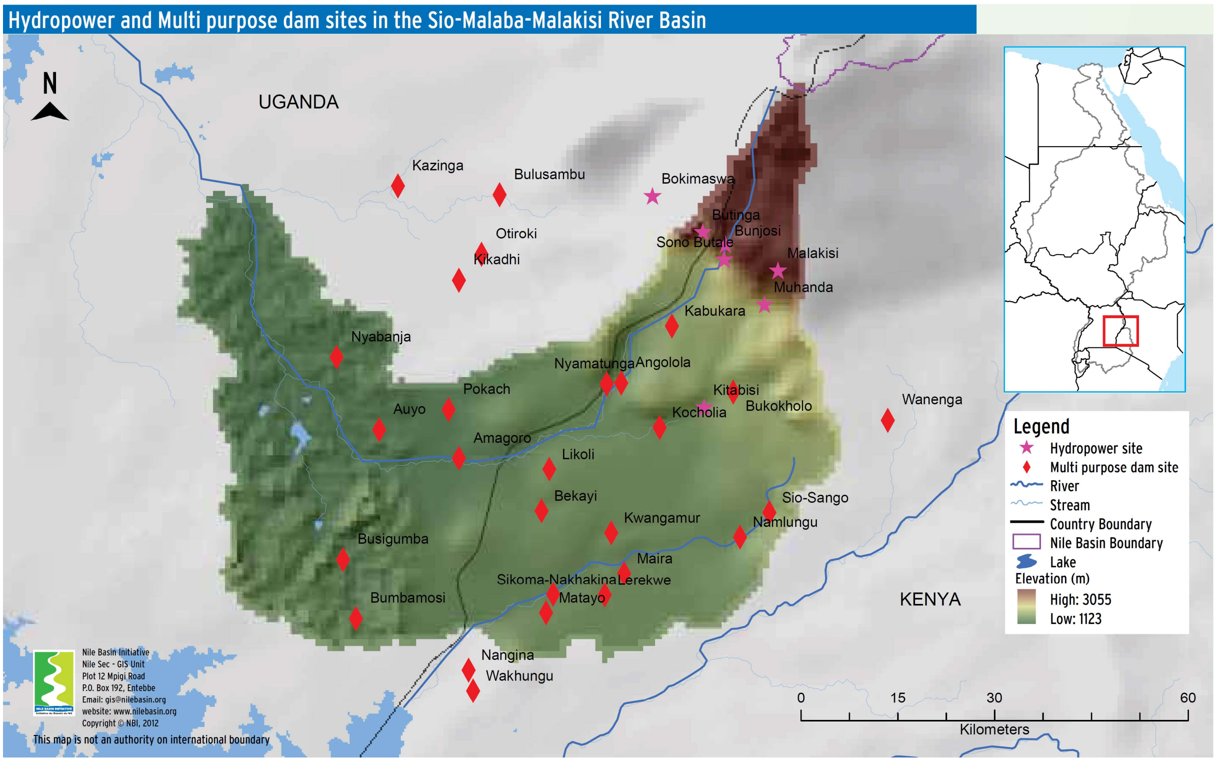


Figure 11 Planned hydropower and multi purpose dam sites in the SMMRB (NBI, 2011)

Figure 11 furthermore shows the planned hydropower sites in the SMMRB. All of these are located in the upper part of the area towards Mount Elgon (NBI, 2011a, b).

3.2 Energy security

3.2.1 Resources for energy production

Biomass is the most important source of energy in Kenya, Uganda, and the SMMRB, i.e. firewood and wood charcoal (Kiplagat et al., 2011; Twaha et al., 2016). Wood is present either as forests in protected areas (Mount Elgon National Park and Busitema Forest Reserve), tree plantations of mostly fast-growing softwood (*Pinus patula, Pinus radiata* and *Eucalyptus saligna*) and to a lesser extent hardwood (*Olea capensis, Vitex keniensis, Podo facaltus,* and *Juniperus procera*), and isolated trees (Kaindi, 2013; Roussel, 2012). The composition of the tree population in the area has changed a lot during the last years. A study carried out by (Barasa et al., 2010) in the Sio River Basin showed that during the last 20 years, the numbers of species like *Milicia excelsa* and various types of *Ficus* have decreased by 20% to 40%, while species like *Musanga cecropioides* and *Eucalyptus* have increased by 24% to 43%. Other biomass sources of energy are wastes and residues from agriculture, i.e. cow dung or crop residues (Tenyhwa et al., 2015) (Lederer et al., 2015; Mugo and Gathui, 2010; Okello et al., 2013a; Treiber et al., 2015).

Other energy resources available in the area are solar, water, and wind, but not fossil fuels and geothermal energy (Kiplagat et al., 2011; Twaha et al., 2016). Solar energy is currently used in the SMMRB, but only on a decentralized level (Kiplagat et al., 2011; Twaha et al., 2016). This is despite the fact that Kenya and Uganda in general as well as the SMMRB receive a fair amount of solar radiation per year. Feasibility studies suggest that the Upper Malaba (Lwakhaka) and the Malakisi rivers have some potential for hydropower (NBI, 2011b). Furthermore, wind data shows that the SMMRB is, in comparison to other areas in the countries, not the most promising location for power production in Kenya as other parts of the country show much larger and more constant wind speeds (Kiplagat et al., 2011). In Uganda, however, the SMMRB is the comparatively most promising location (Pallabazzer and Sebbit, 1998).

3.2.2 Energy conversion

Biomass, i.e. firewood and charcoal are the most important energy sources, and heat for cooking is the most important final energy demand on domestic level. Thus, the most important form of energy conversion is combustion, with the intermediate step of pyrolysis in the case of charcoal production and utilization (Okello et al., 2013b). Anaerobic digesters (biogas plants) that convert the chemical energy in biomass into a gas mixture rich in CH_4, have only lately been introduced in Kenya and Uganda. This also counts for the SMMRB, where particularly districts in Uganda with high cattle populations like Manafwa, are targeted, as cattle manure is the most important input into the plants (Kiplagat et al., 2011; Okello et al., 2013b; Walekhwa et al., 2014; Walekhwa et al., 2009). Through the assistance of international funded programs (i.e. SNV), however, the number has increased a lot in the recent years (Ghimire, 2013; Kiplagat et al., 2011). With respect to the sustainability of these projects, however, a number of studies have been carried out mainly on the Ugandan side and in the form of Master thesis works, indicating high levels of malfunctioning of the biogas plants even after a short time period of operation (Kariko-Buhwezi et al., 2011; Lutaaya, 2013; Mwirigi et al., 2014).

