Assessment of the impacts of climate change on maize production in the Wami Ruvu basin of Tanzania

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ABSTRACT

The IPCC assessment reports confirm that climate change will hit developing countries the hardest. Adaption is on the agenda of many countries around the world. However, before devising adaption strategies, it is crucial to assess and understand the impacts of climate change at regional and local scales. In this study, the impact of climate change on rain-fed maize (*Zea mays*) production in the Wami-Ruvu basin of Tanzania is assessed using process based crop model the Decision Support System for Agro-technological Transfer (DSSAT). The model was calibrated using detailed field and household survey information of (crop yields, soil and management data inputs). Daily minimum and maximum temperatures, rainfall and solar radiation for current climate condition (1971-2000) as well as future climate projections (2010-2039), (2040-2069) and (2070-2099) for two Representative Concentration Path ways (RCPs): RCP45 and RCP85 scenarios were used to drive the crop model. These data are derived from three high-resolution regional climate models (RCMs), used in the Coordinated Regional Climate Downscaling Experiment program (CORDEX). Impact of climate change on maize production is assessed by analyzing the changes in simulated maize yields for the period 2010-2039, 2040-2069 and 2070-2099 relative to baseline period 1971-2000. Projection results from different models showed that due to climate change, the length of growing season and future maize yields over Wami-Ruvu basin will decrease under both RCP4.5 and RCP8.5 at the current, mid and end of the centuries. However, the projected yields estimates and the length of growing season differ from model to model highlighting the uncertainties associated with the projections. Climate data from the ensemble average of five model members was constructed to address the issue of uncertainties from individual climate models and used to drive DSSAT. Results showed that due to climate change future maize yields over Wami-Ruvu basin will slightly increase relative to the baseline during current century under RCP 4.5 and RCP 8.5. Meanwhile, maize yields will decline in the mid and end centuries. The spatial distribution shows that more decline in maize yields are projected over lower altitude regions due to projected increase in temperatures and decreased rainfall in those areas. The eastern part of the basin will feature more decrease in maize yields, while central parts of the basin and the western side of the basin will experience increase in maize yields during current, mid and end centuries under RCP 4.5 and RCP 8.5. The main reason for decrease and increase maize yields is the projected increase in temperatures that will reduce the length of growing seasons and hence affecting maize productivity. It is therefore recommended that appropriate and adequate adaptation strategies need to be designed to help the communities adapt to the projected decrease in maize production.

KEY WORDS: Maize yields, Climate change impacts, Regional climate model, Crop modelling

1. Introduction

Climate change studies including the latest IPCC assessment reports consistently show that many of the world's regions are already experiencing increasing frequency and severity of droughts and floods, increasing inter-annual and inter-seasonal rainfall variability, and warmer temperatures (IPCC 2007, 2013 and 2014). Developing countries, are particularly vulnerable to climate change, especially to extreme weather and climate events due to their high dependence on rain-fed agriculture and natural resources for their livelihoods (Sarker et al, 2012; Akram, 2010; IPCC, 2007, 2012 and 2013).The IPCC (2007) assessment report, projected that between 75 and 250 million of people in Africa will be exposed to increased water stress due to climate change by 2020. In some countries, yields from rainfed agriculture are projected to decline by 50%. Agricultural production, including access to food, in many African countries will be severely compromised (IPCC, 2007). This would further adversely affect food security and exacerbate malnutrition.

African countries need to prioritize on formulation of adaptation strategies and mitigation policy in order to prevent the destructive impacts of future climate change on agriculture (Rowhani et al., 2010). Tanzania as one of African countries will need to seriously consider its adaptation strategies, since agriculture is one of the largest sectors of Tanzania's economy (Ahmed et al., 2011). It is critical to ensure that there are adequate and credible adaptation strategies in this sector. However, in order to begin determining adaptation strategies for the agriculture sector, it is essential to have credible assessment of climate change impacts on crop production to have scientific evidence that would guide the formulation of adaptation policy.

Previous studies in Tanzania (Mwandosya et al., 1998; Agrawala et al., 2003; Ernhart and Twena, 2006; Enfors and Gordon, 2008; Thornton et al., 2009, 2010; Arndt et al., 2011; Ahmed et al., 2011; and Müller et al., 2011) have assessed the impact of climate change on crop production using climate simulation derived directly from General Circulation Models (GCMs). These models classically run at spatial resolution of 300 km or more such that their climate change projections cannot reproduce climate details at local or region scales where farming practices are predominant. The coarse resolution of GCMs, severely limits the direct use of their output in regional and sub regional decision making or in impact studies (Masson and Knutti, 2011; Daniel et al., 2012). This limitation is particularly strictly for countries like Tanzania with high regional heterogeneity of its climate, influenced by heterogeneous topography.

The limitation of direct use of GCMs outputs for decision making at regional and sub regional scales or in impact studies call into questions the many prior assessments of climate change impact on crop productions based on GCMs. Furthermore, adaptation strategies and mitigation policy developed based on GCMs simulations are not realistic and might pose significant challenges for anticipatory adaptation in many countries.

In this study we assess the impact of climate change on maize production over Wami-Ruvu basin of Tanzania using high resolution climate data from Regional Climate models (RCMs) and the uncertainties associated with the assessment from individual RCMs and driving GCMs. The main aim is to update the results from previous studies that were based on coarse resolution climate data from the GCMs. Maize is the most important cereal crop in perspectives on financial value and food security in Tanzania (Rowhani et al., 2010; Washington and Pearce, 2012), therefore deserve special attention to be examined on how future climate will affects its production. The Wami-Ruvu basin of Tanzania is chosen due to the fact that, the basin contain many agriculture projects that aims to develop the Southern parts of Tanzania, into a major regional food producer and engine of national economic development (Milder et al., 2012). Moreover, to the best knowledge of authors, there is no climate change impact study addressing knowledge problem in rain-fed area that have used high resolution climate information.

2. Data and Methodology

2.1 Study Area

Tanzania which is located in East Africa between latitudes 1°S and 12°S and longitudes 29°E to 41°E has nine basins (URT, 2013). The Wami-Ruvu basin which covers an area of about 66,820 km^2 is located in six regions: Dar es Salaam, parts of Coast, Morogoro, Dodoma, Tanga and Manyara in the eastern part of Tanzania along latitudes 5°–7°S and longitudes 36°–39°E. The topographical features of the Wami-Ruvu basin are described in detail in URT (2013), it is covered by low lying and mountains landscape (Fig.1). The dominant mountain landscape includes the Uluguru Mountains with an altitude of 400m to 2500m, Nguru Mountains with an altitude of 400 to 2000 m, Rubeho Mountains with an altitude of 500 to 1000 m, Ukaguru Mountains with an altitude of 400 to 1000 m and Nguu Mountains located in western part of Wami River with an altitude of 400 to 2000 m above mean sea level. The low lying areas include, Mkata plains with an altitude of 400-800 m, Lower Wami with an altitude of 200-400 m, Kisaki located south east of Uluguru mountain with an altitude of 140 to 200 m, Kimbiji and Mbezi located to the southern coastal area of Dar es Salaam with an altitude of 50 to 100 m above mean sea level.

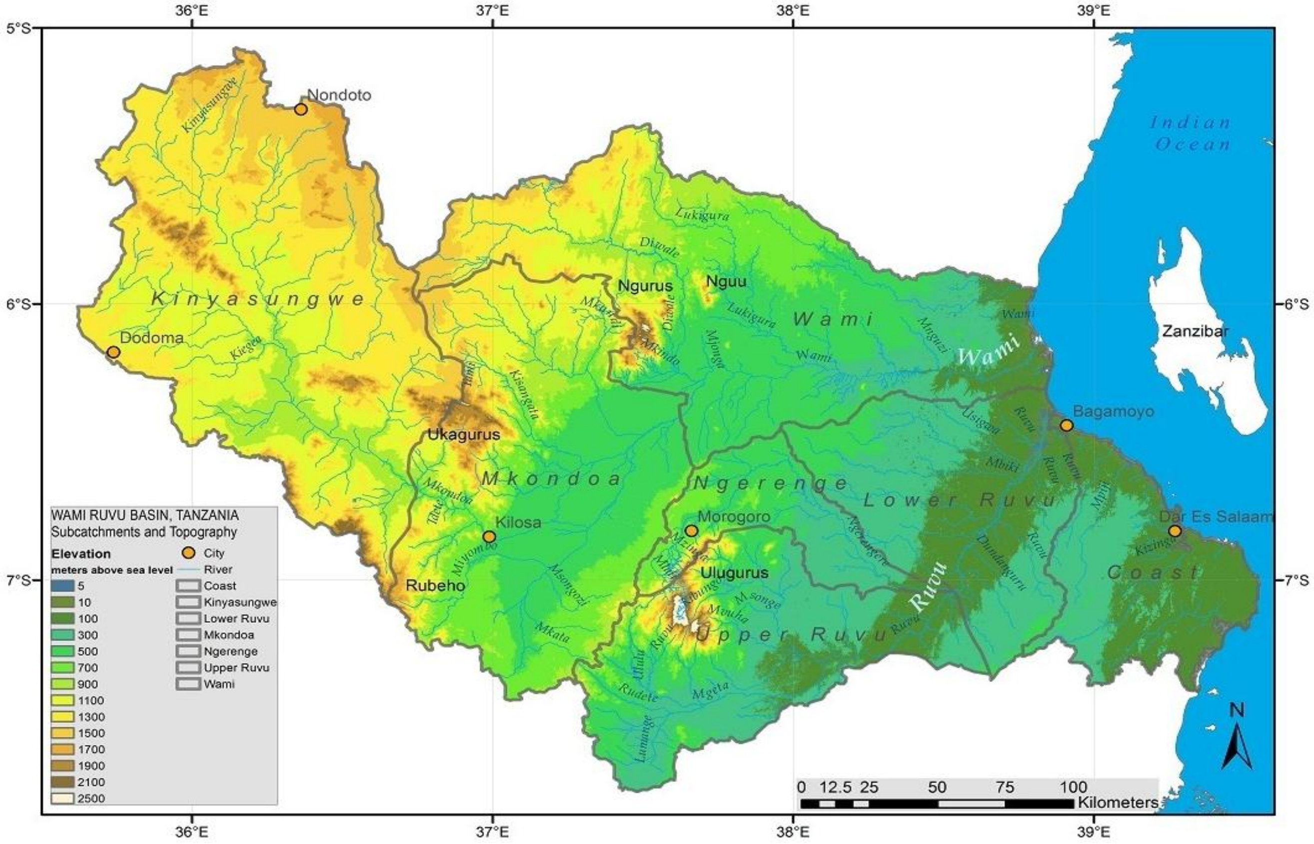

Figure 1. Topographical map of the Wami-Ruvu basin, (adopted from Global Water for Sustainability Program), available at: http://dpanther.fiu.edu/dpService/glowsProjectServices/project/iWASH%20(Tanzania)# accessed on 13.05.2016.

The Wami-Ruvu basin is divided into three sub basins: Wami sub basin which covers an area of 43,946 km^2, the Ruvu sub basin with an area of 18,078 km^2, and Coastal sub basin with an area of 4,796 km^2. These sub basins are further divided into seven sub catchments: Kinyasungwe, Mkondoa, Wami, Upper Ruvu, Ngerengere, Lower Ruvu and Coast sub catchments (Fig. 2).

The climate over Wami-Ruvu basin is mainly controlled by the movement of the Inter Tropical Convergence Zone (ITCZ), where some areas within the basin receive unimodal type of rainfall (due to single passage of the ITCZ), while others receive bimodal rainfall (due to double passages of the ITCZ). The former is experienced in the Wami sub basin (Kinyasungwe sub catchment), while the latter is experienced in Wami sub basin (Mkondoa and Wami sub catchments), Ruvu (Upper and lower Ruvu), Ngerengere and Coast sub catchments.

