Assessing the impacts of climate variability and change on agricultural systems in Eastern Africa while enhancing the...

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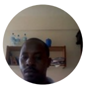

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Final Technical Report

Assessing the impacts of climate variability and change on agricultural systems in Eastern Africa while enhancing the region's capacity to undertake integrated assessment of vulnerabilities to future changes in climate

- Tanzania

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Partner Institutions

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1. Introduction

Agriculture is the most important economic sector in Tanzania as it provides the main source of food and employment among others (URT, 2012). More than 80% of population in Tanzania depends on climate sensitive rain fed agriculture as source of livelihood. However, agriculture is characterized by high production risks due to its dependence on unpredictable and highly variable weather, low returns on investment resulting among others from low productivity, rudimentary technology and inefficient marketing system (URT, 2012). Water scarcity and other natural resource constraints will make it even harder to intensify agricultural production (Meridian Institute, 2013).

As population increases and climate changes, agricultural productivity improvement demands new approaches which, apart from addressing these challenges, should also aim at protecting both the environment and functioning of ecosystem while enhancing the capabilities of communities to attaining sustainable development. It is in this light under which the Agricultural Model inter-comparison and Improvement Project (AgMIP) was formulated.

AgMIP proposes methods and tools that allow integrated assessment of climate change impact by linking climate, crop, and economic modelling (Rosenzweig et al., 2013). Wami River sub-Basin in Tanzania is one of the AgMIP case study sites. Therefore, this study presents the results of the AgMIP integrated climate change impact assessment for Wami River sub-Basin. The objectives for Tanzanian component are as follows:

- To generate and corroborate climate data for baseline and future scenarios in the Wami sub-basin;

- To calibrate and validate crop models and simulate crop growth and development for baseline and future climate (mid-century and end-century) for identified livelihood zones;
- To determine the impacts of changes in productivity of several enterprises on income and food security.

2. Data and Methods of Study

2.1 Description of the study area

Wami sub-basin was identified for this project as the target location. It is located between 5°–7°S and 36°–39°E, where it extends from the semi-arid in Dodoma region to the humid inland swamps in Morogoro region to Saadani Village at the coast of Indian Ocean (Figure 1). It covers an area of approximately 43,000 km^2, with altitude ranging from 0 meters at the coast to 2260 meters in Ukaguru Mountains (MLHHSD, 2009). The agricultural area in the basin covers an area of 16.3% while bushland is 30% (MLHHSD, 2009). The rationale for selecting this area was based on availability of key information that for this study including household panel survey data (NBS, 2012), and also availability of experimental data from the study area necessary to derive maize cultivar specific parameters used in the models (Mourice et al., 2014).

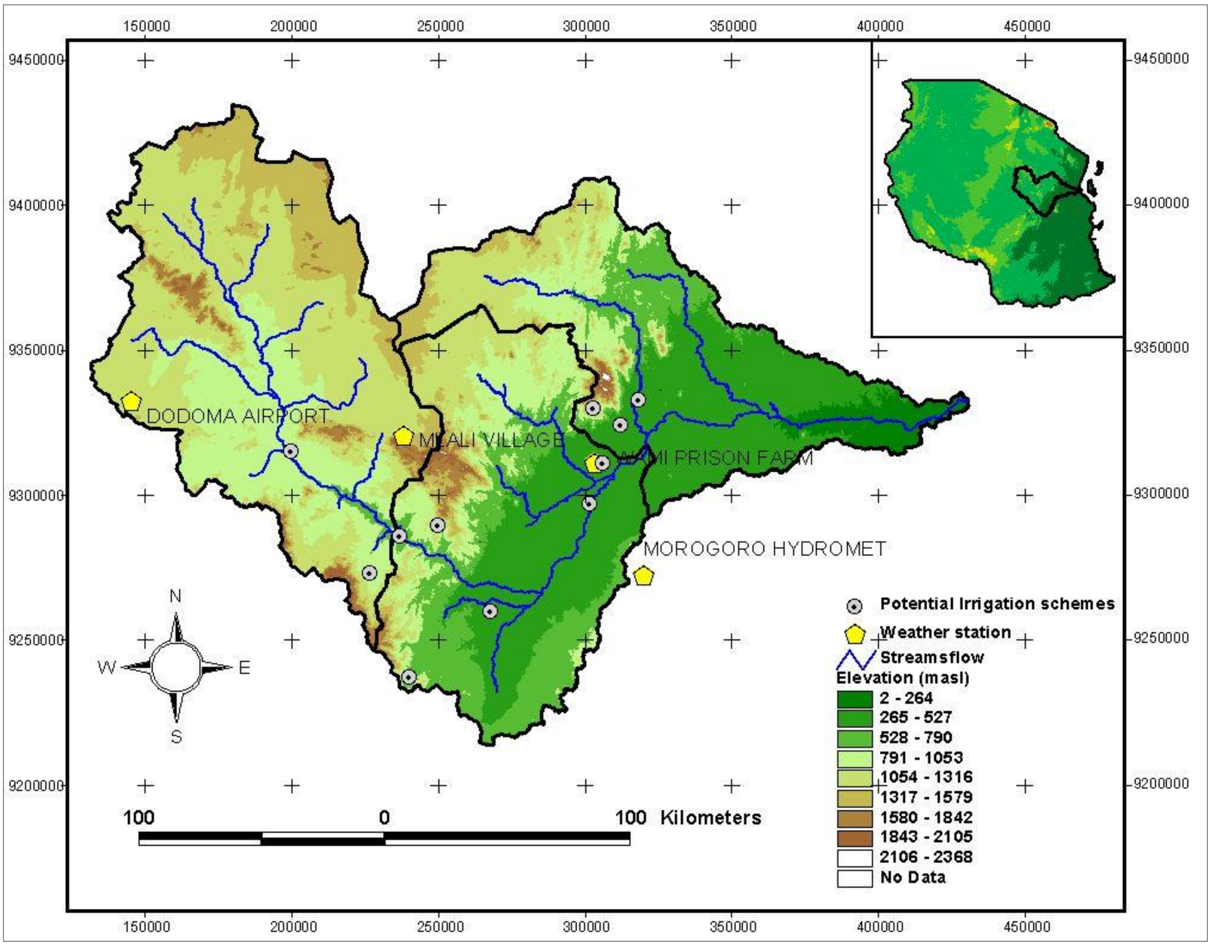


Figure 1: Wami basin

2.2 The Farming System, socio economic characteristics and markets

2.2.1 Farming system

The case study area of Wami River sub-basin covers the farming systems shaped by semi-arid and sub-humid agro-ecologies. The semi-arid area covers part of Dodoma and the sub-humid area covers parts of Morogoro, Tanga and Coast regions. In this study, the two agro-ecosystems are referred to as livelihood zones 1 and 2, respectively. The farming system of study area is characterized by crop production and livestock farming as well as off-farm activities. Crop production is undertaken through small scale subsistence farming of an array of crops including maize, rice, sesame, sorghum, millets, legumes; and to less extent large scale commercial crop production such as sugarcane and sisal plantations. Maize is the staple food crop in the study area also at country level.

Three crop enterprises were identified in the Wami river sub-basin and which are maize only, maize intercropped and other crops (sorghum and millet for zone 1, and rice for zone 2). The average farm size for livelihood zone 1 was 1.58 ha while for zone 2 it was 1.09 ha. The average maize yield per farm ranged between 855 and 922 kg/ha for zone 1 and 2, respectively. Livestock enterprise complements the crop sub-sector for income and food security. On average, the household owned about 1-13 heads of cattle, 2-3 goats and sheep, 1 pig and 1-5 chickens.

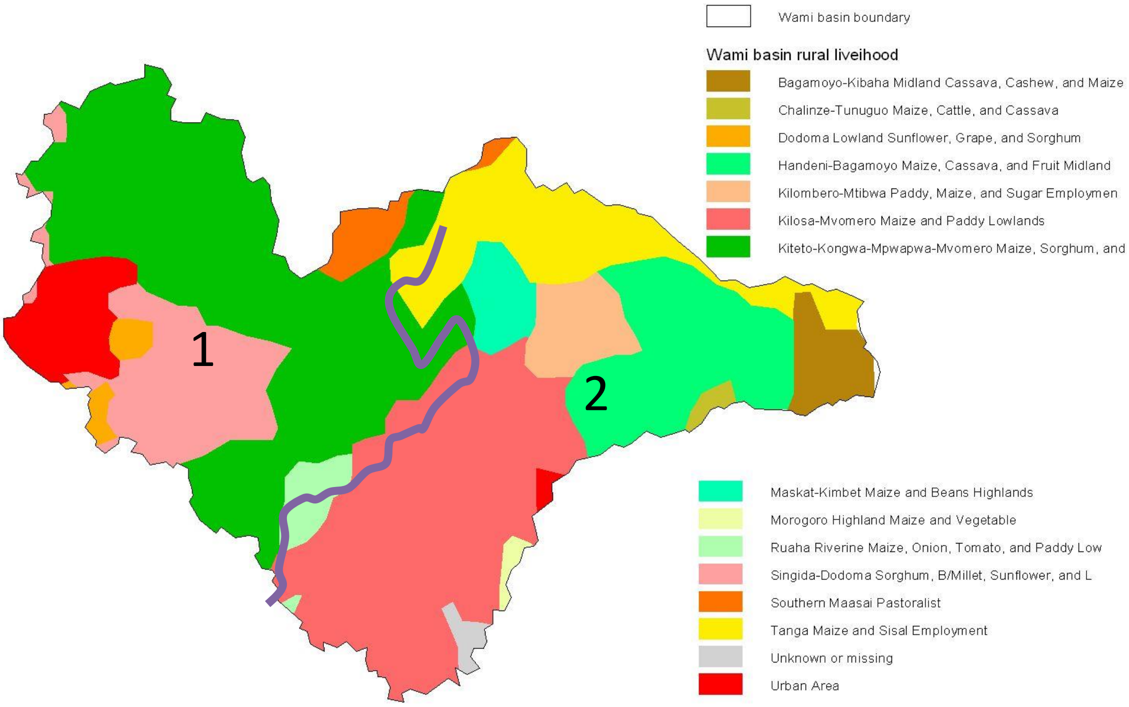


Figure 2: The two livelihood systems considered in the study (zone 1 indicated by 1 zone 2 indicated by 2).

2.2.2 Socio-economic characteristics

Socio-economic data for the Wami River sub-basin was obtained from the Tanzania National Panel Survey (TNPS) of 2010-2011 (NBS, 2012). Tables 1 – 3 provide summary statistics on socio-economic characteristics of the sampled households. The sample size was 83 households for zone 1 and 85 for 2. The household size averaged to around 5.3 and 5.5 persons in zones 1 and 2, respectively. The national average is 4.8 persons per household (URT, 2013a).

The average household income ranged between USD 860 and 1000 per year in zones 1 and 2, respectively. Off-farm activities accounted for 72% and 59% of the household income for zone 1 and zone 2, respectively. The average crop production costs per hectare for maize, maize intercrop and non-maize (mainly sorghum in zone 1 and rice in zone 2) ranged between USD 11 and 49 in the study area. The market price of maize ranged between USD 0.1 to 1.4. Market values per unit of animal breed reflected in prices were USD 176, 21, 35 and 4 for cattle, goats and sheep, pigs and chicken, respectively.

