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Projected impact of climate change on rice yield in two agro-ecological zones in South-Kivu, Democratic Republic of Congo

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ABSTRACT
Rice (*Oryza sativa*) is one of the five most important staple foods in South-Kivu, with high and increasing demand. The gap between the demand and supply has led to increased importation of rice in the region. Changes in climate are likely to further worsen this gap. This study determined the impact of future climate on paddy rice yield in high altitude plateau and semi-arid Lowland plain of South Kivu region. The Agricultural Production Systems Simulator Model (APSIM) was used to simulate the impact of climate change scenarios -two periods: Mid and end-century, and for two Representative Concentration Pathways: 4.5 and 8.5- on rice yield. Based on the APSIM, rice grain yield is projected to increase with climate change in high altitude plateau while in the semi-arid lowland plain a slight increase in grain yield followed by a decline is projected in the end-century under RCP 8.5. These findings have potential to compliment rice farmers increase their coping capacity against climate change especially in semi-arid lowland plain where negative impacts are projected.

Key words: Climate change and variability, DRC, paddy rice, South-Kivu

RESUME
Le riz (*Oryza sativa*) est l'un des cinq aliments de base les plus importants dans le Sud-Kivu, avec une demande forte et croissante. L'écart entre la demande et l'offre a conduit à une augmentation des importations de riz dans la région. Les changements climatiques sont susceptibles d'augmenter cet écart. Cette étude a déterminé l'impact du futur climat sur le rendement du riz paddy sur le plateau de haute altitude et les plaines semi-arides de la région du Sud-Kivu. Le Modèle de Simulation des Systèmes de Production Agricole (MSSPA) a été utilisé pour simuler l'impact des périodes de scénarios de changement climatique sur les périodes de mi et de fin du siècle, et pour deux Voies de Concentration Représentatives (VCR): 4,5 et 8,5- sur le rendement du riz. En se basant sur le modèle MSSPA, le rendement en grain de riz devrait augmenter avec le changement climatique dans la haute altitude du plateau tandis que dans la plaine semi-aride une légère augmentation du rendement en grain suivie d'une baisse est projetée à la fin du siècle sous VCR 8,5. Ces résultats représentent un atout pour le renforcement de la capacité d'adaptation des producteurs de riz face aux changements climatiques en particulier dans les plaines semi-arides où les impacts négatifs sont projetés.

Mots clés: Changement et variabilité climatique, RDC, le riz paddy, Sud-Kivu

INTRODUCTION
Rice (*Oryza sativa*) is a staple food for nearly half of the world's population and is also a key source of employment and income for rural people (FAO, 2003). It is rapidly becoming a major food crop in much of sub-Saharan Africa and is increasingly becoming a key food crop in addition to the traditional maize (*Zea mays*), cassava (*Manihot esculentum*), sorghum (*Sorghum bicolar*), and other cereals in the near future (Kihoro, 2013). In the Democratic Republic of Congo (DRC), the main staple food crops are cassava, maize, groundnuts, and rice. Rice is, however, produced in much smaller quantities despite the high production potential of the soils in the country (Nsombo *et al.*, 2012). In 2007, the national rice production was about 189,708 tonnes against an estimated 416,984 tonnes required annually. This gap is expected to increase with demographic pressure and continued poor land

management (MinAgri, 2013). Due to the gap between the demand and the supply, currently 90% of the rice consumed in the country is imported (Nsombo *et al.*, 2012). In South-Kivu, about 70% of rice consumed is coming from Rwanda (Vwima, 2014). Failure to produce sufficient rice to meet demand is attributed to constraints such as related to climate change challenges.

Climate change is considered as posing the greatest challenge to agriculture and food security in Sub-Saharan Africa (SSA). Reports indicate that areas suitable for agriculture in many African countries would be negatively affected by climatic change. Further the yield potential of many high profile crops produced in the region, particularly along the margins of semi-arid, arid and coastal areas, are projected to decrease (IPCC, 2007). The magnitude of the climate change impact will, however, vary depending on the pathway considered when making projections. Four Representative Concentration Pathways (RCPs) are currently used for making climate change projections based on possible future atmospheric gas emission. The RCPs include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5). Compared to other scenarios the RCP8.5 leads to severe consequence of climate change on crop yield (Riahi *et al.*, 2007; Van Vureen *et al.,* 2011).

Rice production in South-Kivu is therefore likely to be negatively affected by climate variability already occurring in the region and future changes in climate which are projected to happen (Basak *et al.*, 2010). Recent models projections have for example shown that rainfall reduction and temperature increment over the next 40 years in DRC is expected (Nsombo *et al.,* 2012). However, the nature of future changes in climate in South-Kivu is not well documented and how these changes are likely to affect agriculture, especially rice production among smallholder farmers (Ahmed and Fayyaz-ul-Hassan, 2011). Rice production has an enormous potential to increase both in quantity and potential to address persistent food insecurity challenges in DRC and particularly in South-Kivu but it is still unclear how this potential will evolve under a changing climate situation. This study assessed i) the trend in historical rainfall and temperature in the two agro-ecological zones in South-Kivu and ii) projected change in rainfall and temperature for mid- and end century for selected representative pathways, and iii) the impact of projected climate change on paddy rice yield in two selected agro-ecological zones in South-Kivu, DRC.

MATERIALS AND METHODS

Study area

This study was conducted in the South-Kivu province, Eastern DRC, specifically in two agro-ecological zones namely high altitude plateau and semi-arid lowland of the province. One catchment was selected within each of the agro-ecological zone, and these included Luberizi in the semi-arid lowlands located in the Ruzizi plain in the territory of Uvira at altitude 773- 1000m and between latitude 2°21’-3°32’S and longitude: 28°35’-29°56’E; and Kavumu in the high altitude plateau located in the territory of Kabare at altitude 1500m and between latitude 2°15’-2°38’S and longitude: 28°12’-28°42’E. Kavumu has a high altitude tropical climate falling within the Aw3 type according to Koppen classification with an average annual rainfall of 1411 mm per year and mean daily temperature oscillating around 16.45°C while Luberizi in the Ruzizi plains has a semi-arid climate of type Aw4 with an average annual rainfall of 978 mm per year and an average mean temperature of 23.95°C (AgMerra database). Both Kavumu and Luberizi catchments are dominated by ferralsols. Kavumu, however, has clayey soils while Luberizi has sandy to sandy clay soils, with variable levels of clay and generally low organic matter and phosphorus content (Burnotte, 1949; DSRP, 2005).