Although ITCZ is the dominant driver of rainfall within the basin, but its distribution is possibly influenced by orographic features. For example, in the plains annual rainfall ranges from 800 mm to 1000 mm near the Coast and 500-600 mm inland towards Dodoma and North of Wami sub-basin (Kashaigili, 2011). Over the high grounds, in the Uluguru Mountains, the annual rainfall exceeds 1500 mm (Mwandosya et al., 1998). The eastern slopes of Uluguru Mountain, receive highest annual rainfall of 2500 – 4000 mm while the western slopes receive an annual rainfall of 1200-3100 mm (Mbwaga, 2005). The Nguru-Rubeho Mountains receive rainfall between 800-1200mm, and the Ukaguru Mountains receive rainfall between 1000-1800mm annually (Kashaigili, 2011).

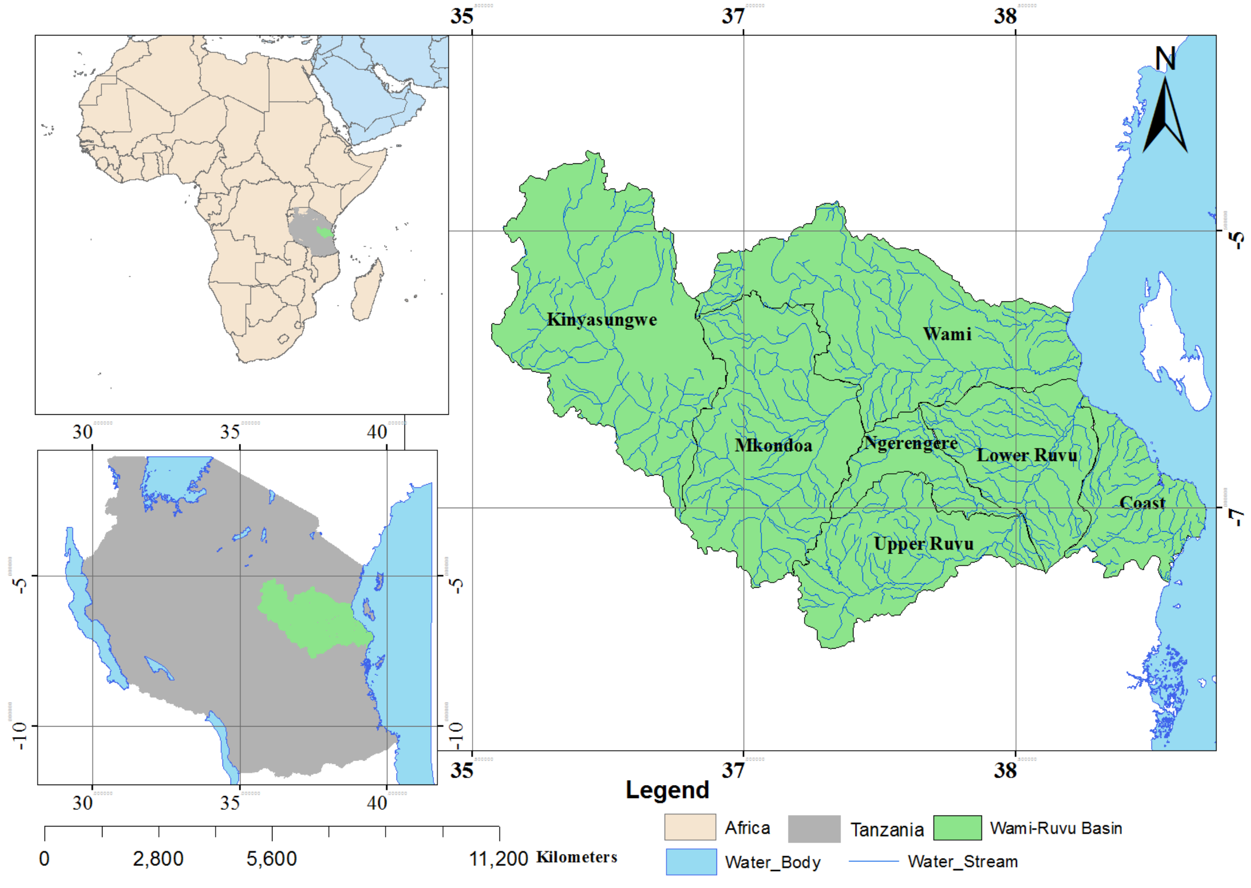

Figure 2 Map of Africa, and Tanzania showing the location of the study area the Wami-Ruvu basin and its seven sub catchment.

The Wami-Ruvu basin is characterized by twelve soils types: Cambisols, Ferralsols, Acrisols, Fluvisols, Luvisols, Lixisols, Arenosols, Leptosols, Nitisols, Vertisols, Planosols and Haplic Phaeozems (Fig.3) (URT, 2013). The dominant soils are Cambisols which cover parts of Bagamoyo, Kisarawe, Mkuranga, Morogoro Rural, Dodoma Urban, Bahi and Chamwino. These types of soils make good agricultural land and are intensively used for agriculture production.

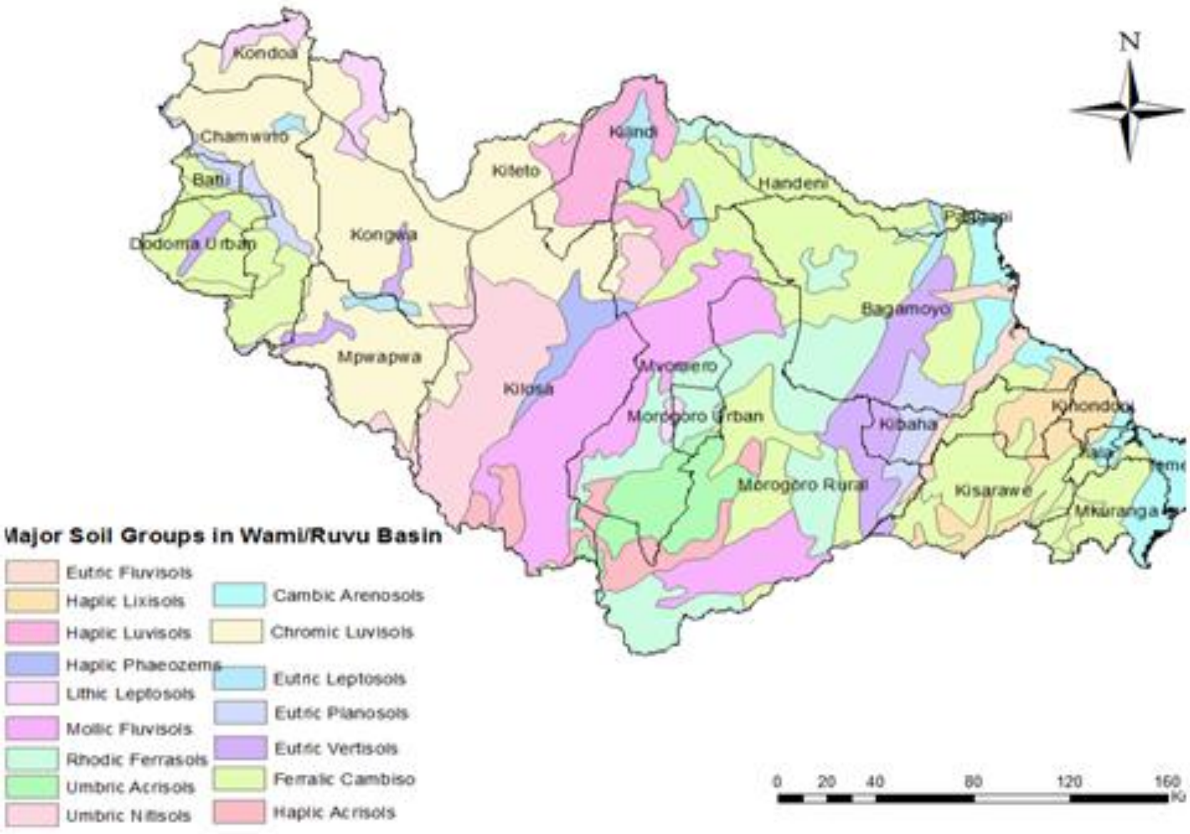

Figure 3, Major soil groups in Wami/Ruvu Basin (adopted from URT, 2013)

Farming activities in Wami-Ruvu basin are shaped by two agro-ecologies: semi-arid and sub-humid agro-ecologies. The earlier covers parts of Dodoma region and the latter covers parts of Morogoro, Tanga and Coast regions. Crop production in the basin is mainly subsistence, with small scales. However in recent years the basin has witnessed many agriculture projects, which are outlined in URT, (2012), includes the FEED the FUTURE with an investment cost of USD 300 million, Tanzania Bread-Basket Transformation Project with an investment cost of USD 173 Million, Southern Agriculture Corridor of Tanzania (SAGCOT) with an investment cost of USD 3.4 billion and Rural Livelihoods Development Programme (RLDP) with an investment cost of USD 21 million.

2.2 Data

2.2.1 Data from RCMs simulations

This study makes use of high resolution climate simulation from the Coordinated Regional Climate Downscaling Experiment program regional climate models (CORDEX_RCMs). CORDEX program is archiving outputs from a set of RCMs simulations over different regions in the world. Fig.4 indicates the CORDEX domain for model integrations. Data sets from CORDEX Africa are accessed from http://cordexesg.dmi.dk/esgf-web-fe/ website. These data sets are quality controlled and may be used according to the terms of use (http://wcrp-cordex.ipsl.jussieu.fr/). The spatial grid resolutions of all CORDEX_RCMs are set to longitude 0.440 and latitude 0.440 using a rotated pole system coordinate where the model operates over an equatorial domain with a quasi-uniform resolution of approximately 50 km by 50 km. For detailed description of CORDEX RCMs and their dynamics and physical parameterization a reader may consult Nikulin et al (2012). The CORDEX_RCMs and their driving GCMs used here are listed in Table 2.

Daily values of minimum, maximum temperatures, rainfall and solar radiation from CORDEX_RCMs for two Representative Concentration Pathways (RCP4.5) and (RCP 8.5) scenarios for the period 1971-2000, 2010-2039, 2040-2069 and 2070-2099 are used. Since climate model simulate climate variables at grids, interpolation technique of inverse square distance weighting average is used to transfer model grid climate simulation to the location where farming is carried out. This enables to use site specific climate information to simulate maize yields. For detailed description about the inverse square weighting average interpolation technique the reader may consult Hartkamp et al (1999) and Ly et al (2013). Interpolated daily minimum, maximum temperatures, rainfall and solar radiations from individual CORDEX_RCMs are used by crop model to simulate maize growth, development and yields.

2.2.3. Data for Soils profiles and Management practices

A total of 20 soil profiles data are used in this study, 8 were excavated within the study region and 12 were obtained from Africa soil profiles database (Leenaars, 2013). The hydrological characteristics of layers for each soil profile are estimated using soil water properties calculator (Saxton and Rawls 2009). Where input parameters are soil type (sand, silt or clay) and organic matter, whereas the output parameters are drained lower limit (SLLL; mm mm−1), drained upper limit (SLDUL; mm mm−1), saturation (SLSAT), and water content for each soil layer (Table 1).

Table 1 Soil physical and chemical characteristics at Mvomero research station, Morogoro, Tanzania

Soil depth	Lower limit	Upper limit	SAT	BD	pH	NO3	NH4	ORG
cm	cm3/cm3	cm3/cm3	cm3/cm3	g/cm3		ugN/g	ugN/g	%
0-5	0.116	0.253	0.432	1.1	5.4	0.45	0.15	0.24
5-15	0.116	0.253	0.432	1.1	5.4	0.45	0.15	0.24
15-30	0.116	0.31	0.452	1.1	5.2	0.45	0.15	0.24
30-45	0.116	0.31	0.452	1.1	5.2	0.45	0.15	0.24
45-67	0.131	0.31	0.468	1.2	6	0.45	0.15	0.11
67-90	0.131	0.31	0.468	1.2	6	0.45	0.15	0.11

Management practices and actual and previous yield information, types of fertilizers were obtained from a comprehensive household panel survey database (National Bureau of Statistics 2012) (Table 2). Information about planting and harvesting dates, planting density and the type of maize cultivars used per farm were obtained from interview conducted across the study region. This information was used to create crop model input data files.

