RUFORUM Working Document Series (ISSN 1607-9345), 2021, No. 19 (1):1028-1038.
Available from http://repository.ruforum.org

Research Application Summary

Projected temperature and rainfall in the semi-arid Lokere and Lokok catchments, northeastern Uganda

Osaliya, R.[1*], Wasonga, O.,[1] Mwanjalolo, J.G.M.,[2] MacOpiyo, L.[1] & Adipala, E.[3]

[1]Department of Land Resource Management and Agricultural Technology, University of Nairobi, P.O. Box 29053-00625, Nairobi, Kenya
[2]School of Forestry, Environment and Geographical Sciences, Makerere University, P.O. Box 7062 Kampala, Uganda
[3] Regional Universities Forum for Capacity Building in Agriculture (RUFORUM), P.O. Box 16811, Wandegeya, Kampala, Uganda
*** Corresponding Author:** osaliya@yahoo.com

Abstract

Trends in global warning over the past decades have been predicted to increase in the 21st Century, causing concerns for disaster preparedness in arid and semi-arid regions. This study utilized downscaled district level future temperature and rainfall scenarios for the semi-arid Lokok and Lokere Catchments in eastern Uganda, from 20 IPCC climate models embedded in the Agricultural Model Intercomparison and Improvement Project (AgMIP). The three periods are 2010-2039 (early century); 2040-2069 (midcentury), and 2070-2099 (end-century). The delta method, using a script provided in the AgMIP protocol, was applied in downscaling climate scenarios. Seasonal (DJF, MAM, JJA and SON) and annual means of station and the Catchments scale ensembles of minimum (Tmin), maximum temperature (Tmax), and rainfall for each of the three periods were computed and compared with 1980-2009 as the baseline period. Temperature is projected to increase, and change in Tmin would be higher than change in Tmax. Tmax in the Catchments would change by 0.7°C and 0.8°C; 1.3°C and 1.9°C; 1.7°C and 3.3°C; while Tmin would change by 0.9°C and 1.0°C; 1.6°C and 2.1°C; and 2.0°C and 3.8°C – for RCP4.5 and RCP8.5 in the early, mid and end-centuries, respectively. Increase in temperature would be higher in the cooler and wetter months and seasons (MAM, JJA) than in the warmer season (DJF) – which shows a temporal variation in change. While rainfall in the Catchments is projected to increase by 10% and 8%; 15% and 16%; and 20% and 30% – for RCP4.5 and RCP8.5 in the early, mid and end-centuries, respectively, the increase would be higher in the drier periods than in the wetter ones. Increase of rainfall alongside increase in temperature could result in increased evaporation to precipitation ratio over the coming years. This in turn creates a likelihood of an increased deficit in soil water and surface water flows. Therefore, crop and livestock producers would have to cope with moisture/water deficits through climate smart (soil) water management practices and crop and animal science.

Key words: Climate scenarios, global warning, North-Eastern Uganda, water management