Determination of historical trends in climatic parameters

Historical climate trends was determined by analyzing 30 years climate information (1980-2010) obtained from the NASA’s Modern Era-Retrospective Analysis for Research and Applications (AgMERRA). This information was grouped into monthly, seasonal and annual and analysed using regression techniques in GenStat 13th edition.

Projected rainfall and temperature change for the mid and end century

Projections of rainfall and temperature values were done using 1980-2010 as reference period (baseline period). A total of four scenarios were considered in this study as a combination of Two projection periods (Mid-century: 2040-2069, and End-century: 2070-2099) and two Representative Concentration Pathways (4.5 and 8.5). Twenty global circulation models (GCMs) namely 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, NorESM1-M, were used in this study. The projection followed the protocol developed under the AgMIP project (Rosenzweig *et al.*, 2013). The AgMIP protocol was chosen because

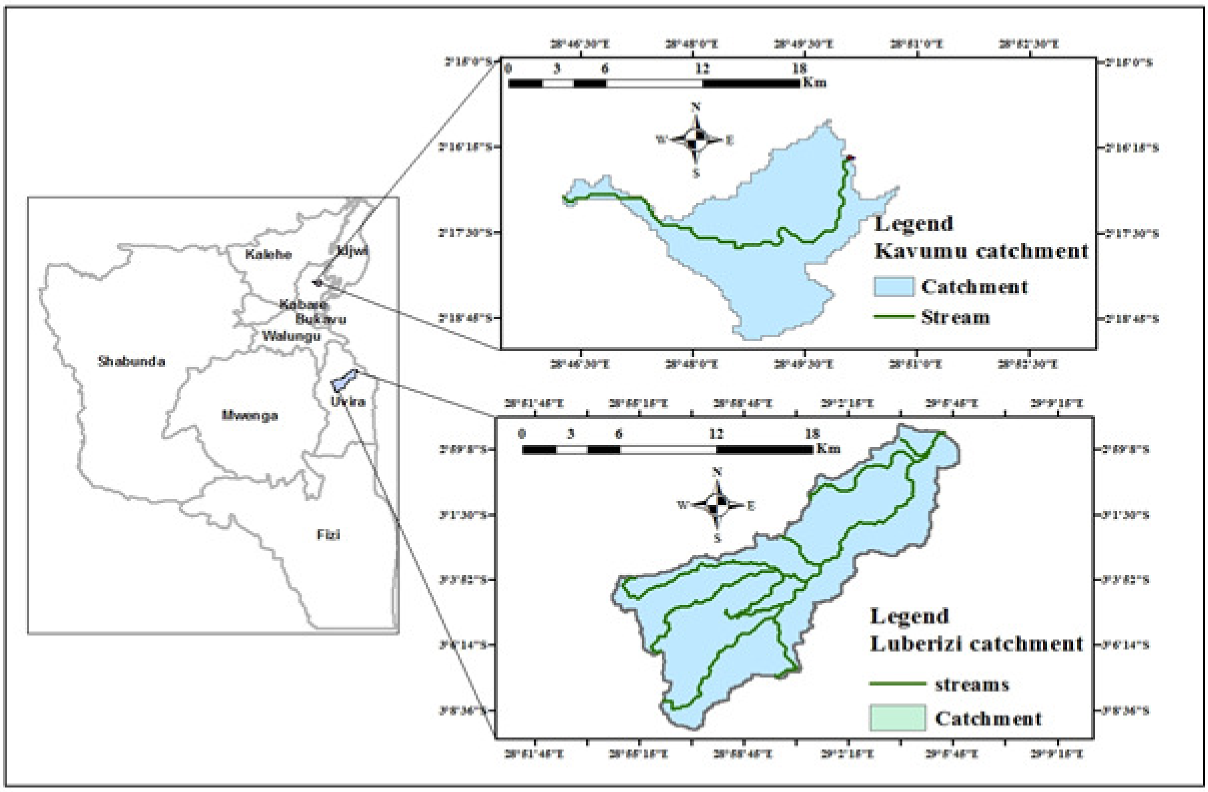

Figure 1: Location of the study area

it enables linked multi-model climate change assessments for agriculture at both regional and global scales in order to place regional changes in agricultural production in a global context.

Assembled mean of the twenty models were computed. The change in rainfall and temperature was determined using the formulas below:

$$\Delta T = Tp - Tb$$

$$R = \frac{(Rp - Rb) \times 100}{Rb}$$

Where:

$\triangle$T is the change in temperature, Tp is the average projected temperature, Tb is the average baseline temperature, R is the percentage change in rainfall, Rp is the average projected rainfall, and Rb is the average baseline rainfall.

Impact of future climate on paddy rice yield

The APSIM-rice model version 7.4 was used to simulate crop yield as a function of climatic conditions. The first step in the simulation process was to create the meteorological (met) files containing the required daily values for rainfall, minimum and maximum temperature and solar radiation. The annual average ambient temperature (TAV) and the annual amplitude in monthly temperature (AMP) were calculated using long-term daily minimum and maximum temperatures. The calculated values of TAV and AMP were inserted in the met files by the software program named “tav_amp”.

Input data related to soil characteristics included soil texture, pH, clay, silt and sand contents, organic carbon, electrical conductivity, cation exchange capacity, Aluminium (Al), Manganese (Mn), Potassium (K), Calcium (Ca), Magnesium (Mg), Sodium (Na) and Boron. Required data on soil characteristics were obtained from secondary data of soil analysis produced by the Catholic University of Bukavu soil laboratory. A local cultivar was used to simulate rice yields for the entire 30-year period (1980- 2010). Management practices used to simulate rice yields are listed in Table 1. In addition, Table 1 also presents the management practices used in the simulations.

Table 1: Management practices used to simulate rice yields

Parameters	Input data
Planting method	Transplanting
Planting date	30-August to 15-september
Plant population density (plants ha^{-1})	160000
Transplant age	21
Plant per hill	4
Irrigation technology	Automatic irrigation

The model was calibrated using measured grain yield data collected in the rice producing areas in Kavumu catchment from 2001 to 2008 (Xavier, 2010). Simple regression was used to compare measured and predicted rice grain yield (Figure 2) and was found to be highly significant ($p<0.05$) with a coefficient of determination (r^2= 0.64). The high coefficient of determination indicated that the trend of grain yield was successfully predicted by the model.