Table 2. Datailed information about the farms used to create crop model data input files

Location name	No.farms	Planting.date	Planting.month	Planting density. (Plants/m2)	Planting spacing (cm)	Nitrogen(Kg/ha)	Maize yields (Kg/ha)	By-product (Kg/ha)	Planting window (mm/dd)
DODOMA	15	1-30	12-1	3	75	50	683	3	12/01-12/15
KONGWA	13	1-30	12-1	3	100	40	603	3	12/01-12/15
MLALI	16	2-28	2-3	4	75	0	571	7	02/02-02/16
MOROGORO	9	2-31	3-3	3	75	40	736	7	03/02-03/16
MLALI-VILLAGE	11	3-29	12-1	2	100	40	1229	2	12/03-12/17
UKAGURU	15	2-28	2-3	3	75	50	871	7	02/02-02/16
NONDOTO	11	2-30	12-1	2	75	0	979	3	12/02-12/16
CHIBWANGULA	10	3-26	12-1	3	75	0	609	3	12/03-12/17
IDIFU	8	2-30	12-1	3	100	0	222	3	12/02-12/16
KIBERASHI	11	1-23	2-3	3	75	0	800	6	02/01-02/15
WAMI-TULIANI	16	1-23	3-3	3	77	30	996	7	03/01-03/15
KILOSA	11	5-31	3-3	3	75	10	1224	5	03/05-03/19
ULAYA	11	7-25	12-1	3	80	10	960	3	12/07-12/21
MBWEWE	8	1-28	2-3	3	75	40	1287	6	02/01-02/15
KIBAKWE	3	15-9	12-1	4	100	40	2167	7	12/15-12/29
GRAND TOTAL	168						861	5	

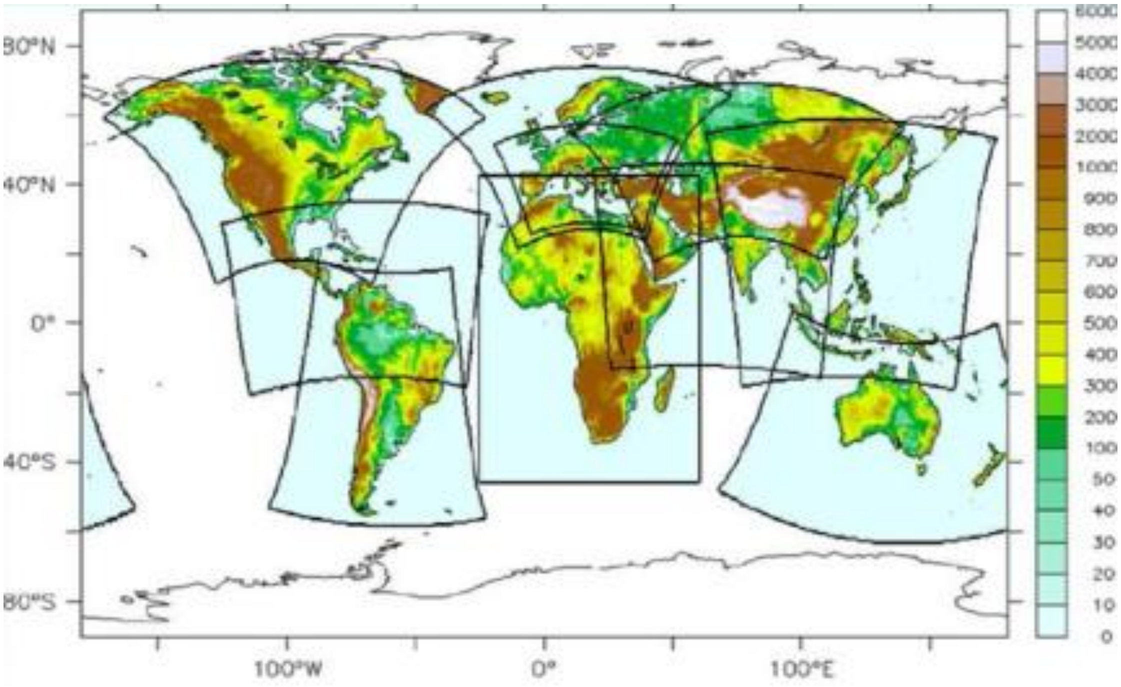

Figure 4 CORDEX regional domain (adopted from Pechlivanidis, 2013)

Table 3. Details of CORDEX-RCMs and the driving GCMs

No	Regional Climate Model	Model Centre	Short name of RCM	Short name General Circulation Model
1	DMI HIRHAM5	Danmarks Meteorologiske Institut(DMI), Danmark	HIRHAM5	ICHEC-EC-EARTH
2	SMHI Rossby Center Regional Atmospheric Model (RCA4)	Sveriges Meteorologiska och Hydrologiska Institut (SMHI), Sweden	RCA4	MPI-M-MPI-ESM-LR ICHEC-EC-EARTH CNRM-CERFACS -CNRM-CM5
3	KNMI Regional Atmospheric Climate Model, version 2.2 (RACMO2.2T)	Koninklijk Nederlands Meteorologisch Instituut (KNMI), Netherlands	RACMO22T	ICHEC-EC-EARTH

2.2.2 Crop model

Crop models simulate crop growth by numerical integration of constituent processes with the aid of computers (Graves et al., 2002). They are used to study crop growth and calculate growth responses to environmental changes. There are different types of crop models that can be classified as descriptive and explanatory. The descriptive model simulates the behaviour of the system (plant organs and processes) in a simple way (Miglietta and Bindi, 1993), where experimental data are used to develop one or more mathematical equations to describe the system. These types of models are suitable only when a quick look is required to describe the behaviour of a crop under field condition where condition relatively remains stable. Explanatory crop models describe quantitatively the mechanisms and processes that cause the behaviour of the system. To develop explanatory crop model a system is analysed where its processes and mechanisms are quantified separately. An example of explanatory crop model is the Decision Support System for Agro-technological Transfer (DSSAT). This model has been widely used worldwide over the last two decades because it is reasonably accurate, process-oriented, simple to use and requires minimum data sets. The model requires daily solar radiations, minimum and maximum temperatures and rainfall. The other input parameter of the model includes soil properties, crop characteristics and management practices such as planting and harvesting dates, row spacing, plant population, irrigation amount, fertilizer rate and date of application. In this study, we use DSSAT version 4.5 to simulate maize yields over Wami-Ruvu basin of Tanzania. This version has 28 different crop models and new tools to facilitate creation and management of experimental, soil, and weather data files. DSSAT version 4.5 has new application programs for analysing crop rotation to assess economic risks and environmental impacts. For instance impacts from irrigation, fertilizer and nutrient management, climate variability, climate change, soil carbon sequestration, and precision management.

3. Model input files

A new protocol of the Agricultural Model inter-comparison and Improvement Project (AgMIP) was used. This protocol has new computing tools for crop modeling and has capacity to handle data from multiple sites through different software such as Data overlay for Mult-model Export (DOME), that contain data for field overlay, AgMIP Crop Experiment (ACE) database that contains site based crop experiment or from farm survey. The data are translated into format ready for crop model using QuadUI desktop utility. For detailed information about AgMIP protocol the reader may visit www.agmip.org. The data preparation was done by creating three excel files: (1) the first file is the FIELD ALL, it contain all information from each farm/field, the file contain information about the planting dates, soil profiles, type and amount of fertilizer used per farm, plant population, plant row spacing and weather stations used (2) the second file the FIELD OVERLAY, it contain information about soil organic carbon, soil water and nitrogen contents, types of cultivars, where in this study SITUKA maize was used due to its drought tolerance and is grown by many farmers in the study area (3) the third file is SEASONAL STRATEGIES contain information about the span of the year from which simulation is carried, the concentration of atmospheric carbon dioxide, automatic planting date and windows. In this study planting date was set to start automatic within planting window only if cumulative rainfall reaches 25mm in three consecutive days. These excel files are translated by QuadUI desktop utility to DSSAT folder. From this folder simulation was initiated by running DSSAT45.BAT file

3.1.0 Model calibration and validation

The Crop–Environment–Resource–Synthesis (CERES)-Maize model is incorporated within DSSAT 4.5 to simulate maize yields as influenced by several factors. The calibration and validation of CERES-Maize model to obtain reasonable estimates of model genetic coefficient was performed by comparing simulated and observed maize yields data at 168 farms (Table 2). The calibration was robust since there was good agreement between simulated and observed yields with coefficient of determination (R^2) of .91. For detailed description on how the model was calibrated and validated a reader may consult Mourice et al (2014).

3.1.1 Simulation of maize yield

Using the calibrated CERES maize model, maize yields simulation was carried out with historical climate data from individual RCMs for the baseline period 1971-2000 and future projections: 2010-2039, 2040-2069 and 2070-2099 for RCP4.5 and RCP 8.5 scenarios. In order to address properly the uncertainties introduced by the climate models in simulating maize yields, an ensemble average of three CORDEX_RCMs driven by three different GCMs was constructed for RCP 4.5 and RCP 8.5 and used to force CERES maize model to simulates maize yields for baseline period (1971-2000), near future (2010-2039) mid (2040-2069) and end centuries (2070-2099).

3.1.2 Spatial interpolation of climate variables, length of growing seasons and maize yields

The spatial distribution of length of growing season, maize yields, seasonal minimum (TN), and maximum (TX) temperatures, rainfall and solar radiation was estimated using the Inverse Distance Weighting (IDW) interpolation technique. This is the deterministic interpolation method. This technique produce interpolated value in the range of input values. The interpolated value is not greater than the highest or lower than the lowest values of input data. The influence of an input point data on interpolated value is isotropic since the influence on the input data point is distance related (Philip and Watson, 1982). The results from this method may not represent the desired surface when the sampling input points are sparse or uneven (Watson and Philip, 1985). This method work in such a way that the characteristics of interpolated surface can be controlled by limiting the input data points used in the calculation of each output data. This can be done using variable or fixed search method. Under variable search method, interpolated value is calculated even if the is no enough points within the maximum distance search radius to meet number of points criteria, then the point within maximum distance are used. If the minimum point required for estimation of unsample data point, the search radius is increased until the required number of points is satisfied. The search radius is increased until the required minimum number of point fall within the radius. The interpolated points used in this study were from 15 farms distributed in the basin almost evenly.

4. Results

The impact of climate change on maize production in the Wami-Ruvu basin of Tanzania is assessed using a dynamic crop growth model CERES-maize embedded within DSSAT version 4.5. The model was run under fixed atmospheric carbon dioxide concentration (of 360ppm). This was to limit simulation of other crop processes such as photosynthesis that can affect yields. The change in maize yields simulated here are due to change in climate variables which are derived from the climate models during the present, mid and end centuries under RCP 4.5 and RCP 8.5 scenarios. The climate projections from the RCMs driven by GCMs are used to drive CERES maize model. It is important to note that all presented results are for the main growing season in the study area, that starts from December and ends early June (Table 2).

4.1 Temporal averaged maize yields for the baseline period (1971 -2000).

The temporal averaged maize yields over Wami-Ruvu basin simulated by CERES forced by climate data from different RCM-GCM combinations for the baseline period (1971-2000) are presented in Table 4-8. These tables show that average maize yields over Wami-Ruvu basin for the baseline period (1971-2000) differs when CERES is forced with different RCM-GCM sets. Highest maize yields of 1303 Kg/ha is simulated by CERES forced with RACMO22T-ICHEC and lowest maize yields of 951 Kg/ha is simulated by CERES forced with RCA4-CNRM. CERES simulates maize yields over Wami-Ruvu basin differently even when forced with RACMO22T and HIRHAM5 both driven by same GCM. Mean maize yields of 1303 Kg/ha and 1158 Kg/ha are simulated by CERES forced with RACMO22T and HIRHAM5 respectively. This variation is mainly due to differences in RACMO22T and HIRHAM5 formulation.

