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

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AgMIP The Agricultural Model Intercomparison and Improvement Project

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CLIMATE CHANGE AGRICULTURE AND FOOD SECURITY

ICRISAT Science with a human face

International Crops Research Institute for the Semi-Arid Tropics

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AgMIP-Eastern Africa team

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

1. Summary and findings

Comprehensive assessment of climate change impacts on smallholder agricultural systems was carried out at selected locations in four Eastern African countries – Ethiopia, Kenya, Tanzania and Uganda. The target areas selected for this assessment are Adama Woreda in Ethiopia, Embu county in Kenya, Wami sub-basin in Tanzania and Hoima and Masindi districts in Uganda. Selection of these sites is based on the representativeness of the country's major agro-ecological zones and availability of the required data. Extensive efforts were made to collect the data required to calibrate, validate and apply climate, crop and economic models from various sources that included published and unpublished reports, farm surveys and individual researchers. The assessment used the methods and protocols developed by AgMIP global team and the process followed was reviewed and commented by the global team at various stages of this work.

Observed Climate data records for the period 1980-2010 for 16 stations located within the target areas was collected and used in this assessment. To capture full range of uncertainty associated with climate change projections downscaled location specific scenarios were generated for mid (2040-2070) and end (2070-2100) century periods for 20 CMIP5 AOGCMs under RCP 4.5 and 8.5 scenarios. To capture the diversity of smallholder farming systems field surveys covering 1469 farmers in the four countries were conducted. The surveys captured among other things, farm size, household size, crops grown, management practices employed, yields achieved and income sources. Crop simulation models APSIM and DSSAT were calibrated to simulate the performance of 10 different maize varieties that are relevant to the target areas by collecting and using data from various trials conducted mostly at the research stations of the national agricultural research institutions in the target countries. Representative Agricultural Pathways (RAPs) were developed to represent the current production system in the future through stakeholder discussions having an interest, knowledge and understanding about the current and future trends in agriculture and other socioeconomic developments in the target countries. These were used while evaluating socio-economic impacts of climate change. Below are some of the key findings from this assessment.

- Analysis of baseline climate data has indicated an increase in temperature at all locations. Though the magnitude of this increase varied from one location to the other, on an average temperatures in the region are increasing at the rate of 0.02^{0}C every year.
- The trends in temperature indicate that within the target region greater warming is taking place at locations away from equator compared to the ones close to equator.
- The increase in minimum temperatures is greater than that in maximum temperatures. The maximum temperature was found to be increasing by about 0.0055^{0}C per year and minimum temperatures by 0.0353^{0}C every year. However, significant differences were observed across the locations.
- While no clear increasing or decreasing trend is observed in rainfall, there is evidence to suggest that changes are taking place in the annual and seasonal variability. At all locations variability in annual and seasonal rainfalls, as indicated by the 10 year moving average of coefficient of variation, is increasing. The increase in CV of annual rainfall ranges from 5-15% at different locations.
- In the bimodal rainfall areas represented by Embu, variability was found to be increasing in SR season (Oct-Dec period) while decreasing in LR season (Mar-May period).
- The downscaled location specific climate change scenarios indicted an increase in both maximum and minimum temperatures. The median value from the 20 GCM projections for maximum temperature is in the range of 3-5°C by end century under RCP 8.5 at different locations. Lowest increase of 3.1^{0}C was predicted at Nazreth, Ethiopia and highest increase of 5.55^{0}C was predicted for Dodoma, Tanzania. The changes projected for different locations indicate higher increase at locations away from equator compared to those located near equator. Further, higher increases are observed in case of locations that are south of equator within the four country study region.
- Similar trends were also observed in case of minimum temperatures but the magnitude of increase is about 1°C higher compared to the increase observed in maximum temperatures. At different locations the median projected increase in minimum temperature is in the range of 4.2 to 6.3^{0}C
- Projected changes in rainfall indicate a general increase in rainfall. Similar to temperature, the locations near equator are likely to get wetter compared to the away locations. The median values

for rainfall change are 5% at Dodoma in the south, 34% at Nazreth in the center and 14% at Adigudom in the north.

- In case of temperature projections no outliers were observed but some rainfall projections are very high. For example, IPSL-CM5A-MR and IPSL-CM5A-LR predict more than 100% increase in rainfall at Nazreth and Embu locations.
- The down scaled climate change projections reflected well the general trends reported at regional scale for eastern and southern Africa.
- Crop simulation models DSSAT and APSIM simulated the growth and performance of different maize varieties fairly well. The models were also found to simulate the response to various management practices such as fertilizer application, planting dates and plant populations fairly well.
- Simulations by both models gave identical results, though DSSAT simulated yields were found to be generally higher compared to APSIM simulated yields. This is due to the inclusion CO_2 fertilization effect in DSSAT.
- Impacts of climate change varied from one agro-ecology to the other and from one season to the other and also the way the crops were managed. The impacts varied from about +60% in Kenya to about -30% in Tanzania.
- Simulation results indicate that, climate change will have a positive impact on maize yields in all AEZs in Ethiopia and in UM2, UM3 and LM3 in Kenya and will have negative impact in all AEZs in Tanzania and Uganda.
- The major factors contributing to increase in maize yields are general increase in rainfall and temperatures moving into more optimal range for maize production from current sub-optimal conditions.
- The simulation results indicated that it possible to adapt to the projected changes in all AEZs in all countries by making simple adjustments to the current management practices. Adaptation packages involving optimal dates of planting, plant population, variety and fertilizer doses were developed for each AEZs.

- Simulations with adapted package of practices indicated that yields can be increased significantly from current levels in all AEZs. Results indicate that yields can be doubled in some AEZs by adopting these practices.
- Economic impacts of these changes in maize yields were assessed using TOA-MD under current and future RAPS based conditions. In general, they followed the trends observed in the maize yields. Net returns and per capita income are expected to increase in Ethiopia and Kenya and decrease in Uganda and Tanzania.
- These changes in income will also affect the poverty rates which are expected to decline in Ethiopia and Kenya and increase in Tanzania and Uganda.
- A substantial population of smallholder farmers will be losers under climate change. This will be as high as 90% in case of Tanzania.
- Except for small differences, the direction and magnitude of impacts of climate change on growth and performance of maize simulated by APSIM and DSSAT models are similar
- One significant finding is that, the level of uncertainty associated with crop impacts and economic impacts is much less than that observed in the climate data. When computing net incomes, per capita incomes and poverty rates, very little difference was observed between GCMs
- This assessment has demonstrated that more accurate and location and farmer specific assessment of climate change impacts on agricultural systems is possible
- Overall, this assessment provided valuable insights about the impacts of climate change on smallholder agriculture and their potential effect on income and food security of the farmers. Stakeholders are highly appreciative of this effort and they would like to see this analysis extended to more crops and locations.

2. Introduction

One of the key messages emerging out of the recent IPCC reports is that the climate change is real, happening and will continue to happen for the foreseeable future, irrespective of what happens to future greenhouse gas emissions. The report also estimates with high confidence that the negative impacts on agriculture outweigh the positives which makes adaptation an urgent and pressing challenge. However, adaptation planning requires accurate information about where, when and how the impacts are going to be felt and who will be more vulnerable. Among the regions, Africa is considered as more vulnerable due to its high dependence on agriculture for subsistence, employment and income. In Eastern Africa, agriculture accounts for 43% of GDP and contributes to more than 80% employment (Omano et al. 2006). Within Africa, Eastern Africa is one of the most vulnerable regions due to its high dependence on rain-fed agriculture for subsistence, employment and income. The region experiences high variability in rainfall (Webster et al., 1999, Hastenrath et al., 2007) which has a direct bearing on the performance of agriculture. Generally the region experiences prolonged and highly destructive droughts covering large areas at least once every decade and more localized events even more frequently. The region recorded severe droughts and/or famines in 1973-74, 1984-85, 1987, 1992-94, 1999-2000, 2005-2006 and more recently in 2010-11. According to UNDP (2006), a single drought event in a 12-year period will lower GDP by 7%–10% and increase poverty by 12%–14%. Extreme events, including floods and droughts, are becoming increasingly frequent and severe (IPCC 2007). Based on the analysis of data from the international Disaster Database (EM-DAT), Shongwe et al. (2009) concluded that there has been an increase in the number of reported disasters in the region, from an average of less than 3 events per year in the 1980s to over 7 events per year in the 1990s and 10 events per year from 2000 to 2006. The negative impacts of climate are not limited to the years with extreme climatic conditions. Even with normal rainfall, the countries in the region do not produce enough food to meet their people’s needs. Left unmanaged, these impacts can have far-reaching consequences on the local food security, economy, and poverty.

Over the past few years, climate research has contributed significantly to increased understanding of how the climate in the region is varying on inter-annual and decadal time scales and on how the climate is changing in response to global warming and other factors. The impacts of this variability and changes in climate on various sectors including agriculture have also received considerable attention. These studies indicate that agriculture, especially the one practiced under rainfed conditions in moisture limiting environments such as semi-arid tropics, is one of the most vulnerable sectors since these are relatively warmer places and rainfall is the only source of water. There is a rapidly growing literature on vulnerability and adaptation to climatic variability and change, but most of these studies are based on assessments made using statistical and empirical models that fail to account for the full range of complex interactions and their effects on agricultural systems (Parry et al., 2004; Cline, 2007; Lobell et al., 2008). Evidence available to date indicates that with 1°C of warming, roughly 65% of current maize growing areas in Africa will experience yield losses (Lobell et al., 2011) and the average predicted production losses by 2050 for most crops are in the range of 10-25% (Schlenker and Lobell, 2010).

For developing and implementing adaptation programs, more detailed information about the impacts of climate change on various components of the smallholder farming systems such as which crops and varieties are more vulnerable and which management practices are unviable is required. This requires a comprehensive assessment using site and location specific climate and crop management information. However, several problems constrain such an assessment. Firstly, downscaled local level climate change projections that are required to make such assessments are not readily available. While climate models provide various scenarios with high levels of confidence at global and sub-regional level, there are challenges in downscaling them to local level (IPCC, 2007). Secondly, lack of information on the sensitivity of smallholder agricultural systems to changes in climate. Though process based crop simulation models can serve as important tools to make a more realistic assessment of impacts of climate variability and change on agricultural systems, application of the same is limited to few location specific studies mainly because of the intensive data requirements and practical limitations including capacity to calibrate, validate and perform detailed analyses. Thirdly, there is scarcity of information on how the impacts of climate change on the production and productivity of agriculture translate into economic impacts including food security at household and national levels.

This assessment is aimed at developing more accurate information on how the projected changes in climate impact the productivity and profitability of agricultural systems that are widely adopted by smallholder farmers in Eastern Africa using the protocols and methods developed by Agricultural Model Intercomparision and Improvement Project (AgMIP) (Rosenzweig et al., 2013). One key aspect of this assessment is the attention paid to capture the complexity and diversity that exists in the smallholder farming systems including the different ways in which the system is managed. The study is an attempt to make a comprehensive assessment of climate change on crop growth and performance under conditions that interactions as well as related economic impacts by integrating state of the art downscaled climate scenarios with crop and economic models. The assessment was carried out in contrasting agro-ecological zones spread over the four major countries in eastern Africa – Ethiopia, Kenya, Tanzania and Uganda. This report summarizes the findings that include trends and changes in the observed and downscaled climate scenarios, quantified information on impacts of these trends and changes on performance of maize under a range of environmental and management conditions, implication of these changes in crop performance on income, poverty and food security of smallholder farmers and potential adaptation strategies that can assist smallholder farmers in minimizing negative impacts.

3. Regional Agricultural Systems and Climate Change Challenges

3.1 About the region

The climate over Equatorial Eastern Africa region is considered as one of the most complex due to large scale tropical controls that include several major convergence zones superimposed on regional factors such as lakes, topography and maritime influences (Nicholson, 1996). Rainfall is seasonal which is associated with the annual migration northwards and southwards of the Inter-Tropical Convergence Zone (ITCZ) (Griffiths, 1972; Jackson, 1989; Osei and Aryeetey-Attoh, 1997), being located over the Equator in March-April and again in October-November. Consequently, much of the region experiences bimodal pattern of rainfall near the Equator which tends to become unimodal with distance from the Equator (Conway et al., 2005). The two seasons that the areas near equator experience are normally referred to as Long Rains (LR) (March to May) and Short Rains (SR) (October-December). Over the region, the Long Rains (March to May) contribute more than 70% to the annual rainfall and the Short Rains less than 20% (**Error! Reference source not found.** 1). Near equator in Eastern Kenya, rainfall is more or less equally distributed over the two seasons with short rains season generally considered as more reliable. North of equator in Ethiopia, the period June to September is the main season. Rainfall during the period March to May is low with very high variability. Hence, much of the cropping is done during June to September period which is locally known as . In case of central and southern Tanzania, the period December to March is the main cropping period. Within these zones, altitude and other localized variables also produce distinctive and widely diverse local climates ranging from desert to forest over relatively small areas, often changing within tens of kilometres. More than a third of the region's total land area of 8.1 m km^2 is covered by arid or semi-arid agro-ecologies which are marginal for crop production and where agricultural systems are highly sensitive to even minor deviation from the normal conditions (Figure 2). All the target locations selected for this assessment fall within semi-arid region.

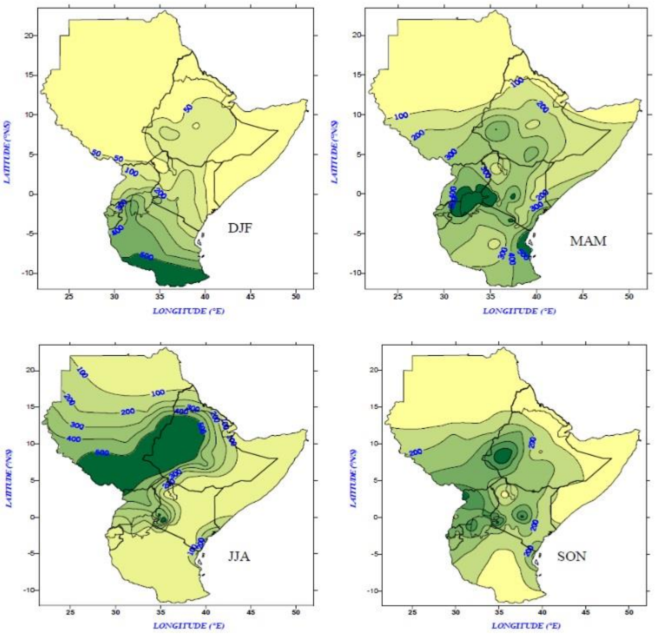


Figure 1: Seasonal rainfall distribution in Eastern Africa (Ogallo, 1989)

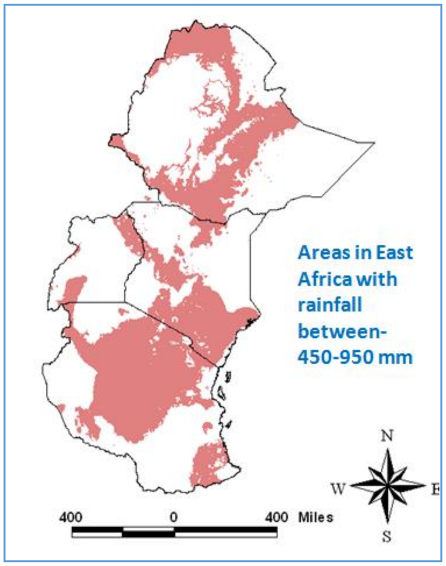


Figure 1: Distribution of semi-arid environments in Eastern Africa

Agricultural systems in the region have evolved along these climatic patterns. Table 1 gives a summary of the main food crops grown in the four target countries and yields currently achieved. Maize, sorghum, millets, and wheat are the major cereal crops while common bean is the most widely grown legume crop. Among the cereals, maize occupies the largest area followed by sorghum. Both these crops and wheat are grown in all the four countries. In addition, teff and barley in Ethiopia and banana in Uganda are the other important crops. Common bean is the major food legume cultivated in all four countries. Other legumes of importance are groundnut, cowpea and pigeonpea. Beans and groundnuts are grown in all countries while pigeonpea and cowpea are grown mostly in Kenya, Tanzania and Uganda.

Table 1: Average harvest area and yield (in parenthesis) of main food crops in the four target countries, 2000–2012 (hectares) (Data source: FAOSTAT)

Commodity	Ethiopia	Kenya	Tanzania	Uganda	Total
Maize	1,833,403 (2264)	1,818,078 (1638)	3,231,598 (1257)	889,600 (2027)	7,772,679 (1677)
Sorghum	1,549,065 (1694)	169,484 (758)	715,819 (956)	324,400 (1263)	2,758,768 (1419)
Millet	375,949 (1300)	106,624 (619)	310,480 (773)	300,400 (1545)	1,093,454 (1170)
Wheat	1,432,347 (1703)	142,022 (2504)	69,027 (1548)	11,000 (1679)	1,654,396 (1769)
Drybeans	246,199 (942)	894,802 (484)	895,546 (513)	895,546 (513)	2,946,678 (633)

Farming is mostly by smallholder farmers on farms of less than one hectare and is generally characterized as low input-low output system. Production is mainly for subsistence and local markets with the exception of a few cases of small and medium sized farmers. Yields of all crops in the region are very low. Average maize yields varied from about 1,257 kg/ha in Tanzania to 2,264 kg/ha in Ethiopia. Average yield of sorghum is about 1,419 kg/ha but varies from 758 kg/ha in Kenya to 1,694 kg/ha in Ethiopia. In general, yields of all crops are relatively high in Ethiopia and low in Tanzania and Kenya. Within the country, yields vary greatly from one location to the other over short distances due to differences in climate, soil type and management. In all countries agro-ecological zones, which have similar combinations of climate, topography and soil types, and similar physical potential for agricultural production have been defined and identified to the village level and the same were used as the basis for conducting this assessment. Below is a brief description of the agro-ecologies in the districts selected for this assessment.