Sensitivity analysis was undertaken to assess the relative importance of temperature, solar radiation, and rainfall on predicted rice yield. Sensitivity analysis was carried out by changing one parameter at a time from the baseline scenario which reflects the actual historical condition for the experimental site. Maximum and minimum temperature were simultaneously increased by 1°C increment up to 5°C maximum possible increase limit. Rainfall was increased by 5% up to a 15% maximum possible increase limit. Atmospheric CO_2 concentration was kept fixed at 350 ppm and any change in solar radiation was considered. The "climate control" module was used to set incremental changes in temperature and rainfall.

Simulations were carried out by incorporating appropriate changes to "operations" file based on the conditions defined in AgMIP protocols. Results of this process are presented in Tables 2 and 3 revealing two trajectories of increase in yield under increasing temperature, especially in Kavumu and decreasing biomass under increased rainfall conditions in both sites.

All other factors remaining the same the impact of climate change was computed as relative change in yield using the average simulated rice yield for the period 1980-2010 being the reference.

Data analysis

Average annual and seasonal values for rainfall and temperature, and their coefficients of variation were computed using the AgMIP temperature and rainfall

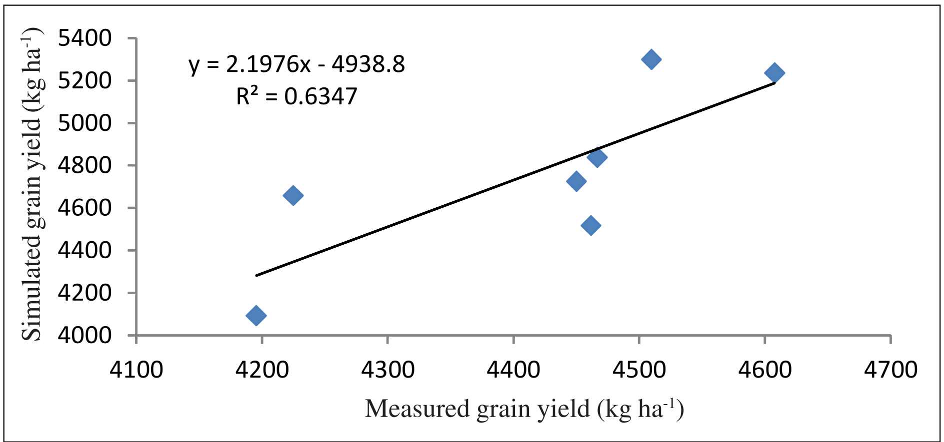

Figure 2: Comparison of measured and predicted rice grain yield grown in Kavumu catchment for years 2001-2008

Table 2: Sensitivity of rice yield to maximum and minimum temperature in the study area

Site	Tmax	Tmin	Biomass (kg ha^{-1})	Biomass change (%)	Yield (kg ha^{-1})	Yield change (%)
Kavumu	Base	Base	18505.06		4723.56	
	Base+1°C	Base+1°C	20144.52	8.86	5005.32	5.96
	Base+2°C	Base+2°C	20894.05	12.91	5365.41	13.59
	Base+3°C	Base+3°C	19335.05	4.49	6890.87	45.88
	Base+4°C	Base+4°C	18143.18	-1.96	7658.78	62.14
	Base+5°C	Base+5°C	17517.07	-5.34	7781.68	64.74
Luberizi	Base	Base	11640.57		4808.63	
	Base+1°C	Base+1°C	11415.9	-1.93	4864.56	1.16
	Base+2°C	Base+2°C	11145.11	-4.26	4868.66	1.25
	Base+3°C	Base+3°C	10927.8	-6.12	4877.15	1.42
	Base+4°C	Base+4°C	10733.23	-7.79	4861.25	1.09
	Base+5°C	Base+5°C	10589.37	-9.03	4847.03	0.8

Table 3: Sensitivity of rice yield to rainfall in the study area

Site	Rainfall	Biomass (kg ha^{-1})	Biomass change (%)	Yield (kg ha^{-1})	Yield change (%)
Kavumu	Base	18505.06		4723.56	
	Base+5%r	18496.73	-0.05	4717.2	-0.13
	Base+10%r	18487.98	-0.09	4711.79	-0.25
	Base+15%r	18483.87	-0.11	4705.96	-0.37
Luberizi	Base	11640.57		4808.63	
	Base+5%r	11563.41	-0.66	4769.1	-0.82
	Base+10%r	11489.35	-1.3	4734.35	-1.54
	Base+15%r	11416.88	-1.92	4700.72	-2.24

analyzer software. Trend analyses were generated in Excel and used to determine seasonal and annual variations in climatic parameters from 1980 to 2010 in the study area.

R software version 3.1 was used following the AgMIP protocol to evaluate climate predictions of the 20 GCMs considered. Regression techniques were further used to determine the possible relationships between projected climate parameters and yield.

RESULTS

Temperature trend (1980-2010) in Kavumu and Luberizi catchments

The trend in mean temperature is shown in Figures 3 and 4 for Kavumu and Luberizi, respectively. Average annual and seasonal temperature tended to increase linearly with time for both catchments ($p<0.01$). The gradient of temperature was relatively higher in Luberizi compared to Kavumu.

Rainfall and temperature trend in Kavumu and Luberizi catchments (1980-2010)

The average annual, and seasonal rainfall in Kavumu and their coefficient of variation are presented in Figures 5 and 6. The average annual rainfall, MAM and SOND rainfall amount did not change significantly with time. ($P>0.05$). The annual rainfall coefficient of variations (CV) and that of SOND decreased linearly with time ($P<0.05$) while the CV of MAM followed a quadratic trend with upward concavity. As for Kavumu the annual and seasonal rainfall did not change significantly with time. The CV tended to decrease linearly with time for annual rainfall amount, followed a quadratic shape with downward concavity, and tended to increase linearly for MAM (Figure 5 a, b, c).

Projected rainfall and temperature variation in Kavumu and Luberizi catchments

Projected temperature and rainfall for the two catchments are presented in Table 4. Under both RCPs (4.5 and 8.5), projected rainfall and temperature for mid and end-centuries are likely to increase in both catchments. The increment in rainfall, minimum and maximum temperatures will be higher in the end-century compared to the mid-century. Similar pattern is projected under RCP 8.5 compared to RCP 4.5 in both catchments. The increment in minimum temperature will be slightly greater than the increment in maximum temperature.