With respect to other energy resources and conversion technologies, decentralized off-grid utilization of solar power for heat and mainly electricity production is common, but hitherto no central on-grid technologies (Twaha et al., 2016). However, a 10 MW solar power station is planned to be built in the Ugandan district of Tororo, being the second of its kind in Uganda (EEAS, 2016).

Hydropower is currently not used in the SMMRB itself, but according to (NBI, 2011a) planned to be introduced in the Upper Malaba (Lwakhaka) and Malakisi rivers (see Figure 11). The relatively high potential on the Ugandan side of the SMMRB also lead to the plan to construct the 20 MW Tororo Wind Power Station in the district of the same name (Alobo, 2013; ERA, 2015) .

3.2.3 Energy consumption

Energy consumption can be divided along institutional (domestic, commercial, industrial consumers), functional (energy for lighting, cooking, heating, transport) and other boundaries.

The largest amount of domestic energy consumption is for cooking, while a smaller amount is used for lighting. For the Ugandan Districts in the SMMRB, namely Busia, Manafwa, and Tororo, national statistical data indicates that energy for lighting is mainly covered by paraffin (80%) and electricity (10%). Energy for cooking mainly comes from firewood (80%) and charcoal (15%) (UBoS, 2016b). On the Kenyan Side, energy for lighting is covered by tin lamps and lanterns (90%) and electricity (5%), while energy for cooking is provided by charcoal (9-13%) and firewood (84-87%) (KNBS and SID, 2013). This energy use profile leads to a large domestic consumption of biofuels (firewood, charcoal, other biofuels), which has been determined by (Kituyi et al., 2001) for various Districts in Kenya including Bungoma and Kakamega Districts and for the East-Ugandan District of Soroti by (Egeru, 2014), indicating average consumption rates (mean value) of between 540 and 640 kg/capita/yr for fuelwood and 100 kg/capita/yr for charcoal.

Commercial consumption of firewood is dominated by small-scale industries such as brick production or restaurants (Mugo and Gathui, 2010; Oteng'i and Neyole, 2007). For large scale industries, the cement industries of Tororo is the largest energy consumer in the SMMRB, importing mainly pet coke.

Energy consumption for transport is covered by gasoline and diesel, both of which are currently imported in Kenya and Uganda (UBoS, 2016a).

- Improved stoves Kenya (Ochieng et al., 2013) .

3.3 Food security

3.3.1 Food production

Crop production in the SMMRB is dominated by smallholder farms, producing mainly staple foods for their domestic demand as well as for the local markets. Cash crops for export are produced, i.e. coffee and cotton in Uganda and sugar in Kenya, but to a much smaller amount. The following tables (Table 4 and

Table 5) give an overview as presented in the latest available statistical data on crop production in the area.

Table 4 Crop production in the Ugandan Districts of Busia, Manafwa and Tororo in 2008/2009, according to (UBoS, 2010c)

	Busia - Manafwa - Tororo							
	Area 2nd season 2008	Production 2nd season 2008	Area 1st season 2009	Production 1st season 2009	Average Area 2008/2009	Average Production 2008/2009	Average Yield 2008/2009	Average Production 2008/2009
	ha/season	t/season	ha/season	t/season	ha	t/yr	t/ha/yr	kg/cap/yr
Maize	14,458	43,765	20,653	61,948	17,556	105,713	6.0	88
Millet	4,949	9,301	9,386	18,846	7,168	28,147	3.9	24
Sorghum	5,790	23,361	5,208	15,768	5,499	39,129	7.1	33
Rice	1,691	21,400	1,519	5,965	1,605	27,365	17.0	23
Beans	10,738	5,998	8,350	2,201	9,544	8,199	0.9	7
Field peas	416	257	150	331	283	588	2.1	0
Groundnut	2,475	4,508	4,108	6,838	3,292	11,346	3.4	9
Plaintain	4,410	27,430	4,722	32,487	4,566	59,917	13.1	50
Cassava	25,918	114,690	19,468	97,919	22,693	212,609	9.4	178
S.potatoes	6,990	37,587	5,826	13,722	6,408	51,309	8.0	43
Staple total	**77,835**	**288,297**	**79,390**	**256,025**	**78,613**	**544,322**		**456**

Table 5 Crop production in the Kenyan Counties of Bungoma and Busia in 2013 and 2014, according to (KNBS, 2015a, b)

	Busia - Bungoma							
	Area 2013	Area 2014	Production 2013	Production 2014	Yield 2013	Yield 2014	Production 2013	Production 2014
	ha/yr	ha/yr	t/yr	t/yr	t/ha/yr	t/ha/yr	kg/cap/yr	kg/cap/yr
Maize	109,875	120,551	297,079	349,674	2.7	2.9	128.4	151.2
F/Millet	6,975	6,278	6,773	6,665	1.0	1.1	2.9	2.9
Sorghum	7,087	4,709	9,368	6,941	1.3	1.5	4.1	3.0
Rice	103	435	17	253	0.2	0.6	0.0	0.1
Wheat	32	315	75	699	2.3	2.2	0.0	0.3
Beans	73,568	79,770	50,747	47,036	0.7	0.6	21.9	20.3
Green grams	185	226	83	122	0.4	0.5	0.0	0.1
S. potatoes	10,447	9,956	49,118	58,955	4.7	5.9	21.2	25.5
Cassava	9,761	10,008	59,374	1,149,701	6.1	114.9	25.7	497.1
Staple total	**218,033**	**232,248**	**472,634**	**1,620,046**	**19**	**130**	**204**	**700**
Fruits	4,537	4,774	22,806	62,680	5.0	13.1	9.9	27.1
Vegetables	16,910	23,660	149,843	231,934	8.9	9.8	64.8	100.3
Nuts	1,117	884	644,518	829	577.0	0.9	278.6	0.4
Tomatoes	1,945	2,207	45,635	52,070	23.5	23.6	19.7	22.5
Cabbages	1,191	1,330	31,912	37,659	26.8	28.3	13.8	16.3
Kales	1,927	1,905	30,595	33,023	15.9	17.3	13.2	14.3
Carrots	62	67	923	963	14.9	14.4	0.4	0.4
Bananas	3,775	4,447	72,337	82,549	19.2	18.6	31.3	35.7
Mangoes	1,315	1,417	24,506	26,576	18.6	18.8	10.6	11.5