3.2 Agro-ecological zones at target areas

We have selected one district or equivalent in each of the four participating countries viz., Ethiopia, Kenya, Tanzania and Uganda for this assessment. The selection of the districts is based on its representativeness of the area in terms of physical, biological and socio-economic characteristics as well as farming systems practiced, availability of required soil, crop and climatic data to parameterize the crop models and synergies with other projects/initiatives such as CCAFS. The areas selected are Adama and Hintalo Wajirat woredas in Ethiopia, Embu County in Kenya, Wami river basin in Tanzania and Hoima and Masindi districts in Uganda (Figure 3). In case of Ethiopia, maize is the main staple grown in Adama while wheat is the main crop at Hintalo Wajirat. A brief description of these sites is given in the following sub sections.

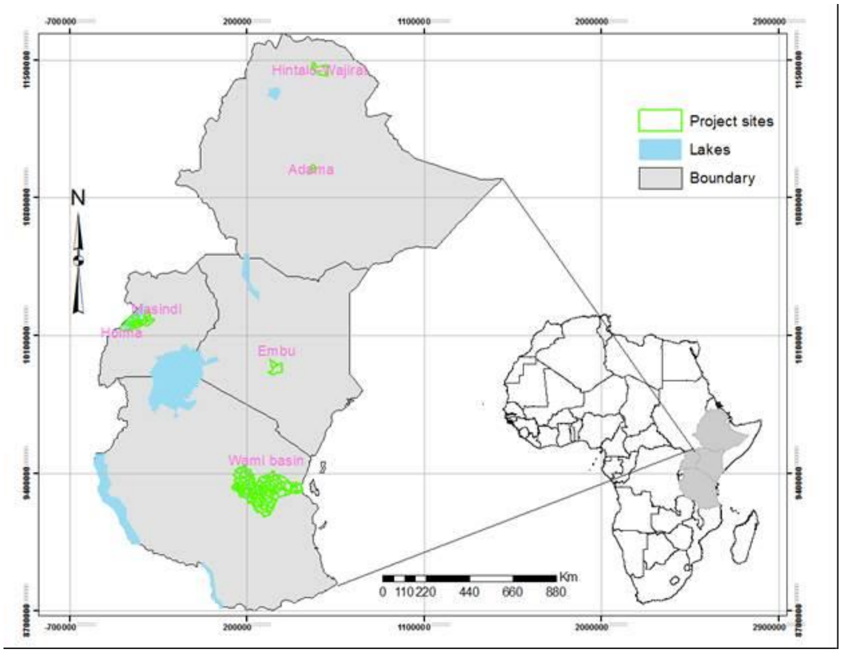


Figure 2: Map showing areas selected for the assessment in Ethiopia, Kenya, Tanzania and Uganda

3.2.1 Ethiopia

Based on the differences in elevation and rainfall regimes, Ethiopia is divided into 18 major and 49 sub-agro-ecologies (MoA, 1998). For this assessment, we have selected two woredas viz., Hintalo Wajirat in the northern and Adama in the central Ethiopia (Figure 4). The three main agro-ecologies present in Adama are warm semi-arid lowlands, warm sub-moist lowlands and Tepid sub-moist mid highlands. Much of the Hintalo Wajirat in the northern Ethiopia is under tepid sub-moist mid Highlands agro-ecology.

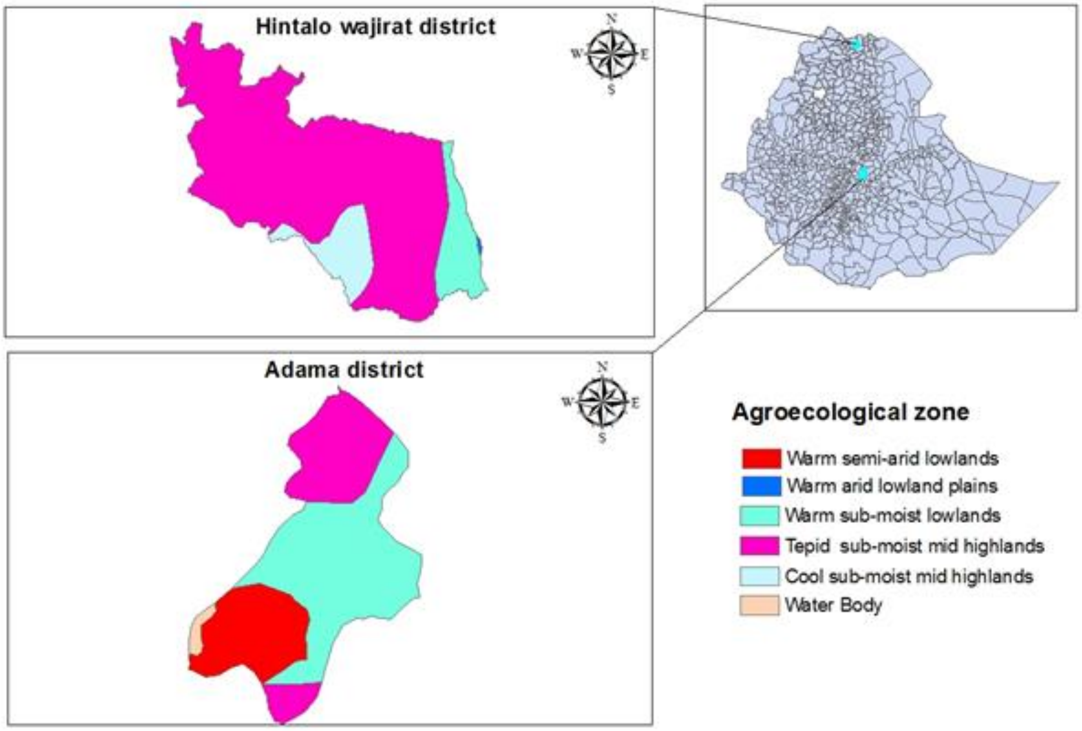


Figure 3: Agro-ecologies of study sites in Ethiopia

The rainfall at both locations is in the range of 550 to 850 mm mostly during the months of June to September. Average annual temperatures are around 20-21^{0}C (Table 2). The maximum temperatures in Adama region are around 26-27^{0}C while in Hintalo Wajirat they are higher by about 1^{0}C. The minimum temperatures are around 14.0^{0}C at both locations

Table 2: Agro-ecological zones in Adama and Hintalo Wajirat in Ethiopia

Agro-ecology	Altitude (m)	Annual Mean Temperature (^{0}C)	Annual Rainfall (mm)
SA2:Warm semi-arid lowlands (Wonji)	1544	20.6	811.7
SM2:Warm sub-moist lowlands (Melkassa)	1461	21.3	733.7
SM3:Tepid sub-moist mid highlands (Nazreth)	1702	21.3	844.6
SM2: warm sub-moist lowlands	2068	20.3	566
SM4: Cool sub-moist mid highlands	2628	20.3	643.7
SM3: Tepid sub-moist mid highlands	2350	20.0	643.7

Soil survey department of Ministry of Agriculture has identified about 19 major soil types throughout the country. The big proportion of the country's landmass is covered by lithosols, nitosols, cambisols and regosols in order of their importance.

In Ethiopia the households are large, about 6 persons per household which is also highest in the region (Table 3). Average farm size is about 1 ha and principle crops grown at Adama are maize and haricot beans and at Hintalo Wajirat main crops are wheat, barley and sorghum. Yields of most crops in the target areas are low and are below the national averages.

Table 3**:** Characteristics of smallholder farms in different AEZs

AEZ	Mean Household size	Mean Farm size (ha)	Fertilizer use (kg N/ha)	Dominant maize variety	Average maize yields (kg/ha)
SA2	6.63	1.2	5	Melkasa1	500
SM2	5.23	1.8	10	Melkassa-2	774
SM3	6.15	1.4	2	Katumani	530
SM2	6.07	0.87	17.6	HAR2501	1103
SM4	5.7	0.97	17	HAR2501	1180
SM3	5.7	0.97	17	HAR2501	1496

3.2.2 Kenya:

Embu County in Kenya, which lies on the south-eastern slopes of Mount Kenya, covers the typical agro-ecological profile of the country, from cold and wet high altitude areas to the hot and dry low altitude areas. The region is bounded by latitude 0°53'S and longitude 37°45'E. The county slopes from west to east (Jaetzold et al., 2007). The average annual rainfall varies from more than 2200 mm at an altitude of 2500 m to less than 600 mm near the Tana River at 700 m. The average annual temperatures vary from 28.8^{0}C in the hottest month to 9.6^{0}C in the coldest month (Jaetzold et al., 2007). The county is divided into 11 agro-ecological zones (AEZs) based on their probability of meeting the temperature and water requirements of the major crops grown in the country (Table 4). The Upper Highlands (UH0) and Lower Highlands (LH0) are so wet and steep that forest is the best land use. In the Lower Highlands Zone (LH1) and Upper Midland Zone (UM1) precipitation is still 1800 mm or more and average annual temperatures are less than 18^{0}C; and the predominant cropping systems are tea and coffee based. Contribution of these AEZs along with relatively small Inner Lowland (IL5) zone to food production in the county is fairly small. The remaining seven zones, ranging from Upper Midland main coffee zone (UM2) to Lower Midland livestock-millet zone (LM5) are the main cropping areas. Rainfall during the main crop growing period declines rapidly from UM2 to LM5 (Figure 5).

Table 4**:** Agro-ecological zones of Embu county and climate of the zones (Jaetzold et al., 2007).

Agro-ecology	Altitude (m)	Annual Mean Temperature (^{0}C)	Annual Rainfall (mm)
UH0: Upper Highland Forest Zone LH0: Lower Highland Forest zone	>2500	NA	NA
LH1: Lower Highland Tea-Dairy Zone	1900-2100	17.7-15.8	1750-2000
UM1: Upper Midland Coffee-Tea Zone	1600-1850	18.9-17.5	1400-1800
UM2: Upper Midland Main Coffee Zone	1400-1600	20.1-18.9	1250-1500
UM3: Upper Midland Marginal Coffee Zone	1280-1460	20.7-19.6	1000-1250
UM4: Upper Midland Sunflower– Maize Zone	1200-1400	20.9-20-0	980-1100
LM3: Lower Midland Cotton Zone	1070-1280	22.0-21.0	900-1100
LM4: Lower Midland Marginal Cotton Zone	980-1220	22.5-21.0	800-900
LM5: Lower Midland Livestock-Millet Zone	830-1130	23.9-21.7	700-800
IL5: Inner Lowland Livestock Millet Zone	600-850	25.4-24.0	500-710

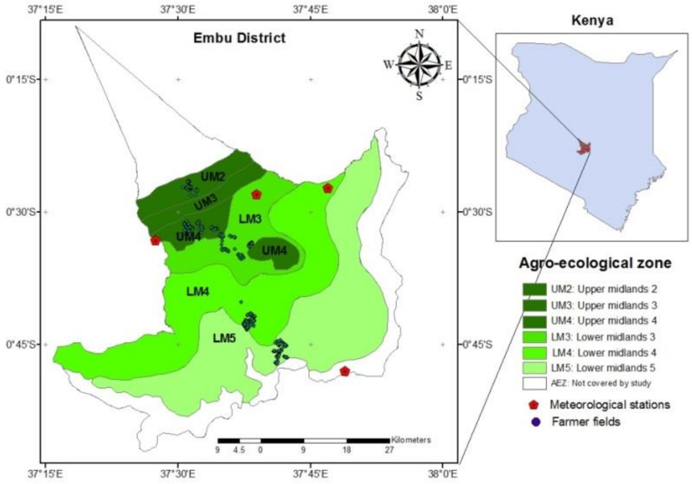


Figure 4**:** Map showing the target AEZs

In UM2, UM3 and UM4 key crops are maize and beans, but farmers also grow coffee as a cash crop. In addition, they also plant bananas, vegetables, and sweet potatoes. Crops grown by farmers in LM3 are similar to those grown in UM2 and UM3 except coffee. Some farmers in this AEZ grow sorghum and millet on small areas. Farmers in LM4 and LM5 plant pigeonpea in addition to other crops grown in LM3. Though farmers in all AEZs grow maize, there are significant differences in the varieties grown and in the management employed. Farmers in the high potential UM2, UM3 and LM3 use long duration high yielding varieties while those in the low potential LM4 and LM5 favor short duration varieties as a drought escaping strategy. In general, use of fertilizer is very low and the number of farmers using fertilizer, especially in agro-ecologies LM4 and LM5 is very limited. The areas occupied by various crops also vary from farm to farm and from season to season. Some important characteristics of the farming systems in the target AEZ are as shown in Table 5.

Table 5**:** Characteristics of smallholder farms in different AEZs

AEZ	Mean Household size	Mean Farm size (ha)	Mean Dairy herd size	Fertilizer use (kg N/ha)	Dominant maize variety	Average maize yields (kg/ha)
UM2	4.3	0.91	2.29	12.1	DK41, H513	1029.63
UM3	5.7	2.21	1.79	15.0	Duma, H513	1194.83
LM3	5.8	1.85	1.83	12.8	Duma, DK43, Katumani,	1020.94
LM4	6.5	2.43	2.2	9.4	Katumani, Duma, DK43	959.87
LM5	6.9	1.74	1.88	4.1	Katumani, Duma	525.44

3.2.3. Tanzania

In Tanzania, the study area is Wami sub-basin located between 5°–7°S and 36°–39°E and covers the semi-arid in Dodoma region, the humid inland swamps in Morogoro region to Saadani Village at the coast of Indian Ocean. 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 accounts for 16.3% of the basin area while bushland is 30% (MLHHSD, 2009). The area is divided into two livelihood zones, LH1 and LH 2 and within which several agro-ecological zones are found (Figure 6). Farming systems in the study area are 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 the Coast regions.

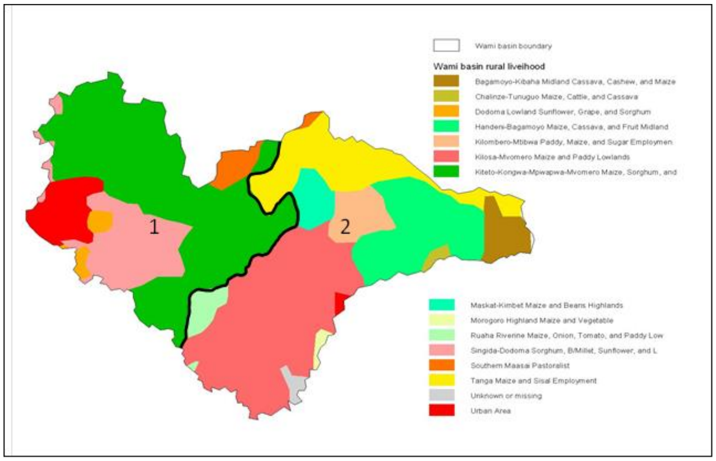


Figure 5: Livelihood and agro-ecological zones of Wami basin

The livelihood zone 1 has its cropping season in the December-March period while livelihood zone 2 has its growing season during March-May period. With respect to annual precipitation, livelihood zone 1 has mean annual precipitation ranging from 550–750 mm, whereas livelihood zone 2 experiences annual mean precipitation of between 900–1000 mm (IUCN, 2010). Farming systems in the study area are characterized by integrated crop and livestock enterprises. As is the case with other countries in the region, crop production is undertaken through small scale subsistence farming with an array of crops including maize, rice, sesame, sorghum, millets and legumes and are generally integrated with livestock. Maize is the staple food crop in the study area just as it is at country level. To a lesser extent, large scale commercial crop production such as sugarcane and sisal plantations is also practiced. Maize is the staple food crop in the study area. Three main crop enterprises in the Wami river sub-basin are; maize as a sole crop, maize intercropped with other crops and other crops grown on their own without maize (such as sorghum and millet for zone 1, and rice for zone 2). The average farm size for livelihood zone 1 is 1.58 ha while for livelihood zone 2 is 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

3.2.4 Uganda

In Uganda, the study was conducted in two districts located in the Albertine region, namely Hoima and Masindi, that straddle the Lake Albert bordering Uganda and DRC (Figure 7). The two districts are located within the western Mid-Altitude Farmlands and Semliki Flats (MAFSF) Agro-ecological zone (Wortmann and Eledu, 1992). Hoima district is located between 1° 00'-2° 00' N and 30° 30'-31°45' E and Masindi District located next to Hoima is bounded between 1^{o} 22'-2^{o} 20' N and 31^{o} 22'-32^{o} 23' E. The total area of the two districts is 15,258 sq. km. The districts lie within an altitude range of 621 m and 1,158 m above sea level, making it one of the lowest and hottest areas in the country. Hoima is drier and warmer compared to Masindi. Average annual temperatures at Hoima are in the range of 23.4-25.6 and in Masindi the temperatures are in the range of 22.7-24.2. The average annual rainfall in Hoima and Masindi ranges between 700-1,000 and 800-1630 mm, respectively with a bi-modal distribution and peaks in March-May and August-November. Table 6 presents the area under major land use systems in the two districts. Of the total area, nearly 21% is occupied by water bodies (mostly Lake Albert) and 38% by protected areas and forests. Area under subsistence and large scale farming accounts for 20% of the total area with the rest being grass/bush land, degraded forests and built up areas.