Table 1: Household characteristics

Zone	**N**	**HH size**		**Income**		**% of off-farm income**	**% poverty**	
		mean	**std**	**mean**	**std**		**World Bank**	**Basin Median**
1	83	5.3	2.80	861	1271.4	72%	57	54
2	85	5.5	2.14	1003	1311.4	59%	48	44

Table 2: Livestock characteristics

Zone	**Cattle**		**Goats/Sheep**		**Pigs**		**Chicken**	
	Average	**std**	**Average**	**std**	**Average**	**std**	**Average**	**std**
1	1.1	4.98	1.7	4.18	0.14	0.64	4.6	8.65
2	4.1	12.86	2.9	7.33	0.65	4.38	0.5	0.93

Table 3: Crop production characteristics

Zone	**Maize only**		**Maize intercropped**		**Non-maize**	
	Average	**std**	**Average**	**std**	**Average**	**std**
	Farm size (ha)					
1	0.37	0.73	0.47	0.95	0.75	1.42
2	0.33	0.5	0.71	1.32	0.05	0.16
	Yield (kg/ha)					
1	855	750.5	808	763.6	770	759.2
2	992	748.9	908	1621.1	858	1225.1

2.3 Climate data

2.3.1 Baseline

A total of 15 weather stations were identified in the study area, of which six stations had a 30-year measured daily weather data and nine had generated 30-year daily weather data from the AgMIP Hybrid Baseline Climate Datasets (AgMERRA; Ruane and Goldberg, In preparation). Modern era-retrospective analysis for research and analysis (MERRA) (Rienecker et al., 2011) was used for generating daily maximum and minimum temperature, solar radiation and precipitation for locations where physical weather data records were difficult to obtain. The summary statistics for the two zones is shown in Table 5. Temporal and spatial characteristics of the basin climate is shown using four representative stations (Dodoma, Morogoro, Wami Prison and Mlali) in Figures 3 through 5.

Table 5: Wami basin climatic characteristics for livelihood zone1 (LHZ1) and zone 2 (LHZ2).

Variable	Dodoma	Kongwa	Mlali	Wami
Representative agro-ecology	LHZ1	LHZ1	LHZ2	LHZ2
Avg annual rainfall (mm)	578.8 (20)	628.7 (19)	914.4 (15)	846.5 (18)
Average LR season rainfall (mm)	568.5 (21)	607.8 (19)	415.7 (20)	363.3 (23)
Average SR season rainfall (mm)	nil	nil	247.4 (45)	225.5 (50)
Average annual Temperature (^{0}C)	23.0	23.8	26.2	24.3
Average annual MaxT (^{0}C)	24.1	24.3	27.7	25.6
Average annual MiniT (^{0}C)	22.2	23.1	25.6	23.7
Average LR season Temperature (^{0}C)	23.4	24.1	26.5	24.5
Average LR season MaxT (^{0}C)	25.6	25.6	28.2	25.9
Average LR season MiniT (^{0}C)	22.5	23.2	25.7	23.9
Average SR season Temperature (^{0}C)	24.5	25.4	27.8	25.6
Average SR season MaxT (^{0}C)	25.3	26.2	28.8	26.8
Average SR season MiniT (^{0}C)	23.7	24.7	27.0	24.9

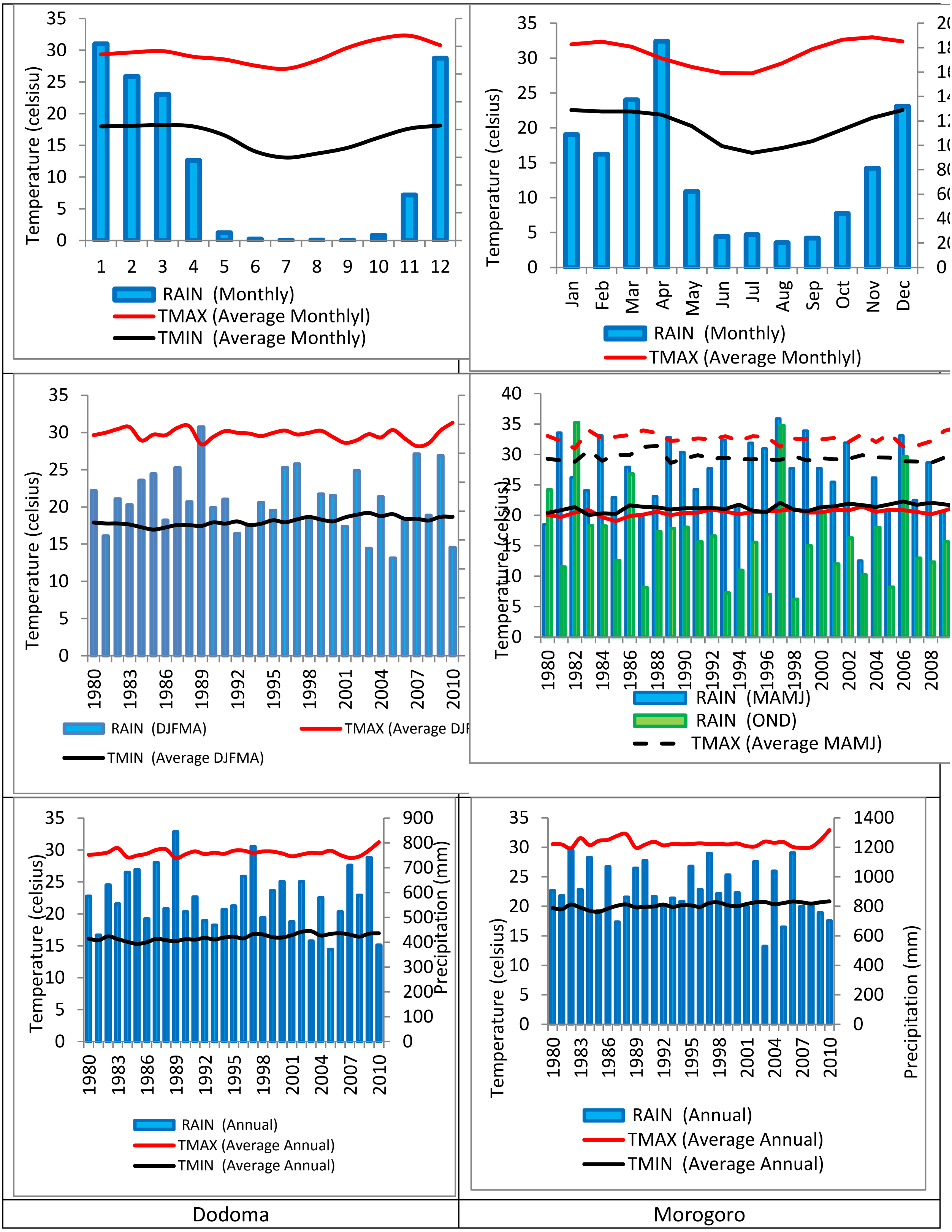


Figure 3: Climate characteristics for Dodoma and Morogoro.

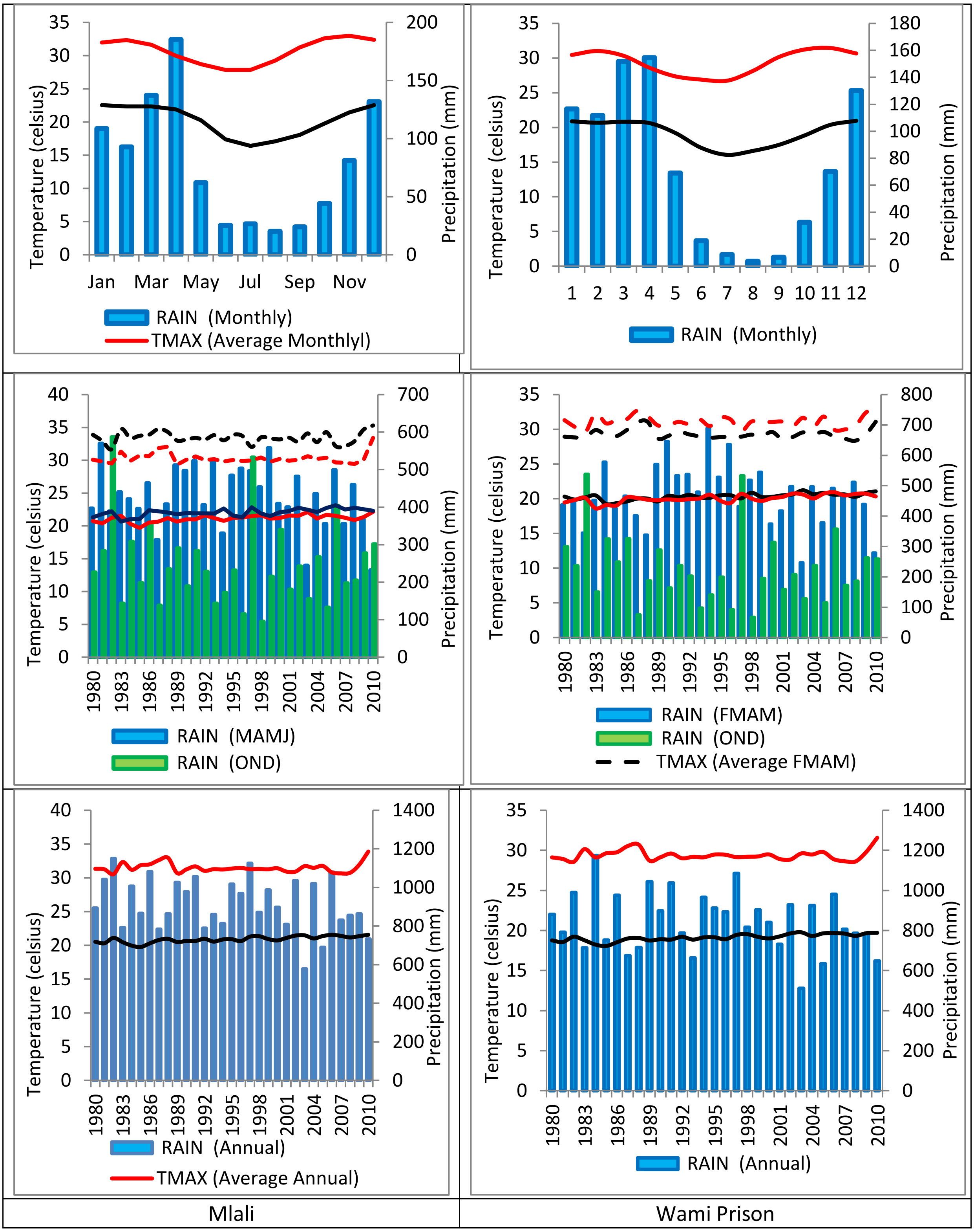


Figure 4: Climate characteristics for Mlali and Wami Prison.