CERES simulates maize yields differently even when forced by same RCM driven by different GCMs. It simulates maize yields of 1126 Kg/ha, 1212 Kg/ha, and 951 Kg/ha when forced with RCA4 driven by

ICHEC, MPI and CNRM respectively. These variations are mainly coming from differences in formulation of the driving GCMs. Therefore simulation of maize yields using climate data from individual RCM-GCM sets have large uncertainties that come from both RCM and driving GCM.

To account for uncertainties that arise from RCM and driving GCM, the ensemble average of 5 climate model members was constructed and used to force CERES. Table 9 shows maize yields simulated by CERES forced with ensemble average. This maize yields differ greatly from that of individual models. This is an indication of large uncertainties involved in climate change impact studies particularly for the agriculture sector. However, results from ensemble average that take into account the uncertainties from individual RCMs and driving GCMs are the best estimate of future climate change in the basin. Therefore CERES driven by ensemble average provide reliable estimate of future maize yields in the Wami-Ruvu basin.

4.2 The impact of climate change on maize yields over Wami-Ruvu basin.

The percentage change in maize yields relative to the baseline over Wami-Ruvu basin for present (2010-2039), mid (2040-2069) and end (2070-2099) centuries under RCP 4.5 and RCP 8.5 are presented in Table 4-9. It is clear that the impacts of climate change on future maize yields are not considerably big in comparison with the simulated baseline yields. Table 4 presents maize yields when CERES is driven by RACMO22T-ICHEC. From this table, decrease in maize yields by 2.2%, 2.8% and 2.2% are projected in 2010-2039, 2040-2069, and 2070-2099 respectively under RCP 4.5. Slightly more decrease in maize yields is projected under RCP 8.5 where maximum decrease in maize yields of 4.8% is projected during the end century. This projected change in maize yields are mainly attributed to increased maximum and minimum temperatures. Hampton et al (2012) indicated the increase in temperatures reduces pollen viability, reduces seed yields and reduces seed germination. Moore et al (2011) suggests that increase in temperatures reduce the length of growing season that can either decrease yields (if currently warm) or increase yields (if currently cool).

Table 4 and 5 allows the analysis of the performance of RCMs in simulating future maize yield over Wami-Ruvu basin whereas CERES forced with RACMO22T and HIRHAM5 both driven by ICHEC GCM simulate future maize yields differently under RCP4.5 and 8.5. For instance decrease in maize yields by 2.2%, 3.4% and 3.0% are projected in 2010-2039, 2040-2069, and 2070-2099 respectively, when CERES was forced with HIRHAM5 under RCP4.5. This change in maize yields slightly differs with what was observed when CERES was forced with RACMO22T under the same scenario during mid and end centuries. Table 5 shows that maximum decrease in maize yields is projected during the end century under RCP8.5 with a decrease of 6.7% whereas the minimum decrease in maize yield is projected during the present century (2010-2039) with a decrease of 0.5% under the same scenario RCP 8.5.

The impact of driving GCMs on simulated maize yield can be characterised in Table 6-8, where CERES forced with RCA4 driven by three different GCMs simulates maize yields differently. The variations in simulated maize yields are mainly due to differences in GCMs formulations.

In general, CERES forced with different RCM-GCM sets simulate maximum decrease in maize yield during the end century under RCP 8.5. Furthermore, projected maize yields over Wami-Ruvu basin showed a consistent decline in present, mid and end centuries, except a slight increase of maize yields is simulated by CERES forced with RCA4-CNRM during present century under RCP 8.5.

Table 9 shows simulated maize yields when CERES is forced by ensemble average. From the table it is clear that increased maize yield is projected during the current century under RCP4.5 and RCP 8.5 and decrease in maize yields is projected during the mid and end centuries under RCP 4.5 and RCP 8.5. Minimum decrease in maize yields of 0.7% is projected during mid century under RCP 4.5 and maximum decrease of 4% is projected during mid century under RCP 8.5. The increase in maize yields during current century and decrease in maize yields in mid and end centuries is due to slightly increased temperatures and rainfall in current century and more increased temperatures during the mid and end centuries that shortened the length of growing season by triggering maturity stages faster.

Table 4 Maize yields and seasonal climatic variable as simulated by crop model fed with climate data from RACMO-RCM for (.)RCP4.5 and (..)RCP8.5

	1971-2000	2010-2039		2040-2069		2070-2099	
	Mean	Mean	% change	Mean	% change	Mean	% change
Maize-yield(kg/h)	1303	1274(.)	-2.2(.)	1266(.)	-2.8(.)	1275(.)	-2.2(.)
		1273(..)	-2.3(..)	1259(..)	-3.4(..)	1240(..)`	-4.8(..)
Length of growing season (days)	130	121(.)	-6.9(.)	114(.)	-12.3(.)	111(.)	-14.6(.)
		121(..)	-6.9(..)	110(..)	-15.4(..)	101(..)	-22.3(..)
Seasonal maximum temp (0C)	24	25(.)	4.2(.)	25(.)	4.2(.)	26(.)	8.3(.)
		25(..)	4.2(..)	26(..)	8.3(..)	27(..)	12.5(..)
Seasonal minimum temp (0C)	15	16(.)	6.7(.)	17(.)	13.3(.)	17(.)	13.3(.)
		16(..)	6.7(..)	17(..)	13.3(..)	19(..)	26.7(..)
Seasonal solar radiation (MJ/m2/day)	19	19(.)	0(.)	19(.)	0(.)	19(.)	0(.)
		19(..)	0(..)	18(..)	-5.3(..)	18(..)	5.3(..)
Total rainfall (mm)	425	406(.)	-4.5(.)	403(.)	-5.2(.)	404(.)	-4.9(.)
		418(..)	-1.7(..)	407(..)	-4.2(..)	392(..)	-7.8(..)
Total evapotranspiration (mm)	366	354(.)	-3.3(.)	355(.)	-3(.)	355(.)	-3(.)
		358(..)	-2.2(..)	357(..)	-2.5(..)	343(..)	-6.3(..)

Table 5 Maize yields and seasonal climatic variable as simulated by crop model fed with climate data from HIRHAM5-RCM for (.)RCP4.5 and (..)RCP8.5

	1971-2005	2010-2039		2040-2069		2070-2099	
	Mean	Mean	% Change	Mean	% change	Mean	% change
Maize-yield(kg/h)	1158	1132(.)	-2.2 (.)	1119(.)	-3.4 (.)	1123(.)	-3.0 (.)
		1152(..)	-0.5 (..)	1111(..)	-4.1 (..)	1080(..)	-6.7 (..)
Length of growing season (days)	110	104(.)	-5.5 (.)	100(.)	-9.1 (.)	98(.)	-10.9(.)
		104(..)	-5.5 (..)	97(..)	-11.8 (..)	90(..)	-18.2
Seasonal maximum temp (0C)	25	26(.)	4.0 (.)	27(.)	8.0 (.)	27(.)	8.0 (.)
		26(..)	4.0 (..)	28(..)	12.0 (..)	29(..)	16.0 (..)
Seasonal minimum temp (0C)	18	19(.)	5.6 (.)	20(.)	11.1 (.)	20(.)	11.1 (.)
		19(..)	5.6 (..)	20(..)	11.1 (..)	22(..)	22.2 (..)
Seasonal solar radiation (MJ/m2/day)	16	17(.)	6.3 (.)	17(.)	6.3 (.)	17(.)	6.3 (.)
		16(..)	0.0 (..)	17(..)	6.3 (..)	17(..)	6.3 (..)
Total rainfall (mm)	356	345(.)	-3.1 (.)	373(.)	4.8 (.)	373(.)	4.8 (.)
		340(..)	-4.5 (..)	358(..)	0.6 (..)	396(..)	11.2 (..)
Total evapotranspiration (mm)	259	255(.)	-1.5 (.)	257(.)	-0.8 (.)	260(.)	0.4 (.)
		255(..)	-1.5 (..)	257(..)	-0.8 (..)	258(..)	-0.4(..)

Table 6 Maize yields and seasonal climatic variable as simulated by crop model fed with climate data from RCA4-ICHEC-RCM for (.)RCP4.5 and (..)RCP8.5

	1971-2005	2010-2039		2040-2069		2070-2099	
	Mean	Mean	% change	Mean	% change	Mean	% change
Maize-yield(kg/h)	1126	1120(.)	-0.5 (.)	1109(.)	-1.5 (.)	1118(.)	-0.7 (.)
		1118(..)	-0.7 (..)	1087(..)	-3.5 (..)	1061(..)	-5.8 (..)
Length of growing season (days)	112	106(.)	-5.4 (.)	101(.)	-9.8 (.)	99 (.)	-11.6 (.)
		105(..)	-6.3 (..)	98(..)	-12.5 (..)	91 (..)	-18.8 (..)
Seasonal maximum temp (0C)	27	27(.)	0.0 (.)	28(.)	3.7 (.)	28 (.)	3.7 (.)
		27(..)	0.0 (..)	28(..)	3.7 (..)	30 (..)	11.1 (..)
Seasonal minimum temp (0C)	16	17(.)	6.3 (.)	18(.)	12.5 (.)	19 (.)	18.8 (.)
		18(..)	12.5 (..)	19(..)	18.8 (..)	21(..)	31.3 (..)
Seasonal solar radiation (MJ/m2/day)	21	21(.)	0.0 (.)	21(.)	0.0 (.)	20(.)	-4.8 (.)
		21(..)	0.0 (..)	21(..)	0.0 (..)	20 (..)	-4.8 (..)
Total rainfall (mm)	349	372 (.)	6.6 (.)	372(.)	6.6 (.)	382(.)	9.5 (.)
		377(..)	8.0 (..)	386(..)	10.6 (..)	418(..)	19.8 (..)
Total evapotranspiration (mm)	280	288(.)	2.9 (.)	284(.)	1.4 (.)	290(.)	3.6 (.)
		284(..)	1.4 (..)	286(..)	2.1 (..)	292(..)	4.3 (..)

Table 7 Maize yields and seasonal climatic variable as simulated by crop model fed with climate data from RCA4-MPI-RCM for (.)RCP4.5 and (..)RCP8.5

	1971-2005	2010-2039		2040-2069		2070-2099	
	Mean	Mean	% change	Mean	% change	Mean	% change
Maize-yield(kg/h)	1212	1150 (.)	-5.1 (.)	1117 (.)	-7.8 (.)	1083 (.)	-10.6 (.)
		1122(..)	-7.4 (..)	1087(..)	-10.3(..)	1032(..)	-14.9 (..)
Length of growing season (days)	108	102 (.)	-5.6 (.)	97 (.)	-10.2 (.)	95(.)	-12.0 (.)
		100 (..)	-7.4 (..)	93(..)	-13.9 (..)	86(..)	-20.4 (..)
Seasonal maximum temp (0C)	27	28(.)	3.7 (.)	29 (.)	7.4 (.)	29(.)	7.4 (.)
		28(..)	3.7 (..)	29(..)	7.4 (..)	31(..)	14.8 (..)
Seasonal minimum temp (0C)	17	18 (.)	5.9 (.)	19 (.)	11.8 (.)	20(.)	17.6 (.)
		19(..)	11.8 (..)	20(..)	17.6 (..)	22(..)	29.4 (..)
Seasonal solar radiation (MJ/m2/day)	21	20(.)	-4.8 (.)	21(.)	0.0 (.)	21(.)	0.0 (.)
		21(..)	0.0 (..)	20 (..)	-4.8 (..)	20(..)	-4.8 (..)
Total rainfall (mm)	415	473 (.)	14.0 (.)	434 (.)	4.6 (.)	430(.)	3.6 (.)
		425 (..)	2.4 (..)	439 (..)	5.8 (..)	443(..)	6.7 (..)
Total evapotranspiration (mm)	314	318 (.)	1.3 (.)	304 (.)	-3.2 (.)	307(.)	-2.2 (.)
		307 (..)	-2.2 (..)	307 (..)	-2.2 (..)	302(..)	-3.8 (..)

