Capacity building on the water-energy-food security Nexus through research and training in Kenya and Uganda | CapNex

Book of Abstracts

2016-2020

Preface

This Book of Abstracts presents results of the academic partnership project “Capacity building on the Water-Energy-Food security Nexus (WEF) through research and training in Kenya and Uganda | CapNex”. The WEF-Nexus can be seen as a framework or way of thinking that addresses the (contradicting) interactions, interrelations and interests between the provision of Water, Energy and Food in adequate quantity and quality. One aim of the capacity-building-through-research-training-and-dialogue-project is to strengthen the capacities of young researchers from Kenyan, Ugandan and Austrian Universities to cope with challenges associated with water quality and quantity, energy provision, and food security in East Africa. The project is funded by the Austrian government through the APPEAR programme of the Austrian Development Cooperation in the period 12-2016 to 12-2019, with a cost-neutral extension until 06-2020. Project partners are TU Wien, Austria, Makerere University, Uganda, Technical University of Kenya, and University of Natural Resources and Life Sciences (BOKU), Austria.

This publication gives an overview of the results from multiple academic disciplines involved in CapNex, ranging from agronomy, pest management, socio-economic studies, remote sensing, hydrology and water resources management, socio-hydrology, soil science or water-, waste-, & resource management. This highlights the need for truly interdisciplinary teams when addressing challenges associated with the WEF-Nexus.

The manifold disciplines involved in CapNex are also clearly reflected in the very diverse titles and abstracts, the data used, but also in the methods applied. The variety is large, probably challenging for the reader. The abstracts report on using Satellite Precipitation Products in data sparse regions, assessing and projecting the current and future land use/cover in the study area, travelling 2600 km in 24 days under difficult road conditions to register around 6000 ground-truthing points to assist in land use classification of satellite imagery, numerical simulations to understand uncertainties in soil erosion modelling, conducting a detailed water quality measurement campaign to understand the spatio-temporal distribution of water quality in the region, the use of remote sensing data to analyse effects of hydropower dams on downstream vegetation, a survey of over 700 farmers on issues related to soil water conservation and other agricultural practices, using that data to analyse the reasons for adoption lags and impacts on crop productivity, but also to analyse the effects of incentives for up scaling adoption rates. Other abstracts deal with the analysis of long-term impacts of nutrient recycling from waste including the application of material flow analysis to understand human excrement recycling; and cattle manure vermicomposting in agricultural systems and the use of earth worms for feeding chicken.

The abstracts presented here mostly cover particular aspects worked on regarding the problem at hand, however, the WEF-topic covers a very wide range of challenges and interactions, which may not be covered here in the case study area of the Sio-Malaba-Malakisi River Basin in the boarder of Kenya and Uganda. On the other hand, the project and endeavour are not over, some data analysis and work is still ongoing to enable us integrate the findings in a more complete manner. A summary of these efforts in form of abstracts are therefore currently not available.

The CapNex team has many people who have, directly or indirectly, contributed to the success of the project. Six PhD students - Arabel Amann, Christoph Schürz, Hope Mwanake, Nathan Muli, Paul Omonge, Stanley Chasia - have contributed substantially to the research. Six Master students - Doris Wimmer, Hyacinthe Nyirahabimana, Joseph Jjagwe, Keneth Chelimo, Leah Schneider, Ronnie Ahumuza – implemented field studies, designed different experiments and worked on their theses within CapNex. Finally, two BSc students completed their undergraduate dissertations on the project - Agnes Nalunga carried out poultry feeding experiments with worms produced in the vermi-composting trials, while Gabriel Stecher established a consistent Geodatabase for three of the in total four case studies, assisted in the fieldwork and helped with data analysis. Then, of course, there are the Senior researchers and Professors, who developed concepts, advised the students, ensured appropriate funding, organised workshops or were responsible for the project management. These included Alice Turinawe, Allan John Komakech, Bano Mehdi, Henry Magala, Joshua Wanyama, Karsten Schulz, Lewis Sitoki, Matthias Zessner, Rosemary Isoto Emegu. Also engaged in these activities, but at the same time carrying the overall responsibilities are the project coordinators from the different Universities - Jakob Lederer (TU Wien), Jeninah Karungi (Makerere), Luke Olang (TU Kenya) and Mathew Herrnegger (BOKU), with Jakob Lederer being the overall project coordinator.

This Book of Abstracts mainly presents results from an academic, scientific point of view and may have limited practical implications on the ground. We, however, anticipate that they highlight the need and chances for necessary changes and potentials to improve livelihoods of the population and the environment. We are hopeful that the dissemination drives in the SMMRB and the policy dialogue that are being implemented are vehicles towards implementing changes, thereby linking the findings from CapNex with the needs on the ground.

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Competition over resources for the provision of water, energy, and food in the Sio-Malaba-Malakisi Basin in Kenya and Uganda – an introduction for dialogue

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Densely populated areas face a large pressure on natural resources (land, soils, forests, rivers) for the provision of water, energy, and food. International organizations and researchers called this the water-energy-food security nexus. The concept behind, however, is often not very explicit and clear. The present research project *Capacity building on the water-energy-food security nexus through research and training in Kenya and Uganda*, in short *CapNex*, aims to bring this concept from its meta-level down to the reality of local and national stakeholders in Kenya and Uganda. Thus, the main objective of the CapNex project is to investigate and increase the capacities on integrated natural resource management particularly of soils, land, organic materials, and rivers, using the case study area Sio-Malaba-Malakisi (Lwakhakha) river basin. This basin system is transboundary and located in the districts of Busia, Tororo, and Namisindwa/Manafwa (Uganda), and the counties of Busia and Bungoma (Kenya).

After presenting the general concept of the water-energy-food-nexus in this introductory presentation, the particular challenges with respect to the provision of food, energy, and water in the area are highlighted. Exemplarily, the impacts of soil erosion on food production and water quality, but also the potentials of the use of animal manure as nutrient source for food production are presented. Furthermore, the potential contradiction between the use of the same resource (e.g. soils, animal manure) for the provision of basic services (e.g. drinking water, food crops, and energy source) are discussed, concluding that an integrated management of natural resources can be beneficial for the provision of more than just one basic needs.