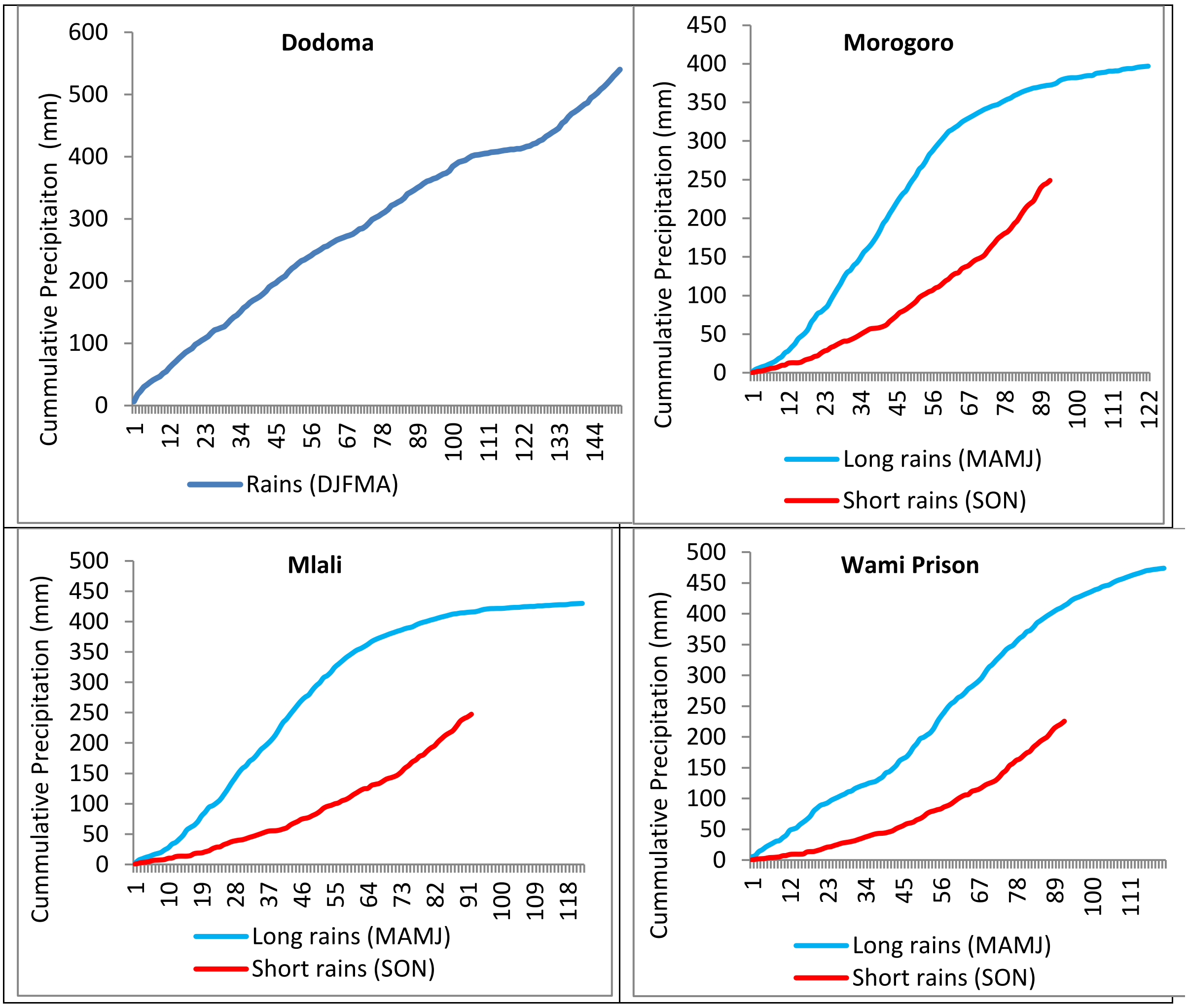


Figure 5: Cumulative precipitation at Dodoma, Morogoro, Mlali and Wami Prison.

2.3.2 Future climate scenarios

Representative concentration pathways (RCPs) 8.5 and five CMIP5 global circulation models (GCMs) with weather data for mid-century (2040-2069) time period were used. The rationale for selecting RCP 8.5 was its correspondence to the scenario with highest green-house gas (GHG) emission due to intensified energy demand and absence of climate change policies (Riahi et al., 2011, Thomson et al., 2011). Therefore, the RCP was selected to understand the impacts of climate change in situations where there is no climate change consciousness. The five global circulation models (GCMs) selected were CCSM4, GFDL-ESM2M, HaDGEM2-ES, MIROC5 and MPI-ESM-MR. The selected GCMs were downscaled using simple delta method (Wilby et al., 2004). Furthermore, the uncertainty in each of the downscaled GCM was considered and the median confidence interval (MCI) approach (Bonett and Price, 2002) was used to estimate the bands of uncertainty for the climate parameters under consideration.

2.4 Soils and crop management

Dominant soil orders in the basin include Cambisols, Luvisols, and Ferralsols. Soil properties necessary for crop models inputs for the current study were obtained from a combination of grey literature and Africa Soil Information Systems (AfSIS) databases (Figure 6). For the sites whose soil information was not available, supplemental soil characterization was done. Farmer's perception regarding characteristics of the soils and agronomic practices were also used to characterize the soils in DSSAT and APSIM crop models. Sandy loam is a dominant soil in zone 1 while zone 2 clay loam is more dominant (Table 6). Majority of the fields in both zones were located in the flat bottom and on slightly sloped areas with 64% and 40% in zone 1 and zone 2 and only 6% of fields in zone 2, which practice surface irrigation. The extent of in-organic fertilizer application is extremely very low at 3% in zone 2 and 13% in zone 1.

Table 6: Field soil and agronomic characteristics as reported by farmers during survey

		soil type distribution (%)			soil quality distribution (%)			slope of fields location (%)				Irrigation (%)		Inorganic fertilizer application (%)	
	N	Sandy	Loam	Clay	Good	Average	Bad	Flat top	Slightly slope	Flat bottom	Very steep	Irrigated	Not irrigated	Apply fertilizer	Do not apply fertilizer
Zone1	83	13	73	14	13	87	0	4	25	64	7	0	100	13	87
Zone2	85	8	62	30	13	87	0	10	34	40	16	6	94	3	97

Data for simulating management practices such as crop type, the share of each crop, and management practices such as fertilizer, irrigation and improved seed were obtained from the Tanzania National Panel Survey (TNPS) of 2010-2011 (NBS, 2012). Crop data for crop models calibration was obtained from work by Mourice et al. (2014) in which cultivar parameters for one medium term maize cultivars namely SITUKA was used. Other crop management information which could not be obtained from the TNPS were obtained from a key-informants' survey conducted on selected locations across the study area. Such information as maize cultivars, planting dates and spacing or plant population were documented and were used to supplement panel survey data and ultimately as model input variables.

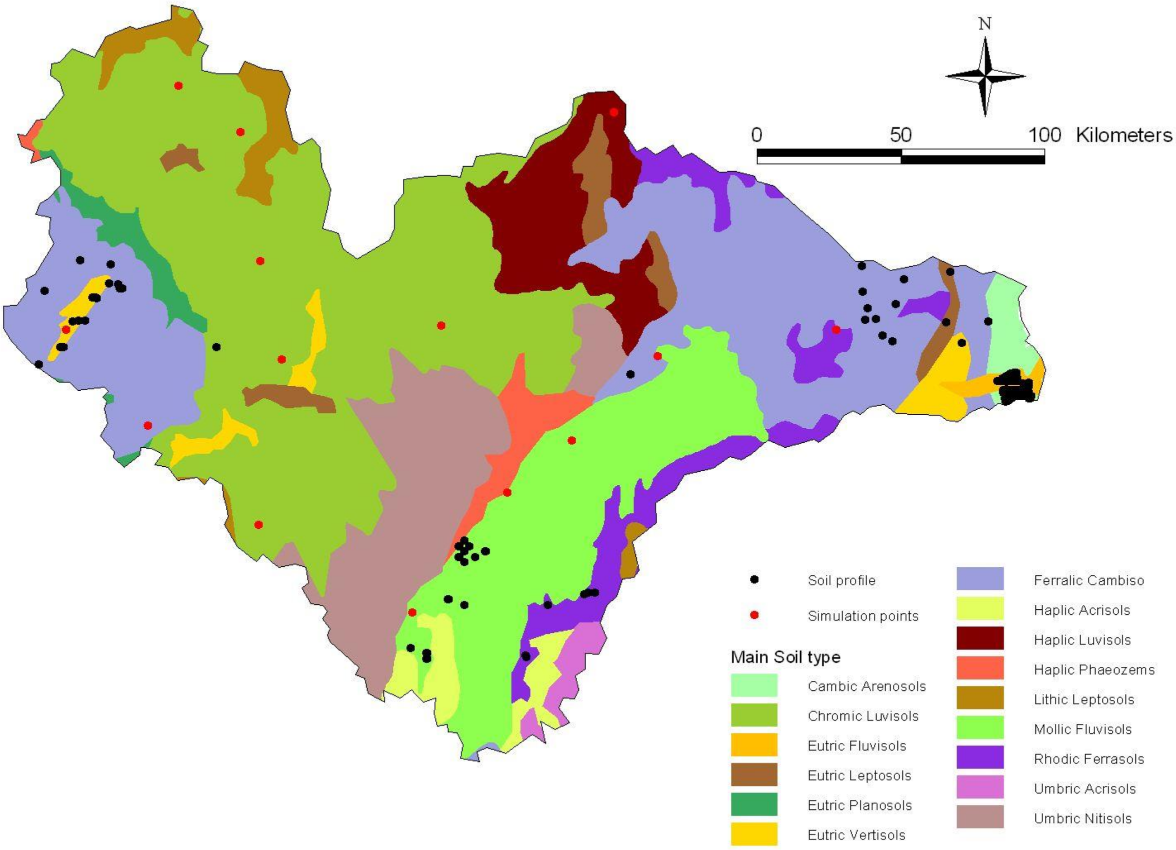


Figure 6: Main soil types and locations with existing soil profiles and simulation points where additional soil profiles done by the project for simulation purposes.

2.5 Crop models simulation

Data overlay for multi-model export (DOME) tool, developed by the AgMIP project, was used to capture additional information that was not reported in survey reports, yield trials, or field experiments. A QUADUI tool, which translates survey, soil, weather and DOME files into a model-ready format, was used to interface the DSSAT and APSIM models. More information on AgMIP methods, procedures and tools are described in Rosenzweig (2013b).

2.6 Adaptation strategy to climate change impacts

Adaptation refers to the adjustment in natural or human systems in response to the natural or expected climatic stimuli or their effects which moderates harm or exploits beneficial opportunities (Parry et al., 2007). In this study, it was important to understand how change in field management would affect crop productivity under changed climate. The adaptation strategies investigated were mainly nitrogen fertilizer application and plant population. It was found that farmers who applied 60 kg N/ha and plant density of 4 plants/m^2, obtained better yields. Therefore, this management strategy was adopted as the adaptation strategy.

2.7 Economic analysis

2.7.1 Representative Agricultural Pathway and Socio-Economic Scenario

Representative agricultural pathways (RAPs) (Rosenzweig et al., 2013b) are set of variables that allow simulation of the future to be done with consistent climate, economics, and field-level assumptions across a range of scales from field to global. The RAPs for the Wami River sub-Basin were developed using global crop and economic models price and production projections, published literature and expert opinions. The agricultural pathway for Wami sub-Basin shows extension services will improve and use of fertilizers will also increase.

In relation to farm characteristics, with exception of off-farm and cash crop income, which is expected to increase 3.5 times based on the study by Kilembe et al. (2013), other characteristics such as household size, farm size, and herd size were expected to remain relatively the same. Over the last ten years the average household size in Tanzania has changed from 4.9 to 4.8, which is most likely that the difference has no statistical significance (URT, 2013b).

Future projections for the non-modelled crops (sorghum and rice) used data from Kilembe et al. (2013), which estimated that climate change would negatively affect sorghum yields while there would not be changes for rice yields. In order to incorporate the effects of development and technological changes in the future, we used yield and price trends obtained from the IMPACT model (Nelson et al., 2013). The IMPACT data showed that yields of coarse grains including maize would increase by between 15% and 50% by 2050, while price of cereals in Wami River sub-basin is projected to increase by 40% due to cost of production, increased demand of cereals especially maize and rice, and GDP growth.