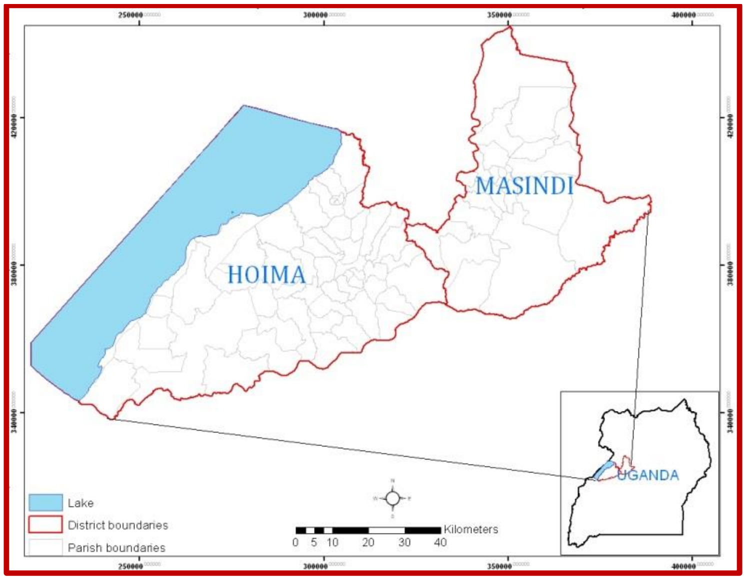


Figure 6: Map showing target areas of Hoima and Masindi in Uganda.

Table 6: Area under major land use categories in the districts of Hoima and Masindi

Particulars	Land area (sq km)	
	Hoima	**Masindi**
Open water&swamps	2,327	930
Fully stocked forests and woodland	1333	4444
Grassland and bushland	802	2,282
Degraded forests	267	20
Subsistence farmland	1,183	1,645
Large-scale farmland	13	109
Others (Built up area, rocks, plantations etc)	4	12
Total area	5,933	9,327

Source: SCRIP (IFPRI, Kampala) for PRIME-WEST

Majority of the people in the region are smallholder farmers with an average farm size of about 3 ha, which is high compared to other countries in the region. The dominant farming systems in the region are banana coffee cattle system and banana millet cotton system (Osiru, 2006). Major crops in the region under large-scale farming are maize, tea, sugarcane, while small-scale farming includes beans, groundnut, rice, sweet potatoes, cassava**,** millet**,** pigeonpea, banana, and sesame (Mubiru *et al*., 2007). The productivity of most smallholder farms depends on soil type and management and varies highly from high to low potential areas within the two districts. The dominant soils in the region include Hoima catena (Petric Plinthosols), Naitondo series (Dystric Regosols), and Kigumba series (Acric Ferralsol) (Figure 8). The productivity of these soils are believed to be lowest in with Hoima catena, medium for Kigumba and highest for Naitondo. Accordingly, the target region is dived into three zones, Dystric Regosols, Petric Plinthosols and Acric Ferralsols, based on the dominant soil type.

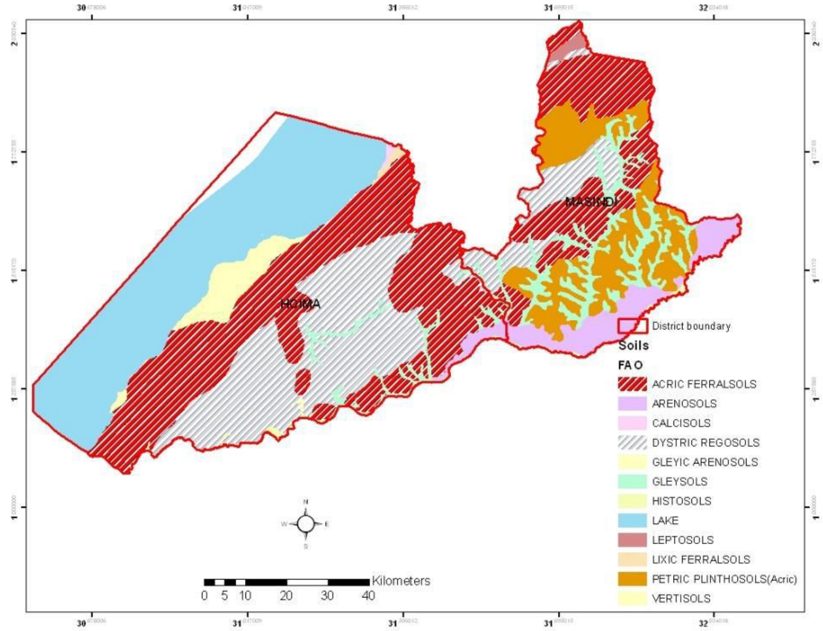


Figure 8: Distribution of soils in Hoima and Masindi districts

Some important characteristics of the farming systems in the target AEZ are as shown in Table 7. Household size is small and farm size is high in Plintosols region compared to the other two regions. Farmers in all regions use the same varieties with local non-descriptive variety as the most preferred. Among the improved varieties Lone 9 has higher yield potential compared to Longe 5. The cost of fertilizers is very high, highest in the region and because of this most farmers do not use inorganic fertilizers. The soil fertility replenishment is mainly through use of legumes and organic manures.

Table 7: Characteristics of smallholder farms in the studied agro-ecological zone of Uganda (AGMIP survey, 2012)

Soil type	Mean Household size	Mean Farm size (ha)	Mean Fertilizer use (kg N/ha)	Dominant maize variety	Average maize yields (kg/ha)
Acric Ferralsols	5.29	3.04	0	Local (traditional), Longe 5, Longe 9	1685
Dystric Regosols	5.18	2.98	0	Local (traditional), Longe 5, Longe 9	2043
Petric Plinthosols	4.89	3.51	0		1917

4. Representative Agricultural Pathways

Since impacts of climate change and vulnerability of the communities to these impacts are long-term in nature and depends on how socio-economic developments shape the future agricultural systems, Representative Agricultural Pathways (RAPs) were developed to represent the current production system in the future. Currently, besides growing maize, farmers in different countries and in different AEZ s are involved in various other farming activities. These include beans, sorghum, millet, tef, banana, groundnuts and livestock. Since these systems are also going to be impacted by climate change, RAPS were developed to predict potential future scenarios. Besides changes in the farms, we also expect that there will be changes at the household level.

Discussions were held with representatives from different government and non-governmental agencies and other organizations dealing with or having an interest in climate change issues and knowledge and understanding about the current and future trends in agriculture and other socioeconomic developments to map future agricultural systems. These were developed against a background of certain demographic and socio-economic developments in the region such as: a) devolution of government; b) increasing population; c) government plans to invest in fertilizer factory; d) current government subsidy on fertilizers; e) improved economic performance which is expected to cause a shift from agriculture to service industry; f) government plans for massive expansion of irrigation; and g) expected increase in extension services and consumption of climate information by farmers due to improved reliability and access.

A brief summary of the projected changes in the biophysical, socio-economic and institutional sectors as perceived by the stakeholder groups is presented in Table 8. Family sizes are expected to decline moderately by about 10% in Ethiopia and Uganda and up to 30% in Kenya. The higher decline in Kenya is mainly due to higher levels of awareness and education. Given the current family sizes, farm subdivision is expected to continue over the next decade resulting in a decrease in farm sizes in all countries. However, this trend will be slowed by increased urbanization and lack of interest in agriculture among the youth and by midcentury some consolidation is expected to take place leading to an increase in the size of the farms that individual farmers are cultivating either by ownership or through renting. This is expected to be high in Kenya and low in Tanzania where availability of land is not a big constraint.

In crop production, there has been a sustained increase in the price of fertilizers in the past few years. This trend is expected to continue, but there are two factors that might slow it: a) the planned establishment of fertilizer factories in the region and b) the discovery of oil and natural gas reserves in Uganda, Kenya and Tanzania. In view of these developments, stakeholders in Ethiopia and Uganda expect a 20% marginal increase in fertilizer prices. However, in Kenya stakeholders expect a decline in fertilizer prices while in Tanzania the expectation is that the prices will double from the current levels. Currently, most farmers are using recycled seeds. However, the region has witnessed a significant increase in the demand for seeds of improved varieties. Some of the improved maize varieties are not only high yielding but are also tolerant to various biotic and abiotic stresses. At the same time, the seed sector has witnessed increased competition due to entry of many competitors and this might slow seed price increases. Overall, these developments are expected to push the seed prices significantly and in all countries the price is expected to nearly double from the current levels. The other component of variable costs expected to change substantially is the cost of hired labor. This is because many people would opt to work off the farm, as the reward to labor from farming is not considered compensatory enough. Many young men are opting for other jobs such as transporting people and goods using motorcycles (boda bodas), and this is taking labor out of agriculture. The cost of labor is therefore expected to increase by about 60% except in Tanzania where labor costs are expected to go up by about 25%. Moderate impacts were also expected from changes in biophysical conditions such as soil degradation, pest and disease incidence and frequency and intensity of extreme events. A combination of the three variable costs implies that the total variable cost of production will increase by 28%.

Grain prices of all crops, both commercial and food crops, are expected to increase by more than 100%. In Kenya, it was estimated that the output prices will go up by 200% mainly due to increased demand, limited land and increased dependence on imports from neighboring countries. Livestock sizes—especially dairy animals-- are expected to increase by 10%. With decreasing land sizes, farmers are expected to move away from free range grazing to zero grazing, and this will increase the number of zero-grazed animals. This is expected to reduce availability of animal feed and the net effect of this will be a 20% decline in milk production. With increased urbanization and growing population, the demand for milk is expected to increase, and this will hike the price of milk by 50% in Kenya. However, it is expected that the cost of milk production will double because of feed scarcity and a shift towards processed feeds which are more costly.

Table 8: Projections for Social, institutional and biophysical indicators to mid-century in the four participating countries

Type of Indicator	Ethiopia			Kenya			Tanzania			Uganda		
Bio-physical	Direction	Magnitude	%	Direction	Magnitude	%	Direction	Magnitude	%	Direction	Magnitude	%
- Soil degradation	+	Mod	10	+	15	Mod	+	Hi	5	+	Mod	10
- Frequency and intensity of floods and droughts	+	Mod	20	+	20	Mod	+	Hi	20	+	Mod	20
- Water resource degradation	+	Mod	20	+	25	Hi	+	Mod	15	+	Mod	20
- Pests and diseases	+	Mod	20	+	5	Low	+	Mod	15	+	Mod	20
- Erosion of bio-diversity	+	Mod	25	+	15	Hi	+	Mod	20	+	Mod	25
Institutional												
- Governance/Transparency	+	Mod	30	+	50	Hi	+	Mod	10	+	Mod	30
- Extension	+	Mod	30	+	50	Hi	+	Mod	4	+	Mod	30
- Fertilizer costs	+	Mod	20	-	20	Mod	+	Mod	20	+	Mod	20
- Grain prices	+	Hi	120	+	200	V.Hi	+	Hi	100	+	Hi	120
- Seed prices	+	Hi	100	+	80	Hi	-	HI	80	+	Hi	100
- Milk prices				+	50	Hi						
Socio-economic												
- Household size	-	Mod	10	-	30	Hi	+	Mod	10	-	Mod	10
- Labor costs	+	Hi	60	+	60	Hi	+	Mod	20	+	Hi	60
- Farm size	+	Mod	20	+	30	Hi	+	Hi	20	+	Mod	20
- Non-agricultural income	+	Mod	30	+	50	Hi	+	Hi	25	+	Mod	30
- Herd size				+	10	Mod						

The global impact model predicts that maize yields will increase by a factor of 1.83, and this was used to transform maize yields in both systems. The yield inflation factor for sorghum according to the global impact model is 2.35. Using historical information, we used yield inflation factors of 1.5, 1.25 and 1.9 for beans, coffee and pigeon peas, respectively. For dairy production, we used a production factor of 1.4 for both systems. The price inflation factors for both systems are shown in Table 9 below.

Table 9: Yield and price trends

Activity	Production	Prices System 1	Prices System 2
Ethiopia			
Maize	1.35	1.39	2.21
Teff	1.30	1.45	2.10
Kenya			
Maize	1.83	1.39	2.21
Beans	1.50	1.40	1.80
Coffee	1.25	1.60	2.00
Pigeon Pea	1.90	1.40	1.80
Sorghum	2.35	1.43	1.79
Dairy	1.40	1.50	2.00
Uganda			
Maize	3.69	1.38	2.21
Beans	1.50	1.10	1.60
Groundnut	1.50	1.10	1.60
Cassava	1.20	1.10	1.70
Banana	1.20	1.10	2.00

5. Data and methods of assessment

This assessment used AEZs representing unique combinations of climatic and soil conditions that are homogeneous with regard to their capacity to support production of a wide range of food and cash crops as the unit for evaluating the impacts of climate variability and change. Relevant data required to calibrate, validate and apply climate, crop and economic models was collected from various secondary sources which included informal publications such as research reports. Since data on several parameters specific to the target areas and as required for setting up simulations with crop and economic models is not readily available, a survey was carried out in all the target areas to characterize the smallholder farming systems with respect to their management and performacne. The information collected included various enterprises that the farmers were involved in, their management, productivity, as well as sources of non-farm income to the households. The methodology used for data collection was a combination of stratified and multistage sampling. A total of 1469 farmers were covered by the survey. The strata for the survey varied from one country to the other and a summary of distribution of households covered by the survey are as shown in Table 10.

Table 10**:** Sampled households in each AEZ

Country	AEZ	Division	Number of HHs
Ethiopia	SA2:Warm semi-arid lowlands	Wonji	79
	SM2 Warm sub-moist lowlands	Melkassa	69
	SM3 Tepid sub-moist mid highlands	Nazareth	92
	SM2: Tepid Semi-arid	Adigudom	200
	SM4:Tepid Semi-arid	Adimesanu	60
	SM3: Tepid Semi-arid	Hintalo	40
Kenya	Upper Midland 2	Kevote, Nembure	81
	Upper Midland 3	Kithimu, Nembure	89
	Lower Midland 3	Riandu, Siakago	107
	Lower Midland 4	Nyangwa, Gachoka	92
	Lower Midland 5	Mavuria, Gachoka	84
Tanzania	Livelihood system 1	Chilanga, Hombolo, Nala, Mvumi, Kongwa Ugogoni, Godegode, matomondo,	83
	Livelihood system 2	Mandege, Msowero, Kwediboma, Mtibwa, Kanga, mazingara, Mahenge, Mazimbu	85
Uganda	Acric Ferralsols	Buraru, Kaseeta, Kisukuma,Butoole, Kibingo	118
	Dystric Regosols	Kihukya, Birungu, Isimba, Kahembe	104
	Petric Plinthosols	Kimengo, Labongo, Kitamba	86

5.1 Climate Data and trends

Long-term historical climate data for the baseline period 1980-2010 for several locations in the target districts was collected from the archives of the National Meteorological Departments of the four countries. Efforts were made to collect daily observations on all parameters - rainfall, maximum temperature, minimum temperature and solar radiation that are required to run the crop models APSIM and DSSAT. However, it is for very limited number of stations that the data on all required parameters is available. In addition, we have also faced problems with the quality of available data. The main problems are with missing data and outliers. Hence, we focused only on those stations that are representative of the target agro-ecology and have good continuous 30 year record with less than 10% missing data. A total of 16 station data was found to be suitable for use in this assessment. Of the 16 locations, six are rainfall only stations and rest have both rainfall and temperature records (Table 11). For most locations solar radiation data is either not available or available for few years.

Table 11: Climate data used in the assessment

Variable	Ethiopia	Kenya	Tanzania	Uganda
Rainfall only	2	3	0	1
Rainfall + temperature	4	1	4	1
Total	6	4	4	2

Historical climate data was subjected to quality control using R-Climdex (Zhang and Feng, 2004) which flagged out the spurious values. Historical climate data were subjected to quality control using R-Climdex, which flagged out the spurious values. Bias corrected bcMERRA (Rienecker et al., 2011) data sets were used to fill the missing values and to replace the spurious ones. The bias correction was achieved by calculating a correction factor between each variable of the MERRA data and the corresponding observations for every month and employing the factor on the MERRA data to estimate the missing values. In case of the six locations for which only precipitation data is available, other variables were all estimated from the MERRA data using appropriate correction factors.

General characteristics of annual and seasonal rainfall and temperature are summarized in (Table 12). The stations Adigudom, Adimesanu, and Hintalo in Hintalo Wajirat district of Ethiopia are the northernmost and Dodoma and Kongwa in Tanzania are the southernmost locations of the study region that lies between latitudes 13.5^{0}N and 7^{0}S. The Kenyan and Ugandan sites are located in the middle, close to equator. In general, annual rainfall is high at the locations in the center or near equator and gets reduced on either side. Adimesanu in the north and Dodoma in the south with an average annual rainfall of about 550 mm are the drier sites. Embu and Karuromo in Kenya and Masindi and Hoima in Uganda are the wetter sites with an annual average rainfall of more than 1000 mm. The Kenyan and Ugandan locations fall within the bimodal rainfall zones and thereby receive rainfall in two distinct seasons. The amount of rainfall received during the two seasons is similar. South of equator in Tanzania, the long rain season becomes less important. At Dodoma and Kongwa rainfall is mainly during the short rain season that starts in December and ends in April. North of equator in Ethiopia, bi-modal rainfall is still observed but the rainfall during LR season is low and exhibits high variability. The main cropping season here is June to September which is locally known as Kiremt or Meher season.