Table 8 Maize yields and seasonal climatic variable as simulated by crop model fed with climate data from RCA4-CNRM for (.)RCP4.5 and (..)RCP8.5

	1971-2005	2010-2039		2040-2069		2070-2099	
	Mean	Mean	% change	Mean	% change	Mean	% change
Maize-yield(kg/h)	951	947(.)	-0.4 (.)	915(.)	-3.8 (.)	909 (.)	-4.4 (.)
		962(..)	1.2 (..)	893(..)	-6.1 (..)	849 (..)	-10.7 (..)
Length of growing season (days)	105	99(.)	-5.7 (.)	95(.)	-9.5 (.)	91(.)	-13.3 (.)
		99(..)	-5.7 (..)	92(..)	-12.4 (..)	85(..)	-19.0 (..)
Seasonal maximum temp (0C)	28	29(.)	3.6 (.)	30(.)	7.1 (.)	31(.)	10.7 (.)
		29 (..)	3.6 (..)	31 (..)	10.7 (..)	32(..)	14.3 (..)
Seasonal minimum temp (0C)	17	18(.)	5.9 (.)	18(.)	5.9 (.)	19(.)	11.8 (.)
		18(..)	5.9 (..)	19 (..)	11.8 (..)	20(..)	17.6 (..)
Seasonal solar radiation (MJ/m2/day)	23	23(.)	0.0 (.)	23(.)	0.0 (.)	23(.)	0.0 (.)
		23(..)	0.0 (..)	23 (..)	0.0 (..)	23 (..)	0.0 (..)
Total rainfall (mm)	256	274(.)	7.0 (.)	263(.)	2.7 (.)	269(.)	5.1 (.)
		292(..)	14.1 (..)	264 (..)	3.1 (..)	267(..)	4.3 (..)
Total evapotranspiration (mm)	230	233(.)	1.3 (.)	233(.)	1.3 (.)	235(.)	2.2 (.)
		246(..)	7.0 (..)	232(..)	0.9 (..)	234(..)	1.7 (..)

Table 9 Maize yields and seasonal climatic variable as simulated by crop model fed with climate data from ENSEMBLE-RCM for (.)RCP4.5 and (..)RCP8.5

	1971-2005	2010-2039		2040-2069		2070-2099	
	Mean	Mean	% change	Mean	% change	Mean	% change
Maize-yield(kg/h)	1238	1241(.)	0.2 (.)	1229(.)	-0.7 (.)	1220 (.)	-1.5 (.)
		1257(..)	1.5 (..)	1188(..)	-4.0 (..)	1198(..)	-3.2 (..)
Length of growing season (days)	112	106(.)	-5.4 (.)	101(.)	-9.8 (.)	99(.)	-11.6 (.)
		105(..)	-6.3 (..)	98(..)	-12.5 (..)	90(..)	-19.6 (..)
Seasonal maximum temp (0C)	26	27(.)	3.8 (.)	28(.)	7.7 (.)	28(.)	7.7 (.)
		27(..)	3.8 (..)	28(..)	7.7 (..)	30(..)	15.4 (..)
Seasonal minimum temp (0C)	17	18(.)	5.9 (.)	18(.)	5.9 (.)	19(.)	11.8 (.)
		18(..)	5.9 (..)	19(..)	11.8 (..)	21(..)	23.5 (..)
Seasonal solar radiation (MJ/m2/day)	20	20(.)	0.0 (.)	20(.)	0.0 (.)	20(.)	0.0 (.)
		20(..)	0.0 (..)	20(..)	0.0 (..)	20(..)	0.0 (..)
Total rainfall (mm)	349	357(.)	2.3 (.)	360(.)	3.2 (.)	357(.)	2.3 (.)
		357(..)	2.3 (..)	355(..)	1.7 (..)	369(..)	5.7 (..)
Total evapotranspiration (mm)	375	376(.)	0.3 (.)	371(.)	-1.1 (.)	375(.)	0.0 (.)
		375(..)	0.0 (..)	372(..)	-0.8 (..)	371(..)	-1.1 (..)

4.3 Spatial distribution of climate variables, length of growing seasons and maize yields

The spatial distribution of minimum temperature (TN), maximum temperature (TX), rainfall, length of growing season and maize yields during the base line period (1971-2000) are presented in Figure 5. This figure shows high temperatures greater than 26 ^{0}C for TX and 17^{0}C for TN are observed in the lower altitude areas, particularly in the eastern part of the basin. Temperatures are particularly higher over eastern part of Wami sub-catchment. Lower temperatures are found in high altitude areas in the western side of the basin. Particularly over western part of Wami sub catchment, North and eastern parts of Kinyasungwe sub catchment.

Seasonal rainfall is higher in high altitude than low altitude areas, particularly over Kinyasungwe sub catchment, eastern parts of Mkondoa, western parts of Wami and over upper Ruvu sub catchments. Meanwhile lower rainfall are found over low altitude than high areas, particularly over Coast, eastern part of Wami, lower Ruvu, and Ngerengere sub catchments. The length of growing season is higher in high altitude than in low altitude areas, which have lower temperatures and higher rainfall. Meanwhile lower lengths of growing season are found in low altitude areas, which have higher temperatures and lower rainfall. Simulated maize yields are highest in areas with highest rainfall, particularly over southeastern parts of Kinyasungwe and northwestern parts of Mkondoa sub catchments.

Figure 6 shows the distribution of changes in temperatures, rainfall, maize yields and length of growing season during the present century under RCP 4.5. Highest change in temperatures of 1.8^{0}C for TX and 1.2^{0}C for TN are found over southeastern parts of Mkondoa and over upper Ruvu sub catchments. Meanwhile lower change in temperatures of 0.5^{0}C for TX and 0.7^{0}C for TN are found over Kinyasungwe sub catchment. Decrease in rainfall of 5mm is found over large part of Mkondoa, eastern part of Ngerengere and southern part of Wami sub catchments. Highest decrease in the length of growing season is found over northern and southeastern parts of Mkondoa, western parts of Wami and over upper Ruvu sub catchments. This is due to increased TX and TN over these areas. Maize yields are projected to decrease by 1 to 5% over parts of northwestern and southeastern of Mkondoa, western parts of upper and lower Ruvu, western and northern parts of Wami sub catchments. Meanwhile, maize yields over large parts of Mkondoa, Kinyasungwe and Wami sub catchments are projected to increase by 3 to 9%. Maize yields over coast and western parts of upper and lower Ruvu are projected to increase by 1 to 3%.

Figure 7 shows the distribution of change in temperatures, rainfall, maize yields and the length of growing season during mid-century under RCP 4.5. High change in temperatures of 1.8^{0}C to 2.7^{0}C for TX and 1.9^{0}C to 2.2^{0}C for TN are found over upper and lower Ruvu, Mkondoa, Ngerengere, coast and western parts of Wami sub catchments. Lower change in temperatures of 0.9^{0}C for TX and 1.5^{0}C for TN are found over Kinyasungwe, southwestern parts of Mkondoa and some eastern parts of Wami sub catchments.

Rainfall is projected to increase by 14 to 49 mm over coast, southern parts of upper Ruvu, southeastern parts of Mkondoa, lower Ruvu, large parts of Kinyasungwe and Wami sub catchments. Meanwhile decrease in rainfall of 3 mm is projected over Ngerengere, southern parts of Wami, large parts of Mkondoa and southeastern parts of Kinyasungwe sub catchments. Highest decrease in length of growing season is found over upper Ruvu, western parts of Wami and large parts of Mkondoa sub catchments. Maize yields are projected to decrease from zero to 8% over upper and lower Ruvu, eastern and northern parts of Wami, Ngerengere, southeastern parts of Mkondoa and western parts of coast sub catchments. Meanwhile maize yields over large parts of Mkondoa, Kinyasungwe, southern parts of Wami and eastern parts of coast sub catchments are projected to increase by 2 to 10%. This increase is mainly due to increased rainfall and small decrease in the length of growing seasons or small increase in TX and TN over those areas. Generally eastern part of the basin is projected to have decreased maize yield. This is due to the high increase in TX and TN that reduced the length of growing season. It is important to note that in some areas such as north of Mkondoa will benefit from projected increase in temperatures, since the observed increased TX and TN that reduced the length of growing season and the projected decrease in rainfall, maize yields continue to increase. Meanwhile other areas such as upper Ruvu, Ngerengere, lower Ruvu, northern and western parts of Wami sub catchments are projected to have decreased maize yields in present, mid and end centuries, due to increased TX and TN.

Figure 8 shows the distribution of temperatures, maize yields, rainfall and the length of growing season during the end century. High change in temperatures in the range of 2.3^0C to 3.2^0C for TX and 2.3^0C to 2.7^0C for TN are found over upper and lower Ruvu, large part of Mkondoa, Ngerengere, coast and western parts of Wami sub catchments. Lower change in temperatures of 1.5^0C for TX and 1.9^0C for TN are found over Kinyasungwe, southwestern parts of Mkondoa and eastern parts of Wami sub catchments. Rainfall is projected to increase by 4 to 30 mm almost over the entire basin except eastern parts of Ngerengere, southwestern parts Mkondoa and southeastern parts of Kinyasungwe sub catchments where is projected to decrease by 9%. Highest decrease in length of growing season is found over upper Ruvu, western parts of Wami and large parts of Mkondoa sub catchments. Maize yields are projected to decrease from 1 to 10% over upper and lower Ruvu, eastern and northern parts of Wami, Ngerengere, southeastern parts of Mkondoa and western parts of coast sub catchments. Meanwhile maize yields over large parts of Mkondoa, Kinyasungwe, southern parts of Wami and eastern parts of coast sub catchments are projected to increase by 2 to 11%.

The distribution of TX, TN, rainfall, and the length of growing season during present, mid and end centuries under RCP 8.5 are presented in Figure 9-11. Temperatures are projected to increase more over central and south eastern parts of the basin. This will reduce maize yields particularly during mid and end centuries. Generally rainfall is projected to increase in many areas of the basin but maize is projected to decrease. This is due to fact that the entire basin is projected to warm in present, mid and end centuries. This warming will reduce the length of growing seasons which in turn reduce maize yields. This is observed under both RCP4.5 and RCP 8.5. Thus regardless of projected increased rainfall that seems to benefits agriculture production, need arises to undertake more studies that address on how to adapt the future increase in TX and TN.