The analysis also considered livestock species - cattle, sheep and goats, pigs and chicken. Analysis of the TNPS data showed that the main product that is derived from livestock is meat. Due to climate change, we projected that in the future the rangelands will be affected resulting into lower body weight of livestock. The percent decrease was assumed to be equivalent to the percent change in crop yield with an assumption that pastures and forages will be impacted by climate change similar to most of non-pasture crops. However, due to developments in technology such as artificial insemination, fattening programs and improved extension services the average body weight of livestock was assumed to increase by 20% without climate change. The price for livestock products was estimated to increase by 5% - 6% by 2050 and variable cost per farming household also was predicted to increase by 20%.

2.7.2 Economic modelling of climate change impacts

The physical impacts of climate change estimated through biophysical climate-crop modeling domain are ultimately reflected in the economic welfare of affected communities. In this study, Tradeoff Analysis for Multi-dimensional Impact Assessment Model (TOA-MD) (Antle, 2011; Antle and Valdivia, 2011; Claessens et al., 2012) was used to simulate the welfare impacts of climate change by integrating its effects on crop yields based on climate and crop model simulations, RAPs and information from global economic models. The model provides information regarding the potential income gains and losses, and poverty rates as a result of farm households opting to upgrade their current system (called system 1) into an upgraded system or future conditions (called system 2).

The AgMIP protocols for economic modeling is based on three major analytical questions – the sensitivity of current agricultural production systems to climate change, the impact of climate change on future agricultural production systems, and the benefits of climate change adaption. For more detailed information about the three questions see Rosenzweig et al. (2013b). In the first question, is analysis assumes that the production system does not change from its current state with the changing climate. The logic behind the scenario is that farmers are initially operating under current production system with a current climate (1980-2009). This combination is defined as system 1. System 2 is defined as the case where farmers continue using the current production system under a future climate (2040-2069). The climate sensitivity is then obtained by comparing between system 1 and system 2.

In the TOA-MD model the climate sensitivity is handled this way: farmers are currently operating at system 1 and expect to receive a farm income v_1 ($/farm/season). When the climate changes the farmers expect to earn v_2 ($/farm/season), the climate sensitivity of changing from system 1 to system 2 is defined as $\omega = v_1 - v_2$, if $\omega < 0$ means farmers gain per capita income under climate change, if $\omega > 0$ means farmers will lose per capita income under climate change. Detailed account of this model is provided in Antle (2011).

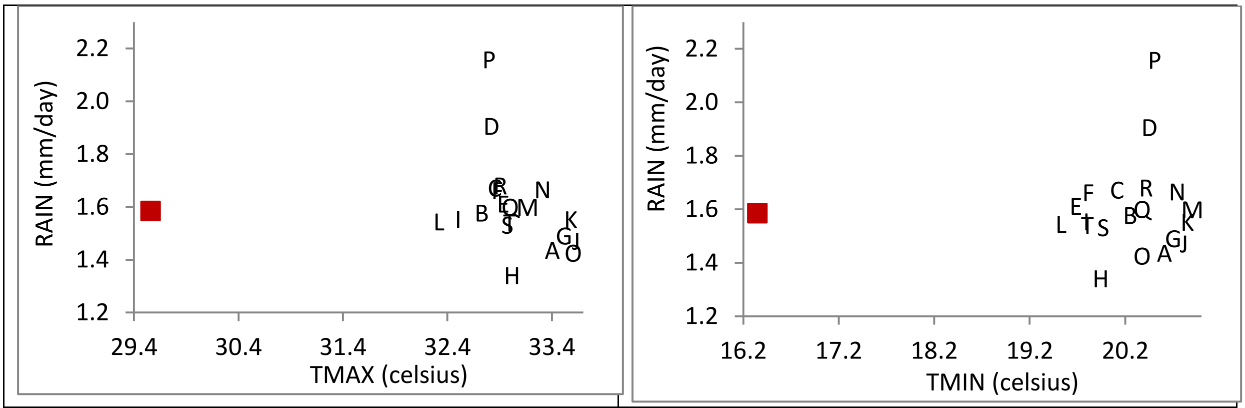
In the second question, farmers are transposed in future period operating under future production systems with a current climate (1980-2009). This combination is defined as system 1. System 2 is defined as the case where farmers are in future period operating under a future production systems with a future climate (2040-2069), (the impact of climate change on future agricultural production system will be to be comparing system 1 and system 2). In the third case, focuses in the quantification of the benefits of climate change adaptations focused on analyzing the benefits of potential adaptation options in the production system of the future, which may offset or capitalize on climate vulnerabilities. The assumption is that farmers are in future period operating under the future production systems with a future socio-economic conditions, technology, and development (2040-2069). This combination is defined as system 1. System 2 is defined as the case where farmers are in future period operating under future production systems using adaptation packages. In this case, the TOA-MD estimates adoption rate due to the adaptation package and other outcome variables.

3. Results and Discussions

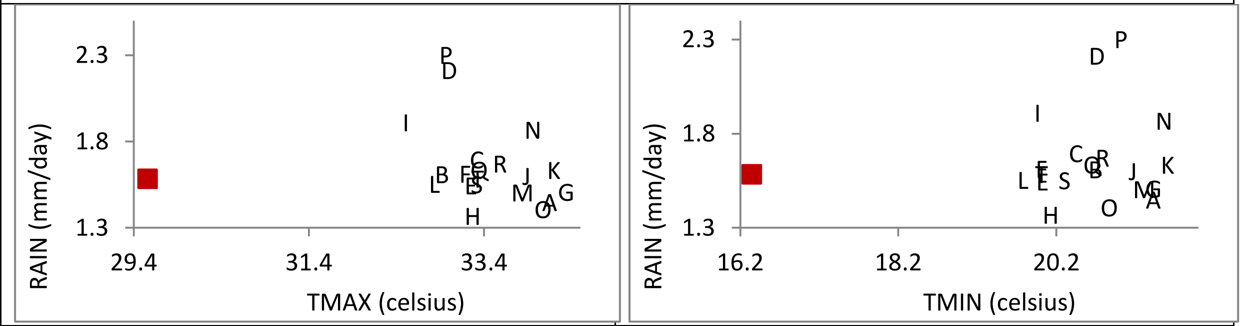
3.1 Climate change projections in Wami Basin

Figure 7 and Figure 8 show changes in the projected future climate for Dodoma and Morogoro stations based on the 20 GCMs. There is a clear increase in minimum and maximum temperature in the mid-century and end-century with the biggest increase expected to happen between now and mid-century. The temperature increase is expected to be about 3^{o}C for both minimum and maximum temperature for Dodoma while for Morogoro the increase is about 2^{o}C for maximum temperature and about 1^{o}C for minimum temperature. Rainfall projections is highly uncertain with some GCMs predicting a decrease on the amount rainfall and some an increase on the amount rainfall. For example for Dodoma, two GCMs (ukmo hadcm3 and csiro) indicate a significant increase in the amount of rainfall in both scenarios and periods (mid- and end century). In the case of Morogoro, most GCMs indicate a decrease in the amount of rainfall in both scenarios and periods.

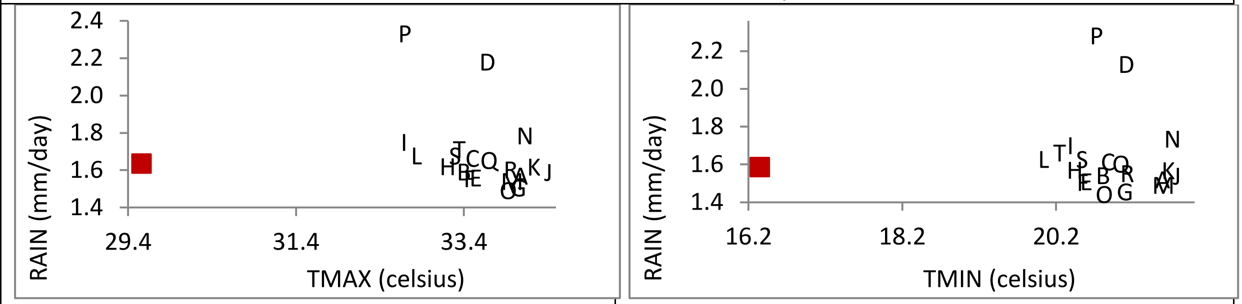
Figure 9 and Figure 10 show changes in the average monthly temperature and rainfall amounts in the form of boxplots of 20 GCMs. It is clear from the figures that temperature is projected to increase uniformly in the different months. However, rainfall is expected to change during the rainfall season. The projections show higher uncertainty in the rainfall amount compared to temperature.