Most food crops are produced for subsistence and local markets. The average annual yield per hectare, as well as the per capita staple food production of food crops is, according to statistics available, higher in the Kenyan Counties of Bungoma and Busia than in the Uganda Districts of Busia, Manafwa, and Tororo.

With respect to animal-based food products, meat, dairy and poultry products are the most important. Additionally to the overview given in Table 6, data on milk production is published by national statistics.

Table 6 Animal holding and production in the SMMRB main districts and counties; data from (KNBS, 2015a, b) and (UBoS, 2010a)

	Live animals [No.]				Animal (meat) products [t]	
	Busia (U)	Manafwa (U)	Tororo (U)	Busia (K)	Busia (K)	Bungoma (K)
Year	2008/2009	2008/2009	2008/2009	2013	2013	2013
Cattle	26,790	76,600	119,590	189,862	1,857	6,768
Goat	73,565	79,928	154,058	65,944	118	545
Sheep	2,910	4,790	13,090	56,090	80	224
Pig	14,200	38,910	45,360	63,047	7	1,135
Chicken	391,310	444,270	591,550	891,971	24	-
Total					2,086	8,672

The most important physical resources for the activity of food production are the soils, the supply with water and nutrients, animals, labor and technologies for planting, growing, harvesting, storage, and transport.

40% of the land in Bungoma and Busia Counties at the Kenyan side of the SMMRB are classified by (KNBS, 2015a, b) as of high agricultural potential and 25% as of medium to low agricultural potential. On the Ugandan side, the natural soil fertility in terms of nutrient and carbon content as well as cation exchange capacity is declining from medium at the slopes of Mount Elgon in Manafwa District to low at the shores of Lake Victoria (Aniku, 2001; Delve and Ramisch, 2006). Nitrogen and particularly Phosphorus contents and availability are low in these areas, but good fertilizer response rates have been determined in a number of experiments (Kaizzi et al., 2012; Kayuki et al., 2017; Okalebo et al., 2006; Ssali, 2001; Tittonell et al., 2010; Tumuhairwe et al., 2014; Waigwa et al., 2003; Woomer, 2007; Wortmann and Ssali, 2001). Nevertheless, the use of mineral fertilizers by smallholder farmers is low, particularly at the Ugandan side. The low mineral fertilizer application rates are not only indicated by agricultural statistics, according to which less than 7% of farmers in Eastern Uganda apply mineral fertilizer (UBoS, 2010b). Case studies from the Ugandan Districts of Busia (Lederer et al., 2015) and Tororo (Andersson, 2015) as well as from the Kenyan Counties of Busia and Bungoma (Okalebo et al., 2006; Waigwa et al., 2003) support these data. Statistics also suggest the high price of fertilizers is one of the limiting factors for their utilization (Kaizzi et al., 2017; UBoS, 2010b). Supporting the soil with nutrients from organic and biogenic nutrient and carbon sources such as animal manure, crop waste and compost application, green manure and biological nitrogen fixation are more common (Jama et al., 2000; Lederer et al., 2015; Tittonell et al., 2010; Tittonell et al., 2008; Tittonell et al., 2007; Tittonell et al., 2005; Tumuhairwe et al., 2014; UBoS, 2010b). This indicates a good understanding of farmers on how to improve productivity of their soils and thus how to contribute to their own and their countries' food security. However, investigations of farm management practices shows many forms of nutrient losses in practice. Nutrients in animal manures are lost for crop farming during free range grazing, manure collection and storage (Rufino et al., 2006; Rufino et al., 2007; Snijders et al., 2009). Better manure management options as suggested by (Zake et al., 2010) may have a significant positive impact on the soil nutrient balance and productivity in crop production (Bayu et al., 2005; Mohamed Saleem, 1998; Nkonya et al., 2005; Wortmann and Kaizzi, 1998), and manure conversion technologies like composting or biogas, which have only recently been introduced in the area, may have a positive impact. However, also these are associated to process-linked nutrient losses (Komakech et al., 2015; Lalander et al., 2015; Sommer and Dahl, 1999). The example of recently established biogas systems furthermore show that not only their medium-term functionality, but also the utilization of the biogas slurry in agriculture, is limited (Okello et al., 2013b; Walekhwa et al., 2014; Walekhwa et al., 2009). Another potential nutrient source with low use but high potential is human urine and feces (Lederer et al., 2015; Semalulu et al., 2011; Semalulu et al., 2012). A study by (Andersson, 2015) shows that particularly urine is used in the area, but to a limited extent. There are a number of explanations for that, such as labor, economic, cultural and knowledge constraints (Simha and Ganesapillai, 2017; Tumwebaze et al., 2011). Nutrient, carbon and soil biota losses through soil erosion have widely been investigated in the area, showing that the steep slopes towards Elgon are these heaviest affected (Mugagga et al., 2010; Roussel, 2012). Soil and water conservation (SWC), which is seen by many researchers as a path out of this dilemma, is usually linked in the area to the prevention of natural disasters such as landslides at the steep slopes towards Mount Elgon (Jiang et al., 2014; Mugagga et al., 2010; Mugagga et al., 2012a, b; Oyana et al., 2015). The impact on crop productivity, particularly in the short run, however, is not entirely clear, and if considering that some forms of SWC like mulching of crop residues may compete with other uses like fodder, only long-term field test which are rear in the region, seem to bring out a clear picture (Giller et al., 2009). Nevertheless, all of this results in negative soil nutrient balances and reduced productivity for food security (Bekunda et al., 2002; Delve and Ramisch, 2006; Lederer et al., 2015; Nandwa and Bekunda, 1998; Nkonya, 2004). Besides soil fertility, the supply of water is an important factor for crop production. Most crop production in the area is rain-fed and thus subject to fluctuations, while irrigation is only practiced on a relatively small amount of land (KNBS, 2015a, b; UBoS, 2010b). Next to limiting nutrient supply, the uncertainty of water supply in these rain-fed crop systems is seen as an Achilles heel, much more than for instance the genotype of crops (Tittonell and Giller, 2013). For instance, only 1.2% of farmers in Tororo report to have any type of irrigation, while non such irrigation forms have been identified in the Ugandan Districts of Busia and Manafwa (UBoS, 2010b). Therefore, other forms of water management like wetland and in-valley cultivation, flood recession cultivation, are practiced by farmers in Uganda (UBoS, 2010b). Also in the Kenyan Counties of Bungoma and Busia, only negligible acreages are under irrigation (KNBS, 2015a, b). The low acreages of irrigation go along with a general low mechanization of crop production in the area (UBoS, 2010b).