Résumé

Les tendances de l'alerte mondiale au cours des dernières décennies devraient s'accentuer au 21e siècle, ce qui suscite des inquiétudes quant à la préparation aux catastrophes dans les régions arides et semi-arides. Cette étude a utilisé des scénarios de température et de précipitations futures à l'échelle du district pour les bassins versants semi-arides de Lokok et Lokere dans l'est de l'Ouganda, à partir de 20 modèles climatiques du GIEC intégrés dans le projet d'inter-comparaison et d'amélioration des modèles agricoles (AgMIP). Les trois périodes sont 2010-2039 (début du siècle), 2040-2069 (milieu du siècle) et 2070-2099 (fin du siècle). La méthode delta, utilisant un script fourni dans le protocole AgMIP, a été appliquée à la réduction d'échelle des scénarios climatiques. Les moyennes saisonnières (DJF, MAM, JJA et SON) et annuelles des ensembles de températures minimales (Tmin), maximales (Tmax) et de précipitations à l'échelle des stations et des bassins versants pour chacune des trois périodes ont été calculées et comparées à la période de référence 1980-2009. La température devrait augmenter, et le changement de Tmin serait plus élevé que celui de Tmax. La Tmax dans les bassins versants changerait de 0,7oC et 0,8oC ; 1,3oC et 1,9oC ; 1,7oC et 3,3oC ; tandis que la Tmin changerait de 0,9oC et 1,0oC ; 1,6oC et 2,1oC ; et 2,0oC et 3,8oC - pour les RCP4.5 et RCP8.5 au début, au milieu et à la fin du siècle, respectivement. L'augmentation de la température serait plus élevée dans les mois et les saisons plus frais et plus humides (MAM, JJA) que dans la saison plus chaude (DJF) - ce qui montre une variation temporelle du changement. Alors que les précipitations dans les bassins versants devraient augmenter de 10 % et 8 %, de 15 % et 16 % et de 20 % et 30 % - pour les scénarios RCP4.5 et RCP8.5 au début, au milieu et à la fin du siècle, respectivement, l'augmentation serait plus importante dans les périodes plus sèches que dans les périodes plus humides. L'augmentation des précipitations parallèlement à l'augmentation de la température pourrait entraîner une augmentation du rapport entre l'évaporation et les précipitations au cours des prochaines années. Ce qui, à son tour, crée une probabilité d'augmentation du déficit en eau du sol et en flux d'eau de surface. Par conséquent, les producteurs de cultures et de bétail devront faire face aux déficits d'humidité et d'eau grâce à des pratiques de gestion de l'eau (du sol) intelligentes sur le plan climatique et à la science des cultures et des animaux.

Mots clés : Scénarios climatiques, alerte mondiale, nord-est de l'Ouganda, gestion de l'eau

Introduction

Global warning trends observed over the past centuries and decades have been predicted to increase over the 21st Century. Global surface temperature changes for the end of the 21st century, 2100, will likely exceed 1.5 C relative to 1850 to 1900 (IPCC, 2013). This trend in global warming is predicted to likely increase during the 21st century under all the Representative Concentration Pathways (RCPs). The projected increases would be 0.3–1.7 1C (RCP2.6); 1.1–2.6 1C (RCP4.5); 1.4–3.1 1C (RCP6.0); and 2.6–4.8 1C (RCP8.5) for 2081–2100 ompared to 1986–2005 baseline (IPCC, 2013).

The predicted warming will also continue to exhibit interannual-to-decadal variability as well as spatial variability as it will not be regionally uniform. Changes in the global water cycle will also occur in response to global warming, and like temperature, spatial and temporal variations will occur with respect to rainfall. It is projected that contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions (IPCC, 2013).

Recent studies show that future rainfall and temperature in eastern Africa will vary or depart from present or historical baselines. ICPAC (2016) reported projected changes in annual and seasonal rainfall and temperature in the 2020s, 2030s, 2050s and 2070s under three different socio-economic scenarios compared to 1971-2000 baseline. Based on estimates from general circulation models (GCMs), Shongwe *et al*. (2011) reported a positive shift of rainfall distribution in East Africa during the wet seasons, projected increase in mean precipitation rates and intensity of high rainfall events but for less severe droughts.

Previous studies have tended to focus on larger regions and to overlook the effect of local features such as East Africa's varied topography (Shongwe *et al*., 2011). Understanding the likely response of climate parameters to global warming is critical in informing development planning and disaster preparedness, especially in a region prone to drought and its consequences such as water scarcity and famine.