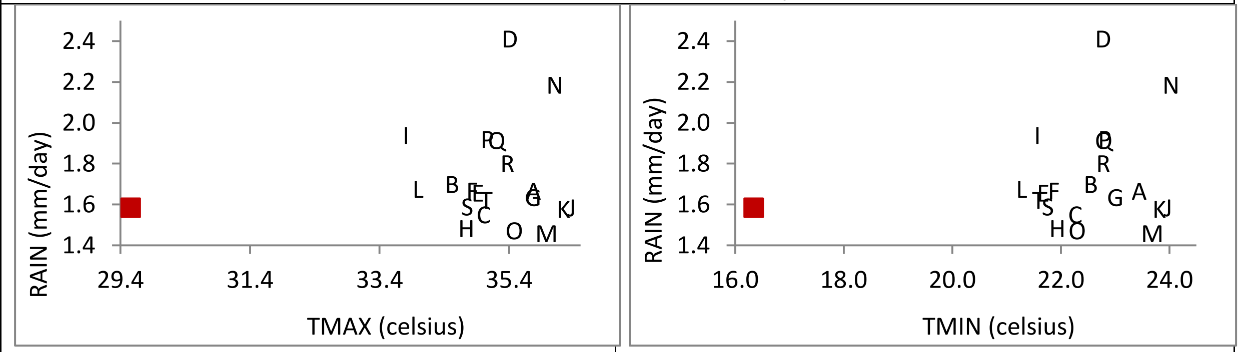
Dodoma RCP 4.5 mid-century



Dodoma RCP 4.5 end-century

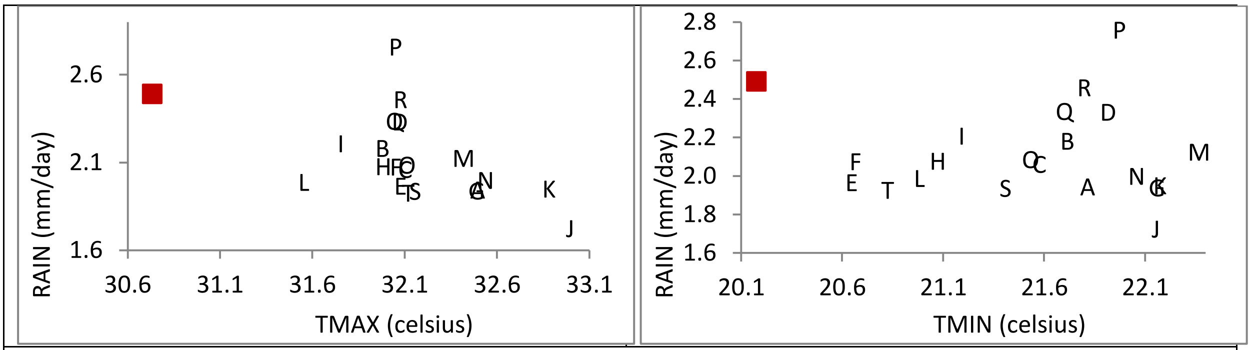


Dodoma RCP 8.5 mid-century

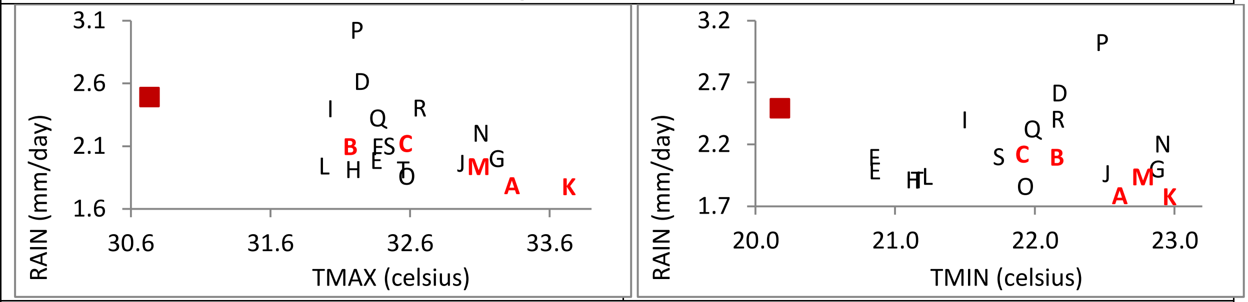


Dodoma RCP 8.5 end-century

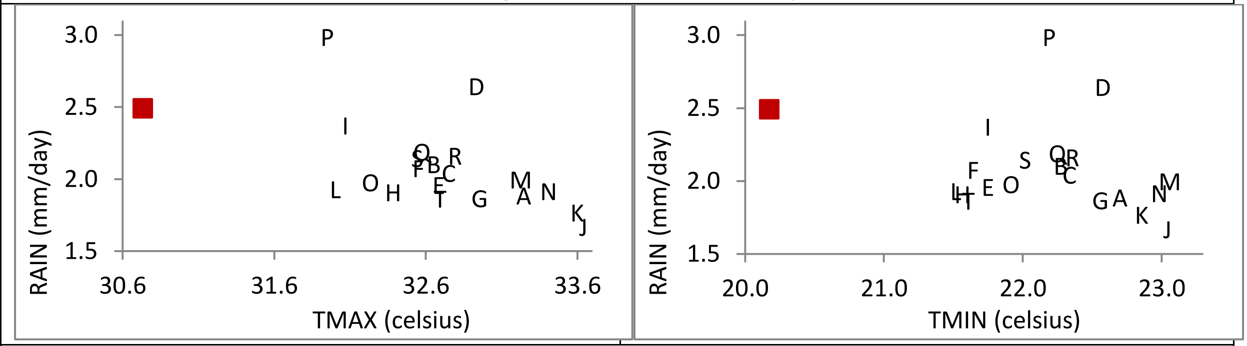
Figure 7: Scatter plots comparing baseline climate and projected future climates for Dodoma station. A = bccr, B = cccma cgcm3, C = cnrm, D = csiro, E = gfdl 2.0, F = gfdl 2.1, G = giss er, H = inmcm 3.0, I = ipsl cm4, J = miroc3 2 medres, K = miub echo g, L = mpi echam5, M = mri cgcm2, N = ncar ccsm3, O = ncar pcm1, P = ukmo hadcm3.



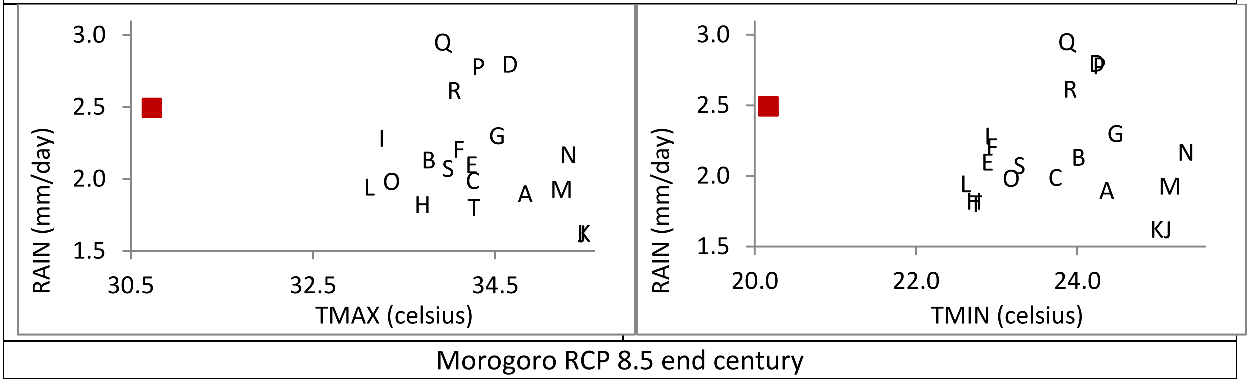
Morogoro RCP 4.5 mid term



Morogoro RCP 4.5 end century

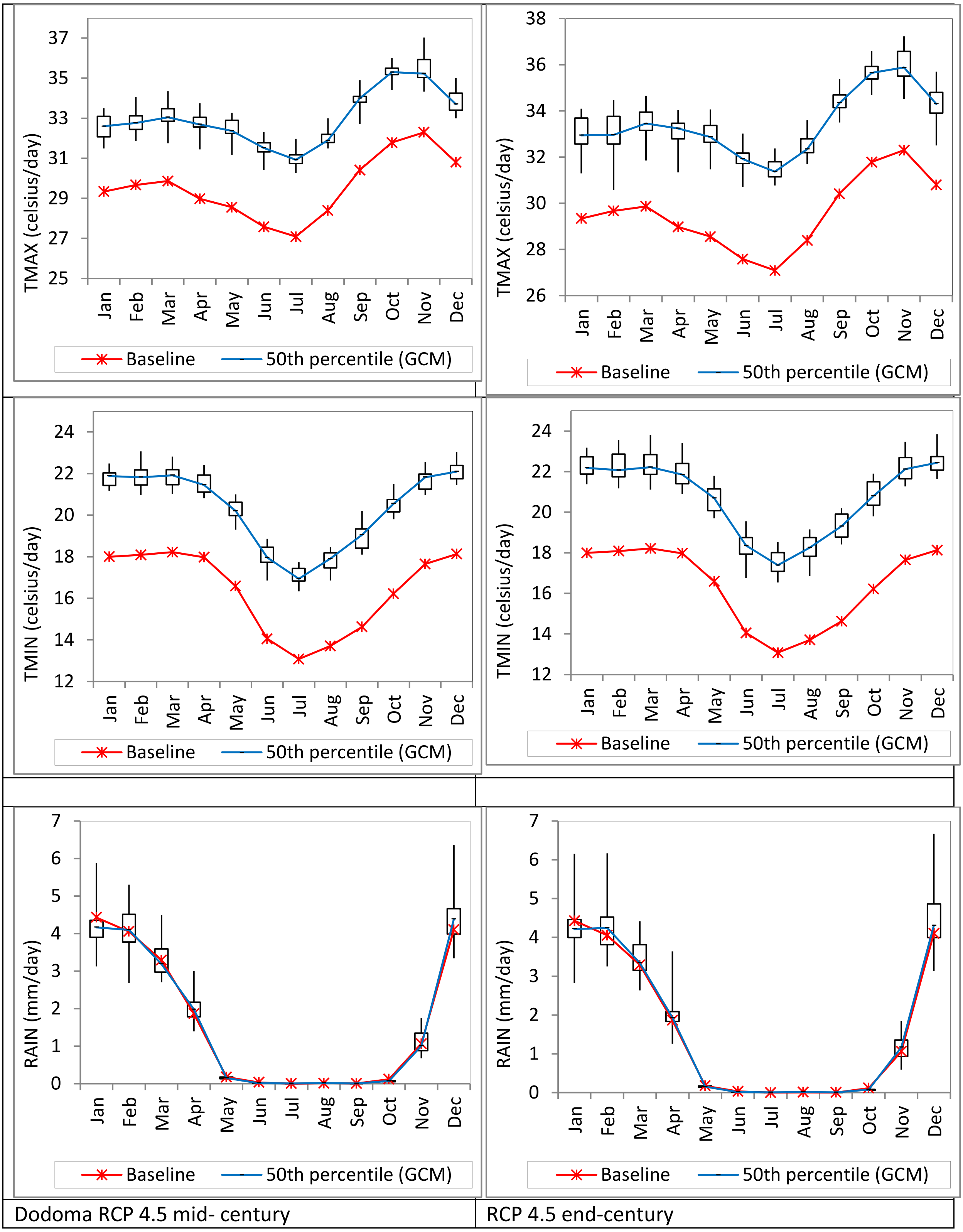


Morogoro RCP 8.5 mid term



Morogoro RCP 8.5 end century

Figure 8: Scatter plots comparing baseline climate and projected future climates for Morogoro station. A = bccr, B = cccma cgcm3, C = cnrm, D = csiro, E = gfdl 2.0, F = gfdl 2.1, G = giss er, H = inmcm 3.0, I = ipsl cm4, J = miroc3 2 medres, K = miub echo g, L = mpi echam5, M = mri cgcm2, N = ncar ccsm3, O = ncar pcm1, P = ukmo hadcm3.



Dodoma RCP 4.5 mid- century

RCP 4.5 end-century

Figure 9: Boxplots of the RCP4.5 scenario projections for different GCMs on monthly rainfall and temperatures in comparison to the baseline climate (1980-2009).