The basis required for this integrated management are capacities of involved stakeholders, and the CapNex project contributed to this capacity building in two ways, namely at academic and at non-academic level. At academic level, 14 bachelors, masters and PhD students were trained in the course of the project, and the results of their studies on the topics of water quantity and quality, erosion, soil and water conservation, and management of organic wastes to improve food production, are presented in this book of abstracts. These results were used to develop course materials on the investigated topics, presented in seminars at Makerere University and Technical University of Kenya. At non-academic level, demonstration sites were set-up and a stakeholder dialogue was started. By doing so, we hope to contribute to a sustainable future in water, energy, and food security in Kenya and Uganda.

Influence of agricultural practices and soil water conservation measures on water quality – interrelating aspects of the Water-Energy-Food Nexus in a practical assessment in the Kenya and Uganda

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Rivers and other surface water bodies frequently provide resources for human drinking water supply. The quality of surface waters strongly depends on the land use in the headwater areas and generally shows a fast reaction to changes, e.g. in agricultural practices. In contrast, the quality of groundwater resources exhibits a stronger dampening of anthropogenic pressures due to the filter and buffer characteristics of the overlying soil layer. This water resource is however frequently not available due to missing geological features, e.g. appropriate alluvial deposits.

In the Sio-Malaba-Malakisi River Basin (SMMRB) in the border region between Kenya and Uganda several surface water extractions for drinking water supply exist. The SMMRB is heavily populated, around 85% of the population of 4 million are engaged in agriculture. Especially during the rainy seasons, the rivers used for drinking water exhibit very high, excessive sediment loads originating from high erosion rates. These high erosion rates are a consequence of the intense agricultural land use in the area, which exhibits one of the highest population densities for rural areas in the world. The high sediment loads originating from the bare soils during the planting season at the beginning of the rains lead to noteworthy technical and financial efforts in processing and purifying the raw water for making it safe for human consumption.

Soil Water Conservation (SWC) measures not only lead to an improvement of soil water characteristics, but also reduce soil erosion and in consequence sediment loads in rivers and the loss of soil and nutrients for agricultural production. The Universal Soil Loss Equation (USLE) is a standard model to assess soil erosion by water. It quantifies soil loss as a product of six input factors representing rainfall erosivity, soil erodibility, slope length and steepness, soil cover and support measures. In this study, the support measures are spatially estimated using the data from a questionnaire survey with over 600 farmers in the region. In the questionnaire survey, the currently applied agricultural practices and SWC measures were assessed.

In the presented study, we combine data from the questionnaire survey, comprehensive water quality data measured within the CapNex Project and the Universal Soil Loss Equation (USLE)

to evaluate the influence of agricultural practices on the water quality at several water intakes in the SMMRB. Different scenarios of land use management and their effects on the water quality are thereby evaluated.

The improvement potential in water quality depends on the current land use / cover in the upstream area. For the Lirima Gravity Flow Scheme, where no or minor human interventions are evident in the watershed, no improvements are therefore found. For the Manafwa - Tororo Gravity Flow Scheme the implementation of Best Management Practices would lead to a reduction of sediment loads of around -3%, due to the rather small catchment share under human pressure. In contrast, larger improvement potentials are found for the water intakes Malaba (Kenya), Malaba – Tororo in Uganda and Sio – Busia (Kenya). Here, reductions of -18%, -20% and over -31%, respectively, are found.

In conclusion, the results underline that appropriate agricultural practices have a noteworthy effect on the quality of the water supply from surface waters and that economical benefits can be expected from the implementation of SWC measures, not only on the local, farmer scale, but also for the greater community depending on the drinking water supply.

Evaluating the applicability of satellite precipitation products over the data sparse Sio-Malaba-Malakisi river basin

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Limited spatio-temporal rain gauge network in Sub-Saharan Africa poses a challenge in hydrological studies in the region. Consequently, satellite precipitation products (SPPs) proffer an alternative source of data.

In this study, seven SPPs were georeferenced, evaluated and compared against gauge observations over the data-sparse Sio-Malaba-Malakisi basin of East Africa. The products included; Tropical Rainfall Measuring Mission (TRMM-3B42 v7), Climate Hazards Group Infrared Precipitation (CHIRPS v2.0), Multi-Source Weighted-Ensemble Precipitation (MSWEP v2.2), Climate Prediction Centre Morphing Technique (CMORPH v1.0), Global Precipitation Measurement (GPM-IMERG v5.0), *Precipitation* Estimation from Remotely Sensed Information using Artificial Neural Networks-Climate Data Record (PERSIANN-CDR) and Tropical Applications of Meteorology using Satellite (TAMSAT).

Secondly, using the SPPs and observed streamflow as reference, the Continuous Semi-distributed Runoff (COSERO) model was applied to simulate streamflow that was cross-compared with observed discharge. All the SPPs were able to detect seasonal rainfall patterns throughout the basin. At lower altitudes, all the products overestimated rainfall events as indicated by the statistical indices. The hydrological model calibration and validation exercise indicated a tendency to overcompensate the discharge simulation performance for products such as PERSIANN-CDR, CMORPH and MSWEP, in comparison with the statistical evaluation of in-situ rainfall data.