Materials and methods

Study area. This study was conducted in the semi-arid region of Kapir catchment (which covers Lokok and Lokere catchments), connecting downstream to part of Teso sub-region in northeastern Uganda. Karamoja sub-region is part of the Karamoja cluster, an area of land that straddles the borders between south-western Ethiopia, north-western Kenya, south-eastern South Sudan and north-eastern Uganda. The sub-region experiences hot and dry weather characteristics of most semi-arid regions in Eastern Africa. Rainfall in Karamoja sub-region is uneven and unimodal, occurring from March to November, and ranging from < 500 mm per year in eastern Karamoja, 500-800 mm in central Karamoja to 700-1000 mm in west Karamoja and the isolated highlands (Mbogga *et al*., 2014). Mean annual rainfall downstream of the Catchment, in Teso subregion, is about 1100-1200 mm, distributed between two seasons of March to July and September to November (Kisauzi *et al*., 2012). Temperatures are generally high throughout the year, with an annual average of 28 and 33 °C for minimum and maximum, respectively, leading to high evapotranspiration levels averaging 2072 mm per annum (Mbogga *et al.,* 2014). Rainfall variability in the region leads to heterogeneity of landscape resources including availability of pasture and water that influences the pastoral way of life as both a coping and adaptation strategy (Egeru *et al*., 2014).

Downscaling of climate scenarios. This study utilized downscaled station level future temperature and rainfall scenarios obtained from twenty of the latest IPCC climate models (ACCESS1-0, bcc-csm1-1, BNU-ESM, CanESM2, CCSM4, CESM1-BGC, CSIRO-Mk3-6-0, GFDL-ESM2G, GFDL-ESM2M, HadGEM2-CC, HadGEM2-ES, inmcm4, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC5, MIROC-ESM, MPI-ESM-LR, MPI-ESM-MR, MRI-CGCM3, and NorESM1-M) embedded in the Agricultural Model Intercomparison and Improvement Project (AgMIP).

The AgMIP simulations follow a set of Representative Agricultural Pathways (RAPs), developed, for consistency with climate modeling, on the basis of the set of SRES emissions scenarios and RCPs used in the IPCC AR4 and AR5, respectively. Representative Concentration Pathways (RCPs), which supersede Special Report on Emissions Scenarios (SRES) projections published in 2000, are four greenhouse gas concentration trajectories adopted by the IPCC for its fifth Assessment Report (AR5) in 2014. These include RCP 2.6; RCP 4.5, RCP 6.0 and RCP 8.5. The four RCPs are based on multi-gas concentration scenarios (Meinshausen *et al*., 2011) and provide a quantitative description of concentrations of the climate change pollutants in the atmosphere over time, as well as their radiative forcing in 2100, spanning from 2.6 to 8.5 W/m^2, selected from a wide range of literature (van Vuuren *et al*., 2011). The RCPs have been used to drive climate model simulations planned as part of the World Climate Research Programme's Fifth Coupled Model Intercomparison Project (CMIP5). The naming represents radiative forcing target level for 2100. RCP 8.5 represents a high emissions scenario, while RCP 4.5 represents a medium mitigation scenario.

Based on climate change simulations from an ensemble of general circulation models (GCMs) from the CMIP3 and CMIP5, AgMIP projections are made for three periods under high (A2) and low (B1) SRES emissions scenarios for CMIP3 and RCPs CMIP5 (Rosenzweig *et al*., 2013). The three periods are: 2010–2039 – near-term period (early century); 2040–2069 – midcentury; and 2070–2099 – end-Century. Target local level ensemble of climate data is then obtained by applying the coarse-scale GCM climate change projections to a high resolution observed (local or station) climate baseline – "the change factor method" (Wilby *et al.,* 2004).

The methodology for downscaling climate scenarios to each station was based on the delta method, using a script provided in the AgMIP protocol (Rosenzweig *et al*., 2013 and Hudson and Ruane, 2015). The method involves imposing temperature and precipitation changes from GCMs for the selected projection periods on each location's daily observations baseline period (Ruane *et al*., 2015). That is, the historical time series is adjusted according to changes in climate indicated by comparing a GCM's projection for the future time period against the same GCM's historical period. Using Ag-MERRA as baseline and future climate scenarios for 20 CMIP5 GCMs obtained from the AgMIP website (http://tools.agmip.org/), station level data was obtained using AgMIP Climate Scenario Generation scripts, performed in R statistical software environment (Hudson and Ruane, 2013; Rosenzweig *et al*., 2015).