An important role to escape from these dilemmas are higher investments in labor and non-labor inputs, including capacity building. An analysis of the statistical data from the Ugandan Census of Agriculture 2008/2009 showed that agricultural non-labor inputs like irrigation, mineral or organic fertilizer use are generally higher in farmer households were household members received agricultural extension services, underlining the relevance of capacity building among farmers in order to increase food security (Adong, 2014; Okoboi and Barungi, 2012; UBoS, 2010b).

3.3.2 Food consumption

Most of the food consumed in the area is also produced in there, mainly by smallholder farmers. Food consumption data is usually available from the statistics department of the Food and Agriculture Organization (FAO). This data, however, is only on a national basis, and food consumption surveys by the World Food Program (WFP) or the United States Agency for International Development (USAID) suggest a large variation within countries like Kenya or Uganda (Harvey et al., 2010; McKinney, 2009). Furthermore, it is based on production, import and export statistics (FAO, 2013). A more regionally specific food consumption survey on women in Uganda has been carried out (Harvey et al., 2010) and validated (Dary and Jariseta, 2012) by researchers for the USAID. Table 7 shows a comparison of these datasets.

Table 7 Food consumption in Uganda, based on 1) (FAO, 2013) and 2) (Harvey et al., 2010), based on kg/cap/yr

Food consumed	Uganda[1]	Kampala[2]	South-West-Uganda[2]	North Uganda[2]
Fruits, vegetables, plantains	184	150	248	106
Roots	183	44	80	66
Cereals	63	26	44	47
Pulses, nuts, oil crops	24	47	58	69
Milk	34	44	106	91
Meat	12	18	22	11
Fish	15			
Eggs	0.5			
Sweeteners	15	11	22	18
Vegetable oils	8	2	2	4
Animal fats	0.4			
Total	539	341	582	412

Theoretically, the staple food supplied by local production should provide enough to cover the food consumption in the area. The food security analysis carried out by the WFP, however, indicates that a large part of the population is not supplied with sufficient food (McKinney, 2009; WFP, 2016). This also counts for subsistence farmers who have to purchase parts of their food consumed from outside their farm.

4 Discussion

4.1 Methods

SWAT in Kenya and Uganda

(Baker and Miller, 2013; Githui et al., 2009)

5 Conclusions

The draft article at hand reviews a number of peer-reviewed WEF nexus articles. Intermediate results suggest that there is more research need in particular world regions facing severe WEF nexus challenges (i.e. Africa, Near East) on lower than national and supranational levels, to be carried out by researchers from research institutions located in the affected countries.

6 References

Adong, A., 2014. Impact of households' membership of farmer groups on the adoption of agricultural technologies in Uganda: Evidence from the Uganda Census of Agriculture 2008/09. Agrekon 53, 108-136.

Alobo, D., 2013. Tentative layout plan pilot wind power park Tororo (Uganda). Brian Xsabo Strategy Consultants.

Andersson, E., 2015. Turning waste into value: using human urine to enrich soils for sustainable food production in Uganda. Journal of Cleaner Production 96, 290-298.

Angella, N., Dick, S., Fred, B., 2014. Willingness to pay for irrigation water and its determinants among rice farmers at Doho Rice Irrigation Scheme (DRIS) in Uganda. Journal of Development and Agricultural Economics 6, 345-355.

Aniku, J.R.F., 2001. Soil Classification and Pedology, in: Mukiibi, J.K. (Ed.), Agriculture in Uganda. General Information. Fountain Publishers / CTA / NARO, Kampala, pp. 66-103.

Baker, T.J., Miller, S.N., 2013. Using the Soil and Water Assessment Tool (SWAT) to assess land use impact on water resources in an East African watershed. Journal of Hydrology 486, 100-111.

Bamutaze, Y., Tenywa, M.M., Majaliwa, M.J.G., Vanacker, V., Bagoora, F., Magunda, M., Obando, J., Wasige, J.E., 2010. Infiltration characteristics of volcanic sloping soils on Mt. Elgon, Eastern Uganda. CATENA 80, 122-130.

Barasa, B., Kakembo, V., Karl, T., 2016. Characterization of artisanal gold mining activities in the tropics and their impact on sediment loading and stream flow in the Okame River catchment, Eastern Uganda. Environmental Earth Sciences 75, 1076.

Barasa, B., Kakembo, V., Mugagga, F., Egeru, A., 2013. Comparison of extreme weather events and streamflow from drought indices and a hydrological model in River Malaba, Eastern Uganda. International Journal of Environmental Studies 70, 940-951.

Barasa, B., Kakembo, V., Mwololo Waema, T., Laban, M., 2017. Effects of heterogeneous land use/cover types on river channel morphology in the Solo River catchment, Eastern Uganda. Geocarto International 32, 155-166.

Barasa, B., Majaliwa, J.G.M., Lwasa, S., Obando, J., Bamutaze, Y., 2011. Magnitude and transition potential of land-use/cover changes in the trans-boundary river Sio catchment using remote sensing and GIS. Annals of GIS 17, 73-80.