An assessment of land use/cover state in Sio-Malaba-Malakisi river basin of Kenya and Uganda

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Land use/ land cover change is one of the key drivers of soil erosion and land degradation. In sub-Saharan Africa, population growth has led to a rise in demand for agricultural land and settlement resulting in heightened land cover change. Furthermore, the effects of global climate change have led to erratic rainfall and elongated dry spells. A combination of land use change and climate variability affects ecosystem integrity leading to heightened risk of soil erosion, crop failure and deterioration of water quality. In this study, land cover change in the Sio-Malaba_Malakisi basin was studied for a period of 30 years (1986 to 2017) at 10-year temporal interval using satellite data as a first step to understanding the change dynamics. Landsat satellite data was analyzed for all the years under study (1987, 1997, 2007, 2017) to prepare land use maps. Seven dominant land cover classes were identified during the analysis which include: cropland, tree cover(forest), open water, marshland, built-up, soil and barren land. The final land use/cover maps were validated using a combination of field data and a high resolution Sentinel 2 satellite data with 10m spatial resolution. Accuracy assessment was carried out in all the maps and Kappa coefficients calculated for each year. Results from the analysis showed a steady increase in cropland and built up areas at 8.9% and 1.4% respectively from 1987, 1997 and 2007. Open soil reduced by 3% from 1987 to 1997, while tree cover area went down by 1.5% in the same period. Land area previously under marshland reduced by 2.5% due to the expansion of rice fields into wetland areas. Results from this research contributes to the knowledge and understanding of land cover change dynamics at catchment scale while also providing baseline data for erosion studies in a trans-boundary basin dominated by farming communities.

Projecting future land use/cover change scenarios in the Sio-Malaba-Malakisi river basin of Kenya and Uganda

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Changes in land use/cover are among the most important anthropogenic transformation on the physical environment affecting proper functioning of the earth system. Hitherto, land characterization has often been conducted using historical satellite data to understand these spatiotemporal changes. However, due to future uncertainties in land use changes, there is need to project future changes at local scale. A modelling framework to simulate empirically quantified relations between land use and its driving factors in the Sio-Malaba-Malakisi catchment area was adopted. Changes for the catchment, were simulated for a period of 30 years (2017 – 2047) using model parameters defining location characteristics, spatial policies, area restrictions, land use demand and conversion elasticity settings. Elevation, slope, population density, soil organic carbon, soil CEC and precipitation were potential factors selected to evaluate the suitability of devoting a grid cell to a land use type using a stepwise regression model. The scenarios used include first growth, slow growth and urbanization scenario. The high ROC value in all statistical tests (>0.72) indicated that the spatial distribution of all land use types could be explained by the selected driving variables. In a fast growth scenario - under policy restriction, areas under open soil were converted to cropland as demand for cash crop and food crop increased in the region. Areas with tree cover and shrubs outside protected zones, were converted to cropland while barren areas remained largely unchanged. In a slow growth scenario, expansion of the area under cropland followed historical trend at 1.25% with a slight increase in the area under agriculture. In an urbanization scenario, built-up areas increased steadily at 1% per annum mainly around existing urban centers. In all the scenarios explored, topography, precipitation, soil characteristics and population density were key drivers of change. Results of this study would enhance understanding of the complexities in land cover change and provide baseline data to support ongoing soil and land management programs.

Challenges in land use classification in heterogeneous landscapes – a case study in the border region between Kenya and Uganda

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With 85% of the approximately 4 million people living in the Sio-Malaba-Malakisi River Basin (SMMRB) being employed in agriculture, the pressure on fertile land and natural resources in the region is high. As a basis for analysis and modelling of interactions for the Water-Energy-Food-Nexus within the CapNEX project and for future planning and management in the basin, it is anticipated to produce a high-resolution landcover map by classifying Satellite images from the multi-spectral Sentinel 2-mission with a resolution from 10 to 60m. However, the spatial characteristics of small-scale subsistence farming, with small field sizes and heterogeneous agricultural practices and soil properties pose a challenge for classification using freely available Satellite Images.

During a 4-week field trip in June/July 2017 ground-data on landcover was collected by members of the project team from Austria, Kenya and Uganda. During this field trip, crop attributes together with coordinates and images of crops and area were collected to facilitate supervised classification and validation of satellite image classification. In total, around 6000 coordinates with landcover information were collected. The emphasis for the data collection was on two objectives: First, the collection of 4000 distinct fields of crops to serve as training data for or validation data of the supervised classification. Second, knowing the limitations and challenges of classifying small-scale farming with a limited resolution images, also around 2000 “areal points” were collected, aiming to portrait and summarize the (percentual) distribution of the vegetation of the surrounding area. The accessibility of some areas (especially towards the slopes of Mount Elgon and around the swamps in Uganda) was not possible and therefore data acquisition was not possible in these areas. Also, consistent sampling of the area due to small field sizes posed a challenge for sampling. Additionally, even though data was collected on 24 full days with more than 2600 km driven during active sampling, the size of the basin with 5230km² posed a challenge to find a compromise between quantity and quality of the data.

First, unsupervised classification was conducted to assess the amount of classes possibly relevant and distinguishable for classification. Then, a supervised classification with the training samples of the collected points was conducted. Classification with collected points did not create satisfactory results. Therefore, single points were revised and categorized on a visual basis with a Sentinel 2 image. According to their visibility as distinct fields and their spectral reflectance optical matching the description of the point, they were divided into 4 classes and the classification was conducted only with points of class one (distinct field and matching reflectance). This still did not generate reasonable results, most likely due to the spectral variations also over a field and the points (with a small buffer around them to create a polygon)

only taking into account very few pixel around the point. This is why on the basis of these class-1 points and georeferenced pictures taken, larger classification polygons were created based on field boundaries of an underlying Sentinel-2 image. With these polygons supervised classification was repeated using the Maximum Likelihood method in Erdas Imagine.

Prevailing small-scale farming makes classification with satellite images with a minimum of 10x10m resolution for some spectral bands challenging. Intercropping of different crops and different agricultural practices (e.g. concerning elimination of weed, density of planting crops, irrigation, mechanisation and harvesting) impede the generation of distinct spectral reflectance curves for different crops. Heterogeneous soil attributes create different spectral reflectance of soil and crops in different areas of the basin. One proposed solution to take into account these spectral variations, was to split the basin up in separate regions for classification. However, also the transition between two different areas is often gradual, which makes it complicated to decide the boundaries for this segmentation. Most roads and rural areas are not paved, therefore bare soil, harvested land and inhabited areas are often not possible to be distinguished. These challenges can already be seen in the unsupervised classification using 12 classes: While some areas, such as water, wetlands, bare soil and populated areas were all summarized in one class, several classes mainly showing (mixed) areas with maize, sugar cane or shrubs were created. In comparison with the collected ground-data, the results were insufficient, failing even to provide a guidance on the amount of appropriate classes. One major limitation worth noting is that only specific crops occur in considerable field sizes: For example while maize and sugar cane often occur on larger fields also, large fields of millet, sorghum, matoke, groundnuts or beans amongst others, are barely present. Therefore, through identifying only clearly visible fields, crops occurring on larger fields can be overrepresented, while others are underrepresented or fully neglected.