Calculation of projected change in rainfall and temperature. Monthly, seasonal (DJF, MAM, JJA and SON) and annual means of station and catchments scale ensembles of minimum and maximum temperature, and rainfall for each of the three periods: early-century; midcentury; and end-Century were computed. Change in means, based on the 1980-2009 baselines was derived as follows:

$$\delta T = T_p - T_b;$$

$$R = \frac{(R_p - R_b)x\ 100}{R_b}$$

Where δT change in temperature is, T_p is the average projected temperature, T_b is the average baseline temperature, R is the percentage change in rainfall, R_p is the average projected rainfall, and R_b is the average baseline rainfall.

Results

Projected change in Maximum temperature in the early and mid-century. In the early-century, annual Tmax is projected to change from the baseline period (1980-2009) by 0.7 °C for RCP 4.5 in all stations; and by 0.8 °C in Kaabong and Kotido and 0.9 °C in Amuria and Moroto for RCP 8.5 (Table 1). Average Change in Catchment annual Tmax is thus projected to be 0.7 °C and 0.8 °C for RCP 4.5 and 8.5 scenarios, respectively. Under RCP 4.5 scenario, JJA had the largest seasonal change (0.8 °C), and SON had the smallest at 0.8 °C and 0.6 °C, respectively. JJA was the season with the largest change (1.0 °C), and SON the smallest (0.7 °C) in the RCP 8.5 scenario.

Table 1. Change in total monthly, seasonal and annual Maximum temperature in early Century

	Amuria		Kaabong		Kotido		Moroto		Catchment	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
DJF	0.6	0.8	0.7	0.8	0.6	0.8	0.6	0.8	0.6	0.8
MAM	0.7	0.9	0.7	0.9	0.7	0.8	0.8	0.9	0.7	0.9
JJA	0.8	1.0	0.8	0.9	0.8	0.9	0.8	1.0	0.8	1.0
SON	0.6	0.8	0.5	0.7	0.6	0.7	0.6	0.8	0.6	0.7
Ann	0.7	0.9	0.7	0.8	0.7	0.8	0.7	0.9	0.7	0.8

In the mid-century annual change will be 1.3 °C and 1.7 °C for RCP 4.5 and RCP 8.5, respectively (Table 2). SON will be the season with the smallest change in Tmax, at 1.2 °C and 1.7 °C for RCP 4.5 and 8.5, respectively.

Table 2. Change in seasonal and annual Maximum temperature in Mid-Century

	Amuria		Kaabong		Kotido		Moroto		Catchment	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
DJF	1.2	1.8	1.3	1.9	1.3	2.3	1.2	1.8	1.2	1.9
MAM	1.4	2.0	1.3	1.9	1.3	2.0	1.4	2.1	1.3	2.0
JJA	1.7	2.3	0.8	1.4	1.7	2.2	1.7	2.3	1.5	2.1
SON	1.4	1.9	0.7	1.2	1.3	1.8	1.4	1.8	1.2	1.7
Ann	1.4	2.0	1.0	1.6	1.4	2.0	1.4	2.0	1.3	1.9

In the end-century (Table 3), under RCP 4.5 scenario, SON will experience the smallest change (1.5 °C), while JJA and MAM will experience the largest change, 1.8 °C each. Also SON will experience the smallest change under RCP 8.5, while JJA is expected to experience the largest change (3.6 °C). Annual catchments level changes will be 1.7 °C and 3.3 °C under RCP 4.5 and 8.5, respectively.