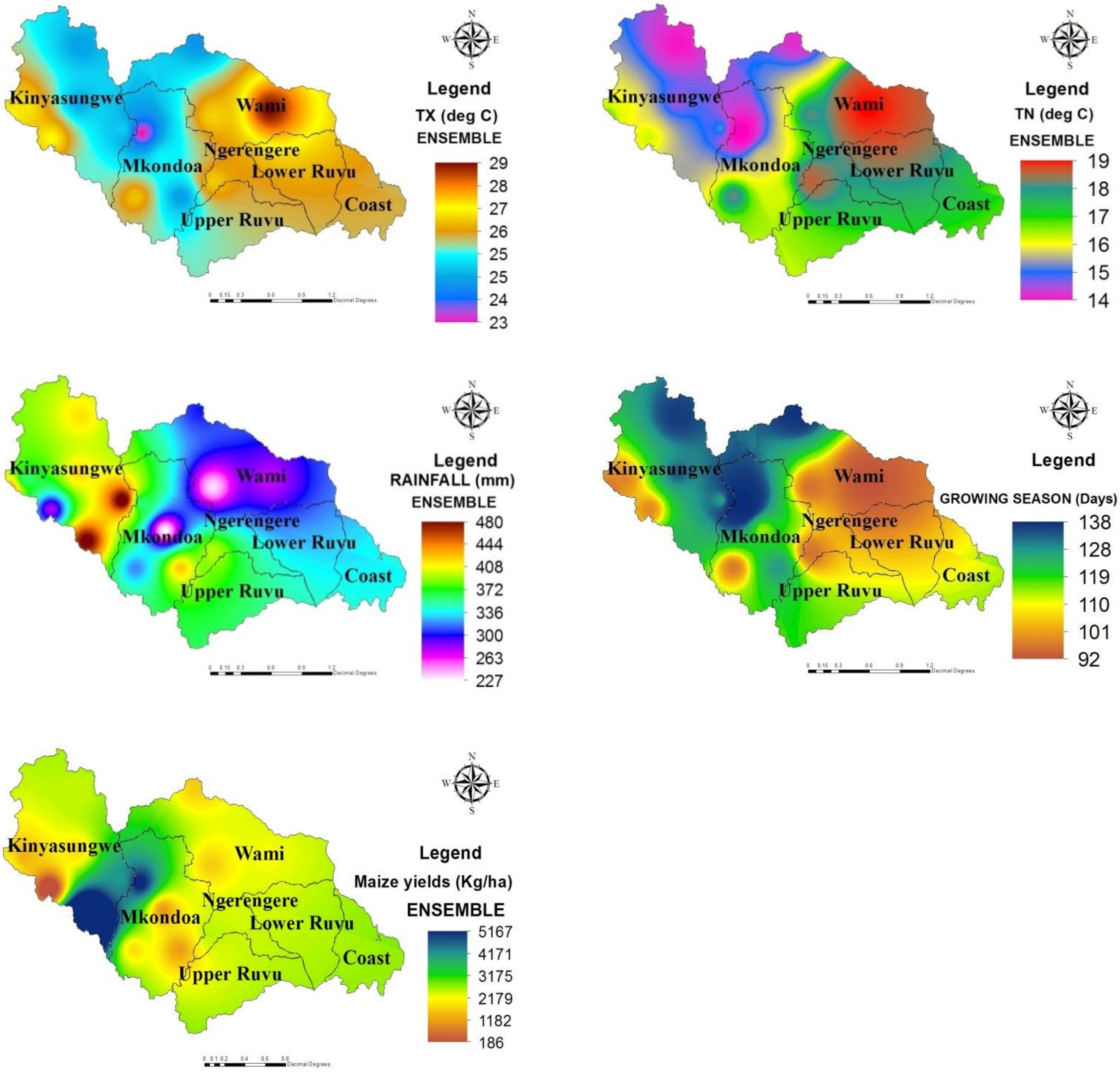

Figure 5. The spatial distribution minimum (TN) and maximum (TX) temperatures, rainfall, length of growing season and maize yields over Wami-Ruvu basin during the baseline period (1971-2000) under RCP 45

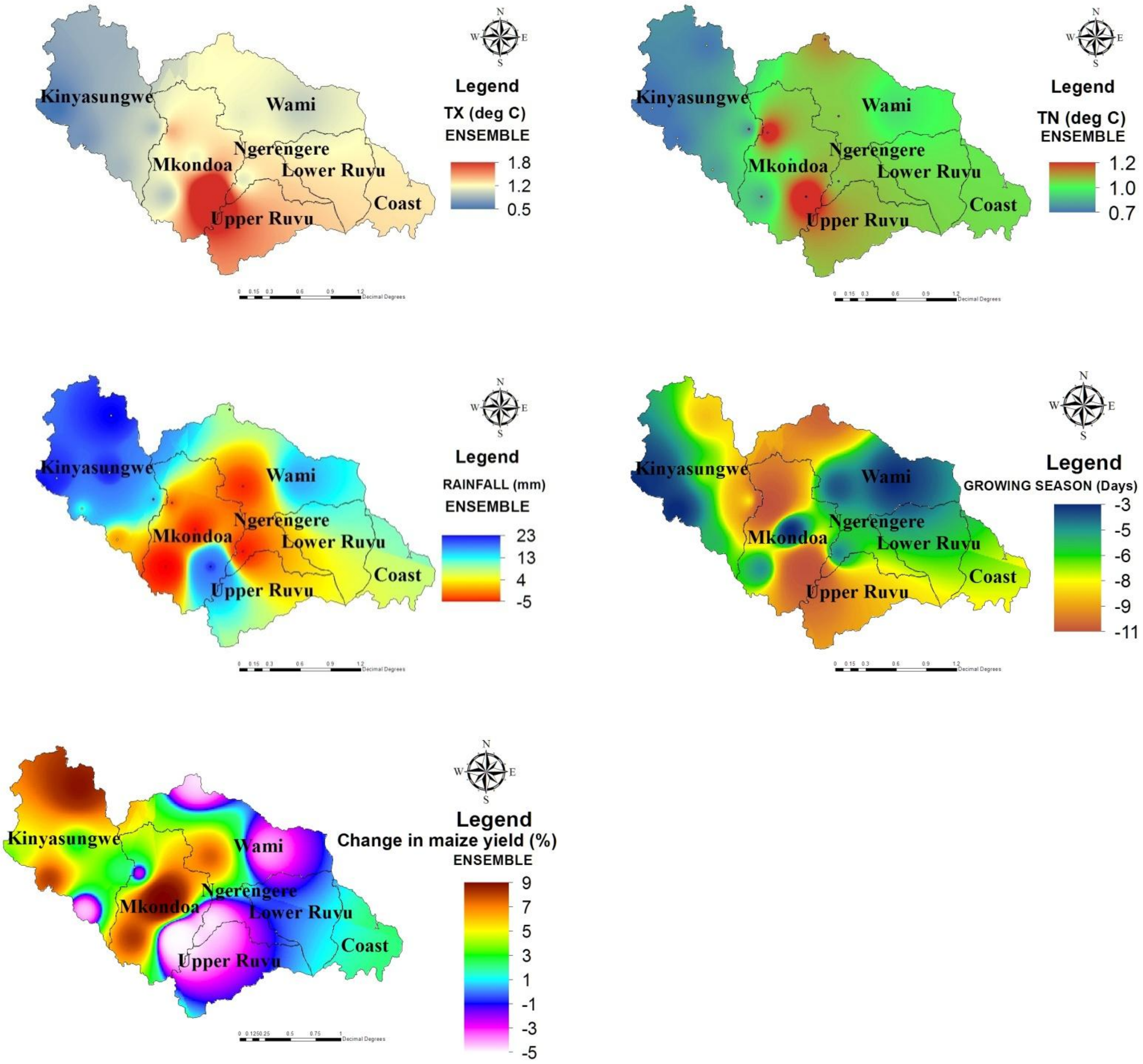

Figure 6. Change in spatial distribution of minimum (TN) and maximum (TX) temperatures, rainfall, length of growing season and maize yields over Wami-Ruvu basin during present century (2010-2039) under RCP 45

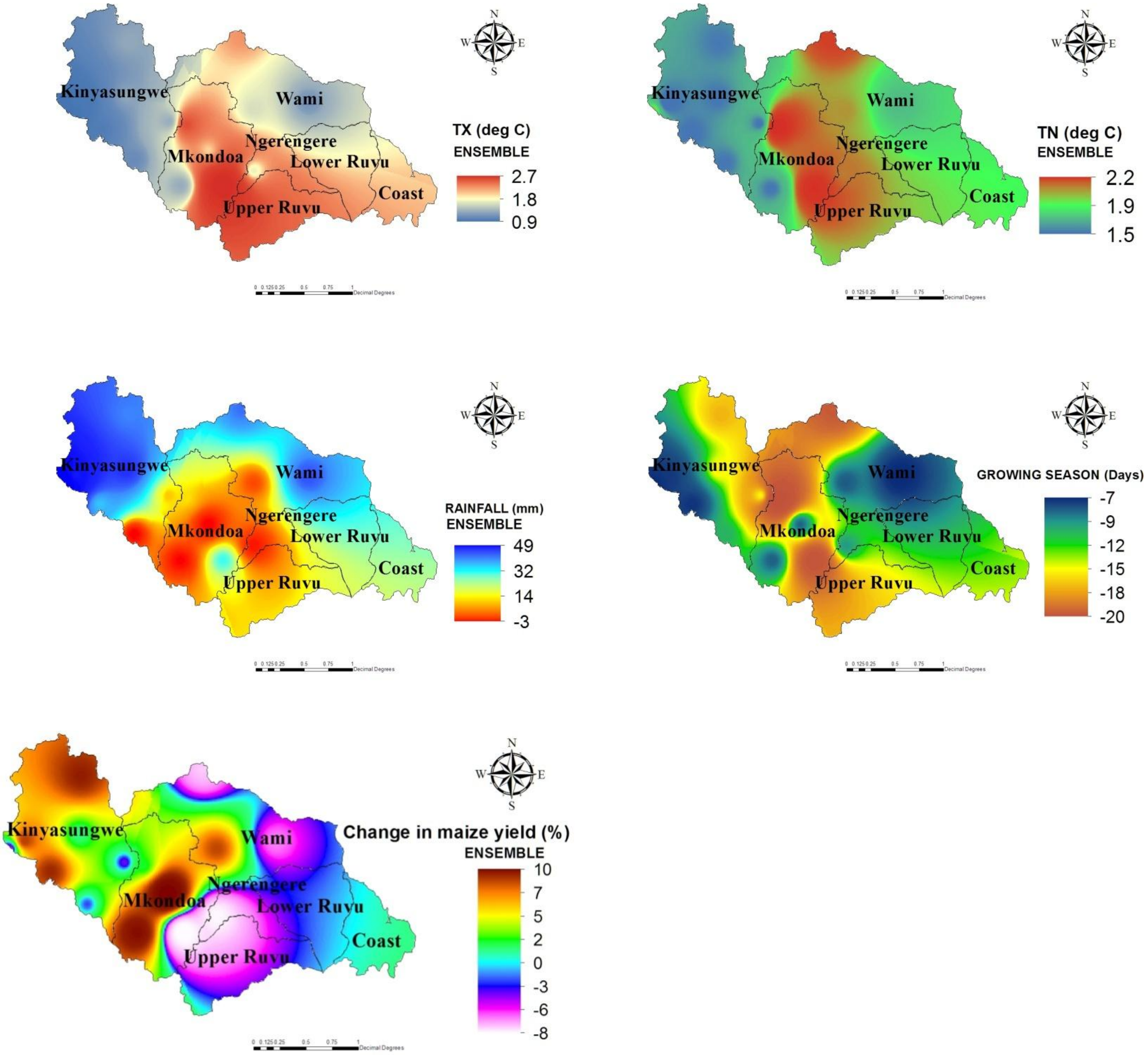

Figure 7. Change in spatial distribution of minimum (TN) and maximum (TX) temperatures, rainfall, length of growing season and maize yields over Wami-Ruvu basin during mid century (2040-2069) under RCP 45