Temporal variation in spectral reflectance (or NDVI) over a longer time period could provide more valuable possibilities for classification: Due to temporal fluctuations in seasons, harvesting and planting times vary from year to year. Nevertheless, the vegetation period for maize is considerably shorter than for sugar cane, while young eucalyptus forests, bushlands and papyrus swamps only show mild fluctuations due to weather conditions but have no harvesting periods at all.

Uncertainties in soil erosion risk estimation - A comprehensive, large scale assessment for Kenya and Uganda

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The Universal Soil Loss Equation (USLE) is the most commonly used model to assess soil erosion by water. The model equation quantifies long-term average annual soil loss as a product of the rainfall erosivity R, soil erodibility K, slope length and steepness LS, soil cover C and support measures P. A large variety of methods exist to derive these model inputs from readily available data. However, the estimated values of a respective model input can strongly differ when employing different methods and can eventually introduce large uncertainties in the estimated soil loss. The potential to evaluate soil loss estimates at a large scale are very limited, due to scarce in-field observations and their comparability to long-term soil estimates. In this work we addressed (i) the uncertainties in the soil loss estimates that can potentially be introduced by different representations of the USLE input factors and (ii) challanges that can arise in the evaluation of uncertain soil loss estimates with observed data.

In a systematic analysis we developed different representations of USLE inputs for the study domain of Kenya and Uganda. All combinations of the generated USLE inputs resulted in 756 USLE model setups. We assessed the resulting distributions in soil loss, both spatially distributed and on district level for Kenya and Uganda. In a sensitivity analysis we analyzed the contributions of the USLE model inputs to the ranges in soil loss and analyzed their spatial patterns. We compared the calculated USLE ensemble soil estimates to available in-field data and other study results and addressed possibilities and limitations of the USLE model evaluation.

The USLE model ensemble resulted in wide ranges of estimated soil loss, exceeding the mean soil loss by over an order of magnitude particularly in hilly topographies. The study implies that a soil loss assessment with the USLE is highly uncertain and strongly depends on the realizations of the model input factors. The employed sensitivity analysis enabled us to identify spatial patterns in the importance of the USLE input factors. The C and K factors showed large scale patterns of importance in the densely vegetated part of Uganda and the dry north of Kenya, respectively, while LS was relevant in small scale heterogeneous patterns. Major challenges for the evaluation of the estimated soil losses with in-field data were due to spatial and temporal limitations of the observation data, but also due to measured soil losses describing processes that are different to the ones that are represented by the USLE.

Reference: Schürz, C., Mehdi, B., Kiesel, J., Schulz, K., and Herrnegger, M.: A systematic assessment of uncertainties in large scale soil loss estimation from different representations of USLE input factors – A case study for Kenya and Uganda, Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2019-602, in review, 2019.

First insights into the spatio-temporal distribution of water quality in the SMMRB

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Agricultural activities have been linked to increased pressures on the river systems. Serious consequences such as nutrient loss, sediment transport and stream pollution loading have been experienced in most river systems in the tropical region of Africa. However, the linkage between such anthropogenic activities, nutrient and sediment loss has been rarely reported in some of the highly dependent river systems.

A study was conducted in the Sio-Malaba-Malakisi River Basin, a tropical, transboundary catchment shared between Kenya and Uganda, where 85% of its inhabitants dependent on agriculture. Water samples for the dry and the wet seasons were collected from the three major rivers Sio, Malaba and Malakisi and analysed for TP, TN and TSS.

Results showed that discharge and nutrients loads were significantly different with seasons. TSS loads ranged between 600-700 tons d-1. The nutrients mass balance showed that all five subcatchments contributed to TSS, TP and TN loads during the wet seasons. Malaba-Malakisi had the highest contributions of 1100 kg d-1, 2500kg d-1 and 470 tons d-1 of TN, TP and TSS respectively. The results imply that agriculturally dominated subcatchments contribute to the high nutrients loads, with steeper areas in higher altitudes also contributing significant amounts of TSS loads.

Water quality monitoring in Sio-Malaba-Malakisi River Basin (SMMRB), Kenya/Uganda

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In the Sio-Malaba-Malakisi River Basin (SMMRB) population pressure has increased, resulting in expansion of agricultural activities. Consequently, there is increased water and tillage erosion, sedimentation, loss of soil fertility leading to alteration of the hydrological soil conditions. Land use practices in SMMRB have been a major cause of water quality degradation due to use of chemical fertilizers on farmlands. This has caused water for domestic and industrial use be unfit during the rainy season when rivers are laden with heavy wash loads of sediments and scarce during the dry periods when streams and rivers have extremely low flows. Few studies have been done to assess soil erosion, sediment yield, water quality, spatial patterns of soil erosion and soil loss rate. The objective of this study was to monitor water quality parameters (pH, Turbidity, conductivity, temperature, TDS, TSS, total phosphates, and total nitrogen), as washload material eroded and transported into the rivers is a major factor associated with the presence of these parameters in SMMRB waters. This study revealed that pH levels fell drastically, especially from the upper reaches to the lower reaches of the basin from 7.5 to 6.0. At RGS 82217 and 82218 pH was exceptionally low 5.9 and 6.0 respectively. Nitrate levels averaged between 9 mg/l and 40 mg/l in the wet season, and in the dry season 0.9 mg/l to 2.5 mg/l. Total phosphorus levels ranged from 0.9 mg/l to 11 mg/l in the wet season, whereas in the dry season, the levels dropped to 5.25 mg/l which is still high as the EPA and WHO recommends 0.005 mg/l to 0.05 mg/l. This stimulates growth of phytoplankton and other aquatic plants. Conductivity in all the rivers showed low values from 120 µs/cm to 175 µs/cm and from 110 to 260 µs/cm during wet and dry seasons, respectively. This suggests a likelihood of low levels of other nutrients which contribute to salinity levels in water since the maximum allowable is 2500 µs/cm. Turbidity, a key test in water quality was above the recommended 5 NTUs and in some cases it was high 550 NTUs. This high turbidity levels necessitate use of high doses of chemical coagulants in water treatment plants. TDS, which combines inorganic and organic substances, was at 60 to 200 mg/l, far below the threshold of 1500mg/l. TSS in water was at 0.02 and 0.3 mg/l, well below allowable limits of 25 mg/l in the natural waters.