Table 12**:** Key climate characteristics at the four selected sites.

	Ethiopia						Kenya				Tanzania				Uganda	
Variable	Adigudom	Adimesanu	Hintalo	Nazreth	Melkassa	Wonji	Embu	Karurumo	Ishiara	Kindaruma	Dodoma	Kongwa	Mlali	Wami	Masindi	Hoima
Representative AEZ	SM2	SA2	SM3	SM2	SM3	SA2	UM2&3	LM3	LM4	LM5	LHZ1	LHZ1	LHZ2	LHZ2		
Avg annual rainfall (mm)	643 (22.1)	566 (21.7)	839 (17.2)	734 (15.6)	885 (16.8)	812 (22.3)	1248 (26)	1141 (24)	823 (25)	833 (29)	578.8 (20)	629 (19)	914 (15)	847 (18)	1197 (15.5)	1292 (12.3)
Avg Season1 rainfall (mm)	105 (49.4)	92 (52)	189 (51)	181 (44.0)	205 (49.3)	198 (51.2)	583 (35)	471 (25)	327 (26)	331 (33)	569 (21)	608 (19)	416 (20)	363 (23)	347 (7.7)	412 (6.3)
Avg Season2 rainfall (mm)	507 (31.3)	450 (29.9)	630 (17)	500 (18.0)	610 (20.6)	545 (25.6)	490 (39)	565 (37)	431 (37)	407 (43)	nil	nil	247 (45)	226 (50)	484 (6.9)	421 (7.2)
Avg annual T (^{0}C)	20.3	20.2	20.0	21.3	21.3	20.6	19.4	19.1	21.2	22.4	23.0	23.8	26.2	24.3	24.3	23.5
Avg. annual MaxT (^{0}C)	26.7	26.6	26.7	28.7	28.1	27.4	24.5	24.3	26.9	28.1	24.1	24.3	27.7	25.6	30.0	29.2
Avg. annual Min T (^{0}C)	13.9	13.8	13.3	14.0	14.5	13.9	14.2	13.8	15.5	16.7	22.2	23.1	25.6	23.7	18.6	17.8
Avg. Season1 T(^{0}C)	21.1	21	20.7	22.5	22.5	21.5	20.5	20.3	22.5	23.8	23.4	24.1	26.5	24.5	24.7	24.2
Avg. Season1 MaxT (^{0}C)	27.8	27.7	27.6	30.2	29.8	28.7	25.6	25.6	28.3	29.5	25.6	25.6	28.2	25.9	30.3	29.6
Avg. Season1 Min T (^{0}C)	14.4	14.3	13.8	14.9	15.2	14.4	15.4	15.0	16.7	18.0	22.5	23.2	25.7	23.9	19.1	18.7
Avg. Season2 T (^{0}C)	21.1	21	20.9	21.6	21.6	21.2	19.6	18.9	20.8	22.3	24.5	25.4	27.8	25.6	23.8	23.1
Avg. Season2 MaxT (^{0}C)	27.0	26.8	27.1	27.7	27.3	27.2	24.7	24.0	26.4	27.8	25.3	26.2	28.8	26.8	29.3	28.6
Avg. Season2 Min T (^{0}C)	15.3	15.2	14.7	15.4	15.9	15.3	14.4	13.7	15.3	16.7	23.7	24.7	27.0	24.9	18.4	17.5

Notes:

- *AEZ is Agro-ecology*
- *Season1 is LR season representing the period March-May except in Ethiopia where it refers to the period February-May*
- *Season1 at Dodoma and Kongwa in Tanzania is from December to April and there is no long rain season here*
- *Season 2 is SR season representing the period Oct-Dec except for Ethiopian sites where it refers to the period Jun-Sep*
- *Figures in parenthesis represent Coefficient of Variation (CV)*

Both annual and seasonal rainfall amounts exhibit high variation between and during the seasons. The coefficient of variation (CV) of annual average rainfall varied from 12.3% to 29% with locations in Kenya recording higher CVs. In case of seasonal rainfall CV varied from 6.3% to as high as 52%. There is strong relationship between the amount of rainfall during the season and its CV. The CV increases with decreasing amount of rainfall (Figure 9). Rainfall during the first season (March-April), also known as Belg season locally at all locations in Ethiopia is low and highly variable making it least dependable for cropping.

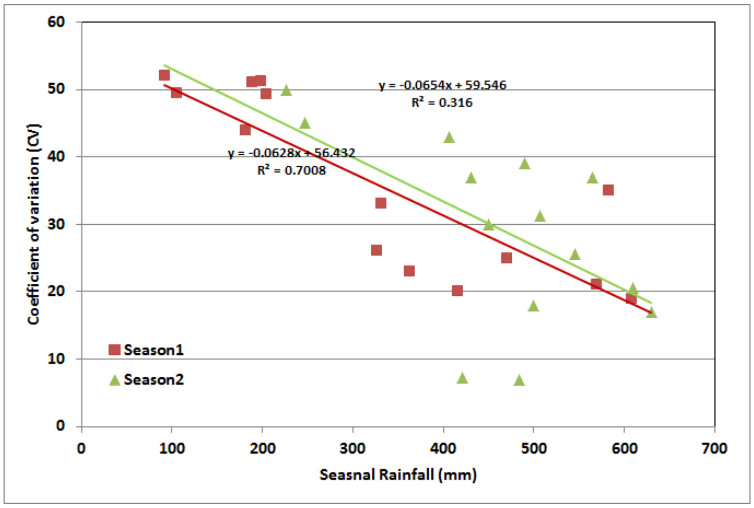


Figure 9: Relationship between coefficient of variation (CV) and amount of rainfall during two seasons in the target areas

Average annual temperatures at all locations in the study area are in the range of 19-26°C. Much of this variation is attributable to the differences in altitude. At a given location, there is no major difference in the average temperature regimes of the two cropping seasons. The SR season is slightly warmer by about 1˚C at locations south of equator while cooler by about the same magnitude at locations north of equator. Seasonal average maximum temperatures are in the range of 25-30˚C while minimum temperatures are in the range of 14-27˚C, at different locations.

Climatic data from all 16 locations was analyzed for variability and trends of annual and seasonal temperature and rainfall. Though, we discuss results of the analysis for four locations viz., Adigudom and Nazreth in Ethiopia, Embu in Kenya and Dodoma in Tanzania, results of other locations are included in the appendices. These four sites represent various points along the target region. Embu, located near the equator is at the center of the region while the Ethiopian sites are located northwards and Tanzanian sites southwards of equator. These are also the stations for which good quality daily records for both rainfall and temperature are available.

Initially, we analyzed the annual rainfall data for trends in the amount of rainfall received. Though the amount of rainfall received at all locations showed high variability with CVs as high as 26%, no clear declining or increasing trend was observed at any of the stations in the study region except at Milali in Tanzania where a slight declining trend was noticed (Figure 10 & Annex 1). However, the year to year variation in rainfall is higher in case of Embu and Dodoma compared to the two sites in Ethiopia, Adigudom and Nazreth. At Embu rainfall varied from 499 mm in 2000 to 1884 mm in 1988. The least variability was observed in case of Nazreth where the minimum recorded during the 1980-2010 period was 576 mm in 2009 and maximum on record was 1186 mm in 1985.

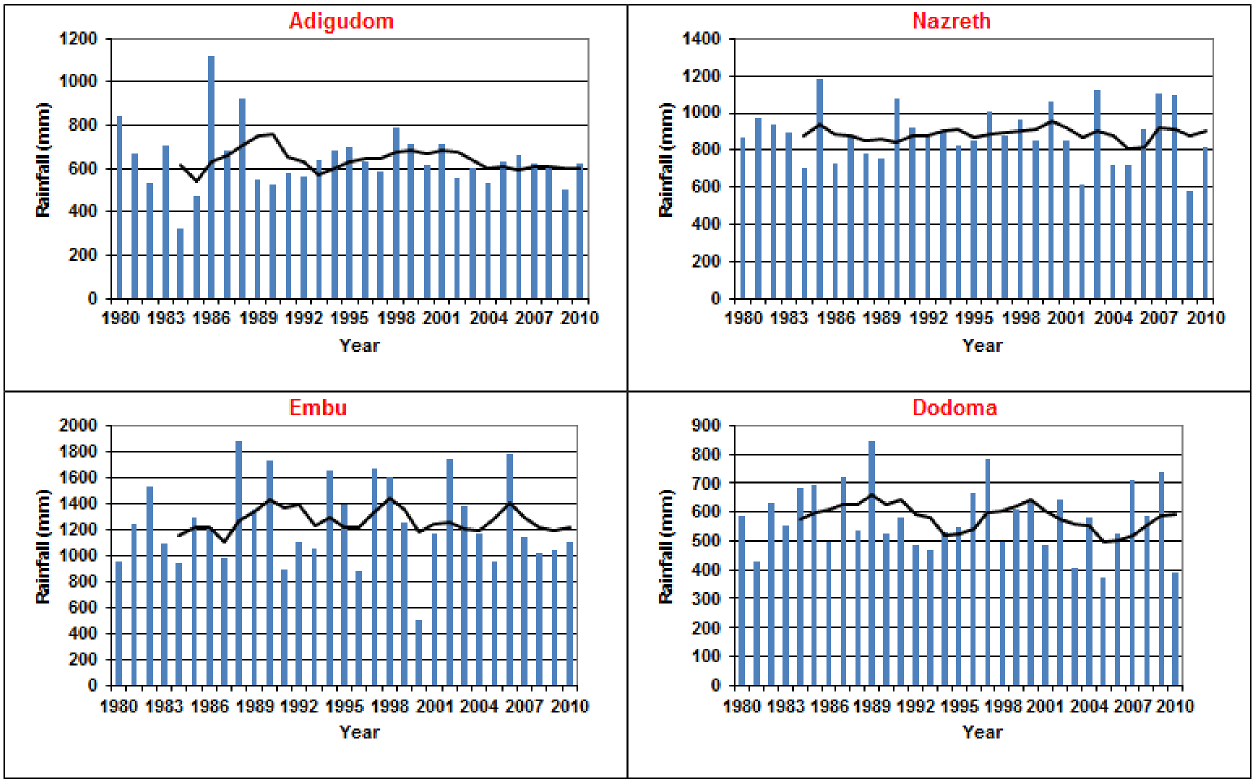


Figure 10: Trends in annual rainfall (solid line is the five year moving average)

There is also no clear trend in the absolute deviations in annual rainfall from long-term average (Figure 11 and Annex 2). At Adigudom, the fluctuations in annual rainfall were very high during 1980s compared to those recorded during the most recent period from mid-1990s. The deviation in annual rainfall is less than 100 mm in 15 out of 18 years since 1993. Though similar trends were observed at the two other locations in the district Adimesanu and Hintalo, a more gradual decline in the anomalies was observed in case of

Hintalo (Annex 2). Nazreth, the annual anomalies followed similar trend up to end of 90s but increased significantly from the year 2000 onwards. Anomalies of more than 100 mm were recorded in 9 out of the 18 years since 1993. At Embu and Dodoma, the year to year variability in rainfall is more random in nature and no clear trend is discernable.

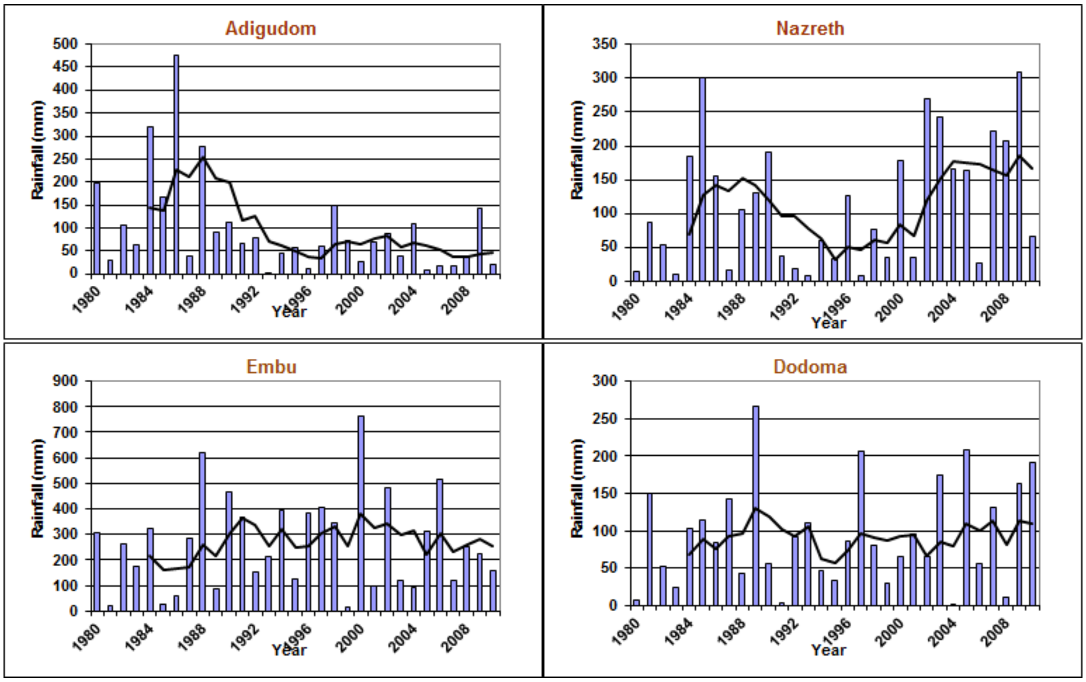


Figure 11: Trends in annual rainfall anomalies (absolute) with five year moving average

A part of the variability is associated with the occurrence of El Nino and La Nina events. During the main rainy season in Ethiopia, El Nino years recorded up to 15% lower rainfall compared to the long-term average while in La Nina years it is higher by 20-40% (Figure 12). In case of Kenya, rainfall during the El Nino years is 10-15% higher while La Nina has very little impact. No major changes were observed in case of sites in Tanzania.

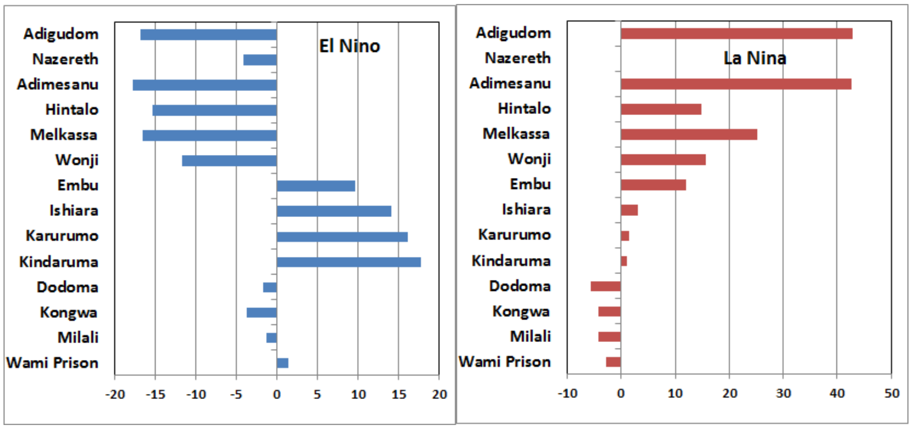


Figure 12: Deviation in seasonal rainfall from long-term average during El Nino and La Nina Years

Though no clear trend was observed in the amount of rainfall, some changes in the variability of annual and seasonal rainfall were observed at all locations. This was explored further by computing ten year moving average of CV. The moving average of CV has shown an increasing trend at all locations except Adigudom. The trend is more clear during the period 1990 onwards (Figure 13 and Annex 3). At Adigudom, the CV declined significantly from about 35% during 80s to about 10% by 2000 and remained at the same level during the period 2000-2010. At Nazreth, the trend is cyclic with CV declining during the 1990-2000 period and increasing thereafter. The CV of recent ten year period is close to 25% which is the highest observed during the past 30 year period. At Embu and Dodoma the variability showed a marginal increase of about 5%.