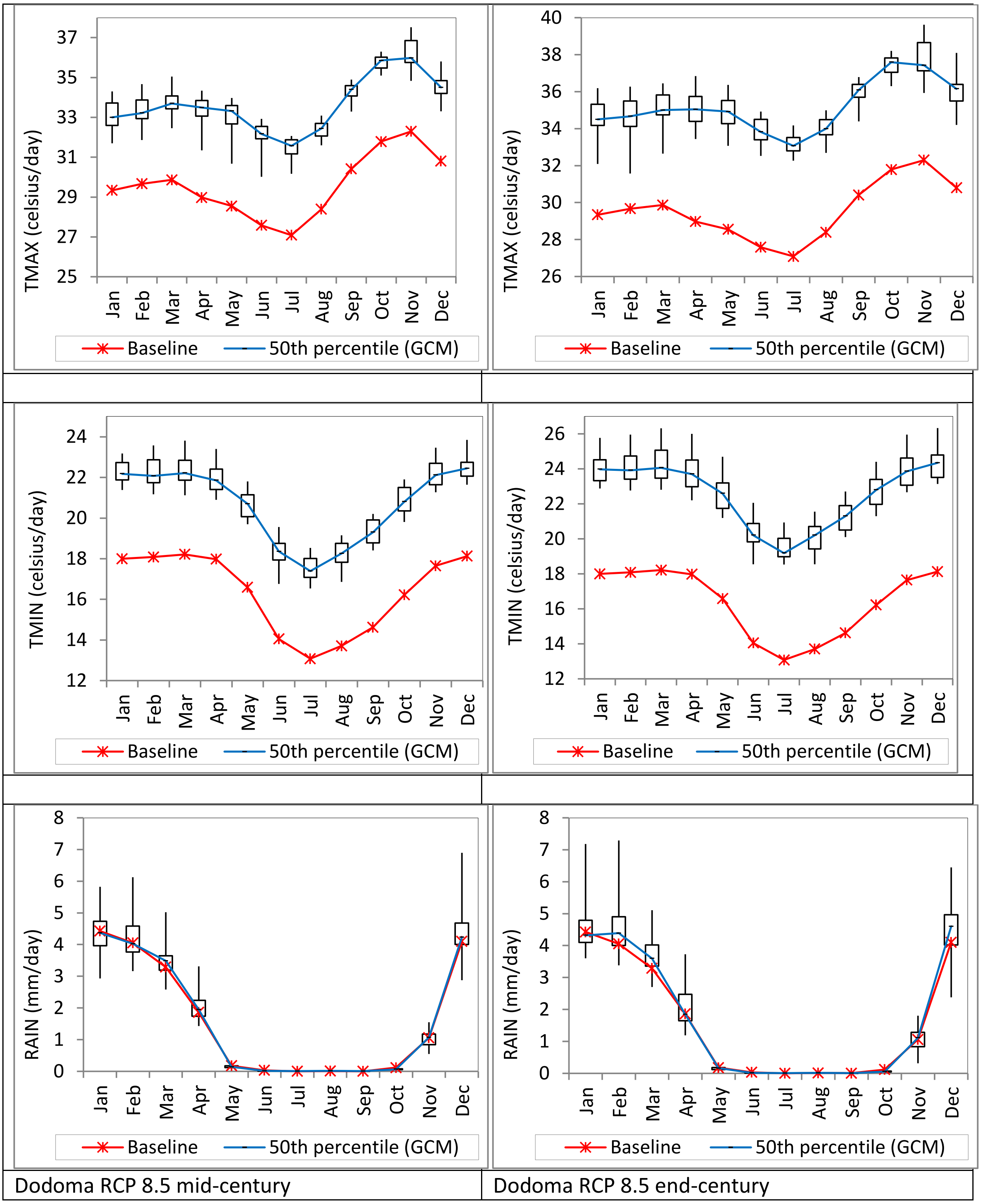


Figure 10: Boxplots of the RCP8.5 scenario projections for different GCMs on monthly rainfall and temperatures in comparison to the baseline climate (1980-2009).

3.2 Climate change impact on maize production

A total of 20 GCMs were used to simulate projected climate change impacts for RCP 4.5 and 8.5 emission scenarios during the mid-century and end-century periods using both DSSAT 4.5 and APSIM (ver 7.4) crop system models (CSM). Projected yields were found to remain the same or decline from baseline production by the mid-century and end century periods for all GCMS and for both CSM. Moreover, the projections from both CSM show that yield decline will be consistent in both livelihood zones (Figures 11-14). The decline is more pronounced with DSSAT model compared to APSIM.

The boxplots patterns for DSSAT model are consistent with a skew towards low yields. Comparison between RCP 4.5 and RCP 8.5 scenarios show that the boxplot spreads is significantly less for the RCP 8.5 scenario compared to RCP 4.5 scenario even though the yield decline is much significant in the case of RCP 8.5 scenario compared to RCP 4.5 scenario. This implies less uncertainty in the projections at high levels of CO_2 concentrations.

APSIM model projections show contradictory results compared to DSSAT model projections. Yield projections for zone 1 are skewed to the low side while for zone 2 are skewed to high yield side. Some of the GCM models show their median yields are higher than the baseline yield. However, most of the GCM models show their median yields are slightly lower than the baseline yield. Contrary to DSSAT, APSIM boxplots for RCP 8.5 scenario are similar to RCP 4.5 scenario for both mid and end centuries.

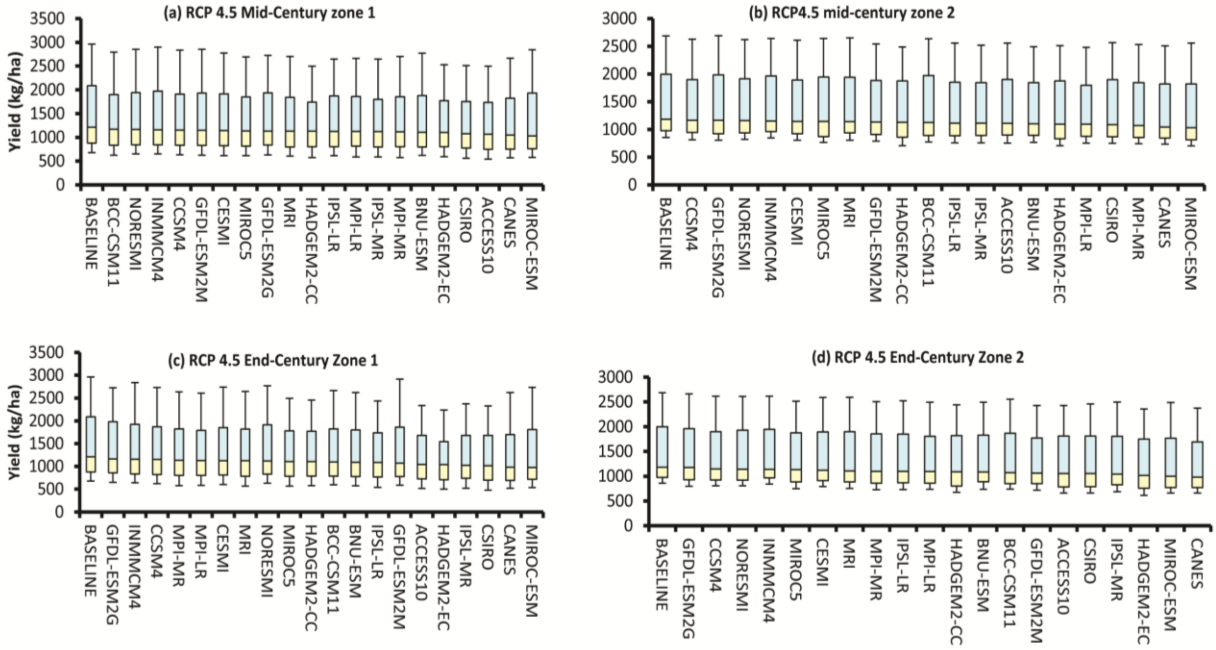


Figure 11: DSSAT simulated yields of maize for zone1 and zone 2 in Wami sub-basin using RCP 4.5 climate change scenario compared to baseline (1980-2009). Solid bar-median yield, Boxes 25th-75th percentile and whiskers 10th/90th percentile.

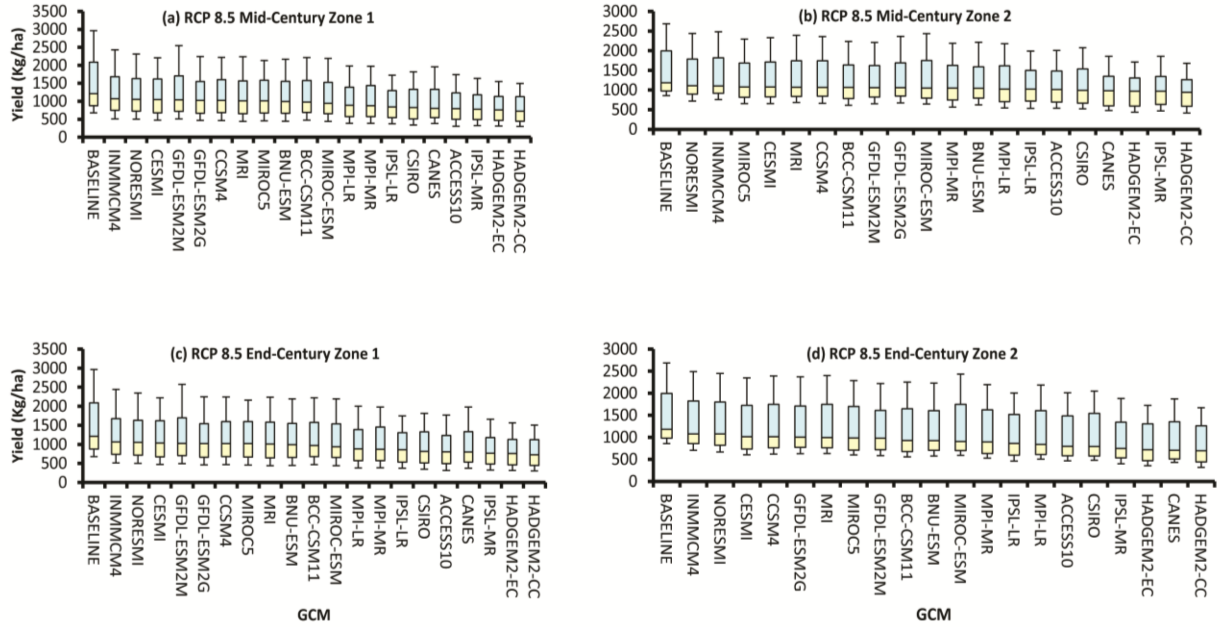


Figure 12: DSSAT simulated yields of maize for zone1 and zone 2 in Wami sub-basin using RCP 8.5 climate change scenario compared to baseline (1980-2009). Solid bar-median yield, Boxes 25th-75th percentile and whiskers 10th/90th percentile.

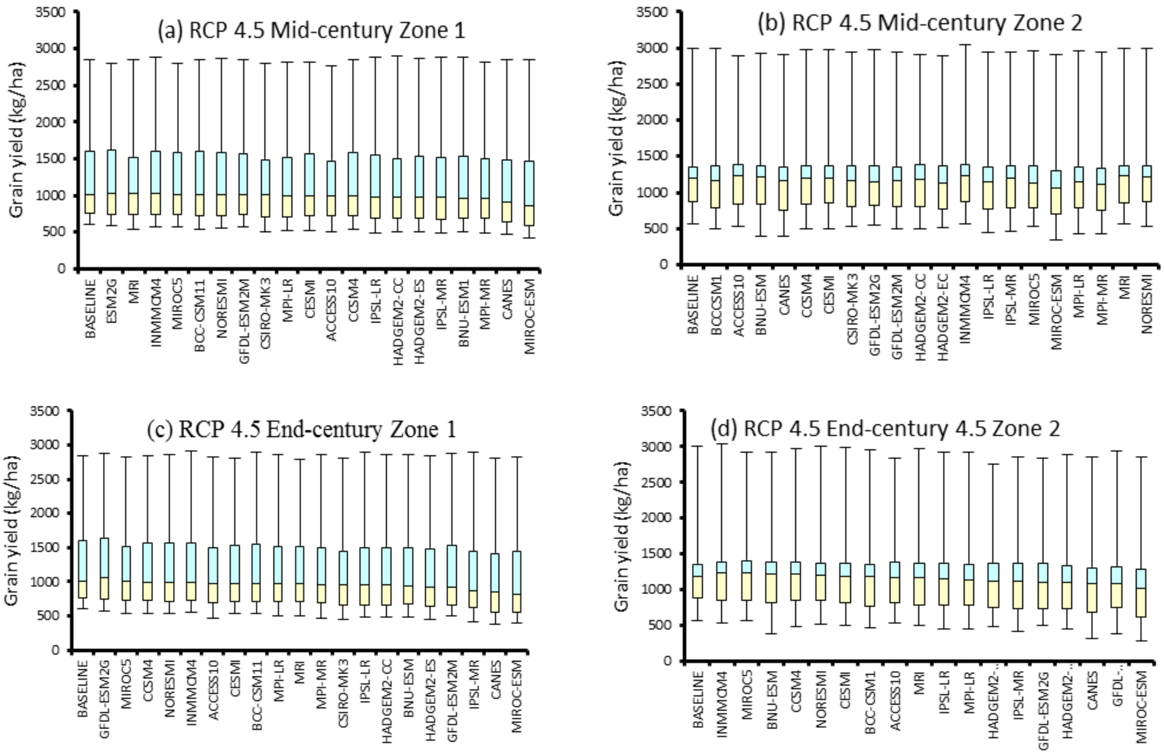


Figure 13: APSIM simulated yields of maize for zone1 and zone 2 in Wami sub-basin using RCP 4.5 climate change scenario compared to baseline (1980-2009). Solid bar-median yield, Boxes 25th-75th percentile and whiskers 10th/90th percentile.