Impact of climate change on rice yield in mid and end century in Kavumu and Luberizi catchment

Model predictions of climate change impact on rice yield in Kavumu for both RCPs under Mid-century are depicted in Figures 7, 8 and 9. Generally, all the models predicted an increment in rice yield for both RCPs, except inmcm4 and Miroc-ESM for RCP 4.5. The predicted rice increment ranged from 2.69 to 44.9 % for RCP 4.5 and 0.28 to 55.1% for RCP 8.5. The highest increments were predicted by the HadGEM2-ES model under both scenarios while the highest decline was predicted by inmcm4 model under RCP 4.5.

All the model predicted rice yield increment for the End-century and both RCPs (Figure 8). The magnitude of rice yield change varied from 2.73 to 55.63% and from 33.07 to 69.36%, under RCP 4.5 and RCP 8.5 respectively. For RCP 4.5 the highest increment was projected by the HadGEM2-ES model (55.63%) while the lowest was projected by the IPSL-CM5A-LR model (2.73%). For RCP 8.5, the highest increment was projected by the MPI-ESM-LR model (69.36%)while the lowest was projected by the NorESM1-M model (33.07%).

Projected rice yield in Luberizi is shown in Figure 9 and 10 for RCP 4.5 and 8.5, respectively. Sixty percent of the models used predicted small increases in rice yield ranging from 1.08 to 3.39% and from 0.38 to 3.78% under RCP 4.5 and RCP 8.5, respectively, for Mid-century. However, some models such as ACCESS1-0 projected a decline of 30.82% and 32.43% under RCP 4.5 and RCP 8.5, respectively

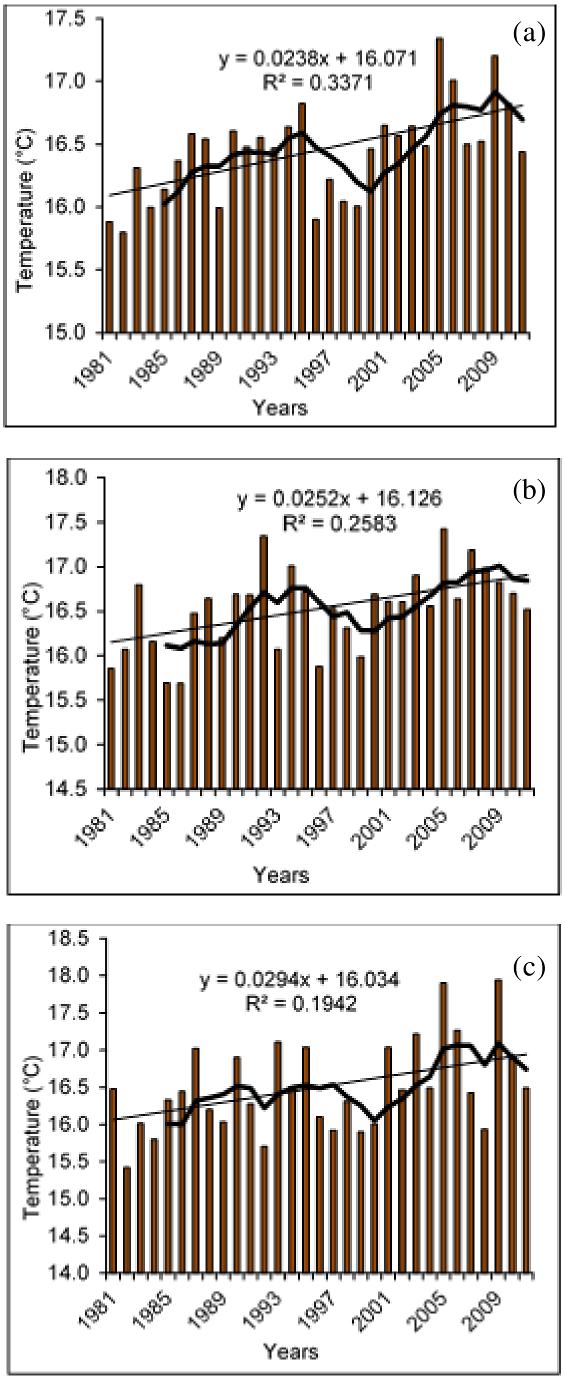

Figure 3: (a) Mean annual temperature trend, (b) mean season 1 (long rain) temperature trend, (c) mean season 2 (short rain) temperature trends, Kavumu catchment

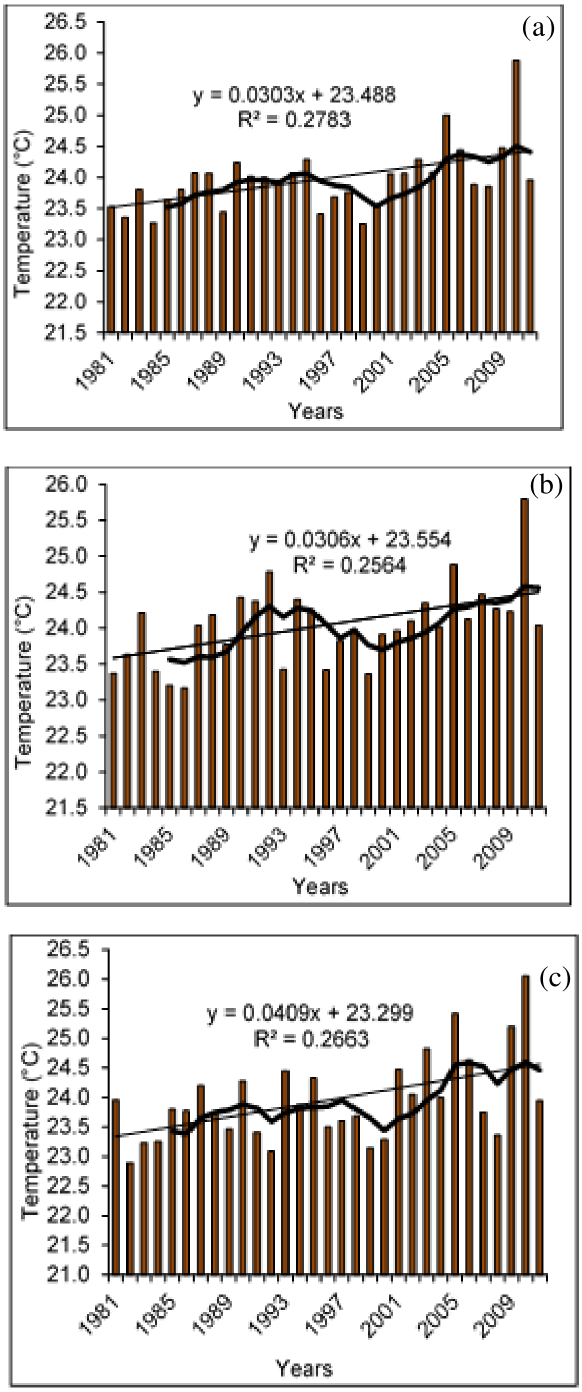

Figure 4: (a) Mean annual temperature trend, (b) mean season 1 (long rain) temperature trend, (c) mean season 2 (short rain) temperature trends, Luberizi catchment