Prediction of sediment yield by sediment Rating Curves and Stream flow in Sio-Malaba-Malakisi River Basin (SMMRB), Kenya/Uganda

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Anthropogenic activities in the Sio-Malaba-Malakisi River Basin (SMMRB) have led to deforestation resulting in water erosion, a threat to food security, energy and water resources. The large scale cutting of trees, bushes and shrubs for charcoal burning and to create land for agriculture, exacerbated soil erosion contributing to land and water quality degradation, heavy sediment yield and transportation and loss of soil fertility. The specific objective of this study was to determine stream discharges and sediment concentrations in the basin. The computation of stream discharge in m^3/s was to facilitate measurement of sediment delivered to the streams in tons/km^2/yr in the basin. Sampling and stream discharge 'Q' measurements were done simultaneously. From data collected, Discharge Rating Curves (DRC) for each of the RGS (Regular Gaging Stations) were developed for accuracy and hydraulic characteristics of the individual stream channel. Propeller type of current meter was used (V= a+bN). From Area-Velocity approach: Q=AV (m^3/s); Discharge Rating Equation developed from $Q = aH^n$ with discharge as a function of stage and sediment concentration $C_s = aQ^b$ or $Cs = q_sC$. From point sampling; Sediment $Cs = \frac{\sum Cq}{\sum q}$. Since an Integrated sampler was used for sediment sampling; sediment load was = $qs = \int_0^d C(y)dy$. At the Busia-Kisumu Bridge (RGS 1AH01), measured Q_{max} = 227.03 m^3/s during the wet season and Q_{mean} obtained was 97.24 m^3/s, a linear regression gave Y = 0.081x + 0.1593 and a coefficient of determination; R^2 = 0.98. At River Malakisi (RGS 1AB01), Q_{mean} was 86.23 and Q_{max} = 231.59m^3/s and generated an equation Y = 0.0257x +0.236 and R^2 = 0.979. River Malaba (Bungoma-Malaba Bridge, RGS 1AAH01) Q_{mean} = 152.55 m^3/s and Q_{max} = 364.71 m^3/s were obtained with Y= 0.013x + 0.4234 and R^2 = 0.980. Lwakhakha at (RGS Mip026) recorded Q_{mean} = 78.94m^3/s and Q_{max} = 197.66 m^3/s this gave Y = 0.013x + 0.2817 and R^2 = 0.851. The RGS 1AH01 yielded SY = 9455 tons/km^2/yr, an equation Y = 55.961x + 2.5312 was generated and R^2 = 0.971. The results are an indicator that immense erosion is taking place in SMMRB. The study revealed subtle changes in stream channel geometry due to growth of aquatic vegetation catalyzed by stream water laden with nutrient rich sediments.

The Water-Energy-Food Nexus' long hand – Does hydropower generation influence vegetation dynamics downstream

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The Turkwel Gorge Dam (TGD) in North-Western Kenya is considered as one of the biggest white elephants of the 1980s. Its construction was firstly conceived in the late 1960s. The initial aim was multipurpose including hydroelectric power generation and to create irrigation schemes downstream. Due to lack in funds, the systematic implementation of the identified 1286 ha of irrigable land and the construction of a pilot scheme (405 ha) was hampered. In the last decades, irrigation schemes were estimated to be 18 km2 encroached into the floodplain forest. Additionally, the Kerio Valley Development Authority proposed plans of large scale irrigation schemes (300 km²) in 2013.

Based on the development in the last decades changes in vegetation conditions along the river and its floodplains can be assumed. This changes may stem from altering the hydrological regime of the Turkwel River caused by the dam operation, changes in climate and from implemented irrigation schemes. The aim of this study is therefore to analyze and quantify these changes utilizing satellite imagery, but also data on precipitation and Lake Turkana water level.

The vegetation analyses along the Turkwel River was carried out using the MODIS MOD13Q1 NDVI (Normalized Difference Vegetation Index) dataset. This dataset provides consistent, spatial and temporal information on global vegetation characteristics. Based on the typical spectral reflectance signatures of plants, the empirical vegetation index is derived as a ratio of the contrast between near infrared and red. High values of NDVI occur over full canopy and minimum values indicate areas with little vegetation.

The analysis of vegetation conditions along the Turkwel River reveals a general increase of vegetation (+28 % in the analysed period 2001-2018). This is explained by an increase in precipitation (+12 %) but also by the altered discharge patterns due to the establishment of the Turkwel Dam. Furthermore, five areas, which show a much higher increase of NDVI, were analysed in more detail and on a higher temporal scale. The significant high increase in these areas indicate changes in land use, caused by the establishment of small-scale irrigation schemes, but also in changes of Lake Turkana water levels. Most of the vegetation changes in the Lake Turkana delta appear to be due to invasive Prosopis. Prosopis seems to benefit from the water level fluctuations as is can tolerate some level of root submergence. Additionally, the pods float and disperse leading to the establishment of seeds as the water levels drop and sediments are deposited.