Barasa, B., Majaliwa, M., Lwasa, S., Obando, J., Bamutaze, Y., 2010. Estimation of the aboveground biomass in the trans-boundary River Sio Sub-catchment in Uganda. Journal of Applied Sciences and Environmental Management 14.

Bayu, W., Rethman, N.F.G., Hammes, P.S., 2005. The Role of Animal Manure in Sustainable Soil Fertility Management in Sub-Saharan Africa: A Review. Journal of Sustainable Agriculture 25, 113-136.

Becker, A., Nemec, J., 1987. Macroscale hydrologic models in support to climate research, in: IAHS (Ed.), The Influence of Climate Change and Climatic Variability on the Hydrologie Regime and Water Resource. Proceedings of the Vancouver Symposium, August 1987. International Association of Hydrological Sciences (IAHS), Wallingford, pp. 431-445.

Bekunda, M., Nkonya, E., Mugendi, D., Msaky, J., 2002. Soil fertility status, management, and research in East Africa. East African Journal of Rural Development 20, 94-112.

Biggs, E.M., Bruce, E., Boruff, B., Duncan, J.M.A., Horsley, J., Pauli, N., McNeill, K., Neef, A., Van Ogtrop, F., Curnow, J., Haworth, B., Duce, S., Imanari, Y., 2015. Sustainable development and the water-energy-food nexus: A perspective on livelihoods. Environmental Science and Policy 54, 389-397.

Bizikova, L., Roy, D., Swanson, D., Venema, H.D., McCandless, M., 2013. The Water–Energy–Food Security Nexus: Towards a practical planning and decision-support framework for landscape investment and risk management. International Institute for Sustainable Development (IISD), Winnipeg.

BRL, 2008. Kagera River Basin Monograph. BRL ingenierie for the Nile Basin Initiative (NBI), Entebbe.

Conway, D., Van Garderen, E.A., Deryng, D., Dorling, S., Krueger, T., Landman, W., Lankford, B., Lebek, K., Osborn, T., Ringler, C., Thurlow, J., Zhu, T., Dalin, C., 2015. Climate and southern Africa's water-energy-food nexus. Nature Climate Change 5, 837-846.

Dary, O., Jariseta, Z.R., 2012. Validation of Dietary Applications of Household Consumption and Expenditures Surveys (HCES) against a 24-Hour Recall Method in Uganda. Food and Nutrition Bulletin 33, S190-S198.

Delve, R., Ramisch, J., 2006. Land Management Options in Western Kenya and Eastern Uganda. Strategies for sustainable land management in the East African Highlands, 319-331.

Dubois, O., Faurès, J.-M., Erika Felix, A.F., Hoogeveen, J., Pluschke, L., Puri, M., Ünver, O., Forlano, N., Morgan, J., 2014. The Water-Energy-Food Nexus - A new approach in support of food security and sustainable agriculture. Food and Agriculture Organziation of the United Nations (FAO), Rome.

DWD, 2011. Uganda Water Supply Atlas. Directorate of Water Development (DWD), Ministry of Water and Environment, Republic of Uganda, Kampala.

Ebanyat, P., de Ridder, N., de Jager, A., Delve, R.J., Bekunda, M.A., Giller, K.E., 2010. Drivers of land use change and household determinants of sustainability in smallholder farming systems of Eastern Uganda. Population and Environment 31, 474-506.

EEAS, 2016. European Union inaugurates Uganda's first Solar Power Plant. Delegation of the European Union in Uganda, European External Action Service (EEAS), Kampala.

Egeru, A.S., 2014. Rural Households' Fuelwood Demand Determinants In Dryland Areas of Eastern Uganda. Energy Sources, Part B: Economics, Planning, and Policy 9, 39-45.

Endo, A., Tsurita, I., Burnett, K., Orencio, P.M., 2017. A review of the current state of research on the water, energy, and food nexus. Journal of Hydrology: Regional Studies 11, 20-30.

ERA, 2015. Application for a License for the Establishment of a 20 MW Solar Photo Voltaic Power Project in Gomba District and 20 MW Wind Power Project in Tororo District Electricity Regulatory Authority (ERA), Kampala.

FAO, 2013. FAOSTAT. Food and Agriculture Organization (FAO), Rome.

FAO, 2014. The Water-Energy-Food Nexus. A new approach in support of food security and sustainable agriculture. Food and Agriculture Organization of the United Nations (FAO), Rome.

Ghimire, P.C., 2013. SNV supported domestic biogas programmes in Asia and Africa. Renewable Energy 49, 90-94.

Giller, K.E., Witter, E., Corbeels, M., Tittonell, P., 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Research 114, 23-34.

Githui, F., Gitau, W., Mutua, F., Bauwens, W., 2009. Climate change impact on SWAT simulated streamflow in western Kenya. International Journal of Climatology 29, 1823-1834.

Harvey, P., Rambelson, Z., Dary, O., 2010. The 2008 Uganda Food Consumption Survey. Determining the Dietary Patterns of Ugandan Women and Children. Global Alliance for Improved Nutrition (GAIN).

Hoff, H., 2011. Understanding the Nexus, Bonn2011 Conference The Water, Energy and Food Security Nexus Solutions for the Green Economy. Stockholm Environment Institute, Stockholm., Bonn.

Jama, B., Palm, C.A., Buresh, R.J., Niang, A., Gachengo, C., Nziguheba, G., Amadalo, B., 2000. Tithonia diversifolia as a green manure for soil fertility improvement in western Kenya: A review. Agroforestry Systems 49, 201-221.

Jiang, B., Bamutaze, Y., Pilesjö, P., 2014. Climate change and land degradation in Africa: a case study in the Mount Elgon region, Uganda. Geo-spatial Information Science 17, 39-53.

JICA, MWE, 2011. The Development Study on Water Resources Development and Management for Lake Kyoga Basin in the Republic of Uganda. Japan International Cooperation Agency (JICA), Ministry of Water and Environment (MWE), Kampala.