Figure 10 depicts the projected change in rice yield in Luberizi at the end of the century. Sixty five percent of the models used predicted small increases in grain yield ranging from 0.39 to 7.20% under RCP 4.5. Like in the mid-century, ACCESS1-0 predicted the highest decline in rice yield of 33.55% and 39.08% under RCP 4.5 and RCP 8.5, respectively.

DISCUSSION

Annual and seasonal rainfall amounts in both catchments had remained constant during the 1980-2010 periods but temperature increased gradually with time in both catchments. The same pattern was observed by Nimusiima *et al.* (2013) in his study analyzing the nature and dynamics of climate variability in the Uganda cattle corridor. In both sites, most of the models predicted an increase in rainfall and temperature. The increment in rainfall amount is however projected to be relatively higher for Kavumu; while the increment in maximum temperature is projected to be relatively higher in Luberizi. The behavioral difference between the two sites is basically

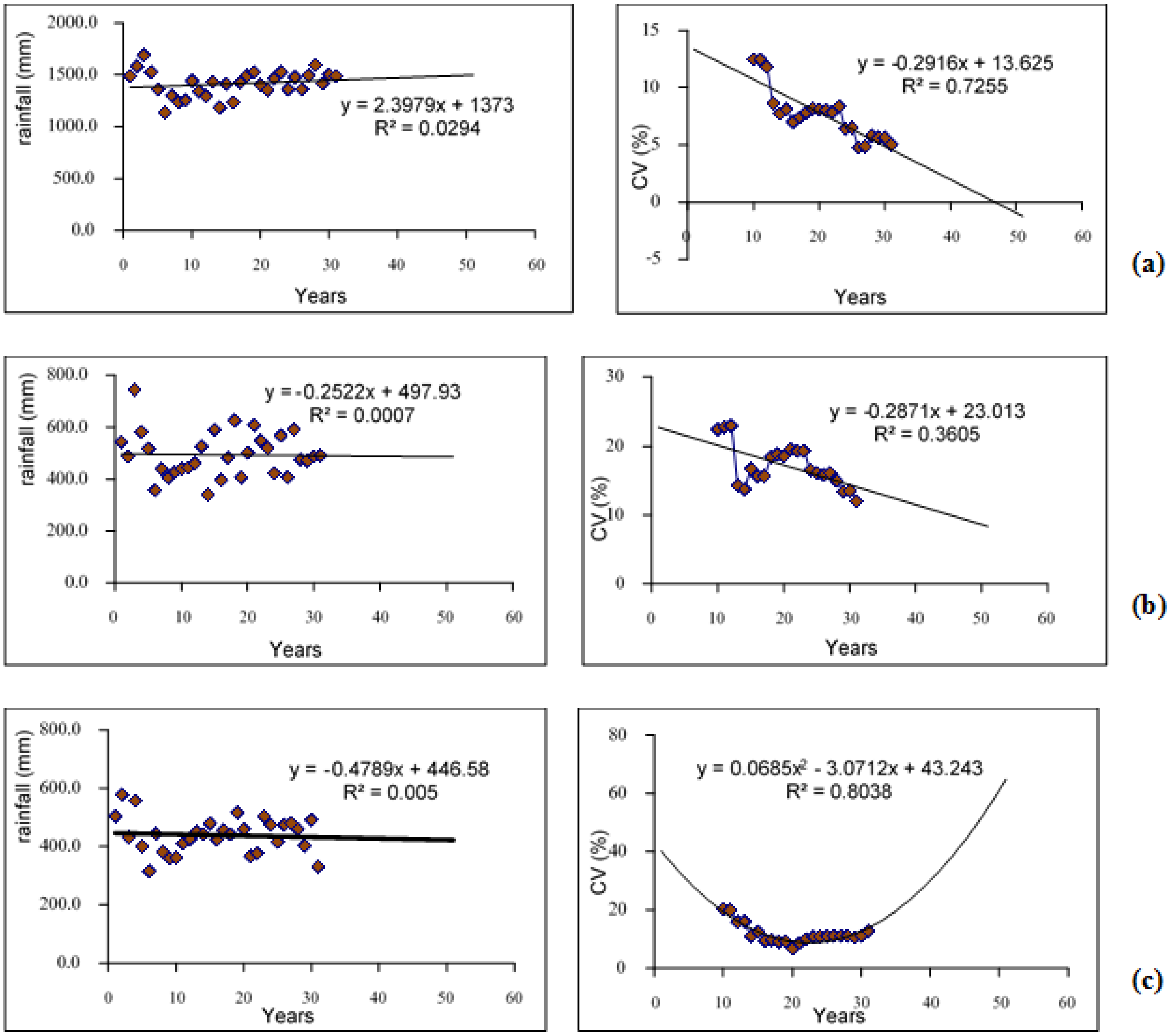

Figure 5: (a) Annual rainfall trend and its CV, (b) season 1 (SOND) rainfall trend and its CV, (c) season 2 (MAM) rainfall trend and its CV, Kavumu catchment

Table 4: Assembled means of projected changes in climate in mid and end centuries under RCP 4.5 and RCP 8.5 in Kavumu and Luberizi catchments

Site	Period	RCP 4.5			RCP 8.5		
		△Tmax (°C)	△Tmin (°C)	Rainfall (%)	△Tmax (°C)	△Tmin (°C)	Rainfall (%)
Kavumu	Mid-century	1.52	1.74	5.18	1.94	2.2	6.67
	End-century	2.35	2.43	6.1	4.09	4.19	14.72
Luberizi	Mid-century	1.7	1.88	3.14	2.09	2.34	4.74
	End-century	2.45	2.54	4.1	4.18	4.33	10.65

due to altitude. Altitude is recognized by several scholars (Siegenthaler and Oeschger, 1980; Gonfiantini *et al.*, 2001; McGuire *et al.*, 2005; Vimeux *et al.*, 2005, 2011; Kattan, 2006; Scholl *et al.*, 2009; Peng *et al.*, 2010; Morán-Tejeda *et al.,* 2013) as key measure of spatial variability, especially in mountainous catchments that cover high altitudinal ranges. Despite the complexity of the relationship between elevation, precipitation and temperature, it is a consensus that rainfall increases with altitude while temperature decreases with it.