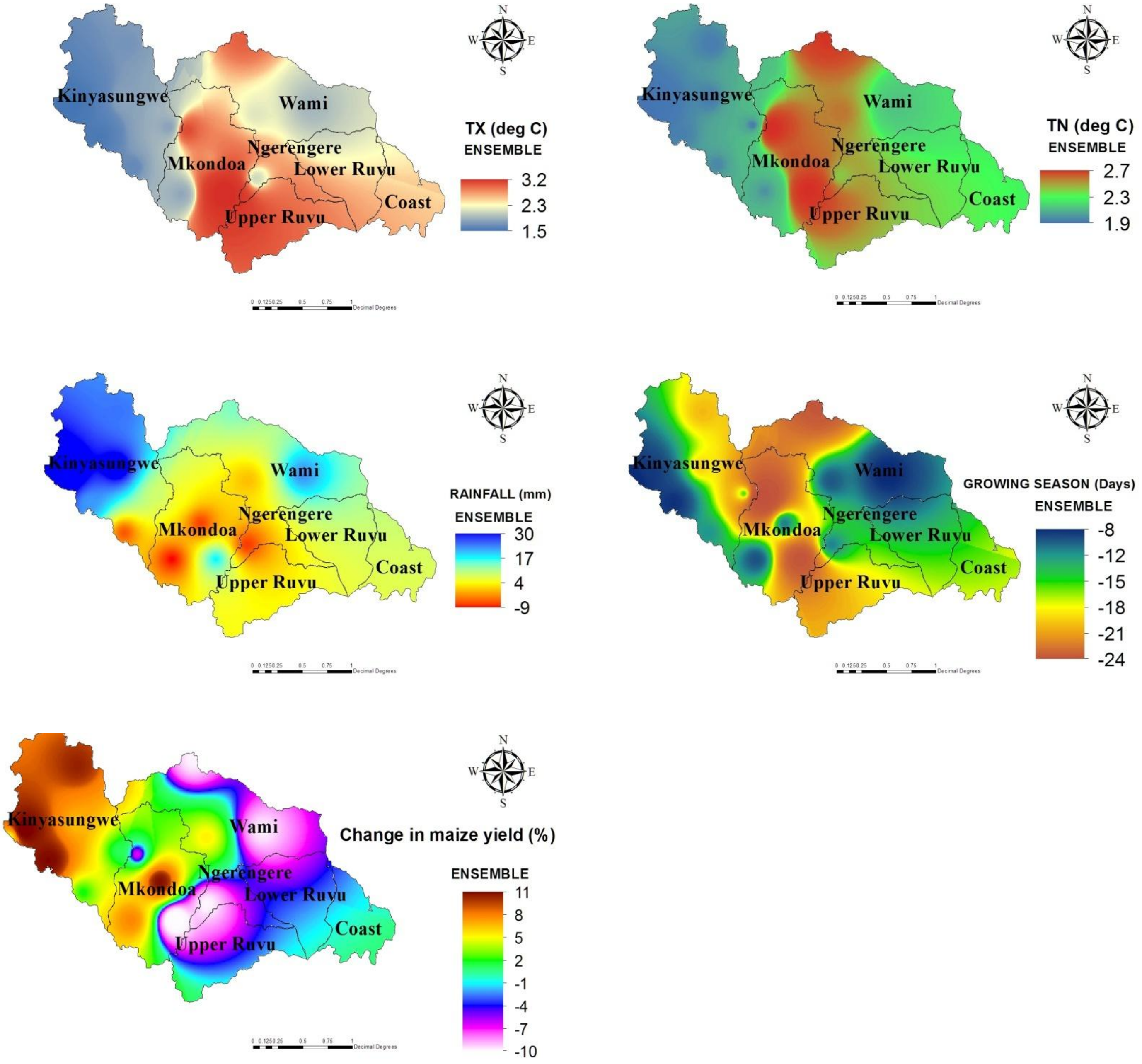

Figure 8. Change in spatial distribution of minimum (TN) and maximum (TX) temperatures, rainfall, length of growing season and maize yields over Wami-Ruvu basin during mid century (2070-2099) under RCP 45

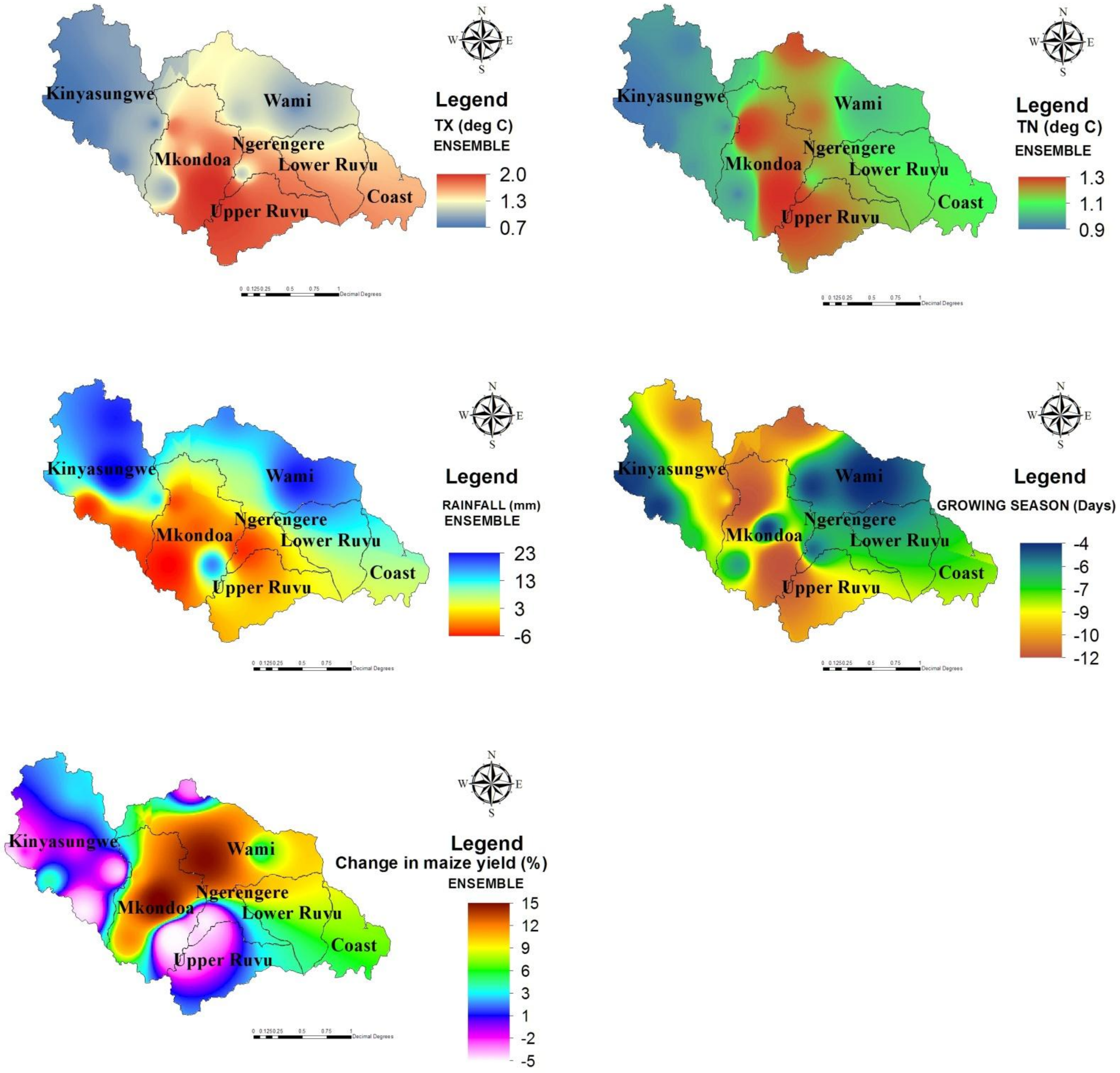

Figure 9. Change in spatial distribution of minimum (TN) and maximum (TX) temperatures, rainfall, length of growing season and maize yields over Wami-Ruvu basin during present century (2010-2039) under RCP 85

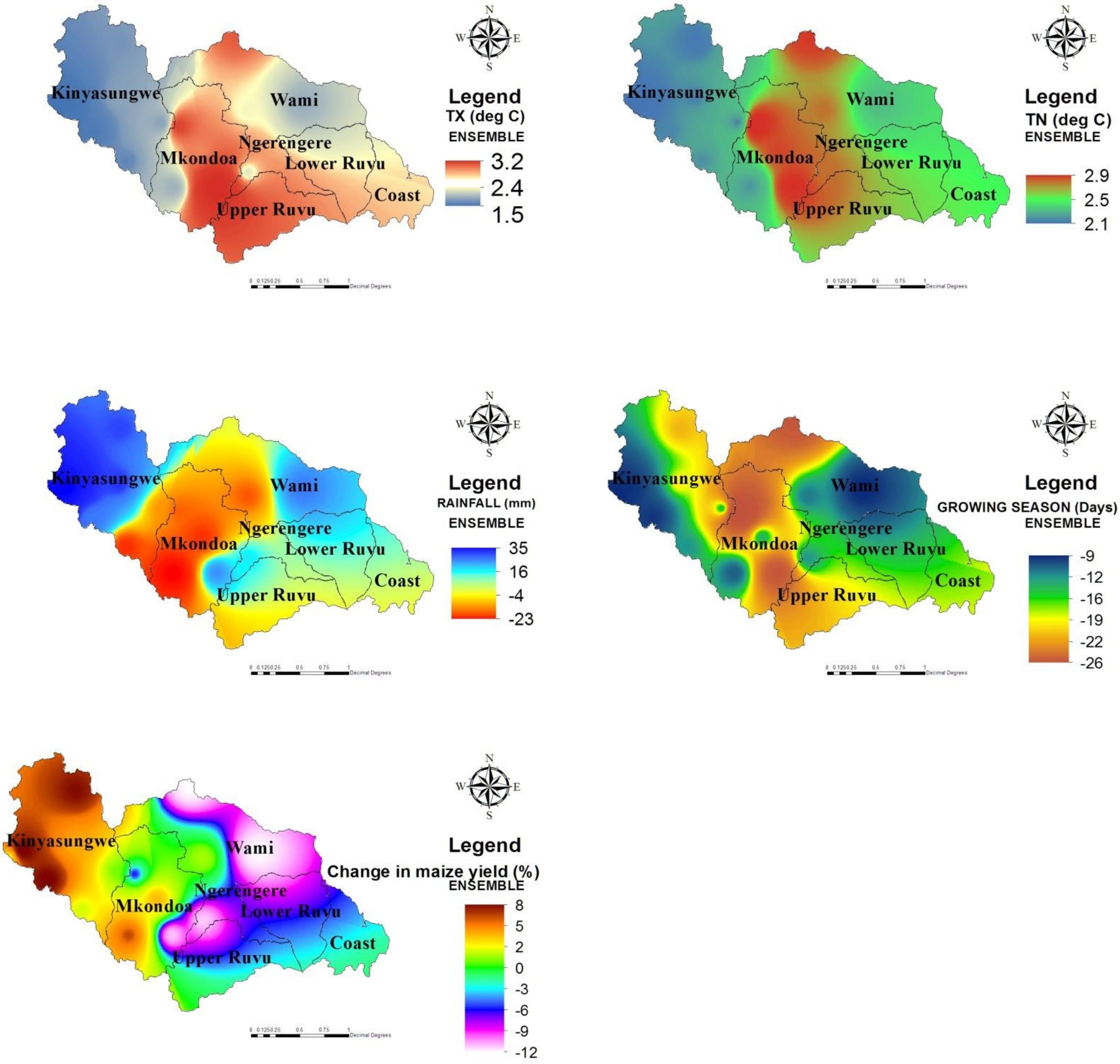

Figure 10. Change in spatial distribution of minimum (TN) and maximum (TX) temperatures, rainfall, length of growing season and maize yields over Wami-Ruvu basin during mid century (2040-2069) under RCP 85