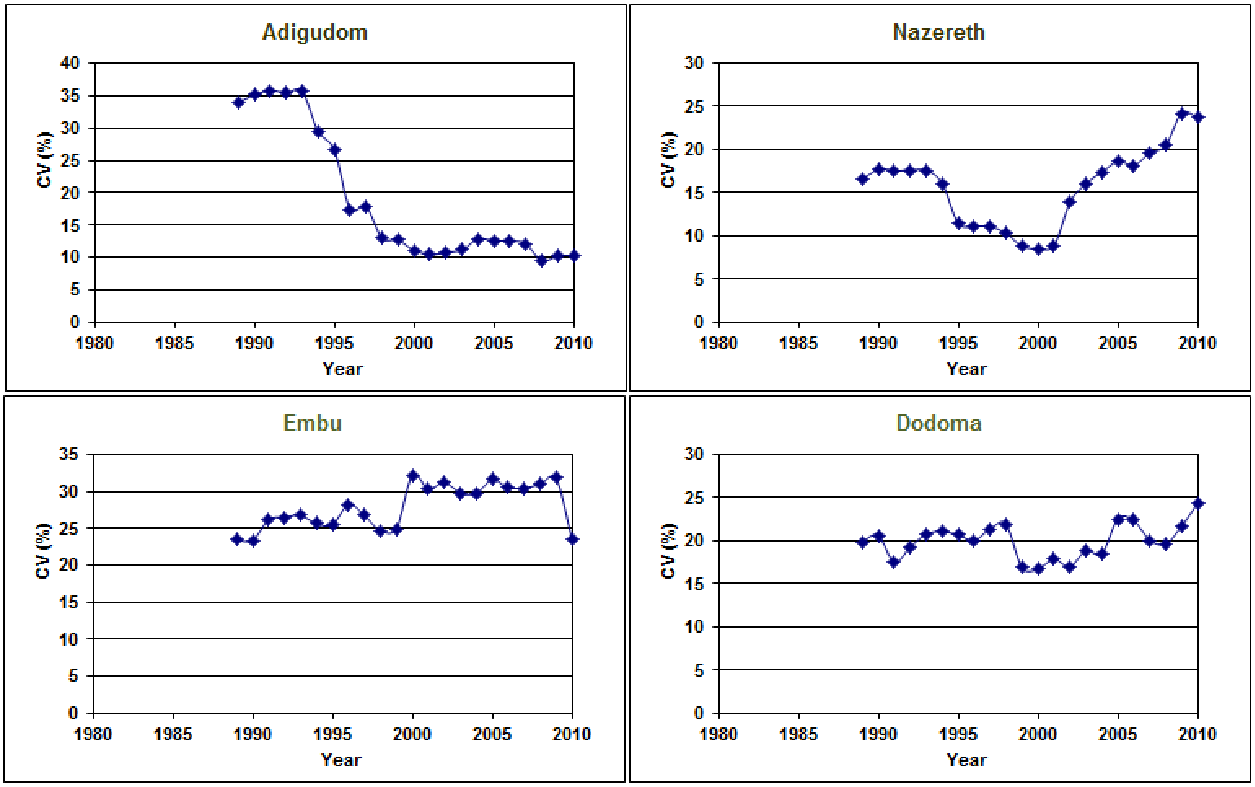


Figure 13: Trends in ten year moving coefficient of variation in annual rainfall

In case of Embu and surrounding sites where annual rainfall is distributed equally over two distinct seasons, variability was found to be increasing during the SR season (Figure 14). The CV increased from about 30% to 45% during the thirty year period starting from 1980. This is a significant change from the current situation and will have major impacts on smallholder farms who currently consider this as the main cropping season with more reliable rainfall. This is also the season in which the main food crop maize is extensively grown.

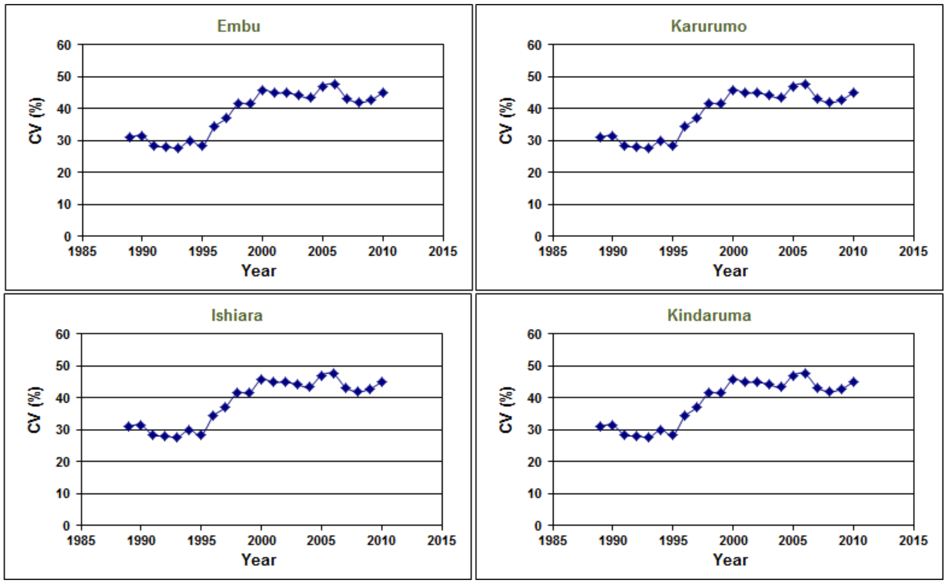


Figure 14: Ten year moving coefficient of variation (CV) of rainfall starting from 1980 during short rain season at the four sites in Embu County, Kenya

In case of temperature, a clear increasing trend is evident at all the locations, especially from 1995 onwards (Figures 15-17). Interestingly, this is also the period during which an increase in variability of rainfall was observed. The two locations away from equator, Adigudom in Ethiopia and Dodoma in Tanzania have recorded a higher increase compared to Embu located near equator. At all locations, the increase in minimum temperatures is higher than that in maximum temperatures. At Nazreth, the maximum temperature showed a declining trend while at Dodoma no change was observed. However, at both the locations minimum temperatures increased significantly.

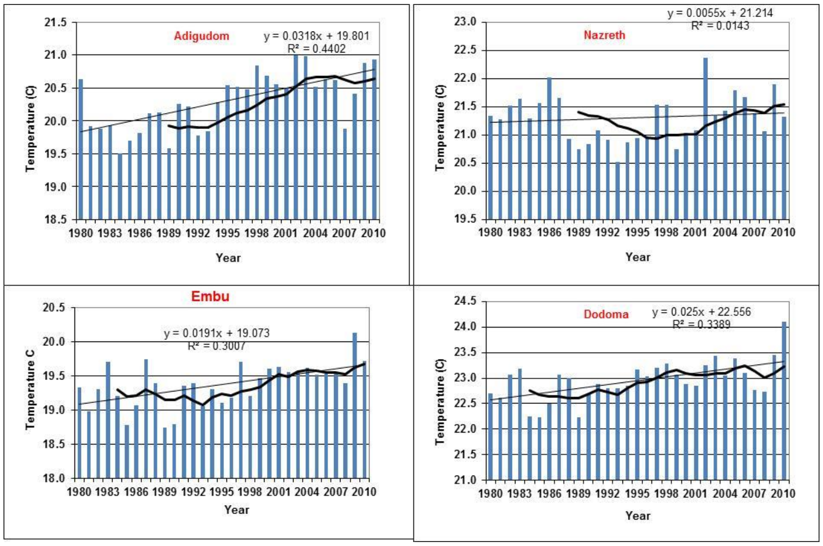


Figure 15: Trends in annual average temperature at the four locations

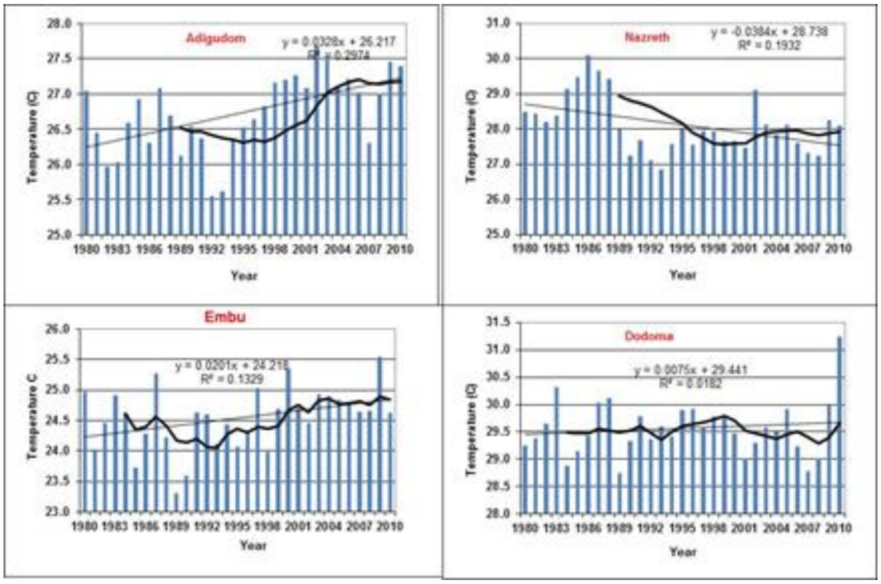


Figure 16: Trends in annual maximum temperature at the four locations

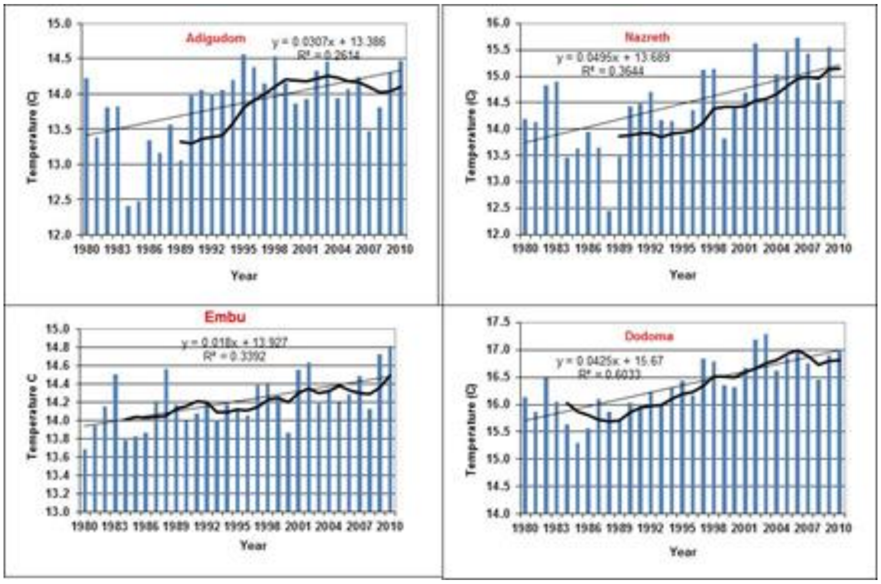


Figure 17: Trends in annual minimum temperature at the four locations

Average rate of increase in temperature was computed by fitting linear equations to maximum, minimum and average annual temperatures (Table 13). The highest increase in annual average temperatures was observed at Adigudom where temperatures are increasing at the rate of 0.032˚C every year followed by Dodoma and Embu. While the rate of increase in maximum and minimum temperatures remained almost the same at Adigudom and Embu, the increase in minimum temperatures is significantly higher than that in maximum temperature at Dodoma. At Nazreth the maximum temperatures are declining by about 0.04˚C while minimum temperatures are increasing by about 0.05°C per year.

Table 13: Average rate of increase in temperature at different locations

Variable	Adigudom	Nazreth	Embu	Dodoma	Average
Average Temp	0.0318	0.0055	0.0190	0.0250	0.0203
Max Temp	0.0328	-0.0384	0.0201	0.0075	0.0055
Min Temp	0.0307	0.0495	0.0180	0.0425	0.0352

When analyzed for decadal wise increase in average temperatures, a progressive increase in temperature was observed over the three decades (Figure 18) at all locations except Nazreth, where average temperatures declined during the decade 1991-2000.

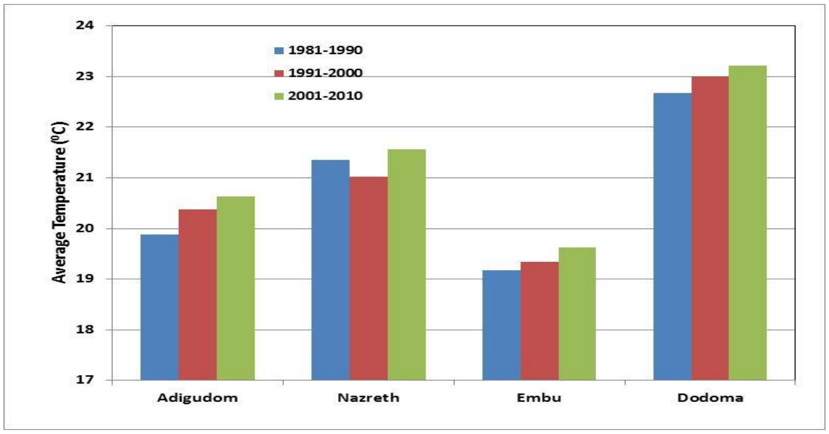


Figure 78: Decadal wise average annual temperatures at the four locations.

Overall, analysis of baseline climate data for the period 1980-2010 has indicated certain trends in rainfall and temperature. Key observations include the following:

- Though the amount of rainfall received annually and seasonally showed high temporal variability, no clear increasing or declining trend is noticeable.
- However, evidence indicates that the variability in annual and seasonal rainfall amounts is increasing.
- In the bimodal rainfall areas, represented by Embu, variability was found to be increasing during SR season and decreasing in LR season
- At all locations an increase in temperature is evident though the magnitude varied from one location to the other. On an average, the annual rate of increase in average temperature is about 0.02^{0}C.

- Evidence suggests that increase in minimum temperatures is greater than that in maximum temperatures
- The trends in temperature indicate that greater warming is taking place at locations away from equator compared to the ones close to equator

5.2 Climate change scenarios

Location specific climate change scenarios were developed using delta method in which monthly changes in temperature and precipitation from coupled atmosphere-ocean general circulation models (AOGCM), calculated at the grid scale, are added to the corresponding observed station data. The delta method assumes that future model biases for both mean and variability will be the same as those in present day simulations (Mote and Salathe, 2009). Climate change scenarios for mid-century (2041-2070) and end-century (2071-2100) periods were developed for 20 AOGCMS from the Coupled Model Inter-comparison Project phase 5 (CMIP5) for two Representative Concentration Pathways (RCPs) 4.5 and 8.5. The climate change scenarios were developed and analyzed for all the 16 stations used in this assessment.

Downscaled climate change scenarios showed continuous increase in surface maximum and minimum temperatures over different time periods and RCPs. Projections by all GCMs under RCP 8.5 are much higher and more variable than those under RCP 4.5 (Figures 19 -21). The projected changes to mid-century under RCP 8.5 are about 40-45% higher than those predicted under RCP 4.5 and end-century projections under RCP 8.5 are nearly double to the ones under RCP 4.5 for most locations (Tables 14 and 15 and Annex 4 and 5). On an average, the increase in predicted temperatures for end-century period are 60% higher than those predicted for mid-century under RCP 8.5 while in case of RCP 4.5 the end century projections are higher by about 20%. Most GCMs predicted a higher increase in minimum temperature than maximum temperature, a feature that is also noticed with the observed data. The projected increase is also higher for locations away from equator, especially those located south of equator compared to those located near the equator. The increase in both minimum and maximum temperatures at Dodoma is 1.5 to 2.5^{0}C higher compared to other locations that are located north of it. The median value for projected increase in maximum temperature under RCP 8.5 for mid-century period at Dodoma is about 4.1°C while that for Embu it is 1.9°C. Among the GCMs, temperature projections from ACCESS1, CanESM2, CSIRO-MK3, HadGEM2-ES, HadGEM2-CC, IPSL-CM5A-MR, IPSL-CM5A-LR MIROC-ESM, MPI-ESM-MR and MPI-ESM-LR, are generally higher than the median value. Projections by HadGEM and IPSL group models tend to be on higher side compared to other GCMs at all locations. However, there are differences across the stations.