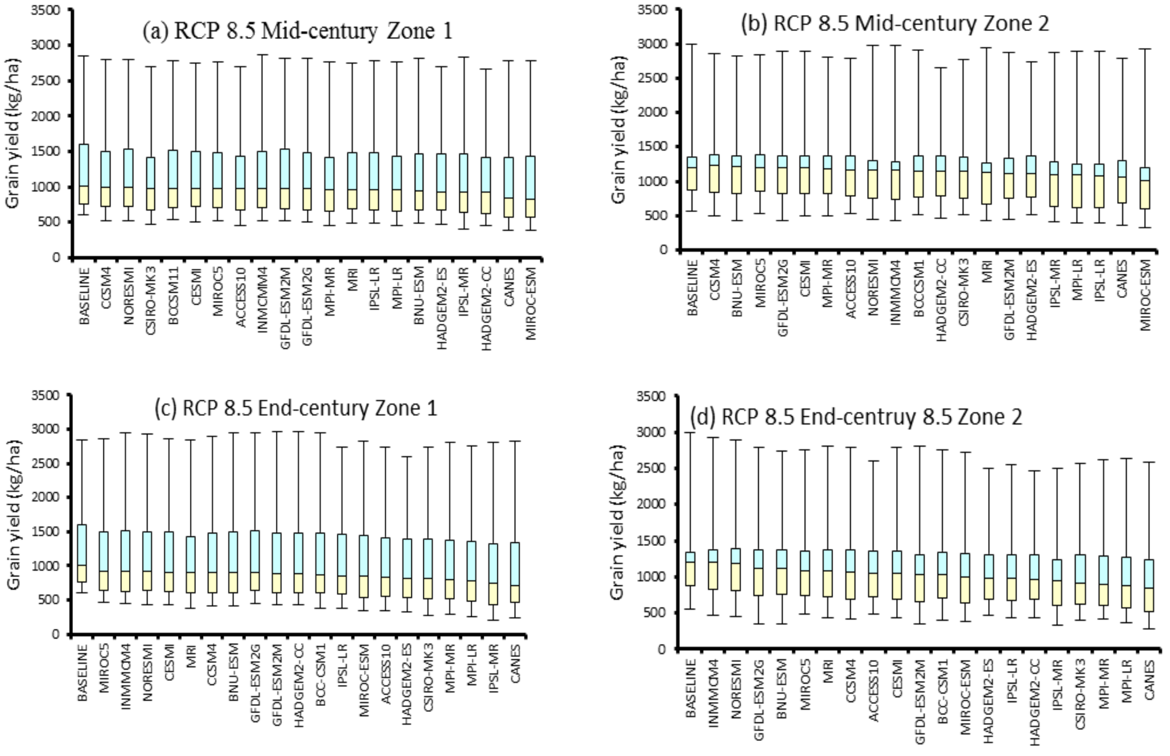


Figure 14: APSIM simulated yields of maize for zone1 and zone 2 in Wami sub-basin using RCP 8.5 climate change scenario compared to baseline (1980-2009). Solid bar-median yield, Boxes 25th-75th percentile and whiskers 10th/90th percentile.

3.3 Economic Analysis

3.3.1 The sensitivity of current agricultural production system to climate change

The sensitivity of current agricultural production system to climate change (Table 7) was analysed by assessing its impact on different economic welfare including poverty rate, per capita income, and per farm net returns. The results for all GCMs show that if the current production in the study is subjected to climate change, maize production will decrease.

Climate change is expected to decrease the per capita income as well as net farm returns making the poverty rate to go high in both zones (1&2) as shown in Figure 15, 16 and 17. The results further show that zone 2 is much affected by climate change than zone 1 as the percent of losers is high in zone 2.

Table 7: Simulated and observed maize yields in zone 1 and 2

ZONE	**Observed mean maize yield (Kg/ha)**	**Scenario 1: Sensitivity of current agricultural production systems**									
		APSIM Time averaged Relative yield (r=b2/b1)					**DSSAT Time averaged Relative yield (r=b2/b1)**				
		CCSM4	**GFDL**	**HadGEM _2ES**	**MIROC-5**	**MPI_ESM _MR**	**CCSM4**	**GFDL**	**HadGE M_2ES**	**MIRO C-5**	**MPI_ESM _MR**
ZONE 1	987.72	0.81	0.84	0.60	0.79	0.70	0.95	0.94	0.90	0.94	0.90
ZONE 2	891.90	0.83	0.79	0.57	0.80	0.75	0.98	0.92	0.95	0.99	0.97
AGG	939.81	0.82	0.86	0.59	0.80	0.73	0.97	0.93	0.93	0.97	0.94

Table 8: Percent of losers from climate change in scenario 1

ZONE	DSSAT					APSIM				
	CCSM 4	GFDL	HadGEM _2ES	MIROC- 5	MPI- ESM	CCSM 4	GFDL	HadGEM_2 ES	MIROC- 5	MPI- ESM
ZONE 1	65.29	62.25	69.86	65.86	68.46	53.57	53.36	55.48	53.93	56.03
ZONE 2	76.89	79.55	89.88	78.06	82.52	54.16	62.58	56.53	51.76	55.28
Aggregate	69.44	68.43	77.02	70.22	73.49	53.78	56.65	55.86	53.16	55.76

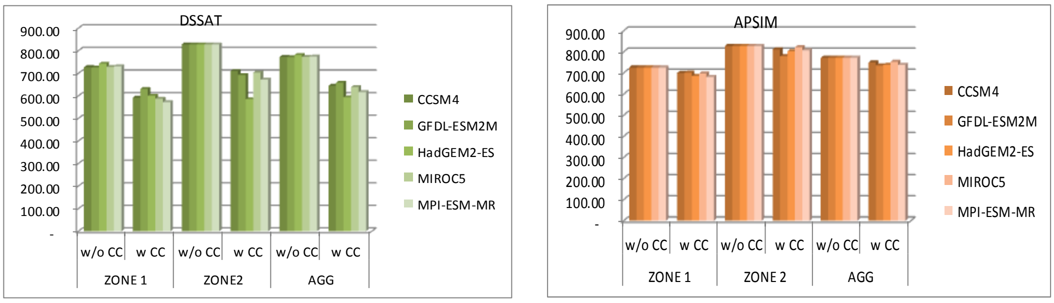


Figure 15: Net returns with and without climate change

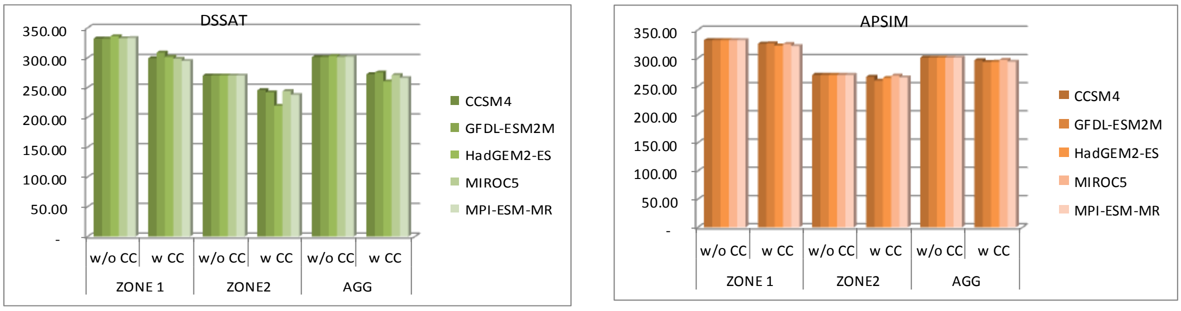


Figure 16: Per capita income with and without climate change

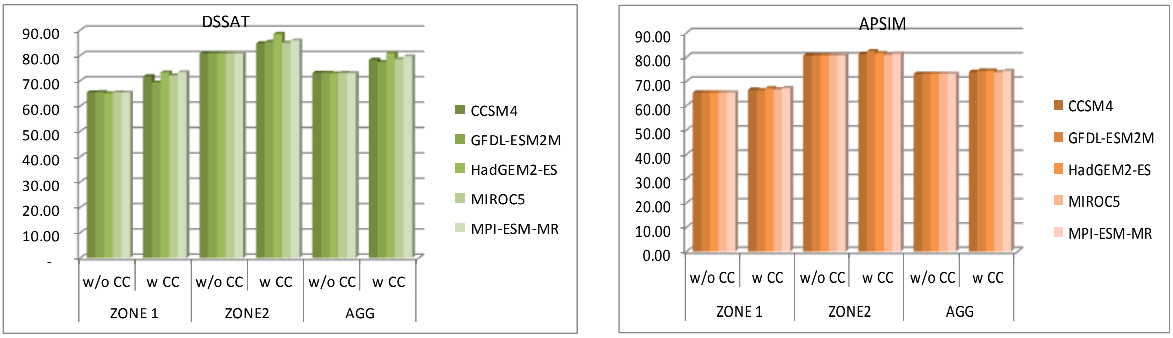


Figure 17: Poverty rate change due to climate

3.3.2 Impact of climate change on future agricultural production systems

Contrary to scenario 1, if the future production system in the study area (zone 1 &2) is subjected to climate change, all models predict to have the least percent of losers in all GCMs except HadGEM2 which show a large percent of losers in zone 1 (61%) and about 45% in zone 2 (Table 9 and Figure 18, 19 & 20). The poverty rate is projected to decrease due to increased per farm net returns as shown in Table 9. An increase in net returns while yields declining is because of increased price. The higher the market price the higher the per farm returns.