Table 3. Change in seasonal and annual Maximum temperature in End-Century

	Amuria		Kaabong		Kotido		Moroto		Catchment	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
DJF	1.5	3.1	1.7	3.2	1.6	3.1	1.6	3.1	1.6	3.1
MAM	1.8	3.4	1.7	3.3	1.7	3.3	1.9	3.5	1.8	3.4
JJA	2.1	4.0	1.2	2.9	2.0	3.7	2.1	3.9	1.8	3.6
SON	1.7	3.3	1.1	2.5	1.6	3.1	1.6	3.2	1.5	3.0
Ann	1.8	3.5	1.4	3.0	1.7	3.3	1.8	3.4	1.7	3.3

Projected change in minimum temperature. Change in Tmin is projected to be larger than that of Tmax. Respective Catchment level change in Tmin in early, mid and end-Century will be 0.9 °C and 1.0; 1.6°C and 2.1; and 2.0 and 3.8 °C for RCP 4.5 and RCP 8.5, respectively (Table 4, 5 and 6).

In the early century, JJA and DJF are projected to realise the biggest change under RCP 8.5(1.1 °C each), while SON is expected to have the smallest change (0.9 °C). Change is annual Tmin will be the same in all the stations, projected to be 0.9 °C and 1.0 °C for RCP 4.5 and RCP 8.5, respectively.

In the mid-century, projected change in Tmin under RCP 8.5 will be largest in JJA (2.4 °C) and smallest in SON (2.2°C). Under RCP 4.5, with the exception of Kaabong where change in annual Tmin will be smallest (1.1 °C), the stations are projected to have 1.8 °C change in temperature. The change will be more varied under RCP 8.5, ranging from 1.8 °C in Kaabong to 2.5 °C in Kotido and Moroto.

Table 4. Change in seasonal and annual minimum temperature in early Century

	Amuria		Kaabong		Kotido		Moroto		Catchment	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
DJF	0.9	1.1	0.9	1.1	1.0	1.1	0.9	1.1	0.9	1.1
MAM	0.8	1.0	0.9	1.0	0.9	1.0	0.9	1.0	0.9	1.0
JJA	0.9	1.1	0.9	1.0	0.9	1.0	0.9	1.1	0.9	1.1
SON	0.8	1.0	0.8	0.9	0.8	0.9	0.8	1.0	0.8	0.9
Ann	0.9	1.0	0.9	1.0	0.9	1.0	0.9	1.0	0.9	1.0

Table 5. Change in seasonal and annual minimum temperature in Mid-Century

	Amuria		Kaabong		Kotido		Moroto		Catchment	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
DJF	1.8	2.5	1.0	1.8	1.9	2.7	1.8	2.6	1.6	2.4
MAM	1.7	2.3	1.3	2.0	1.8	2.5	1.8	2.5	1.7	2.3
JJA	1.9	2.5	1.3	2.1	1.9	2.6	1.9	2.6	1.7	2.4
SON	1.7	2.4	0.8	1.5	1.7	2.4	1.7	2.4	1.5	2.2
Ann	1.8	2.4	1.1	1.8	1.8	2.5	1.8	2.5	1.6	2.3

In the end-century, annual Tmin is expected to change by 2.2 °C under RCP 4.5 in all the stations, with the exception of Kaabong where the change is projected to be smallest (1.5 °C). The change will however be varied under RCP 8.5, ranging from 3.5 °C in Kaabong to 4.3 °C in Kotido and Moroto. SON is projected to have the smallest change for both RCP 4.5 and 8.5, averaging 1.8 °C and 3.8°C, respectively at catchment level, and ranging from 1.1 °C and 3.0 °C in Kaabong to 2.0 °C and 4.0 °C in Amuria, Kotido and Moroto. The largest change in seasonal Tmin under RCP 8.5 (4.3 °C) will occur in DJF, while for RCP 4.5 it is projected to occur in MAM and JJA (2.1 °C).