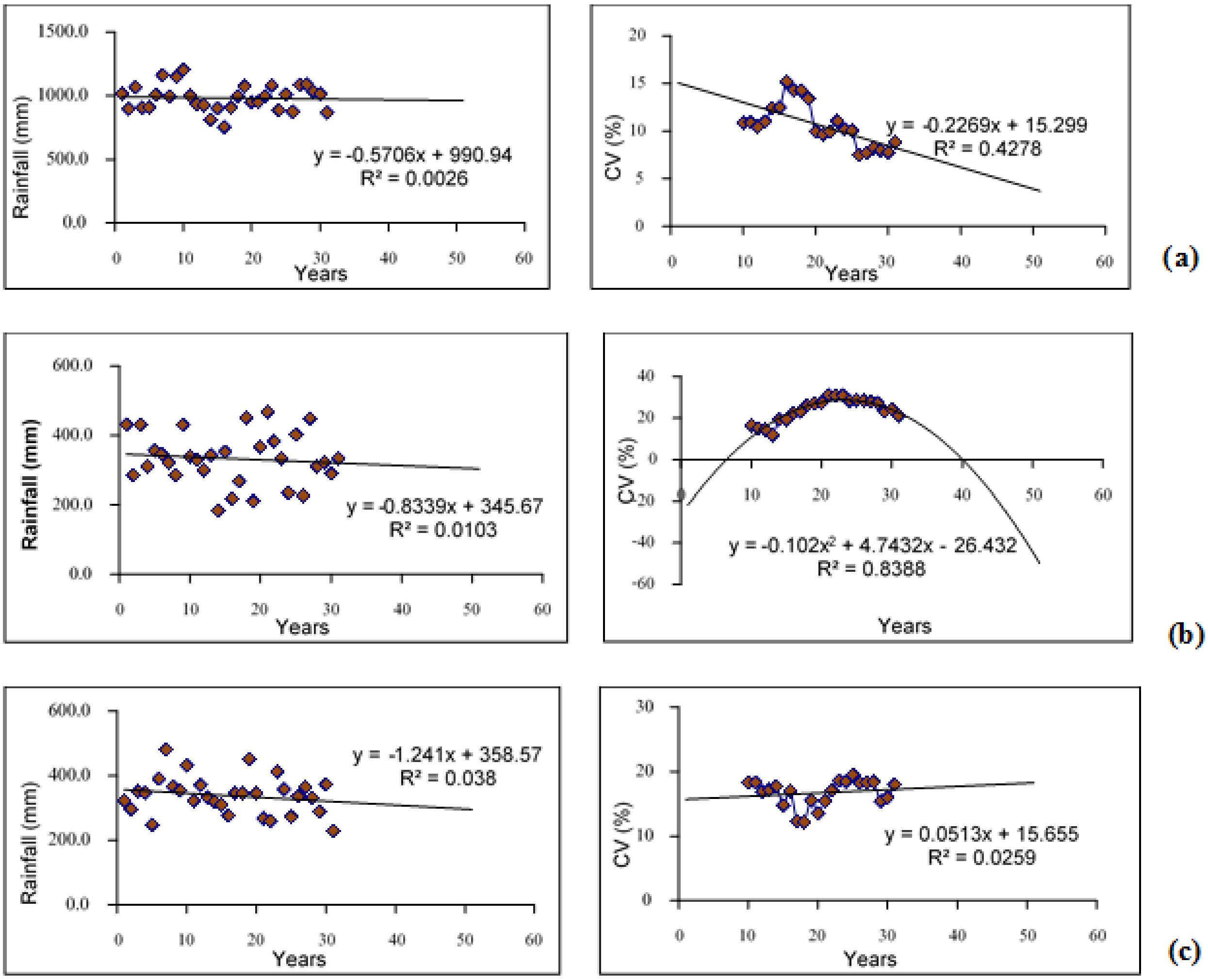

Figure 6: (a) Annual rainfall trend and its CV, (b) season 1 (SOND) rainfall trend and its CV, (c) season 2 (MAM) rainfall trend and its CV, Luberizi catchment

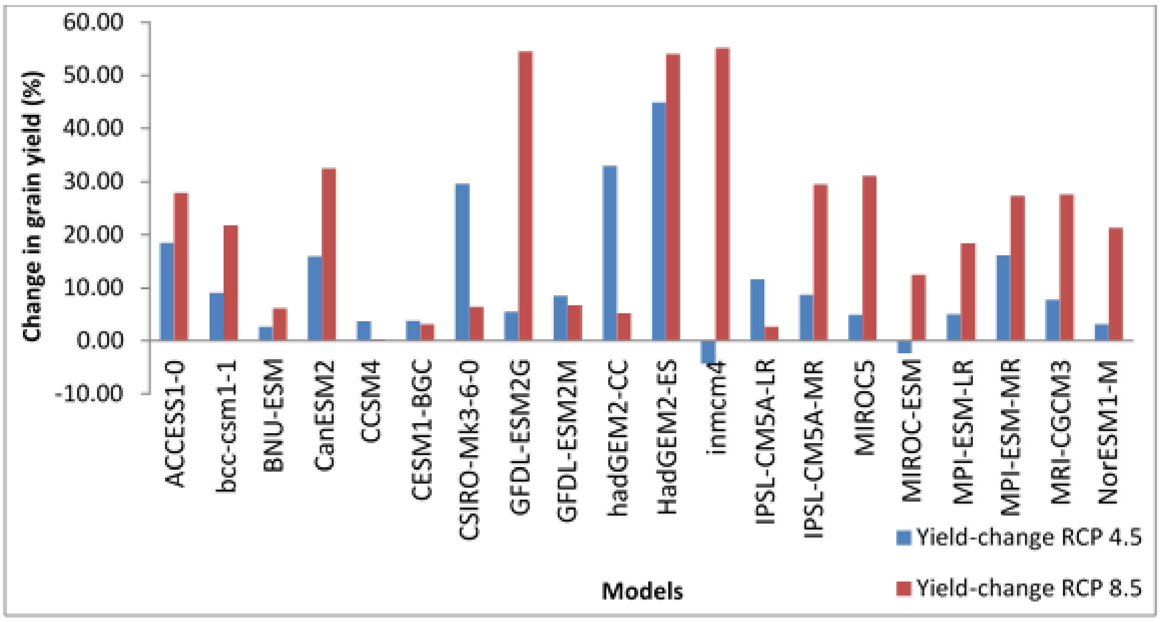

Figure 7: Impact of climate change on paddy rice grain yield in Kavumu catchment for RCP 4.5 and RCP 8.5 in mid-century