Jones, A., Breuning-Madsen, H., Brossard, M., Dampha, A., Deckers, J., Dewitte, O., Gallali, T., Hallett, S., Jones, R., Kilasara, M., Le Roux, P., Micheli, E., Montanarella, L., Spaargaren, O., Thiombiano, L., Van Ranst, E., Yemefack, M., R., Z., 2013. Soil Atlas of Africa. European Commission, Publications Office of the European Union, Luxembourg.

Kaindi, J.N., 2013. Final Report State of the River Sio Basin. Nile Basin Initiative (NBI), Nairobi.

Kaizzi, C.K., Nansamba, A., Musisi, F.M.F., 2017. 15. Optimizing Fertilizer Use within the Context of Integrated Soil Fertility in Uganda, in: Wortmann, C.S., Scones, K. (Eds.), Fertilizer Use Optimization in Sub-Saharan Africa. CABI, pp. 193-209.

Kaizzi, K.C., Byalebeka, J., Semalulu, O., Alou, I.N., Zimwanguyizza, W., Nansamba, A., Odama, E., Musinguzi, P., Ebanyat, P., Hyuha, T., Kasharu, A.K., Wortmann, C.S., 2012. Optimizing smallholder returns to fertilizer use: Bean, soybean and groundnut. Field Crops Research 127, 109-119.

Kariko-Buhwezi, B., Mwesigye, A., Arinaitwe, J., Colonna, G., 2011. Challenges to the sustainability of small scale biogas technologies in Uganda, Proceedings of the Second International Conference on Advances in Engineering and Technology, Entebbe, Uganda.

Kayuki, K.C., Angella, N., Kabuye, F.M., 2017. 15. Optimizing Fertilizer Use within the Context of Integrated Soil Fertility in Uganda in: Wortmann, C.S., Sones, K. (Eds.), Fertilizer Use Optimization in Sub-Saharan Africa. CABI, pp. 193-209.

Kiplagat, J.K., Wang, R.Z., Li, T.X., 2011. Renewable energy in Kenya: Resource potential and status of exploitation. Renewable and Sustainable Energy Reviews 15, 2960-2973.

Kituyi, E., Marufu, L., Huber, B., O. Wandiga, S., O. Jumba, I., O. Andreae, M., Helas, G., 2001. Biofuel consumption rates and patterns in Kenya. Biomass and Bioenergy 20, 83-99.

KNBS, 2015a. County Statistical Abstract Bungoma County 2015. Kenya National Bureau of Statistics (KNBS), Nairobi.

KNBS, 2015b. County Statistical Abstract Busia County 2015. Kenya National Bureau of Statistics (KNBS), Nairobi.

KNBS, 2015c. County Statistical Abstract Kakamega County 2015. Kenya National Bureau of Statistics (KNBS), Nairobi.

KNBS, SID, 2013. Exploring Kenya's Inequality - pulling apart or pooling together. Busia Bungoma Kakamega County Reports. Kenya National Bureau of Statistics (KNBS) and Society for International Development (SID) - East Africa, Nairobi.

Komakech, A.J., Sundberg, C., Jönsson, H., Vinnerås, B., 2015. Life cycle assessment of biodegradable waste treatment systems for sub-Saharan African cities. Resources, Conservation and Recycling 99, 100-110.

Lalander, C.H., Komakech, A.J., Vinnerås, B., 2015. Vermicomposting as manure management strategy for urban small-holder animal farms – Kampala case study. Waste Management 39, 96-103.

Leck, H., Conway, D., Bradshaw, M., Rees, J., 2015. Tracing the Water-Energy-Food Nexus: Description, Theory and Practice. Geography Compass 9, 445-460.

Lederer, J., Karungi, J., Ogwang, F., 2015. The potential of wastes to improve nutrient levels in agricultural soils: A material flow analysis case study from Busia District, Uganda. Agriculture, Ecosystems & Environment 207, 26-39.

Lutaaya, F., 2013. Quality and Usage of Biogas Digesters in Uganda.

LVBC, 2013. Mara river basin-wide water allocation plan. Lake Victoria Basin Commission (LVBC), Kisumu.

Makalle, A.M., Obando, J., Bamutaze, Y., 2008. Effects of land use practices on livelihoods in the transboundary sub-catchments of the Lake Victoria Basin. African Journal of Environmental Science and Technology 2, 309-317.

McKinney, P., 2009. Comprehensive Food Security & Vulnerability Analysis (CFSVA) Uganda. World Food Programme, Uganda Country Office, Kampala.

Meigh, J.R., McKenzie, A.A., Sene, K.J., 1999. A Grid-Based Approach to Water Scarcity Estimates for Eastern and Southern Africa. Water Resources Management 13, 85-115.

Minghua, Z., Patric, B., David, P., Mariana, C.R., Timothy, R., Klaus, B.-B., 2014. Regional nitrogen budget of the Lake Victoria Basin, East Africa: syntheses, uncertainties and perspectives. Environmental Research Letters 9, 105009.

Mohamed Saleem, M.A., 1998. Nutrient balance patterns in African livestock systems. Agriculture, Ecosystems & Environment 71, 241-254.

Mugagga, F., Buyinza, M., Kakembo, V., 2010. Livelihood diversification strategies and soil erosion on Mount Elgon, Eastern Uganda: a socio-economic perspective. Environmental Research Journal 4, 272-280.

Mugagga, F., Kakembo, V., Buyinza, M., 2012a. A characterisation of the physical properties of soil and the implications for landslide occurrence on the slopes of Mount Elgon, Eastern Uganda. Natural Hazards 60, 1113-1131.

Mugagga, F., Kakembo, V., Buyinza, M., 2012b. Land use changes on the slopes of Mount Elgon and the implications for the occurrence of landslides. CATENA 90, 39-46.

Mugo, F., Gathui, T., 2010. Biomass energy use in Kenya, ESPA workshop on biomass energy. International Institute for Environment and Development (IIED), Practical Action Kenya, Parliament House Hotel, Edinburgh.

MWE, 2016. Water and Environment Sector Performance Report 2016. Ministry of Water and Environment (MWE), Republic of Uganda, Kampala.