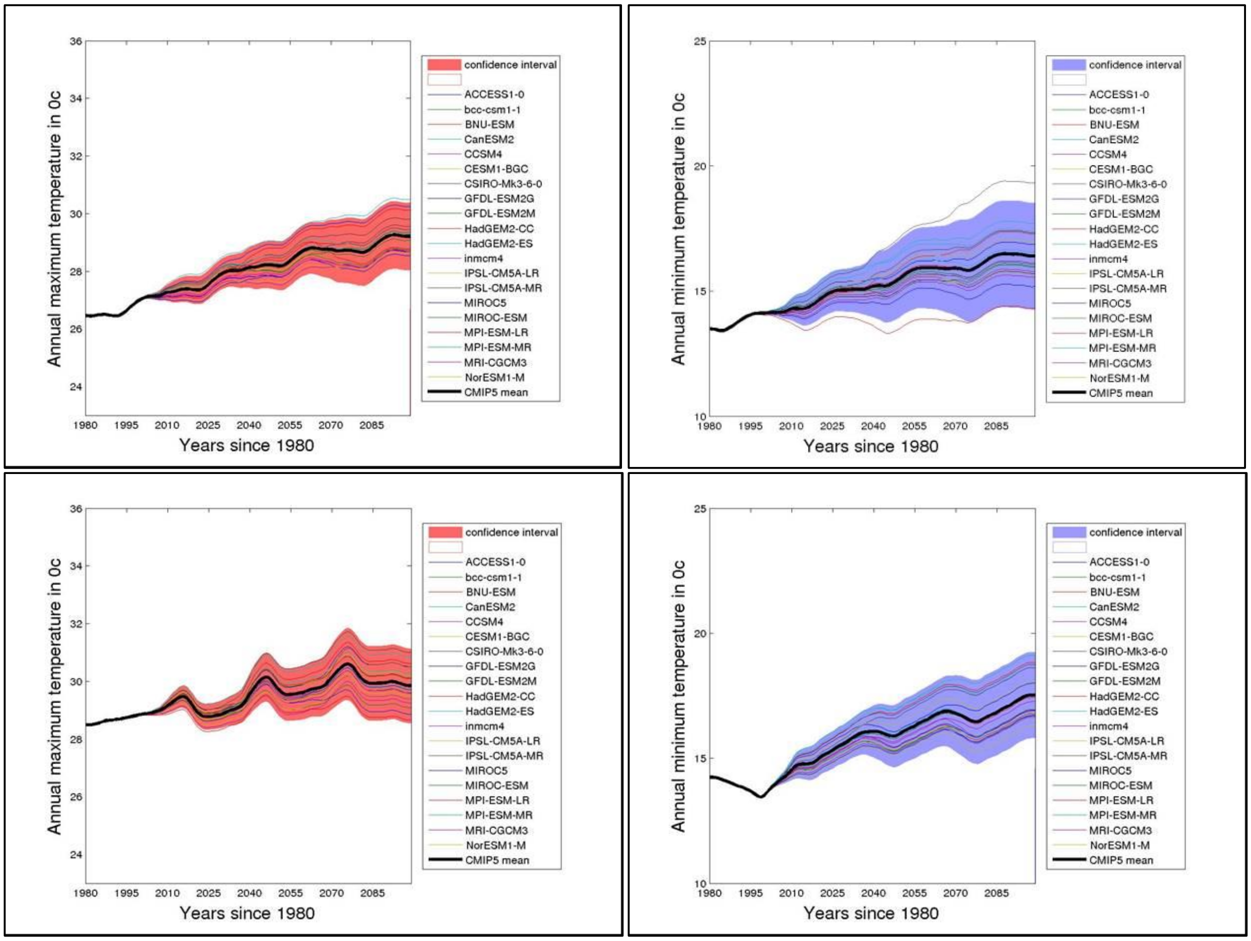
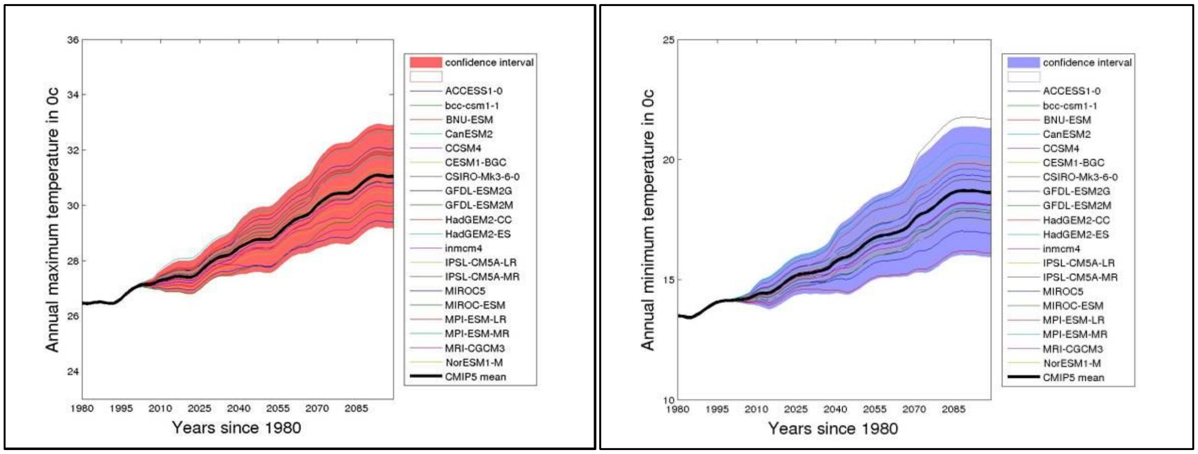


Figure 19: Projected maximum and minimum temperatures at Adigudem (top) and Nazreth (bottom) under RCP 4.5.



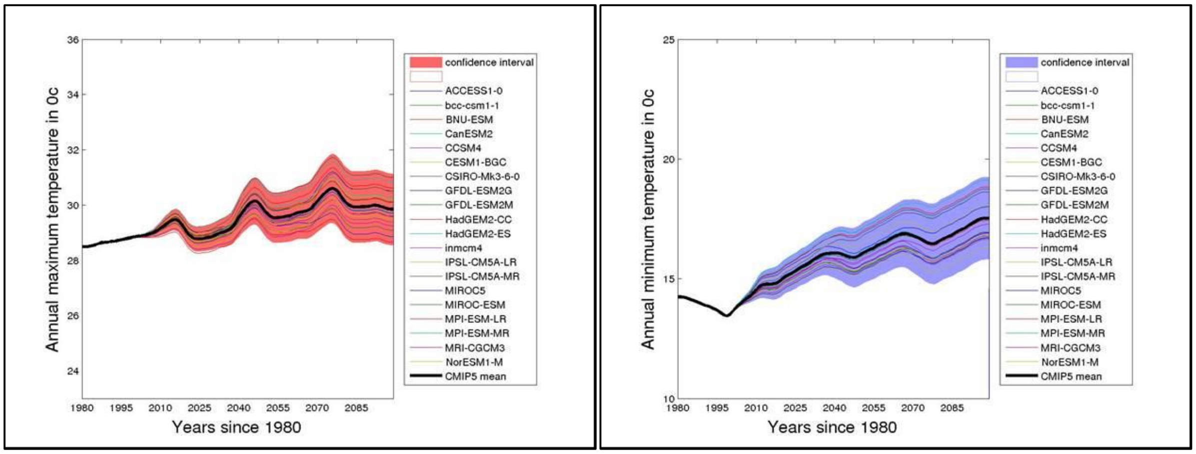


Figure 20: Projected maximum and minimum temperatures envelopes for Adigudem (top) and Nazreth (bottom) under RCP 8.5.

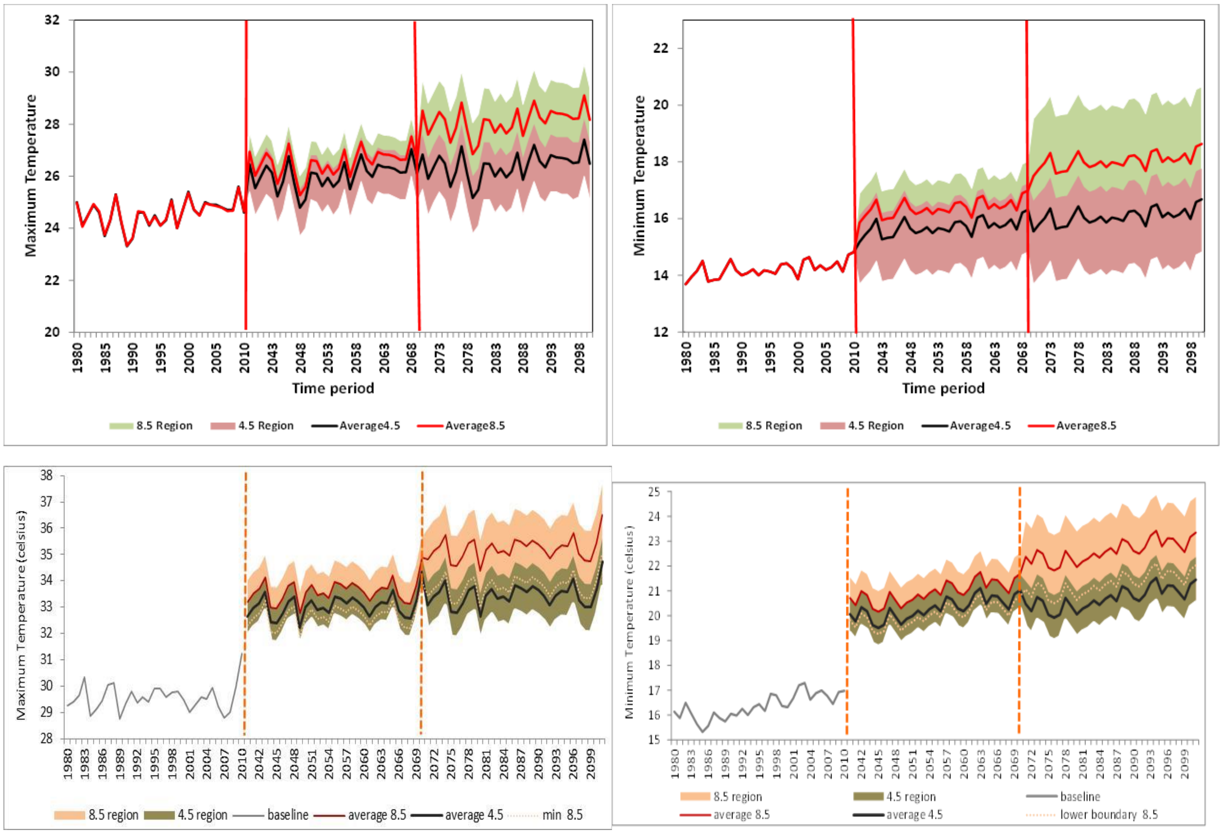


Figure 21: Projected maximum and minimum temperature envelopes for Embu (top) and Dodoma (bottom).

Table 14: Projected changes in maximum temperature for selected locations in the target countries

GCMS	**4.5 MID**				**4.5 END**				**8.5 MID**				**8.5 END**			
	Adi-gudom	**Nazeret**	**Embu**	**Dodoma**	**Adi-gudom**	**Nazeret**	**Embu**	**Dodoma**	**Adi-gudom**	**Nazeret**	**Embu**	**Dodoma**	**Adi-gudom**	**Nazeret**	**Embu**	**Dodoma**
ACCESS1	2.5	**1.4**	1.9	3.8	3.2	2.2	2.4	4.6	3.1	2.2	2.5	4.5	5.0	3.9	4.0	6.2
bcc-csm1	1.7	**0.9**	1.3	3.2	2.1	1.3	1.5	3.4	2.3	1.5	1.9	3.8	4.1	3.3	3.1	5.0
BNU-ESM	1.7	**0.5**	1.4	3.3	2.1	0.3	1.7	3.8	2.3	0.8	1.7	3.9	4.1	2.2	3.2	5.4
CanESM2	1.8	**1.1**	0.4	3.3	2.3	1.4	0.5	3.4	2.7	1.9	1.2	4.1	4.0	3.0	2.2	5.8
CCSM4	1.4	**1.0**	1.3	3.4	1.7	1.3	1.6	3.7	2.0	1.6	1.9	4.0	3.6	3.2	4.0	5.4
CESM1-BGC	1.6	**0.9**	1.1	3.3	1.7	1.2	1.4	3.6	1.9	1.3	1.6	3.9	3.4	2.7	2.9	5.3
CSIRO-Mk3	2.1	**2.0**	1.7	4.0	2.8	2.7	2.2	4.8	2.6	2.4	2.0	4.5	4.8	4.7	3.7	6.2
GFDL-ESM2G	1.4	**0.8**	1.5	3.5	1.5	0.5	1.7	3.7	2.2	1.6	2.1	3.6	3.8	3.0	3.7	5.2
GFDL-ESM2M	1.5	**0.6**	1.3	2.9	2.3	0.8	1.7	2.9	2.5	1.3	1.8	3.1	3.8	2.7	3.3	4.2
HadGEM2-CC	2.4	**1.6**	2.1	4.1	3.1	2.3	2.5	4.3	3.2	2.2	2.7	4.8	5.7	4.3	4.7	6.8
HadGEM2-ES	2.6	**1.9**	2.2	4.0	3.5	2.5	2.7	4.6	3.4	2.5	2.7	4.7	5.6	4.3	4.7	6.7
inmcm4	1.1	**0.4**	0.7	2.8	1.7	0.9	1.1	3.3	1.3	0.4	1.0	3.3	2.7	1.7	2.2	4.4
IPSL-CM5A-LR	1.7	**1.4**	1.9	3.6	2.3	1.9	2.6	4.3	2.4	2.0	2.6	4.4	4.3	3.8	4.8	6.4
IPSL-CM5A-MR	1.7	**0.9**	1.7	3.7	2.5	2.2	2.5	4.4	2.9	1.8	2.5	4.6	4.9	3.4	4.3	6.5
MIROC5	1.4	**1.0**	1.8	3.2	1.7	1.4	2.3	3.4	1.4	1.4	1.9	3.1	2.4	2.3	2.8	5.5
MIROC-ESM	1.5	**1.4**	2.1	4.0	1.7	1.8	2.3	4.5	1.3	1.3	1.8	4.4	3.0	3.0	4.0	5.9
MPI-ESM-LR	1.9	**1.4**	1.7	3.4	2.4	1.8	1.9	3.8	2.8	2.2	2.1	4.1	4.8	4.2	3.8	5.6
MPI-ESM-MR	2.1	**1.5**	1.7	3.3	2.4	1.9	2.0	4.0	2.8	2.2	2.4	4.4	4.7	4.3	4.0	5.8
MRI-CGCM3	1.4	**0.8**	1.0	3.4	1.7	1.1	1.3	3.8	2.0	1.3	1.6	3.7	3.1	2.6	2.5	5.2
NorESM1-M	1.2	**0.6**	1.0	3.4	1.6	1.1	1.4	3.8	1.8	1.2	1.6	3.8	3.0	2.2	3.0	5.5
Average	1.7	**1.1**	1.5	3.5	2.2	1.5	1.9	3.9	2.3	1.7	2.0	4.0	4.0	3.2	3.5	5.7
Median	1.7	**1.0**	1.6	3.4	2.2	1.4	1.8	3.8	2.4	1.6	1.9	4.0	4.0	3.1	3.7	5.6

Table 15: Projected changes in minimum temperature for selected locations in the target countries

GCMS	**4.5 MID**				**4.5 END**				**8.5 MID**				**8.5 END**			
	Adi-gudom	**Nazeret**	**Embu**	**Dodoma**	**Adi-gudom**	**Nazeret**	**Embu**	**Dodoma**	**Adi-gudom**	**Nazeret**	**Embu**	**Dodoma**	**Adi-gudom**	**Nazeret**	**Embu**	**Dodoma**
ACCESS1	2.1	**2.7**	1.9	4.3	2.9	3.6	2.7	5.1	3.2	3.8	2.7	5.2	5.3	5.9	4.7	7.1
bcc-csm1	1.6	**1.9**	1.4	3.9	2.0	2.2	1.8	4.3	2.3	2.6	2.1	4.5	4.1	4.1	3.6	6.2
BNU-ESM	1.6	**2.1**	0.7	3.8	2.0	2.3	1.4	4.1	2.3	2.8	1.8	4.5	4.1	4.4	2.9	5.9
CanESM2	2.8	**3.6**	2.1	4.1	3.4	4.2	2.5	4.4	4.2	5.0	2.9	4.8	6.6	7.4	4.8	6.4
CCSM4	1.5	**2.3**	1.2	3.3	1.8	2.5	1.4	3.7	2.1	2.8	1.9	4.2	3.8	3.9	4.7	5.3
CESM1-BGC	1.5	**1.8**	1.2	3.5	1.7	1.9	1.5	3.7	2.1	2.2	1.8	4.2	3.7	3.4	3.2	5.5
CSIRO-Mk3	2.5	**3.3**	2.1	4.4	3.3	4.2	2.8	5.1	3.2	3.9	2.5	4.7	5.5	6.4	4.6	6.7
GFDL-ESM2G	1.0	**1.8**	1.1	3.6	1.2	2.3	1.3	3.8	1.9	2.6	1.9	4.1	3.5	4.1	3.3	5.6
GFDL-ESM2M	1.3	**1.9**	0.6	3.4	2.0	2.5	0.7	3.6	2.5	2.8	1.1	4.0	3.8	4.2	2.7	5.2
HadGEM2-CC	2.3	**3.5**	2.1	4.5	3.3	4.4	2.9	4.8	3.8	4.5	2.9	5.4	5.8	7.3	4.9	7.6
HadGEM2-ES	2.9	**3.6**	2.4	4.5	3.7	4.7	2.7	5.3	3.9	4.4	3.0	5.3	6.1	7.2	4.9	7.5
inmcm4	1.3	**1.9**	1.0	3.2	1.5	2.2	1.3	3.4	2.3	2.8	1.8	3.7	4.1	4.3	3.3	4.9
IPSL-CM5A-LR	2.3	**3.0**	1.8	4.6	3.0	3.6	1.4	5.0	3.3	4.2	2.9	5.2	5.9	6.5	4.2	7.3
IPSL-CM5A-MR	3.5	**3.4**	2.0	4.4	5.3	4.3	2.8	5.2	4.2	4.5	3.2	5.4	7.7	7.6	5.8	7.7
MIROC5	1.4	**2.1**	1.4	4.2	1.7	2.4	1.7	4.7	1.6	2.6	1.8	4.4	2.9	3.9	2.9	6.5
MIROC-ESM	1.7	**2.4**	2.3	4.0	2.1	3.1	2.9	4.5	1.9	3.0	2.6	4.5	3.9	4.9	4.6	6.0
MPI-ESM-LR	1.9	**2.6**	1.7	4.0	2.4	3.0	2.0	4.3	2.9	3.6	2.4	4.7	5.1	5.6	4.2	6.4
MPI-ESM-MR	2.2	**2.7**	1.7	4.1	2.6	3.1	2.1	4.4	2.9	3.3	2.4	4.8	5.1	5.6	4.2	6.4
MRI-CGCM3	1.6	**2.3**	1.2	3.6	2.1	2.8	1.6	4.0	2.4	3.2	1.9	4.2	4.1	5.0	3.2	5.4
NorESM1-M	1.3	**2.0**	1.2	3.5	1.7	2.4	1.6	3.7	2.0	2.6	1.8	3.9	3.5	3.7	3.2	5.2
Average	1.9	2.5	1.6	3.9	2.5	3.1	2.0	4.3	2.8	3.4	2.3	4.6	4.7	5.3	4.0	6.2
Median	1.7	2.4	1.6	4.0	2.1	2.9	1.7	4.4	2.5	3.1	2.2	4.5	4.1	4.9	4.2	6.3

Rainfall projections by various AOGCMs showed higher variability compared to temperature (Figure 22). Projections by HadGEM2-ES, MIROC-ESM, CanESM2, BNU-ESM, IPSL-CM5A-MR and IPSL-CM5A-LR are generally higher than the projections by other GCMs at most locations. Unlike temperature projections, GCMs are not consistent in their rainfall projections across locations. For example, IPSL-CM5A-LR projected highest increase in rainfall at Adigudom and Nazreth but its projections for Dodoama are the lowest of all GCMs. Rainfall projections by GFDL-ESM2G, inmcm4 and NorESM1-M are generally lower for all locations.