Table 6. Change in seasonal and annual minimum temperature in End-Century

	Amuria		Kaabong		Kotido		Moroto		Catchment	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
DJF	2.3	4.4	1.2	3.6	2.4	4.6	2.3	4.5	2.0	4.3
MAM	2.2	4.0	1.8	3.7	2.3	4.2	2.3	4.2	2.1	4.0
JJA	2.3	4.3	1.7	3.8	2.2	4.3	2.3	4.4	2.1	4.2
SON	2.0	4.0	1.1	3.0	2.0	4.0	2.0	4.0	1.8	3.8
Ann	2.2	4.2	1.5	3.5	2.2	4.3	2.2	4.3	2.0	4.1

Projected change in rainfall. In early Century, mean total annual rainfall over the Catchments is projected to change by 10 percent and 8 percent under RCP 4.5 and 8.5 scenarios, respectively (Table 7). The change is projected to be highest in Amuria and Moroto stations under RCP 4.5, by 11 percent and in Moroto under RCP 8.5, by 9 percent. Relative change in annual rainfall will be lowest in Kaabong and Kotido stations, at 9 percent and 6 percent for RCP 4.5 and RCP 8.5 scenarios, respectively; which is lower than the highest relative changes by 3 percentage points.

Table 7. Change in total monthly, seasonal and annual rainfall in early Century

	Amuria		Kaabong		Kotido		Moroto		Catchment	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
DJF	30	23	30	24	24	19	25	19	28	21
MAM	6	5	5	4	5	4	6	5	6	5
JJA	11	5	8	4	8	4	12	7	10	5
SON	12	10	11	11	10	11	12	13	11	11
Ann	11	8	9	6	9	6	11	9	10	8

The projected relative change in Catchment rainfall could nearly double in the mid-century, to increase by 15 percent and 16 percent under RCP 4.5 and RCP 8.5 scenarios, respectively (Table 8). Further increase from the baseline of 10 percent and 33 percent, could occur in the end-century for the respective scenarios (Table 9). In the mid-century, Kaabong followed by Moroto are projected to realise the highest relative increase in rainfall of 18 percent and 17 percent, respectively, for both RCP 4.5 and RCP 8.5 scenarios. Amuria and Kotido are projected to realise the same percentage relative increase in rainfall, at 16 percent and 14 percent under RCP 4.5 and RCP 8.5 scenarios, respectively, in the mid-century.

Table 8. Change in seasonal and annual rainfall in Mid-Century

	Amuria		Kaabong		Kotido		Moroto		Catchment	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
DJF	44	57	34	49	34	-2	38	52	40	45
MAM	15	17	3	4	14	14	16	15	15	15
JJA	6	5	25	22	8	5	8	6	7	5
SON	19	18	24	25	20	21	23	23	20	20
Ann	16	16	18	18	14	14	17	17	15	16

Table 9. Change in total monthly, seasonal and annual rainfall in End-Century

	Amuria		Kaabong		Kotido		Moroto		Catchment	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
DJF	64	93	54	83	51	88	53	86	58	90
MAM	18	32	6	18	18	33	19	36	18	33
JJA	15	20	29	37	11	17	14	21	13	19
SON	20	34	25	44	21	41	24	43	21	38
Ann	21	33	22	35	18	32	21	36	20	33

Smallest and largest projected relative changes in seasonal rainfall occurred in different times and scenarios in the stations. In the early-Century, DJF, the driest season has been projected to experience the highest relative change in seasonal rainfall over the catchments; 28 percent and 21 percent under RCP 4.5 and RCP 8.5, respectively. However, the lowest projected relative change in seasonal rainfall over the catchments occurs in JJA (6 percent under RCP 4.5) and in SON and JJA (5 percent) under RCP 8.5.

Discussion

Projected change in temperature. The change in temperature reported in this study is consistent with global warming trends of 1.3°C to 1.7°C by 2050 relative to 1980–1999 under SRES scenarios (IPCC, 2007) and of 0.3°C to 0.7°C for the period 2016–2035 relative to 1986–2005 under RCP scenarios (IPCC, 2013). The change is also consistent with change in Maximum temperatures in the Greater Horn of Africa of 0.5 to 1.5°C under the RCP4.5 and RCP8.5 scenarios compared to 1971-2000 baseline (ICPAC, 2016).