Mwirigi, J., Balana, B.B., Mugisha, J., Walekhwa, P., Melamu, R., Nakami, S., Makenzi, P., 2014. Socio-economic hurdles to widespread adoption of small-scale biogas digesters in Sub-Saharan Africa: A review. Biomass and Bioenergy 70, 17-25.

Nakano, Y., Otsuka, K., 2011. Determinants of household contributions to collective irrigation management: The case of the Doho Rice Scheme in Uganda. Environment and Development Economics 16, 527-551.

Nandwa, S.M., Bekunda, M.A., 1998. Research on nutrient flows and balances in East and Southern Africa: state-of-the-art1Paper contributes to EC INCO-DC project IC18-CT96-0092 (Spatial and temporal variation of soil nutrient stocks and management in sub-Saharan African farming systems).1. Agriculture, Ecosystems & Environment 71, 5-18.

NBI, 2011a. One River One People One Vision. The Nile Basin (Kenya). Nile Basin Initiative (NBI), Entebbe.

NBI, 2011b. One River One People One Vision. The Nile Basin (Uganda). Nile Basin Initiative (NBI), Entebbe.

Nkonya, E., 2004. Strategies for Sustainable Land Management and Poverty Reduction in Uganda. International Food Policy Research Institute (IFPRI), Nairobi.

Nkonya, E., Kaizzi, C., Pender, J., 2005. Determinants of nutrient balances in a maize farming system in eastern Uganda. Agricultural Systems 85, 155-182.

Ochieng, C.A., Tonne, C., Vardoulakis, S., 2013. A comparison of fuel use between a low cost, improved wood stove and traditional three-stone stove in rural Kenya. Biomass and Bioenergy 58, 258-266.

Okalebo, J.R., Othieno, C.O., Woomer, P.L., Karanja, N.K., Semoka, J.R.M., Bekunda, M.A., Mugendi, D.N., Muasya, R.M., Bationo, A., Mukhwana, E.J., 2006. Available technologies to replenish soil fertility in East Africa. Nutrient Cycling in Agroecosystems 76, 153-170.

Okello, C., Pindozzi, S., Faugno, S., Boccia, L., 2013a. Bioenergy potential of agricultural and forest residues in Uganda. Biomass and Bioenergy 56, 515-525.

Okello, C., Pindozzi, S., Faugno, S., Boccia, L., 2013b. Development of bioenergy technologies in Uganda: A review of progress. Renewable and Sustainable Energy Reviews 18, 55-63.

Okoboi, G., Barungi, M., 2012. Constraints to fertilizer use in Uganda: insights from Uganda Census of Agriculture 2008/9. Journal of Sustainable Development 5, 99.

Oteng'i, S.B.B., Neyole, E.M., 2007. Brick Making Activities and their Environmental Impacts in Busia, Siaya, Bondo and Butere-Mumias Districts of the Lake Victoria Basin of Kenya. International Journal of Disaster Management and Risk Reduction 1, 24-28.

Otim, D., 2008. Drought Analysis for Busia District (Uganda), Istituto Agronomico per l'Oltremare, Facoltá di Agraria. Università degli Studi di Firenze, Florence.

Oyana, T.J., Kayendeke, E., Bamutaze, Y., Kisanga, D., 2015. A field assessment of land use systems and soil properties at varied landscape positions in a fragile ecosystem of Mount Elgon, Uganda. African Geographical Review 34, 83-103.

Pallabazzer, R., Sebbit, A.M., 1998. The wind resources in Uganda. Renewable Energy 13, 41-49.

Roussel, J., 2012. Feasibility Study and Preparation of an Integrated Watershed Management Program and Investment Proposal for the Sio-Malaba-Malakisi Sub-Basin. Final Report–Investment Project Proposal. Final Report–Investment Project Proposal. Nile Basin Initiative, Entebbe, Uganda.

Rufino, M.C., Rowe, E.C., Delve, R.J., Giller, K.E., 2006. Nitrogen cycling efficiencies through resource-poor African crop–livestock systems. Agriculture, Ecosystems & Environment 112, 261-282.

Rufino, M.C., Tittonell, P., van Wijk, M.T., Castellanos-Navarrete, A., Delve, R.J., de Ridder, N., Giller, K.E., 2007. Manure as a key resource within smallholder farming systems: Analysing farm-scale nutrient cycling efficiencies with the NUANCES framework. Livestock Science 112, 273-287.

Scheren, P.A.G.M., Zanting, H.A., Lemmens, A.M.C., 2000. Estimation of water pollution sources in Lake Victoria, East Africa: Application and elaboration of the rapid assessment methodology. Journal of Environmental Management 58, 235-248.

Semalulu, O., Azuba, M., Makhosi, P., Lwasa, S., 2011. Potential for Reuse of Human Urine in Peri-urban Farming, in: Bationo, A., Waswa, B., Okeyo, J.M., Maina, F., Kihara, J.M. (Eds.), Innovations as Key to the Green Revolution in Africa: Exploring the Scientific Facts. Springer Netherlands, Dordrecht, pp. 651-660.

Semalulu, O., Azuba, M., Makhosi, P., Semyalo, F., Lwasa, S., 2012. Nutrient Recycling Using Human Urine: Potential for Low Input Farming. Journal of Agricultural Science and Technology. B 2, 919.

Simha, P., Ganesapillai, M., 2017. Ecological Sanitation and nutrient recovery from human urine: How far have we come? A review. Sustainable Environment Research 27, 107-116.

Snijders, P., Davies, O., Wouters, A., Gachimbi, L., Zake, J., Ergano, K., Abduke, M., Van Keulen, H., 2009. Cattle manure management in East Africa: review of manure quality and nutrient losses and scenarios for cattle and manure management. Wageningen UR Livestock Research.

Sommer, S.G., Dahl, P., 1999. Nutrient and Carbon Balance during the Composting of Deep Litter. Journal of Agricultural Engineering Research 74, 145-153.

Ssali, H., 2001. Soil fertility, in: Mukiibi, J.K. (Ed.), Agriculture in Uganda. General Information. Fountain Publishers / CTA / NARO, Kampala, pp. 104-135.