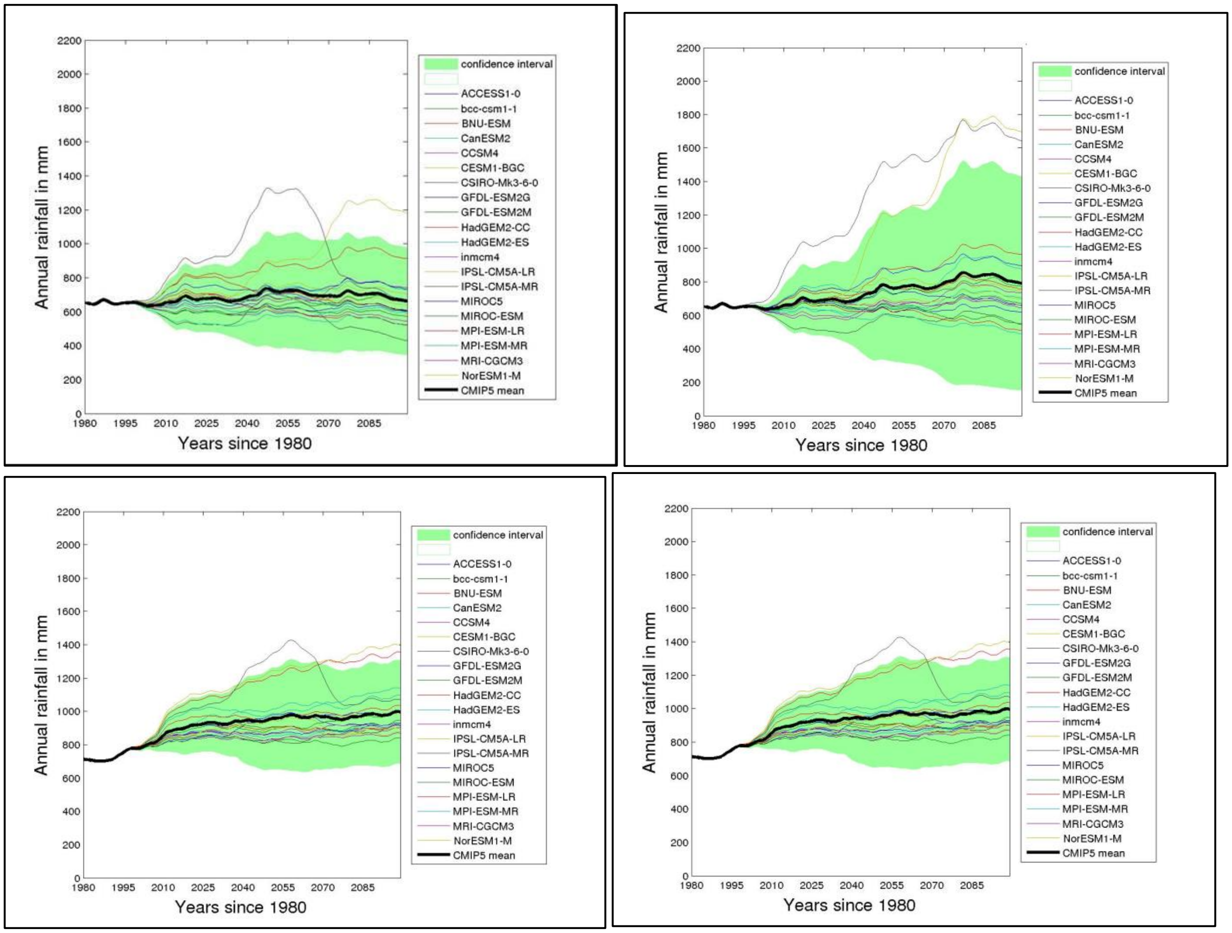


Figure 22: Rainfall projections for Adigudom (top) and Nazreth (bottom) under RCP 4.5 and RCP 8.5

As is the case with temperature, the sites south of equator differed from the sites in the north over the magnitude of change. Under RCP 8.5 the median value for rainfall change to mid-century at Dodoma is an increase of 5.1% while that for Embu is 12.2, for Nazreth is 5.9% and for Adigodam it is 5.5% (Table 16). All GCMs projected a substantial increase in rainfall at Nazreth to mid and end-century periods under both RCPs. A decline in rainfall was projected by 6 GCMs at Adigudom and by 5 GCMs at Embu and Dodoma under RCP 8.5 to mid-century.

Table 16: Changes in rainfall (%deviation from observed) projected by different GCMs

GCMS	4.5 MID				4.5 END				8.5 MID				8.5 END			
	Adi-gudom	Nazeret	Embu	Dodoma	Adi-gudom	Nazeret	Embu	Dodoma	Adi-gudom	Nazeret	Embu	Dodoma	Adi-gudom	Nazeret	Embu	Dodoma
ACCESS1	-4.8	-2.4	2.8	-9.2	-2.3	1.2	24.6	-8.4	14.4	1.5	21.9	-4.0	8.0	8.7	40.9	5.3
bcc-csm1	-4.4	0.6	3.0	-0.3	-7.0	2.3	-0.3	1.7	-1.7	6.6	2.9	-2.6	9.8	11.3	10.2	7.4
BNU-ESM	33.8	38.5	79.9	5.6	48.7	49.0	70.7	7.1	34.3	48.3	67.8	2.0	56.1	54.2	111.4	-1.9
CanESM2	14.2	16.2	38.3	20.4	18.5	18.9	57.2	39.8	17.1	22.1	52.6	34.6	44.7	50.3	87.4	52.4
CCSM4	4.6	-6.3	4.1	1.8	8.2	-0.8	0.1	-2.3	3.0	-8.2	-4.3	-4.6	7.8	4.5	40.9	4.8
CESM1-BGC	17.3	0.6	16.8	5.0	13.8	-3.7	14.1	1.9	25.4	1.5	16.5	-4.8	20.1	10.6	26.3	5.4
CSIRO-Mk3	6.2	-7.9	1.9	-5.8	-26.3	-0.6	20.2	-4.7	-9.1	4.4	12.2	-8.0	-6.8	-4.1	29.5	3.4
GFDL-ESM2G	8.5	9.4	-17.0	-15.3	-1.0	3.2	-17.7	-13.5	-2.6	-11.2	-21.9	-0.8	0.3	0.9	-24.7	-6.2
GFDL-ESM2M	4.6	1.7	-3.0	-1.8	-1.2	8.4	15.6	20.7	0.4	0.6	9.7	7.4	-10.5	4.9	-1.9	22.6
HadGEM2-CC	9.8	1.2	-13.5	-7.1	-0.3	0.6	-13.9	1.1	16.6	9.0	17.2	-2.7	25.4	16.8	21.7	0.2
HadGEM2-ES	-8.9	-4.2	-10.1	-1.9	-4.1	1.4	4.2	3.3	-0.1	0.2	12.2	-0.9	15.0	13.6	26.5	-0.3
inmcm4	-8.5	-6.0	3.6	-2.5	-10.4	-4.0	2.7	-1.8	3.1	5.8	8.9	2.8	5.9	6.5	8.5	5.9
IPSL-CM5A-LR	36.6	41.0	33.1	1.0	94.1	52.6	41.9	-4.9	88.8	53.6	34.9	-5.8	175.4	78.4	72.3	-7.8
IPSL-CM5A-MR	106.4	57.3	30.9	5.2	11.0	17.2	30.1	18.0	135.9	86.6	42.4	9.6	168.5	126.5	89.4	38.1
MIROC5	13.5	9.8	-4.1	36.3	19.7	10.6	-11.5	45.4	34.3	19.8	-13.7	44.1	45.9	43.4	-7.9	21.4
MIROC-ESM	-0.8	-7.4	43.0	-9.9	5.2	-8.7	58.6	-11.0	14.4	-2.2	66.3	-8.9	24.0	0.2	70.5	-6.9
MPI-ESM-LR	-7.4	9.4	0.2	1.1	-13.5	12.6	8.4	3.4	-3.2	8.5	5.3	1.3	-14.8	24.4	14.4	21.0
MPI-ESM-MR	-11.8	11.3	7.0	6.2	-14.1	23.9	12.2	5.6	-9.9	16.8	-4.8	-1.9	-18.0	16.9	-5.5	13.8
MRI-CGCM3	2.7	-1.5	19.0	-3.2	20.9	3.2	23.5	-1.9	4.5	6.0	17.6	2.8	20.6	11.7	47.9	0.5
NorESM1-M	11.3	7.6	-2.7	-2.7	3.9	-1.6	-6.3	0.2	6.4	-4.5	-9.1	5.0	13.5	7.7	-7.8	2.5
Average	**11.2**	**8.4**	**11.7**	**1.1**	**8.2**	**9.3**	**16.7**	**5.0**	**18.6**	**13.3**	**16.7**	**3.2**	**29.5**	**24.4**	**32.5**	**9.1**
Median	**5.4**	**1.5**	**3.3**	**-1.1**	**1.8**	**2.7**	**13.2**	**1.4**	**5.5**	**5.9**	**12.2**	**-0.8**	**14.2**	**11.5**	**26.4**	**5.0**

Among the GCMs BNU-ESM, CanESM2, IPSL-CM5A-LR and IPSL-CM5A-MR generally predicted a higher increase in rainfall at all locations while GFDL-ESM2, inmcm4, HadGEM2-ESG and HadGEM2-CC are amongst the GCMs that generally predicted a negative or relatively small increase in rainfall. However, there are differences in the projected changes from one GCM to other at different locations and for the same GCM for the same location from mid to end century periods and under RCP 4.5 and 8.5. Overall, the projected changes at different locations are in line with the global projections which suggest that rainfall will increase near the equator in Eastern Africa and decline on either side of it. The projection of significant increase in rainfall for Embu and Nazreth locations which fall near the equatorial region of Eastern Africa and a decline or marginal increase at Dodoma is in agreement with this general projection. At locations where rainfall is bimodal, some differences were also observed in the seasonal rainfall and temperature projections (Figure 23). At Embu, most GCMs predicted a higher temperature and lower rainfall during the LR season compared to SR season.

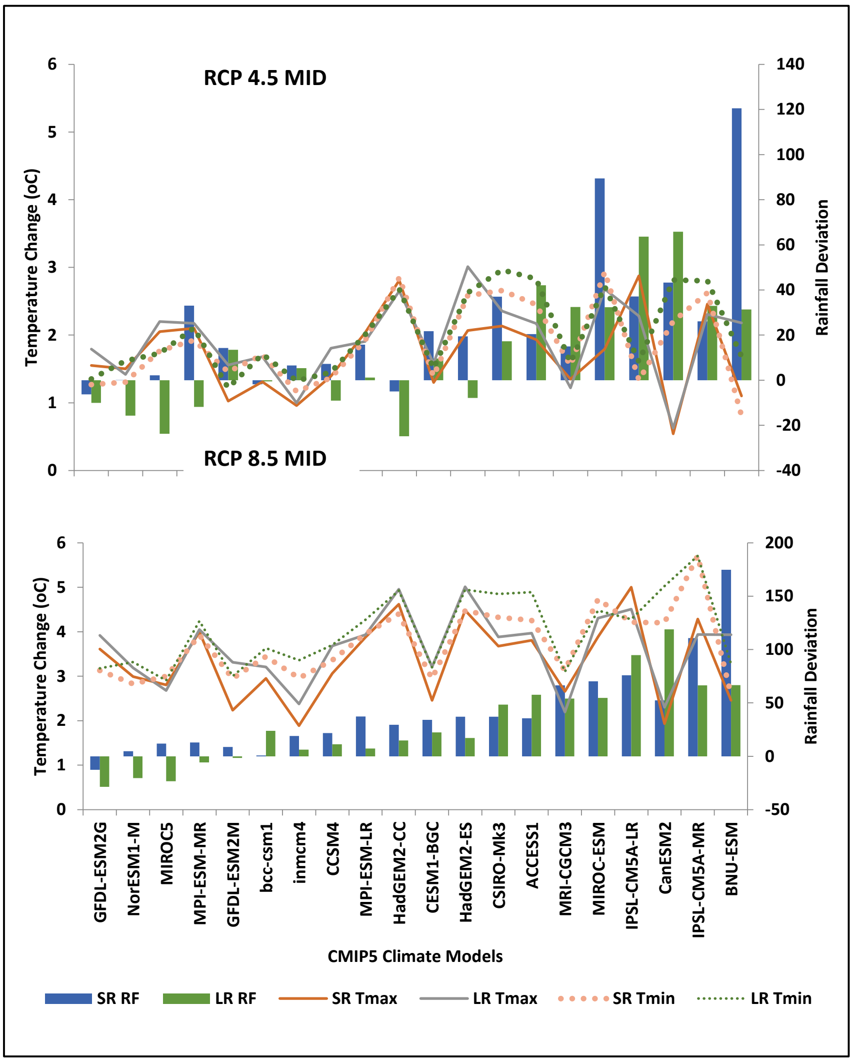


Figure 23: Projected changes in rainfall (percent deviation from historic rainfall) and temperatures (absolute change) for RCP 4.5 and 8.5 to midcentury for Embu station

Though not significant, a positive relationship exists between increase in temperature and change in rainfall at different locations (Figure 24). The relationship is better in case of locations near equator than those away. However no relationship was observed in case of Dodoma.

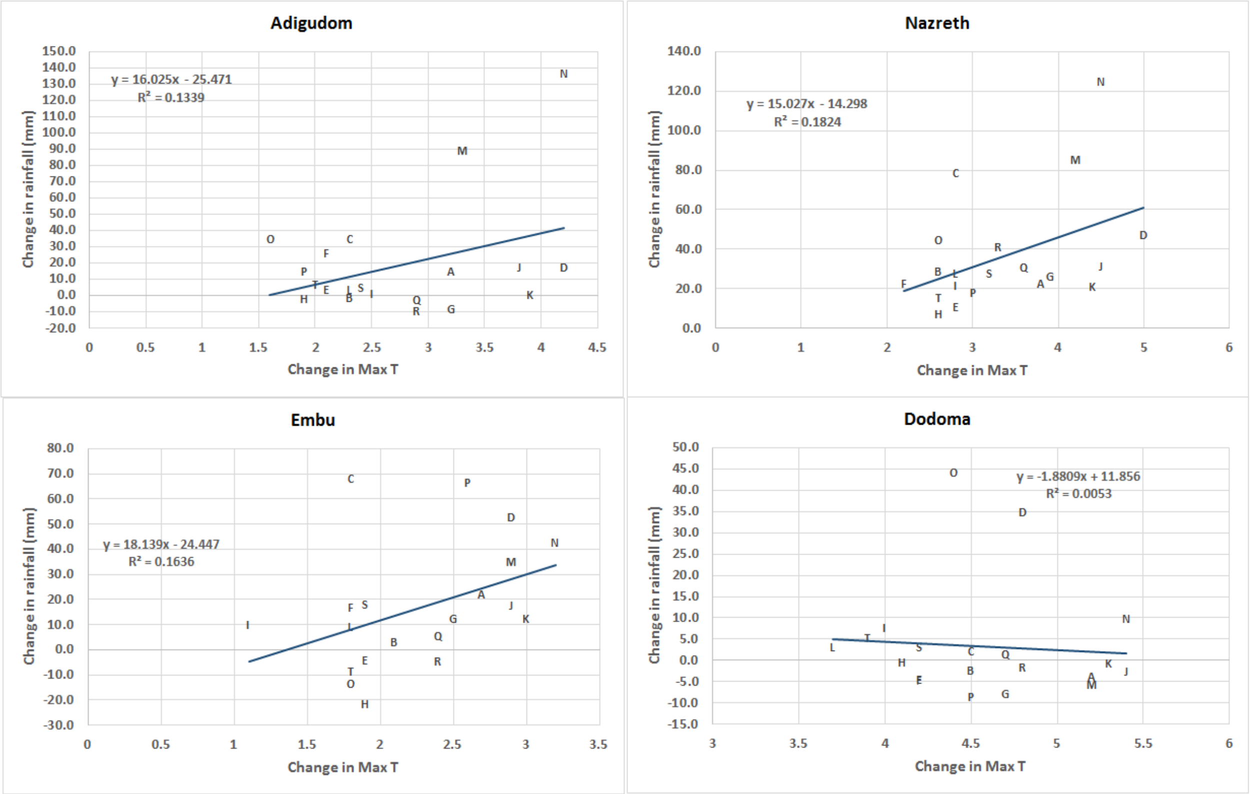
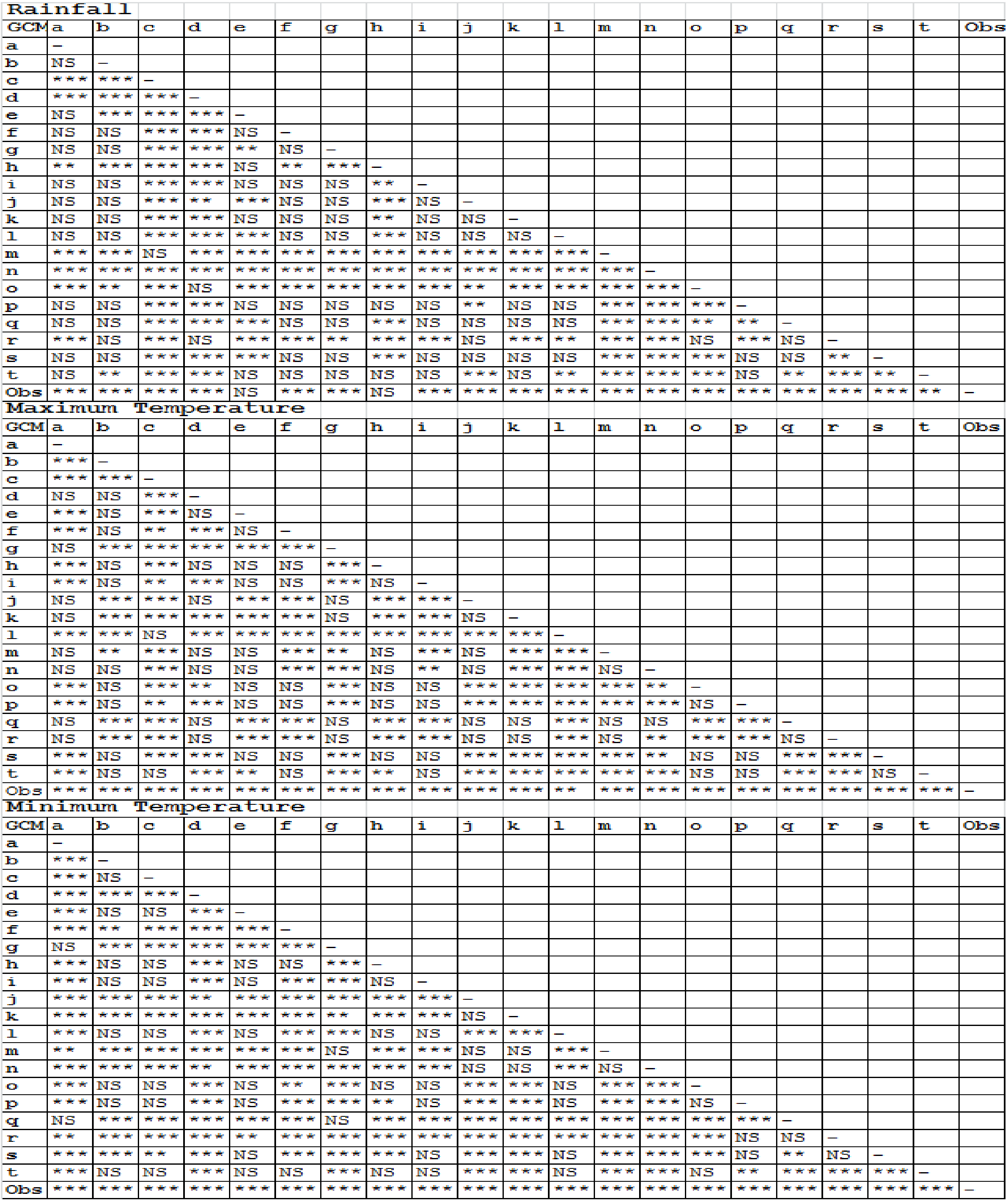