Impact of adaptation lag of soil and water conservation practices on crop productivity in the Sio-Malaba-Malakisi River Basin in the Kenya and Uganda border region

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Soil and Water Conservation Practices (SWCPs) are key for efficient and sustainable use of existing cropland. Adoption of Soil and Water Conservation Practices can reduce rates of land degradation, improve crop productivity, and contribute to global efforts to meet increasing food demand. However, adoption rate of these Soil and Water Conservation practices is still low, especially in Sub-Saharan Africa. Even where farmers are exposed and aware of the Practices, they take long to adopt them. Delayed adoption is costly, both in terms of lost value of production and soil quality. There is limited empirical evidence on determinants and impact of adoption lag (time between exposure to a technology and adoption) of Soil and Water Conservation Practices and its impact. This study determined adoption lag of Soil and Water Conservation Practices, its determinants and impact on crop productivity in the Sio-Malaba Malakisi River Basin (SMMRB) located in the Kenya-Uganda border region. Data was collected from 507 randomly selected households in five districts. The duration analysis model and generalized propensity score matching methods were employed to analyze the collected data. Results indicated that the average adoption lag was about 10 years, with no significant differences in adoption lag of individual Soil and Water Conservation Practices between Kenya and Uganda. Significant differences in adoption lag for individual Soil and Water Conservation Practices were observed between male and female-headed households. Education level of the household head, number of accessible markets, access to credit, size of farmland owned, participation in social groups, tropical livestock units, and off-farm work were found to significantly influence adoption lag. Results from estimation of the impact of adoption lag of Soil and Water Conservation Practices on crop productivity indicated that the longer the farmers take to adopt, the lower the crop productivity. The estimated impacts have some variations between Kenya and Uganda. Means to enhance timely adoption of SWCPs as well as increased access to credit and markets are recommended.

Effect of incentives for scaling up adoption rates of soil and water conservation technologies in in the Sio-Malaba-Malakisi River Basin in the Kenya-Uganda border region

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The high rate of land degradation and the resulting challenges of widespread decline in soil fertility and agricultural productivity are a current pertinent concern globally. Adoption rates of soil and water conservation practices (SWCPs) which are advanced as a possible remedy to declining soil quality are still low, especially in developing countries. There is current debate on whether adoption rates of soil and water conservation practices can be increased through giving incentives to farming households. Some schools of thought argue that sustainable adoption cannot be driven by apparent benefits alone, without some kind of additional incentive. This study was done in the Sio-Malaba Malakisi River Basin (SMMRB) located in the Kenya- Uganda border region. The objectives of the study were to assess the effect of incentives aimed at increasing adoption, on the adoption rates of soil and water conservation technologies, by subsistence households. The study further assesses the impact of adoption on household agricultural productivity and poverty levels. Data were collected from 507 randomly selected households in five districts: Busia, Tororo and Namisindwa in Uganda, and Busia and Bungoma in Kenya. The Trade-off Analysis for Multi- Dimensional Impact Assessment (TOA-MD) model was used to analyze the data. Results indicate a range of adoption rates for different soil and water conservation technologies, ranging between 56 - 80 percent, and with a potential of going up to about 90%, when incentives are introduced. The results point to positive benefits to adopting households, in terms of increased agricultural productivity and reduction in poverty rates. The study recommends that incentives that can aid access to capital for adoption be made available to farmers. For the incentive delivery process to be sustainable, the self-supporting capacity of the farmers has to be built such that they are able to stand on their own even when programs providing adoption incentives have withdrawn.

Long-term impacts of nutrient recycling projects from human excreta on food production in Western Kenya

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A promising fertilizer source for farmers of Sub-Saharan Africa can be products of human excreta recycling. One sanitation technology for making the recycling possible is a urine-diverting dry toilet (UDDT). There are several implementation projects of this technology in Africa and many short-term studies and experiments regarding their use and the fertilizing effect of the UDDT products. However, the long-term impact of these human excreta recycling projects on agricultural production in an environment that is not controlled, is unknown. Consequently, this study focuses on th long-term evaluation of nutrient recycling projects and their impact on crop production and food security of smallholder farmers. 94 farmers, who were beneficiaries of an UDDT implementation project between 2006-2010, were interviewed in Western Kenya. The questionnaire survey showed that 50% of the interviewed owners still use the UDDT and 50% do not use it anymore. The main problems were lack of training and missing of a long-term local support network. However, the most common driver for the continuing use of the UDDT is the fertilizer itself. To show the impact of the fertilizer on crop production and food security, a graphical analysis and a Material Flow Analysis (MFA) were conducted. Both methods showed that UDDT products can be an important complement to increase the nutrient input, the agricultural production and in further consequence the food security of a farming household in Western Kenya since the use of inorganic fertilizer is very low in this area. The results could also be valid for other regions in Sub-Saharan Africa.

Human excrement recycling to agriculture in Sub-Sahara-Africa

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Agricultural productivity in Sub-Sahara-Africa is limited by high nutrient deficits in soils and a loss of biomass through soil erosion. Different initiatives in the region aim to address the problem of low nutrient inputs to agricultural soils by recycling nutrients from human excreta. Some technologies (e.g. urine-dry-diverting-toilets) require considerable monetary input while providing also adequate sanitation, others (e.g. urine collection in jerrycans) are comparatively cheap, but collect only part of human excrements. While the theoretical potential of human excreta recycling has been determined as substantial in recent studies, impacts of user behavior and the importance of these additional inputs for varying farming systems have not been studied so far.

This study therefore compares the theoretical and realistic potential of the mentioned technologies to decrease the soil nutrient deficit in 5 districts/counties (Bungoma & Busia County (K), Busia, Manafwa & Tororo District (U)) at the border of Uganda and Kenya.

The method of Material Flow Analysis (MFA) was chosen to (i) gather all nutrient flows in the 5 districts/counties that are associated with agricultural production and human excreta management (ii) determine the net-soil-nutrient-balance per ha of agricultural land for these districts and (iii) analyse the potential of different recycling scenarios for the improvement of the soil-nutrient-balances in these districts/counties.