The results reveal projected temporal variation in temperature change, with warning higher in the cooler and wetter months and seasons (MAM, JJA) than the warmer season (DJF). This is consistent with ICPAC (2016) that reported higher projected changes in maximum temperatures by 2030 during MAM and JJAS (by 1.0 to 2.5°C compared to base period) over most parts of the greater Horn of Africa, than in OND – a period of short rains .

Projected change in temperatures in the end-Century is also consistent with projected global-mean surface temperatures (GMST) for 2081–2100, which is projected to 2.6°C (RCP4.5) and 2.6°C to 4.8°C (RCP8.5), relative to 1986–2005 (IPCC 2013). In the greater Horn of Africa, changes in annual maximum temperatures in 2070s were projected to be 3.5 to 5 °C higher than the 1971-2000 reference period under the RCP8.5, with further warming expected during MAM and JJAS (June, July, August and September).

ICPAC (2016) also reported projected annual maximum temperatures of 1.5 to 2.5°C higher under the RCP4.5 and 2.5 to 3.5°C higher under the RCP8.5 scenarios over most parts of the GHA by 2050 compared to 1971-2000 baseline. This is also consistent with Otieno and Anyah (2013) who reported a projected approximate temperature increase of 2°C and 2.5-3°C in the GHA by the middle of 21st century under RCP 4.5 and RCP 8.5, respectively.

Projections show higher change in Tmin than Tmax in all periods, but with similar temporal and spatial variation. This is also consistent with reports by IPCC (2013) that the frequency of warm days and warm nights will increase in most regions, while the frequency of cold days and cold nights will decrease in the next decades. ICPAC (2016) also reported higher changes in minimum temperatures than maximum temperatures but with similar patterns in the Greater Horn of Africa. Annual minimum temperatures were projected to be warmer in almost all the Greater Horn of Africa region by 1.0 to 3.0°C by 2030 and 2050, and 4 to 5°C by 2070, than during 1971-2000; and warmest during the MAM and JJAS under the RCP8.5 scenario (ICPAC, 2016).

Projected change in rainfall. Rainfall in the Catchment will increase with temperature. IPCC (2013) projects that long term global precipitation will increase with increased global mean surface temperature at a rate of 1 to 3 percent per °C for scenarios other than RCP2.6. The drier months and seasons (DJF season) are projected to realise higher relative change in rainfall than the wetter months and seasons (JJA, MAM and SON). ICPAC (2016) also reported that over the Greater Horn of Africa, the short rains (OND) are expected to increase over most parts of the region under all the three scenarios (>50 percent), while the long rains (MAM) and JJAS will decrease over most part of the region (10-70 percent), with slight increase (10-25 percent) in MAM rains over the southeastern part of Lake Victoria Basin. Hulme *et al*., (2001) suggested that under intermediate warming scenarios, parts of equatorial East Africa will likely experience 5-20 percent increased rainfall from December-February and 5-10 percent decreased rainfall from June- August by 2050.

Conclusion

Temperature is projected to increase, with larger change in minimum temperatures increasing more than maximum temperature. Increase in temperature will be higher in the cooler and wetter months and seasons (MAM, JJA) than the warmer season (DJF), signifying a temporal variation in change. Whereas rainfall is projected to increase, the increase will be higher in the drier periods than in the wetter ones, and the increase of rainfall alongside increase in temperature could result in increased evaporation to precipitation ratio over the coming years. This in turn creates a likelihood of an increased deficit in local moisture supply, for both soil water and surface water flows or availability Therefore crop and livestock producers would Soil and water management options would therefore have to cope with such moisture/water deficits through climate smart (soil) water management practices and crop and animal science.