Table 9: Losers from climate change in senario 2

ZONE	DSSAT					APSIM				
	CCSM4	GFDL	HadGEM_2ES	MIROC-5	MPI-ESM	CCSM4	GFDL	HadGEM_2ES	MIROC-5	MPI-ESM
1	35.28	32.50	60.75	37.10	48.06	29.69	30.79	30.31	29.76	31.03
2	17.29	19.02	45.48	18.15	22.59	13.03	14.40	12.99	12.53	13.40
Aggregate	23.73	27.68	55.29	30.33	38.95	23.73	24.93	24.11	23.60	24.73

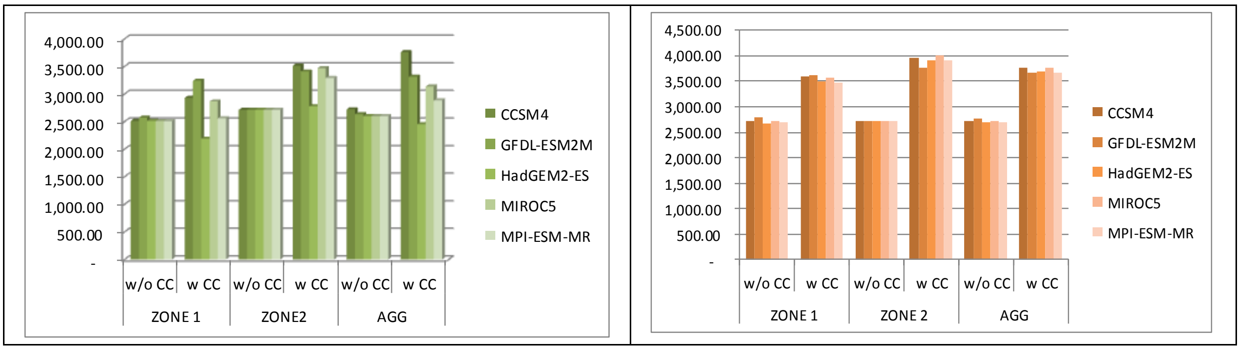


Figure 18: Projected net returns with and without climate change

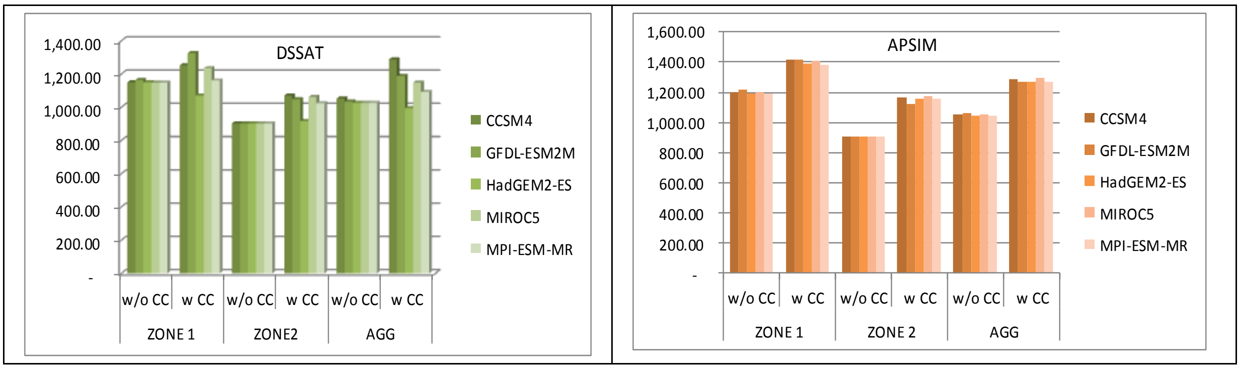


Figure 19: Projected per capita income with and without climate change

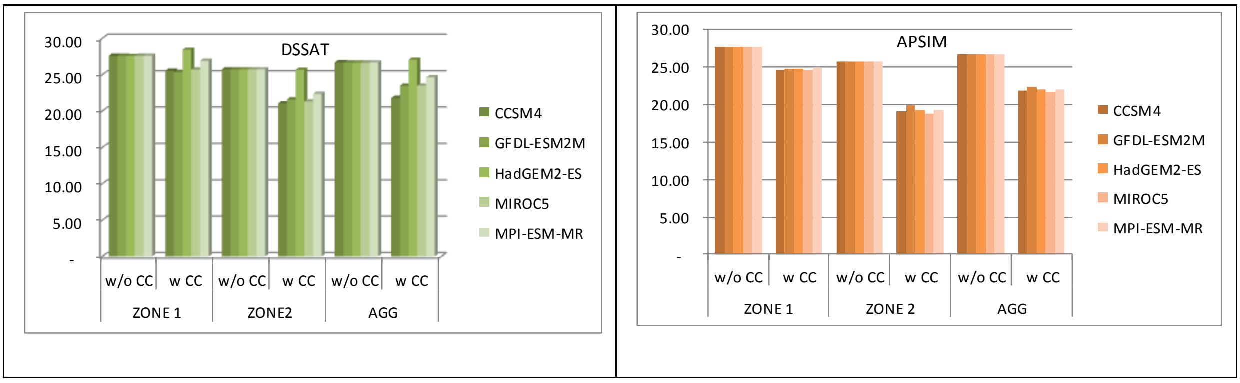


Figure 20: Projected poverty rate with and without climate change

3.3.3 Benefits of climate change adaptations

TOA-MD results in Table 10 and Figures 21-24 indicate the welfare outcomes as the future climate change impacts on the future production system with robust adaptations amid of development and transformative trajectories. The adoption rate is very high (68 – 87%), mean net returns with adaptation is between 30% and 50% for the two zones. In addition, rate of poverty decreased by 15 and 42% in the two zones.

Table 10. Projected maize yields with technology change to 2050.

ZONE	Projected mean maize yield (Kg/ha) Without climate change	Scenario 3: The benefits of climate change adaptations									
		APSIM Time averaged Relative yield (r=b2/b1)					DSSAT Time averaged Relative yield (r=b2/b1)				
		CCSM4	GFDL	HadGEM_2ES	MIROC-5	MPI_ESM	CCSM4	GFDL	HadGEM_2ES	MIROC-5	MPI_ESM
1	2613.63	2.13	2.62	1.36	2.02	1.85	2.17	2.26	2.13	2.15	2.13
2	2084.61	1.84	1.95	1.03	1.71	1.65	2.84	2.84	2.66	2.81	2.82
AGG	2311.33	1.99	2.28	1.20	1.86	1.75	2.51	2.55	2.40	2.48	2.47

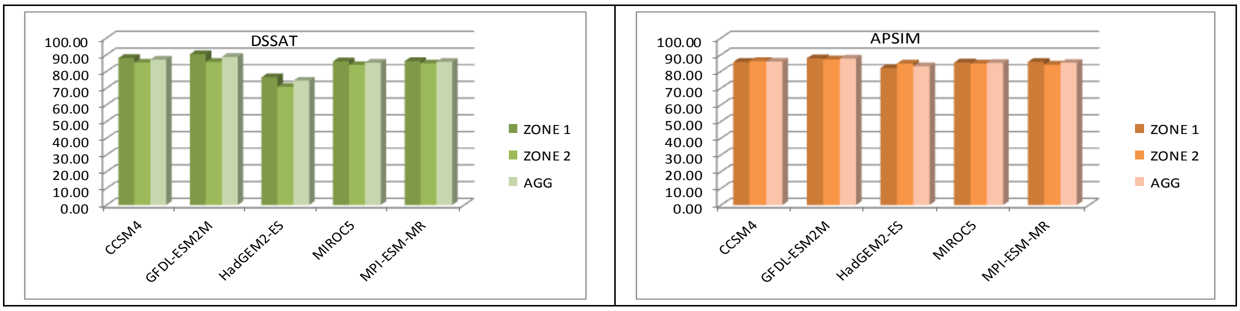


Figure 22: Adoption rate

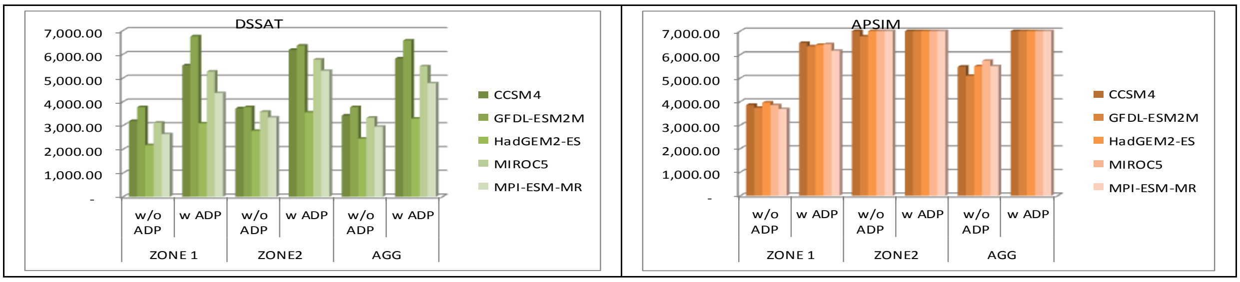


Figure 23: Change in net farm returns

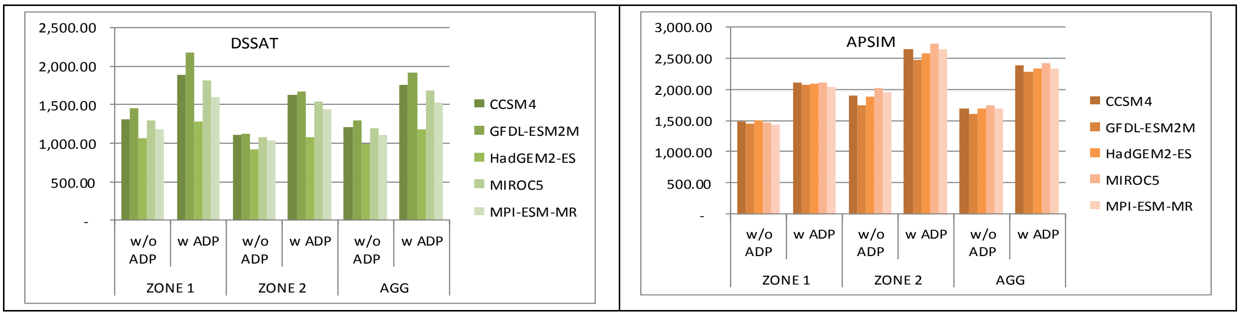


Figure 24: Change in per-capita income (USD)

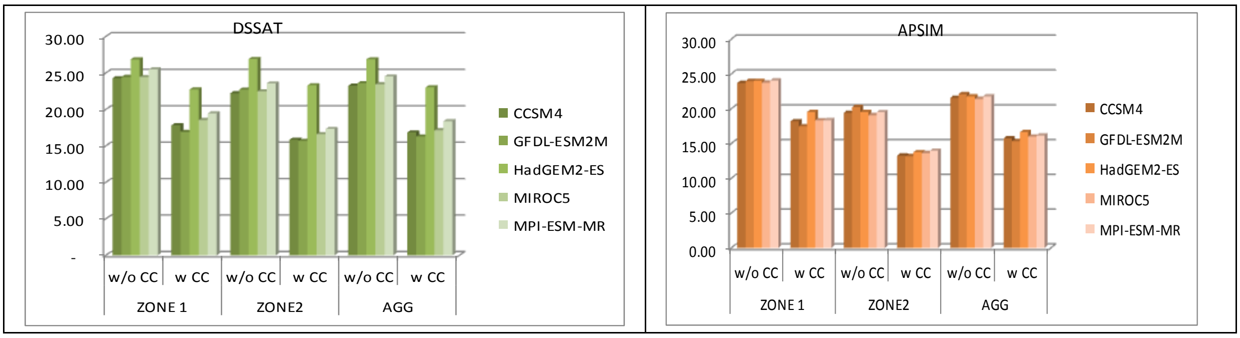


Figure 21: Poverty rate with and without adaptation

4. Conclusions

This chapter underpins a systematic and comprehensive assessment of climate change impacts on agriculture through an analytical protocol that integrates climate, crop and economic models. The developmental trajectories vested in the Representative Agricultural Pathways (RAPs) were also integrated in the crop and economic modeling processes. Such integrated assessment is based on the case of Wami River sub-basin in Tanzania – covering diverse semi-arid and sub-humid farming systems.

The study has shown that in the absence of robust adaptation and transformative development trajectories, maize yields are projected to decrease by between 5% and 42% from the baseline. Such negative impacts on yields will translate into increased poverty rates. The developmental and transformative trajectories will modestly mitigate the adverse impacts of climate change crop yields and welfare of farming households in the absence of robust adaptations. Adoption of robust adaptations – increased used of fertilizer and optimal spacing – reduced the negative impacts of climate change.

Therefore, developmental transformative trajectories and robust adaptations are necessary to proof agriculture from climate change related production risks in order to safeguard the livelihood of farming communities. Therefore, implementation of the development agendas and climate change action plans is necessary.