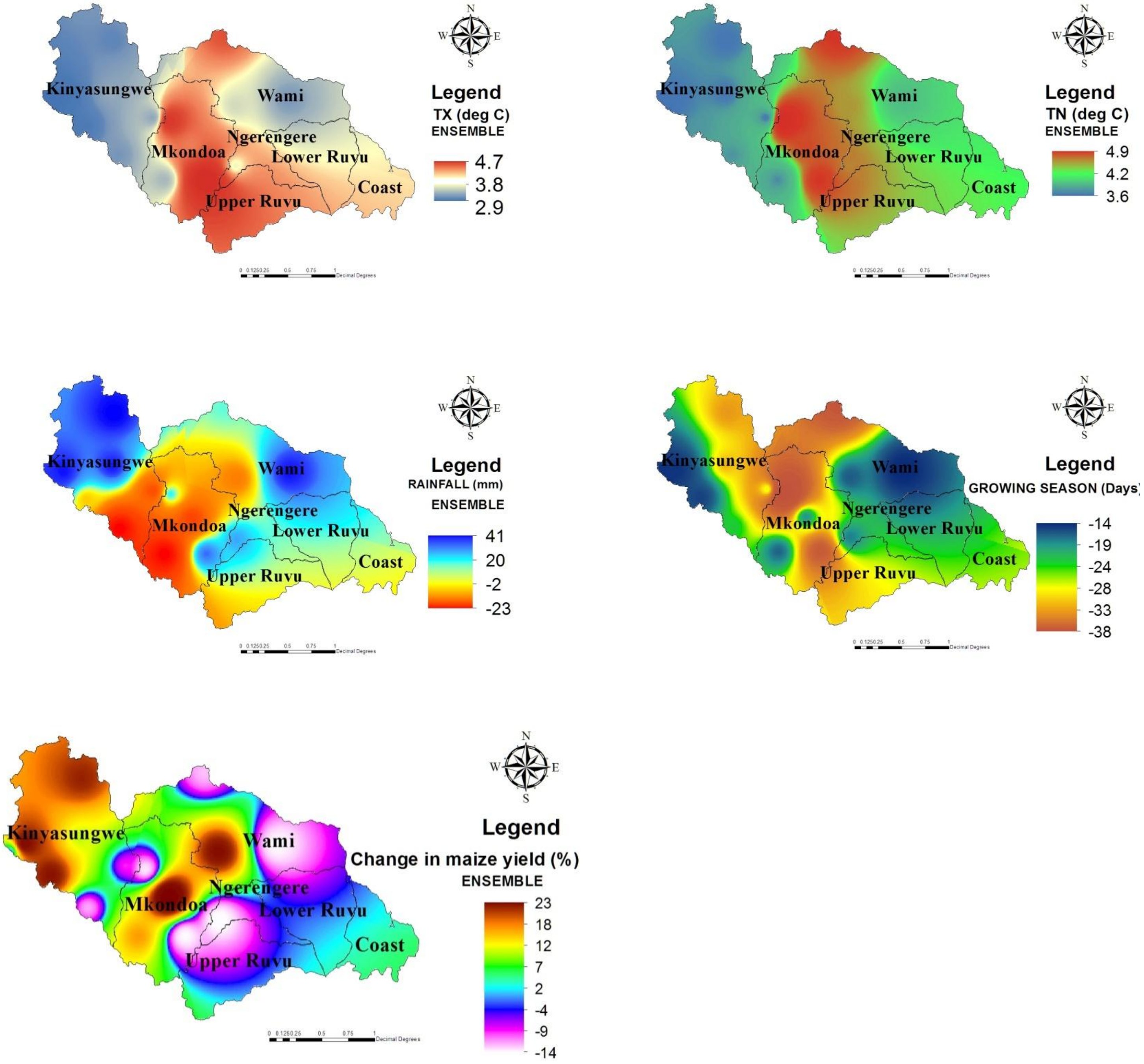

Figure 11. Change in spatial distribution of minimum (TN) and maximum (TX) temperatures, rainfall, length of growing season and maize yields over Wami-Ruvu basin during end century (2070-2099) under RCP 85

5. Discussion

In this paper, high resolution climate change information derived from three Regional Climate Models (RCMs) driven by three General Circulation Models (GCMs) and process based crop model CERES-maize model embedded in DSSAT version 4.5, are used to simulate maize yields over Wami-Ruvu basin during current, mid, and end centuries under RCP 4.5 and RCP 8.5. The primary aim was to examine, how climate change will affect maize yields in the basin. The analysis is limited within the growing season which starts from December and continues to June. We found that temperatures are projected to increase through the basin. Different RCM-GCM combination projects increase in temperatures differently. However, all the RCMs-GCMs combinations agree that the basin will experience high change in temperatures during the end century under RCP 8.5. Highest increase in TN of 31.3% (5^0C) is projected by RCA4 driven by ICHEC under RCP 8.5 and no change in temperature is projected by the same model during current century under both RCP 4.5 and RCP 8.5. The ensemble average also suggests highest change in temperatures within the basin during the end century under RCP 4.5 and RCP 8.5. TN will increase by 23.5% (4^0C) under RCP 8.5 and TX will increase by 15.4% (4.4^0C) under the same scenario RCP 8.5. These increases in temperatures will reduce the length of growing seasons and reduces maize yields particularly in warmer low altitude areas (Moore et al, 2011). In general presented results in this study agree with prior study by GLOWS – FIU, (2014), who indicated that the temperatures within the basin will rise by 4^0C in the last quarter of the century.

Our results differ greatly with prior studies (e.g. Mwandosya et al., 1998; Paavola, 2003; Matari et al., 2008; Moore et al, 2011; GLOWS – FIU, 2014), which examined climate change within the basin or assessed its impacts on maize yields based on GCMs simulations. For instance, a more referenced paper Mwandosya et al. (1998) that was used for development of climate change policies in Tanzania indicated that maize yield over central Tanzania (Dodoma) region will decline by 80 to 90% towards the end of century. In this study it is found that maize yields over Dodoma will increase by 5 to 8% and 7 to 23% during the end century under RCP 4.5 and RCP 8.5 respectively. Generally Dodoma region which is located in southwestern part of Kinyasungwe sub catchment is predicted to have small change in temperatures, length of growing season and increasing rainfall during present, mid and end centuries under RCP 4.5 and RCP 8.5. Moore et al, (2011) used data from the GCMs indicated that maize yields over Ngerengere, lower and upper Ruvu sub-catchments will increase by 20 to 30% towards the mid-century. However, we found that maize yields will decrease in those areas during mid century under both RCP 4.5 and RCP 8.5. Maize yields will decrease by 3 to 8% and 3 to 12% under RCP 4.5 and RCP 8.5 respectively during mid-century. Studies that used climate simulations from GCMs to characterize the climate over different regions in Tanzania may have considerable uncertainties since the country has heterogeneous climate over shorter distances which are unlikely to be resolved by coarse resolution GCMs. More recently GLOWS – FIU, (2014) used 16 GCMs to assess the vulnerability of water resources to climate/forest cover change over Wami-Ruvu basin indicated that the western parts of the basin is expected to see a lager temperatures as compared with the coast, giving reason that due to the proximity to the Indian ocean, that regulates temperatures over the coast. The report indicated further that, temperatures within the basin will increase from inland to coast. In this study we found the vice versa, temperatures are expected to increase over the lower altitudes compared to the high altitudes, the eastern part of the basin over coast, upper and lower Ruvu, Ngerengere and eastern side of the Wami sub catchments are projected to have increased temperatures in current, mid and end centuries. Recently Tumbo et al (2015) analyzed the impact of climate change on maize yields over Wami-Ruvu basin where 20GCMs were statistically downscaled using delta method. The downscaled GCMs data were used to force CERES to simulate maize yields in the present and future centuries under RCP 4.5 and RCP 8.5. They found that maize yields over the basin will decrease by 5 to 40% due to projected increase in temperature. Although statistical downscaling may improve the coarse scale of the GCMs but depends to the choices of the predictor (Wilby and Dawson, 2004) and the choice of mathematical transfer function (Wilby and Hayley, 2011). Delta method is not strictly downscaling methods (Hewitsone et al., 2014). The uncertainties of this method are detailed described by Wilby and Hayley (2011). In this study it is found that maize yields in the Wami Ruvu basin will increase during current century under RCP 4.5 and RCP 8.5 and decrease during mid and end centuries. The minimum decrease in maize yields of 0.7% and maximum decrease of maize yield of 4% is projected in the mid-century under RCP 8.5 and RCP 4.5 respectively. The decrease in maize yields during the mid and end centuries are attributed to projected increase in temperatures that will shorten the growing season. The spatial distribution indicates that climate changes will contribute to increased maize yields over high altitude areas such as over Kinyasungwe, western side of Wami and Mkondoa sub catmints. However, the low altitude areas such as lower and upper Ruvu, coast, Ngerengere and western parts of Wami sub catchments will have decreased maize yields due to projected increase in temperatures. Furthermore western parts of the basin are projected to have increased rainfall, small change in temperatures and length of growing season. Meanwhile the eastern side of the basin is projected to have high increase in temperatures, decrease in rainfall and length of growing season.

Presented results may be used by farmers and decision markers to plan how to adapt the projected increase in temperatures particularly over low altitude areas where the negative impact of climate on maize yields are projected. Since the Wami-Ruvu basin has many national and international projects and contains many sources of water for big cities regions like Dar es Salaam and Morogoro, it is crucial to developed adaptation strategies to the projected increase in temperatures and decrease in rainfall particularly in the eastern side of the basin. It is also recommended that more studies need to be carried out that addresses the impact of climate change on crop production in many agro ecological zones of Tanzania using high resolution climate change projections. It is important to note that one season actual crop yields data (2009/2010) was the only available data used to validate the crop model. This may be a limitation of this study, therefore more studies need to be carried that uses long time actual yields data to validate crop models to update the findings of this study.

6. Conclusions

In this study the assessment of the impacts of climate change on maize (*Zea mays*) production over Wami-Ruvu region is carried out using high resolution Regional Climate models (RCMs). The RCMs used are those driven by boundary condition from General Circulation Models (GCMs). Daily minimum, maximum temperatures, rainfall and solar radiations for the period of 1971-2000, 2010-2039, 2040-2069 and 2070-2099 were fed into the Decision Support System for Agro -technological Transfer (DSSAT) to simulate maize growth and yields. In addition to climate data, detailed field and house hold survey information (crop yield, soil and management data inputs) were used to calibrate the crop model. Maize simulations were carried out under RCP4.5 and RCP8.5. We found that crop model (DSSAT) simulate maize yield over Wami-Ruvu basin differently when fed with climate data from RCMs GCMs combinations. In general DSSAT simulates decreased in maize yields over Wami Ruvu basin during mid and end centuries. This decrease is small relative to the baseline. Since climate data fed to crop model results into different maize yields production, climate data from ensemble average of five model members was constructed and used as input into DSSAT to simulate maize growth and yields. Results also showed that maize yield slightly decreased relative to the base line. The maximum decrease of maize yield is projected during the mid century under RCP8.5 and the minimum decrease is projected over the same time period (mid century) under RCP 4.5. On other hand there is increase in maize yields in current century (2010-2039) under RC P4.5 and RCP 8.5 respectively.

The spatial distribution of seasonal TX, TN, rainfall, length of growing season and maize yields during present, mid and end centuries have shown similar patterns. The central and the eastern parts of the basin are projected to have high increased TX, TN. It is important to mention here that in some places TX and TN are projected to increase by 4.7^{0}C and 4.9 ^{0}C during the end century under RCP 8.5. The western and north western parts are projected to have low increased temperature. Rainfall is projected to increase of most areas during present, mid and end centuries under RCP 4.5 and RCP 8.5. However maize yields are projected to be impacted by increased temperature than increased rainfall. The increase in temperature shorten the length of growing season that contribute to the projected decrease in maize yields in current, mid and end centuries. However, in some cases a slight increase in maize yield is projected due to slight increase in rainfall. The assumption made during maize simulation was that all agronomical and management practices were constant. We recommend more research geared towards minimizing the uncertainties and necessary for designing effective and adequate adaptation strategies that will enhance and sustain crop production in the context of the projected climate change over Wami-Ruvu basin.

ACKNOWLEDGEMENTS

Authors are grateful to Tanzania Meteorological Agency research section for providing computing facilities and CORDEX Africa for providing model data used in this study.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper

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