Tenyhwa, M.M., Mukwaya, P.I., Bamutaze, Y., Luswata, C.K., Kirya, D., 2015. Institutional factors and governance arrangements affecting crop residue utilization in Mt. Elgon Region, Uganda. Journal of Geography and Regional Planning 8, 65.

Tittonell, P., Giller, K.E., 2013. When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. Field Crops Research 143, 76-90.

Tittonell, P., Muriuki, A., Shepherd, K.D., Mugendi, D., Kaizzi, K.C., Okeyo, J., Verchot, L., Coe, R., Vanlauwe, B., 2010. The diversity of rural livelihoods and their influence on soil fertility in agricultural systems of East Africa – A typology of smallholder farms. Agricultural Systems 103, 83-97.

Tittonell, P., Shepherd, K.D., Vanlauwe, B., Giller, K.E., 2008. Unravelling the effects of soil and crop management on maize productivity in smallholder agricultural systems of western Kenya—An application of classification and regression tree analysis. Agriculture, Ecosystems & Environment 123, 137-150.

Tittonell, P., Vanlauwe, B., de Ridder, N., Giller, K.E., 2007. Heterogeneity of crop productivity and resource use efficiency within smallholder Kenyan farms: Soil fertility gradients or management intensity gradients? Agricultural Systems 94, 376-390.

Tittonell, P., Vanlauwe, B., Leffelaar, P.A., Rowe, E.C., Giller, K.E., 2005. Exploring diversity in soil fertility management of smallholder farms in western Kenya: I. Heterogeneity at region and farm scale. Agriculture, Ecosystems & Environment 110, 149-165.

Treiber, M.U., Grimsby, L.K., Aune, J.B., 2015. Reducing energy poverty through increasing choice of fuels and stoves in Kenya: Complementing the multiple fuel model. Energy for Sustainable Development 27, 54-62.

Tumuhairwe, J.B., Amoding, K.A., Robert, D., Bashir, J., Rwakaikara-Silver, M.C., 2014. In-situ mineral nitrogen following soil incorporation Crotalaria grahamiana and Mucuna pruriens biomass and financial benefits of legume short-fallow in Eastern Uganda. International Journal of Agronomy and Agricultural Research (IJAAR) 5, 110-123.

Tumwebaze, I.K., Orach, C.G., Nakayaga, J.K., Karamagi, C., Luethi, C., Niwagaba, C., 2011. Ecological sanitation coverage and factors affecting its uptake in Kabale municipality, western Uganda. International Journal of Environmental Health Research 21, 294-305.

Twaha, S., Ramli, M.A.M., Murphy, P.M., Mukhtiar, M.U., Nsamba, H.K., 2016. Renewable based distributed generation in Uganda: Resource potential and status of exploitation. Renewable and Sustainable Energy Reviews 57, 786-798.

UBoS, 2010a. The National Livestock Census Report 2008. Uganda Bureau of Statistics (UBoS), Kampala.

UBoS, 2010b. Uganda Census of Agriculture 2008/2009 Volume III Agricultural household and holding characteristics report. Uganda Bureau of Statistics (UBoS), Kampala.

UBoS, 2010c. Uganda Census of Agriculture 2008/2009 Volume IV: Crop area and production report. Uganda Bureau of Statistics (UBoS), Kampala.

UBoS, 2016a. 2016 Statistical Abstract. Uganda Bureau of Statistics (UBoS), Kampala.

UBoS, 2016b. National Population and Housing Census 2014 - Main Report. Uganda Bureau of Statistics (UBoS), Kampala.

UNEP, UNEP-DHI, **2015**. Transboundary River Basins: Status and Future Trends. . United Nations Environment Programme (UNEP) and Danish Hydraulic Institute (DHI), Nairobi.

Waigwa, M., Othieno, C., Okalebo, J., 2003. Phosphorus availability as affected by the application of phosphate rock combined with organic materials to acid soils in western Kenya. Experimental Agriculture 39, 395-407.

Walekhwa, P.N., Lars, D., Mugisha, J., 2014. Economic viability of biogas energy production from family-sized digesters in Uganda. Biomass and Bioenergy 70, 26-39.

Walekhwa, P.N., Mugisha, J., Drake, L., 2009. Biogas energy from family-sized digesters in Uganda: Critical factors and policy implications. Energy Policy 37, 2754-2762.

Waughray, D., 2011. Water Security : the Water-Food-Energy-Climate Nexus the World Economic Forum Water Initiative. Island Press, Washington.

Westerhof, P., Härmä, P., Isabirye, E., Katto, E., Koistinen, T., Kuosmanen, E., Lehto, T., Lehtonen, M.I., Mäkitie, H., Manninen, T., Mänttäri, I., Pekkala, Y., Pokki, J., Saalmann, K., Virransal, P., 2014. Geology and Geodynamic Development of Uganda with Explanation of the 1:1,000,000 Scale Geological Map. Geological Survey of Finland Special Paper 55.

WFP, 2016. Comprehensive Food Security and Vulnerability Analysis (CFSVA) Kenya 2016. World Food Program (WFP), Nairobi.

Wong, K.V., Pecora, C., 2015. Recommendations for Energy-Water-Food Nexus Problems. Journal of Energy Resources Technology, Transactions of the ASME 137.

Woomer, P.L., 2007. Costs and Returns of Soil Fertility Management Options in Western Kenya, in: Bationo, A., Waswa, B., Kihara, J., Kimetu, J. (Eds.), Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities. Springer Netherlands, Dordrecht, pp. 881-890.

Wortmann, C.S., Kaizzi, C.K., 1998. Nutrient balances and expected effects of alternative practices in farming systems of Uganda. Agriculture, Ecosystems & Environment 71, 115-129.

Wortmann, C.S., Ssali, H., 2001. Integrated nutrient management for resource-poor farming systems: A case study of adaptive research and technology dissemination in Uganda. American Journal of Alternative Agriculture 16, 161-167.

WREM, 2010. Sio-Malaba-Malakisi River Basin. WREM International, Nairobi.

Zake, J., Tenywa, J.S., Kabi, F., 2010. Improvement of Manure Management for Crop Production in Central Uganda. Journal of Sustainable Agriculture 34, 595-617.