Results reveal a relatively high potential of unused human excrements to reduce soil nutrient deficits in agricultural land in the 5 studied district/counties. The theoretic potential of unused human excrements to improve the soil nutrient balance lies around 90 – 120% for Nitrogen, 60 – 220% for Phosphorus and 30 – 60% for Potassium. Through accounting for the drawbacks of the analysed technologies, it can be shown that their realistic potential to recycle nutrients lies around 50 – 65% of the theoretic potential. Future steps in this work are to implement further results from the CapNex project improving the knowledge on soil-nutrient-balances in these districts and to do an economic evaluation of the impacts of excreta recycling on small-holder farmers.

Assessment of a cattle manure vermicomposting system using Material Flow Analysis – A case study from Uganda

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Growth in cattle population is associated with increased manure generation whose current management in low-income countries is associated with health and environmental problems as well as low utilization rates. This trend can be reversed through promoting better manure management technologies. This study assessed vermicomposting as one of the technologies to manage organic wastes, using the case study of Uganda. A vermicomposting system using cattle manure and earthworms (*Eudrilus euginea*) was monitored for one year with harvesting of products (compost, earthworm biomass) after every three months. Vermicompost samples from the beginning of the experiment and after every harvest were analyzed for the following parameters: pH, ash content, volatile and total solids, nutrients N, P, K, and C. Emissions of CO_2, CH_4, NH_3 and N_2O were also measured. Material flow analysis was used to determine the flows and retention of nutrients within the system. Results showed that total solids, ash, N, P and K content significantly increased, while contents of volatile solids and C, as well as the pH, significantly decreased over time. Of the materials that entered the vermicomposting system, 46% went to vermicompost, 2% into earthworms, and 52% was lost to the atmosphere. Substance flow analysis showed that 30% of C went to vermicompost, 69% was emitted to the atmosphere and 2% ended up in earthworms while 75% of N was transferred to vermicompost, 7% went to earthworms and 18% escaped into the atmosphere. The cumulative emissions were 102 g CO_2 kg^{-1} waste, 7.6 g CH_4 kg^{-1} waste and 3.943 x 10^{-5} g N_2O kg^{-1} waste on a dry basis, while NH_3 was not detected throughout the measurement time. Compared to other manure management methods, vermicomposting demonstrated good potential in conserving nutrients as well as reducing greenhouse gas emissions.

Comparative performance of organic fertilizers in Maize (*Zea Mays L.*) growth, yield, and economic results

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Maize is a major crop grown and consumed in Uganda and it requires a high fertilizer input. However, the existing inorganic fertilizers on market are often not affordable especially to small scale farmers resulting in decreased maize yields in the country. On the other hand, there is an abundance of unutilized animal manure which when treated can be used to increase maize yields. This study evaluated the response of maize to products of different cattle manure treatment methods as well as inorganic fertilizer. The treatments namely cattle manure stored under shade (T), cattle manure stored in open (M), cattle manure slurry digestate (S), vermicompost (V), and an inorganic fertilizer, DAP (D) were all applied in completely randomized block plots at an equal application rate of 50 kg N ha^{-1} with four replications per treatment. Control plots (C) where no fertilizer was applied were also considered. The experiment was done for two planting seasons in 2018. Number of leaves, plant height, cob and grain yields were used to evaluate the performance of different fertilizer treatments. Economic assessment of all the six treatments was also carried out to determine the economic viability of applying these fertilizers on maize. Maize growth parameters and yields were all significantly increased ($p<0.05$) with an application of both organic and inorganic fertilizers when compared with the control. However, there was no significant difference ($p>0.05$) in the maize yields under the different fertilizer treatments. Vermicomposting was the most economically viable manure treatment method due to low operating costs and higher returns on investment that are supplemented with production of chicken fodder (earthworm biomass) and thus can be recommended to farmers for production of a fertilizer that increases maize yields with assurance of economic returns.

Earthworms (*Eudrilus Eugeniae*) as a potential protein source in poultry feeds

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The increasing cost of animal protein sources in the poultry feeds has necessitated need for use of alternative protein sources. One such source is earthworm meal (EW), (*Eudrilus Eugeniae*). This study evaluated the effect of inclusion of EW meal in the diet of broilers on their growth performance, carcass traits and meat quality. Five feed rations were formulated using EW and these included T1 (0%EW), T2 (1%EW), T3 (3%EW), T4 (5%EW) and T5 (7%EW). A total of 150 day old chicks were randomly allocated to the five treatments, with three pens per treatment and 10 birds in each pen. At six weeks of age, 45 birds were randomly selected from the pens and their Body weight Gain (BWG), Average Daily Weight Gain (ADWG), Average Daily Feed Consumption (ADFC), weight of body organs and sensory attributes of the broiler meat were determined. The sensory attributes determined included chicken aroma, chewiness, juiciness, taste, tenderness and residue. The study showed that birds in T3 had the highest BWG (1.216 kg). The highest food consumption was in T1 while the least food consumption was in T5. The findings also showed that chicken taste and juiciness significantly ($p<0.05$) improved with increasing inclusion of EW. However, the amount of residues increased with increasing EW inclusion ($p<0.05$). There was no significant difference ($p>0.05$) in the different treatments for chicken aroma, tenderness and chewiness. In conclusion, EW is a good alternative protein source and can replace fishmeal.