Acknowledgement

The study was funded by a grant from the Carnegie Corporation of New York, Provided through the Regional Universities Forum for Capacity Building in Agriculture. This paper is a contribution to the Seventh Africa Higher Education Week and RUFORUM Triennial Conference held 6-10 December 2021 in Cotonou, Benin.

References

Hudson, N.I. and Ruane, A.C. 2015. Appendix 2. Guide for Running AgMIP Climate Scenario Generation Tools with R in Windows, Version 2.3. pp. 387-440. In: Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project (AgMIP) Integrated Crop and Economic Assessments, Part 1. Rosenzweig, C. and Hillel, D. (Eds.), ICP Series on Climate Change Impacts, Adaptation, and Mitigation Vol. 3. Imperial College Press.

IGAD Project Predictions and Applications Centre (ICPAC). 2016. Projected changes in rainfall and temperature over Greater Horn of Africa (GHA) in different scenarios. Retrieved on 17th July 2017from: http://rcc.icpac.net/wp-content/uploads/Progress_Report_March_Hussen.pdf

Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., van Vuuren, D.P., Carter, T.R., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F.B., Nakicenovic, N., Riahi, K., Smith ,S.J., Stouffer, R.J., Thomson, A.M., Weyant, J.P. and Wilbanks, T.J. 2010. The next generation of scenarios for climate change research and assessment. *Nature* 463 (7282):747–756.

Rosenzweig, C., Jones, J.W., Hatfield, J.L., Antle, J.M., Ruane, A.C., Boote, K.J., Thorburn, P.J., Valdivia, R.O., Porter, C.H., Janssen, S. and Mutter, C.Z. 2015. Appendix 1. Guide for Regional Integrated Assessments: Handbook of Methods and Procedures, Version 5.1. pp. 331-386. In: Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project (AgMIP) Integrated Crop and Economic Assessments, Part 1. C. Rosenzweig, and D. Hillel, Eds., ICP Series on Climate Change Impacts, Adaptation, and Mitigation Vol. 3. Imperial College Press.

Ruane, A.C., Winter, J.M., McDermid, S.P. and Hudson, N.I. 2015. AgMIP climate datasets and scenarios for integrated assessment. pp. 45-78. In: Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project (AgMIP) Integrated Crop and Economic Assessments, Part 1. Rosenzweig, C. and Hillel, D. (Eds.), ICP Series on Climate Change Impacts, Adaptation, and Mitigation Vol. 3. Imperial College Press. doi:10.1142/9781783265640_0003.

Shongwe, M. E., Van Oldenborgh, G. J., Van Den, H. B. and Van Aalst, M. 2011. Projected changes in mean and extreme precipitation in Africa under global warming. Part II: East Africa. *Journal of Climate* 24 (14): 3718-3733.DOI: 10.1175/2010JCLI2883.1

Otieno, V. O. and Anyah, R. O. 2013. Projected precipitation, temperature and hydrological cycle changes over the Horn of Africa based on latest IPCC, AR5 (CMIP5) models. American Geophysical Union, Fall Meeting 2013, abstract #A33E-0253. Retrieved on 26th July 2017 from: http://adsabs.harvard.edu/abs/2013AGUFM.A33E0253O

van Vuuren, D.P., Edmonds, J., Kainuma, M.L.T., Riahi, K., Thomson, A., Matsui, T., Hurtt, G., Lamarque, J-F., Meinshausen, M., Smith, S., Grainer, C., Rose, S., Hibbard, K.A., Nakicenovic,N., Krey, V. and Kram, T. 2011. Representative concentration pathways: An overview. *Climatic Change* 109 (1): 5-31. doi:10.1007/s10584-011-0148-z

Wilby, R.L., Charles, S., Zorita, E., Timbal, B., Whetton, P. and Mearns, L. 2004. Guidelines for use of climate scenarios developed from statistical downscaling methods. In: IPCC Supporting Material, available from the DDC of IPPC TGCIA.