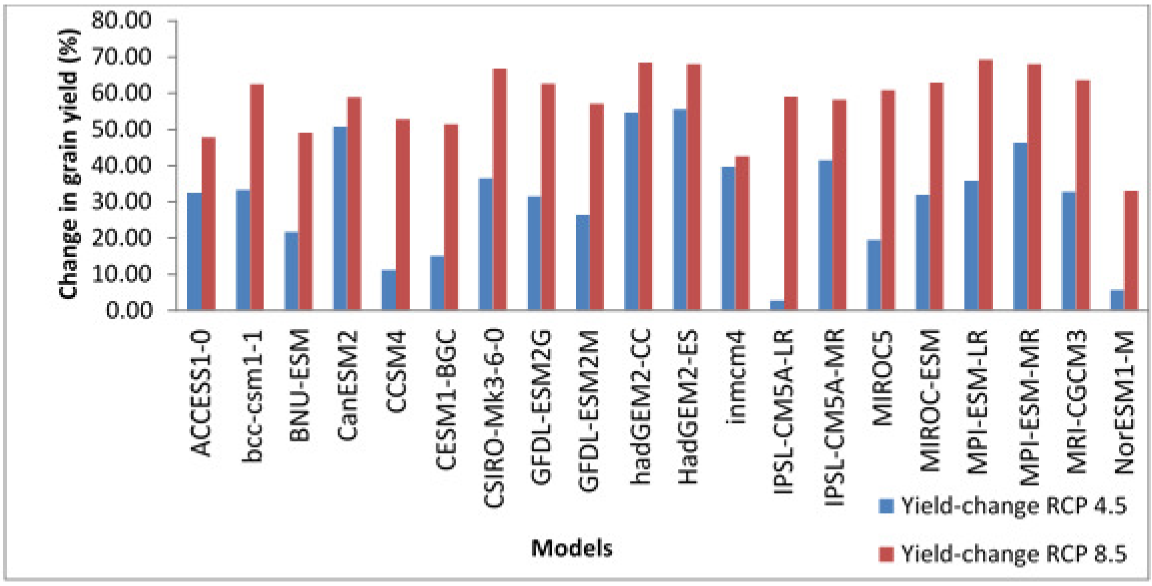

Figure 8: Impact of climate change on paddy rice grain yield in Kavumu catchment for RCP 4.5 and RCP 8.5 in end-century

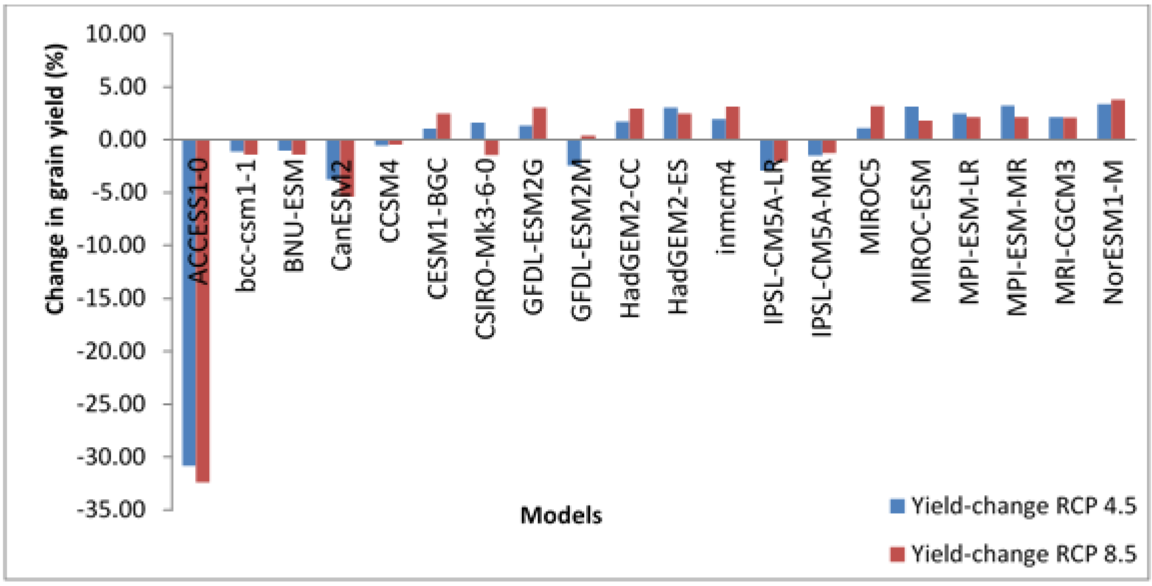

Figure 9: Impact of climate change on paddy rice grain yield in Luberizi catchment under RCP 4.5 and RCP 8.5 in mid-century

Subarna *et al.* (2014) noted a strong relationship (89%) between rainfall and elevation in the Cisangkuy watershed Bandung regency in Indonesia. Garcia-Martino *et al.* (1996) working on rainfall, runoff and elevation relationships in the Luquillo Mountains of Puerto Rico characterized by a subtropical maritime climate also found a significant relationship between elevation and mean annual rainfall as well as elevation and the average number of days per year without rainfall. A comparison of rainfall patterns between a high and a low elevation station indicated that annual and seasonal variations in rainfall are similar along the elevational gradient.