Performance assessment of cattle manure management technologies: A case of Sio-Malaba-Malakisi River Basin, Uganda

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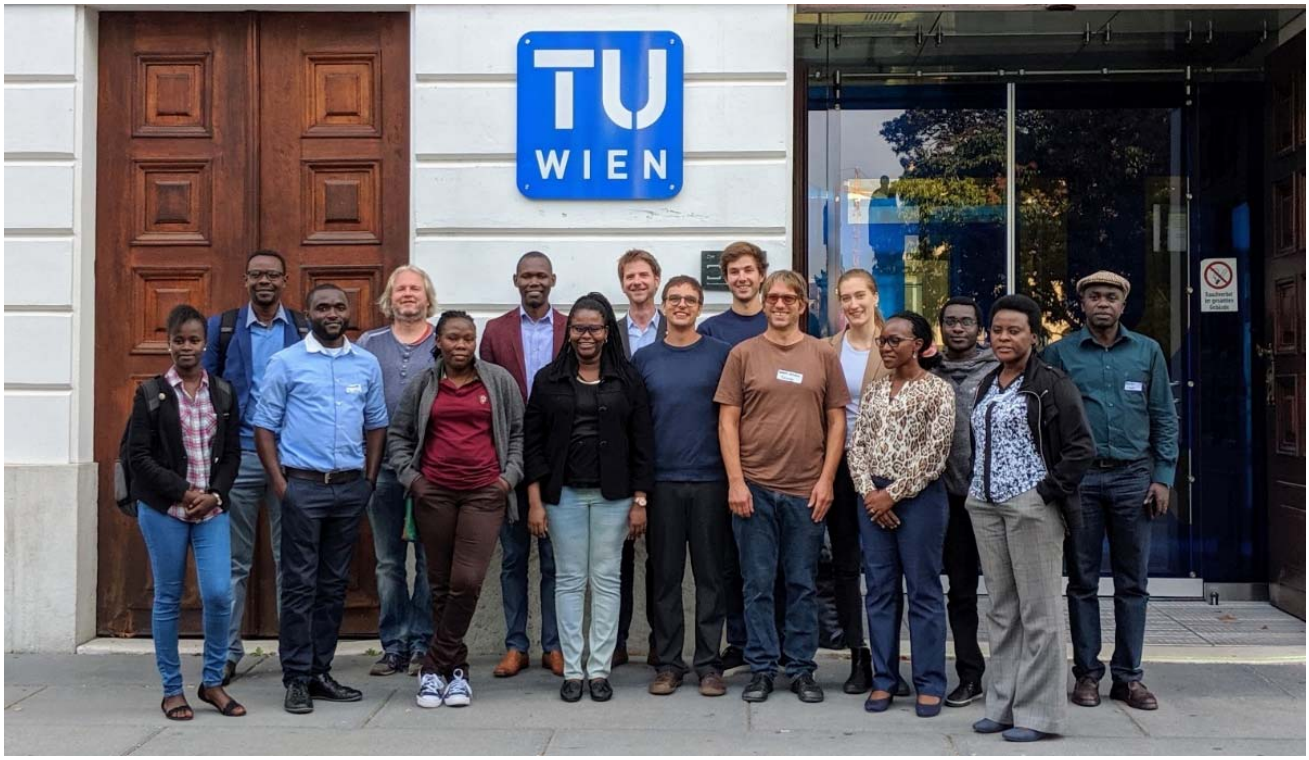
BSc. Agricultural Engineering; REG NO.: 2016/HD02/104U

Dissertation submitted to the Department of Agricultural and Bio-Systems Engineering in partial fulfilment of the requirements for the award of a master of science in agricultural engineering of Makerere University.

Most Ugandan households are engaged in agriculture with 58% in livestock farming. With up to 16 million Tropical Livestock Units (TLU), the manure generated is yet to be well managed to reduce associated environmental hazards such as greenhouse gas (GHG) emissions. Under shade manure storage (USMS), open manure storage (OMS) and bio-digester with under shade slurry storage (USSS) are some of the technologies used by farmers to manage manure however, their uptake is still low in Uganda. This study assessed these technologies from a technical, environmental and economic viewpoint to create awareness and develop recommendations for adoption. To determine the commonly practiced manure management technologies, a questionnaire survey was conducted in the study area Sio-Malaba-Malakisi River Basin (SMMRB). Experiments were set up to monitor losses of nutrients and gaseous emissions from the different technologies during three months period of manure storage. In addition, an economic assessment of the manure management technologies was performed using net present value, benefit-cost ratio and internal rate of return techniques. The study established that about 34% of cattle farmers in SMMRB practiced open dumping, 1.2% used it as feedstock for bio-digester, 1.2% burnt it while 63.6% stored manure either in open OMS or in USMS. For the farmers who stored manure, the majority practiced OMS (89.4%) while 9.6% and 1% practiced USMS and storage in sacks respectively. Results revealed that, bio-digester and USSS retained 52.9% (w.b) of the original mass of fresh manure while OMS and USMS respectively retained 46.2% (w.b) and 34.4% (w.b) of the initial mass. For nutrient retention, bio-digester and USSS retained the highest TN and TC of 67.5% and 61.8% respectively followed by USMS (59.8% and 56.8%) and lastly OMS (47.8% and 45.4%). Conversely, bio-digester and USSS retained the least TP and TK of 65.1% and 40.8% respectively followed by OMS (98.0% and 46.5%) and finally USMS (99.8% and 99.2%). Environmental performance showed that OMS had the least emission of CH_4 at 0.09% with emission factor of 1.43 g GHG kg^{-1} waste while USSS and USMS respectively had 0.11% and 1.96 g GHG kg^{-1} waste, and 0.13% and 2.15 g GHG kg^{-1} waste. Similarly, OMS and USSS had least emissions and emission factors for NH_3 (0.13 ppm and 0.0002 g kg^{-1} waste) compared to 0.83 ppm and 0.0015 g kg^{-1} waste for USMS. Economic analysis suggested that at Bank of Uganda interest rate (13.9%), OMS had the highest NPV (UGX. 2,463,880) while USMS and bio-digester with USSS had UGX. 466,027 and UGX. 1,503,760 respectively. At the same interest rate, the respective B/C of the three technologies were 28.38, 2.12 and 1.22. However, at 24% interest rate, NPV and B/C of bio-digester with USSS were least at UGX. -1,745,769 and 0.75 respectively compared to the other technologies. The IRRs were respectively 426%, 32% and 18% for OMS, USMS and bio-digester with USSS. At Bank of Uganda interest rate, all the technologies had B/C and IRR values above threshold (1 and 11% respectively) signifying their feasibility. In general, bio-digester and USSS retained more mass, TN and TC, was environmentally friendly as well as economically viable for manure management compared to OMS and USMS.



Some members of the project team at TU Wien in September 2019.

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