These projections are in line with earlier work by FAO (2008) that projected wetter conditions for wet areas of temperate regions and drier conditions for dry areas in the tropics. The results also corroborate projections of Herrero *et al.* (2010) in Kenya and Gwimbi *et al.* (2012) in Lesotho. Herrero *et al.* (2010) in Kenya, found that the coastal and lowland regions are likely to become drier, while the highlands and Northern Kenya are likely to become wetter. Gwimbi *et al.* (2012) using the CSIRO model, also projected that temperature will increase by 1 to 2°C throughout Lesotho by 2050, with lower increments in mountainous and highland zones. The model further projected a significant

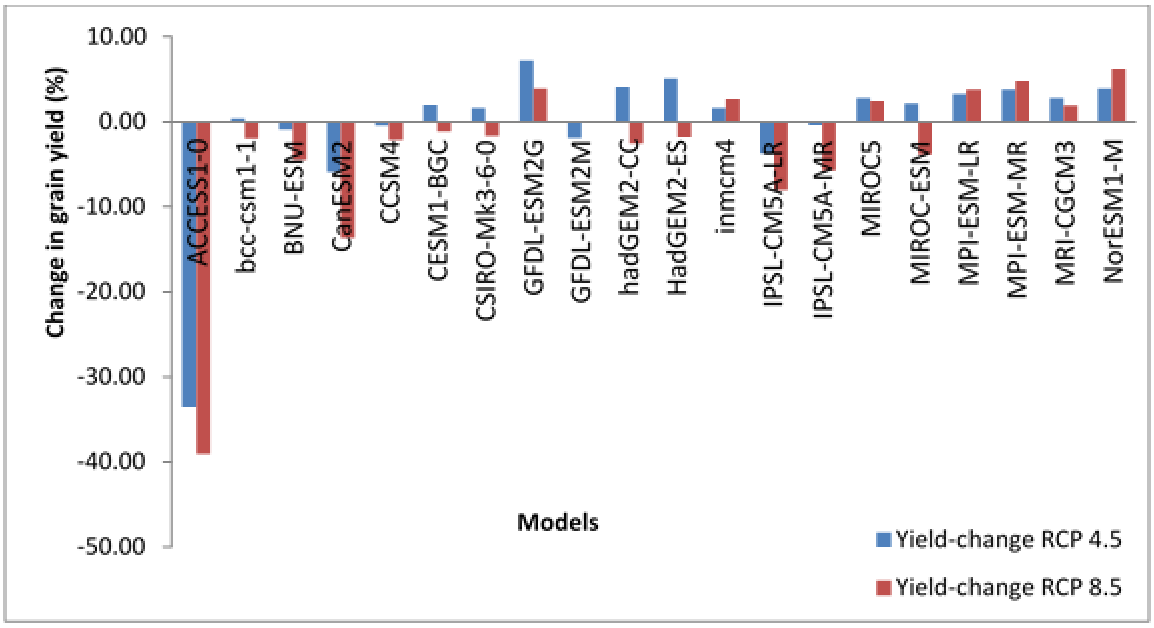

Figure 10: Impact of climate change on paddy rice grain yield in Luberizi catchment under RCP 4.5 and RCP 8.5 in end-century

decrease in rainfall (between 50mm and 100mm annually) in the lowlands and foothills, with little change in the mountains.

In the Kavumu catchment, grain yield is projected to increase with climate change. However, the magnitude of the increment will vary depending on the period and the scenario considered. Grain yield enhancement in Kavumu catchment is mostly attributed to the combined effect of the increase in temperature and rainfall as can be noted by the positive relationship between grain yield and temperature ($p<0.01$) and between grain yield and rainfall ($p<0.01$).

The low temperatures in the Kavumu catchment were found to be a limiting factor to rice production and that could be the reason why each increment in temperature had a direct positive impact on grain yield. Increase in rainfall on the other hand improved water availability. Rice farmers should take advantage of the weather induced benefits which are projected in the Kavumu catchment so as to boost rice production and hence food supply and rural development.

In the Luberizi catchment, grain yield is projected to slightly increase except for the end-century under RCP 8.5 where the majority of the models considered predicted a decrease. In this catchment the average daily temperature (23.96°C) at the baseline was already within the optimum range for rice production before any change in climate is considered.

Yield decline in Luberizi catchment in the end-century under RCP 8.5 could then be mostly associated with high-temperature-induced spikelet sterility (Matsui *et al*., 1997) as well as by the shortening of the growth duration, decrease in sink formation and increase in maintenance respiration (Matthews and Wassmann, 2003). According to Bachelet and Gay (1993), the acceleration of the development process of the crop due to temperature increase leading to shortening of the growth duration, results at the same time in most cases in incomplete grain filling and therefore reductions in yield. Stigter and Winarto (2013) recently found that temperatures beyond critical thresholds not only reduce the growth duration of the rice crop, but also increase spikelet sterility, reduce grain-filling duration, and enhance respiratory losses, resulting in lower yields and lower-quality rice grain. Rice producers in the Luberizi catchment would be negatively affected by climate change and hence the farm income as well as future food supply.

Adaptation strategies could then help rural farmers mitigate the impact of climate change in the area. This may include selection for varieties with improved tolerance to heat or drought, or adapted to take advantage of a longer growing season for increased yield (Wolfe *et al.,* 2008). Changing planting date and selection for shorter-maturing varieties to reduce exposure to extreme temperatures might even be a better strategy (Matthews *et al.*, 1997). Management practice is further one of the important strategies to overcome the adverse effects of climate change on rice production. Warmer temperatures and increased drought will lead to increase agricultural water use. Water storage facilities should be expanded and managed more efficiently. Use of water saving technologies in irrigation would also avoid oversupply at critical stages (Vaghefi *et al.*, 2011).

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this study the impact of climate change on rice production is predicted to be valid depending on location. Rice yield is projected to increase with climate change in Kavumu. Contrary, in Luberizi, a decline in rice biomass and a slight increase in rice yield followed by a decline in the end-century under RCP 8.5 is anticipated. Rice producers in the Luberizi catchment would be negatively affected by climate change resulting in reduced farm income as well as food supply. Positive effects are on the contrary projected for the Kavumu catchments.

Rice farmers and decision makers should be sensitized to take advantage of the weather induced benefits which are projected in the Kavumu catchment so as to boost rice production while appropriate adaptation strategies should be adopted in the Luberizi catchment which is projected to be more sensitive than the Kavumu catchment to future climate change. The downscaled climate information should also be used to assess the impacts of climate change on other crops and other sectors, as well as other part of the country in order to guide the development of a comprehensive climate change adaptation and mitigation strategy.

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STATEMENT OF NO CONFLICT OF INTEREST

We the authors of this paper hereby declare that there are no competing interests in this publication.

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