Figure 24: Relationship between changes in minimum and maximum temperature and rainfall at different locations (A=ACCESS1, B=bcc-csm1, C=BNU-ESM, D=CanESM2, E=CCSM4, F=CESM1-BGC, G=CSIRO-Mk3, H=GFDL-ESM2G, I=GFDL-ESM2M, J=HadGEM2-CC, K=HadGEM2-ES, L=inmcm4, M=IPSL-CM5A-LR, N=IPSL-CM5A-MR, O=MIROC5, P=MIROC-ESM, Q=MPI-ESM-LR, R=MPI-ESM-MR, S=MRI-CGCM3, T=NorESM1-M)

Statistical analysis of annual rainfall and maximum and minimum temperature projections has indicated that GCM differences are highly significant (significant at P<0.0001) at all locations. However, projections by some GCMs are not significantly different from each other. Figure 25 presents the correlation matrix for rainfall, maximum temperature and minimum temperature generated by 20 GCMs for Nazreth for mid-century period under RCP 8.5. Trends at other locations are very similar. The correlation matrix for temperature and rainfall based on the level of significance of "t values" indicate that all temperature and rainfall projections are significantly different from baseline conditions. In case of rainfall, except for GCMs CCSM4 and GFDL-ESM2G, projected rainfalls are also significantly different from the baseline conditions.

Figure 25: Matrix indicating the level of significance of t values for annual rainfall, maximum and minimum temperatures projected by 20 GCMs under RCP 8.5 to midcentury at Nazreth.



Rainfall

GCM	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	Obs
a	–																				
b	NS	–																			
c	***	***	–																		
d	***	***	***	–																	
e	NS	***	***	***	–																
f	NS	NS	***	***	NS	–															
g	NS	NS	***	***	**	NS	–														
h	**	***	***	***	NS	**	***	–													
i	NS	NS	***	***	NS	NS	NS	**	–												
j	NS	NS	***	**	***	NS	NS	***	NS	–											
k	NS	NS	***	***	NS	NS	NS	**	NS	NS	–										
l	NS	NS	***	***	***	NS	NS	***	NS	NS	NS	–									
m	***	***	NS	***	***	***	***	***	***	***	***	***	–								
n	***	***	***	***	***	***	***	***	***	***	***	***	***	–							
o	***	**	***	NS	***	***	***	***	***	**	***	***	***	***	–						
p	NS	NS	***	***	NS	NS	NS	NS	NS	**	NS	NS	***	***	***	–					
q	NS	NS	***	***	***	NS	NS	***	NS	NS	NS	NS	***	***	**	**	–				
r	***	NS	***	NS	***	***	**	***	***	NS	***	**	***	***	NS	***	NS	–			
s	NS	NS	***	***	***	NS	NS	***	NS	NS	NS	NS	***	***	***	NS	NS	**	–		
t	NS	**	***	***	NS	NS	NS	NS	NS	***	NS	**	***	***	***	NS	**	***	**	–	
Obs	***	***	***	***	NS	***	***	NS	***	***	***	***	***	***	***	***	***	***	***	**	–

Maximum Temperature

GCM	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	Obs
a	–																				
b	***	–																			
c	***	***	–																		
d	NS	NS	***	–																	
e	***	NS	***	NS	–																
f	***	NS	**	***	NS	–															
g	NS	***	***	***	***	***	–														
h	***	NS	***	NS	NS	NS	***	–													
i	***	NS	**	***	NS	NS	***	NS	–												
j	NS	***	***	NS	***	***	NS	***	***	–											
k	NS	***	***	***	***	***	NS	***	***	NS	–										
l	***	***	NS	***	***	***	***	***	***	***	***	–									
m	NS	**	***	NS	NS	***	**	NS	***	NS	***	***	–								
n	NS	NS	***	NS	NS	***	***	NS	**	NS	***	***	NS	–							
o	***	NS	***	**	NS	NS	***	NS	NS	***	***	***	***	**	–						
p	***	NS	**	***	NS	NS	***	NS	NS	***	***	***	***	***	NS	–					
q	NS	***	***	NS	***	***	NS	***	***	NS	NS	***	NS	NS	***	***	–				
r	NS	***	***	NS	***	***	NS	***	***	NS	NS	***	NS	**	***	***	NS	–			
s	***	NS	***	***	NS	NS	***	NS	NS	***	***	***	***	**	NS	NS	***	***	–		
t	***	NS	NS	***	**	NS	***	**	NS	***	***	***	***	***	NS	NS	***	***	NS	–	
Obs	***	***	***	***	***	***	***	***	***	***	***	**	***	***	***	***	***	***	***	***	–

Minimum Temperature

GCM	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	Obs
a	–																				
b	***	–																			
c	***	NS	–																		
d	***	***	***	–																	
e	***	NS	NS	***	–																
f	***	**	***	***	***	–															
g	NS	***	***	***	***	***	–														
h	***	NS	NS	***	NS	NS	***	–													
i	***	NS	NS	***	NS	***	***	NS	–												
j	***	***	***	**	***	***	***	***	***	–											
k	***	***	***	***	***	***	**	***	***	NS	–										
l	***	NS	NS	***	NS	***	***	NS	NS	***	***	–									
m	**	***	***	***	***	***	NS	***	***	NS	NS	***	–								
n	***	***	***	**	***	***	***	***	***	NS	NS	***	NS	–							
o	***	NS	NS	***	NS	**	***	NS	NS	***	***	NS	***	***	–						
p	***	NS	NS	***	NS	***	***	**	NS	***	***	NS	***	***	NS	–					
q	NS	***	***	***	***	***	NS	***	***	***	***	***	***	***	***	***	–				
r	**	***	***	***	**	***	***	***	***	***	***	***	***	***	***	NS	NS	–			
s	***	***	**	***	NS	***	***	***	NS	***	***	NS	***	***	***	NS	**	NS	–		
t	***	NS	NS	***	NS	NS	***	NS	NS	***	***	NS	***	***	NS	**	***	***	***	–	
Obs	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	–

***Note:** ***and ** indicate significance at 99% and 95% level and NS denotes no significance. GCMs: a=ACCESS1, b=bcc-csm, c=BNU-ESM, d=CAN-ESM, e=CCSM4, f=CESM1-BGC, g=CSIRO-Mk3, h=GFDL-ESM2G, i=GFDL-ESM2M, j=HadGEM2-CC, k=HadGEM2-ES, l=inmcm4, m=IPSL-CM5A-LR, n=IPSL-CM5A-MR, o=MIROC5, p =MIROC-ESM, q=MPI-ESM-LR, r=MPI-ESM-MR, s=MRI-CGCM3, t=NorESM1, Obs=Baseline*

In summary, the climate change scenarios highlight the following changes.

- The median values suggest that the maximum temperatures in the region increase by 1.6 to 4.0^{0}C to mid-century and by 3.1-5.6°C to end-century under RCP 8.5. Higher increase was observed in case of locations south of equator. The projected increase in maximum temperatures at Dodoma is higher by 1.0-2.5^{0}C over the locations near equator

- The trends in projected increase in minimum temperatures are similar to those observed in case of maximum temperatures but the magnitude of increase is higher than that in maximum temperatures by about 1°C
- Projected changes in rainfall showed greater variability than that observed in temperature projections. The variability is much higher at Adigudom and Embu than at Dodoma. For example at Adigudom projected rainfall by different GCMs varied from about -10% to 135% from baseline under RCP 8.5 to mid-century period.
- The variability in rainfall is not uniform across the months and seasons. The changes are more positive and are of higher magnitude during the Oct-Dec season compared to Mar-May season.
- A non-significant linear relationship was observed between the projected changes in maximum temperature and rainfall. However, there is no relationship was observed at Dodoma
- The results indicate that the increase in temperature at locations away from equator, especially those located south of equator is higher compared to locations near equator. Further, changes in rainfall at these locations are marginal compared to the locations near equator.
- No outliers were observed in case of temperature projections by different GCMs. However, rainfall projections by some GCM projections for rainfall are very high. For Nazreth and Embu IPSL-CM5A-MR and IPSL-CM5A-LR predict morbbe than 100% increase in rainfall
- The down scaled climate change projections reflect the general trends reported at regional scale for eastern and southern Africa and also in agreement with the changes observed in the baseline conditions

5.3 Crop and soil Data

5.3.1 Soil data

Required soil data was collected from soil survey reports of the national agricultural research institutions in the four countries. Initially, major soil formations in the target region were identified using available soil maps. Then representative soil profiles for each of the major soil types were identified from the soil survey reports. Using this approach data on six soil profiles in Ethiopia, four in Kenya, five in Tanzania and three in Uganda were identified. The key parameters used while setting the soil profiles for DSSAT and APSIM models are presented in Table 17.

Table 17: Main characteristics of the soil profiles used with crop simulation models

a. Ethiopia:

Properties	Melkassa	Wonji	Nazareth	Adigudom	Adimesanu	Hintalo
Target Agro-ecology	SM3	SA2	SM2	SM2	SM4	SM3
Soil type	Leptosols	Fluvisols	Fluvisols	vertisol	Leptosol/cambisol	Fluvisols
Soil layers/depth (cm)	3/230	7/215	4/215	4/200	6/200	3/200
Sand, silt, clay (% in 0-15cm)	78,17,5	54,35,11	68,22,9	9, 41, 50	43, 35, 22	59, 17, 24
Plant available water	20	35	75	40	45	25
Organic matter (top three layers)	2.09, 1.49, 0.91	3.61,2.29,1.58	2.29, 1.58,0.92	3.06, 3.17, 2.68	3.15	1.49

b. Kenya

Properties	Embu	Kavutiri	Gachuka	Machanga
Target Agro-ecology	UM2	UM3 and LM3	LM4	LM5
Soil type	Typic Palehumult	Othoxic Palehumult	Typic Haplorthox	
Soil layers/depth (cm)	4/102	6/200	4/104	4/80
Sand, silt, clay (% in 0-15cm)	20,24,56	20,26,54	20,24,56	-
Plant available water	93.7	152.2	89.4	100
Organic matter (top three layers)	2.09, 1.49, 0.91	3.61,2.29,1.58	2.29, 1.58,0.92	0.58, 0.5,0.4

c. Tanzania

Properties	LHZ1	LHZ1	LHZ2	LHZ2	LHZ2
Soil order	Ferralic Cambisols	Chromic Luvisols	Mollic Fluvisols	Ferralic Cambisols	Haplic Luvisols
Soil layers/depth (cm)	4/180	6/180	5/185	4/180	4/106
Sand, silt, clay (% in 0-15cm)	61,16,23	73,10,17	60,16,24	54,12,34	31,12,57
Plant available water	93.7	152.2	89.4	100	
Organic matter (top three layers)	0.72,0.43,0.19	0.36,0.33,0.16	0.24,0.11,0.09	0.56,0.42,0.3	1.25,0.96,0.32

d. Uganda

Properties			
Soil order	Petro Plinthic	Dystric regosols	Acric Ferralsol
Soil layers/depth (cm)	4/101	6/203	7, 213

Sand, silt, clay (% in 0-15cm)	69,8,23	67,10,23	62,6,26
Plant available water	83	120	135
Organic matter (top three layers)	2.355, 1.301, 0.935	2.69,0.98,0.91	2,78, 0.92,0.51

The profile description taken from the soil survey reports is considered as representative of average soil conditions in the study area. Considering high variability in the soil conditions across the farms, two variants (good, average and poor) were created for each soil profile by increasing or decreasing the soil organic matter and plant available water contents by 20%. With these variants, a total of 54 soil profiles were created. These profiles are then assigned to individual farms based on the location of the farm and perception of the farmer about fertility status of his farm. During the survey, farmers were asked to rate fertility status of their farm as good, average and poor when compared to general conditions in that area and this information was used as a basis in identifying appropriate soil profile for individual farmers.

5.3.2 Crop data

Crop management parameters used in setting simulations for individual farms were derived from the survey conducted during 2011-2012. The survey was designed to capture among other things, variety used, date planted, amount of seed used and fertilizer and manure applied during 2012 crop seasons along with yields harvested. Farmers in the region used a large number of varieties and for many of these varieties required data to derive model parameters is not available. Hence, while setting up parameters for these varieties, we have identified and used an equivalent variety for which data to derive model parameters is available. The identification of equivalent variety is based on the duration and yield potential of that variety and Table 18 presents the farmer used variety and its equivalent in the model. Variety Katumani is used as a local variety.

Table 18: Maize varieties used by farmers and the identified equivalent in the model

Variety used by farmer	Duration	Yields	Variety in the Model
Ethiopia			
Melkassa-1	105-114	4100-5600	Melkass-1
Melkassa-2	145-155	3200-7000	Melkass-2
Local			Katumani
HAR2501 (Wheat)	90 - 115	2000 - 3500	kotuku
Kenya			
DK41		5-6	Deka_lb
DK43		6-7	H511
H513	4-5	6-8	H511
H613	6-8	8-10	H513

Local	All		Katumani
Duma	4-5	6-7	H511
Pioneer	5-6	8-10	H513
Others	Considered as local		Katumani
Tanzania			
STAHA	110-120	4-5	STAHA
SITUKA	85-110	3-5	SITUKA
KILIMA	90-120	5-6	STAHA
TMV1	100-120	4-4	TMV1
LOCAL			SITUKA
PIONEER	90-115	4-6	PIONEER HB3252
DEKALB	110-140	5-8	SITUKA
PANNAR	90-120	4-7	STAHA
Uganda			
Nafa, Ndele, Longe 1, Longe 4	100-105	1.5-1.8	Local traditional (Katumani)
Longe 5, dk	115	4-5	Longe 5
Longe 2H, Longe 6H, Longe 10H	120	7-8	Longe 9

Challenges were also faced in setting up plant population levels, since farmers are generally not familiar with the number of plants per ha or ac. However, they were able to provide more accurate information on the amount of seed used. Hence, we have used the amount of seed used by farmers as a surrogate measure to estimate plant population. Previous studies in the region have indicated that plant population on farmer fields varied from about 20,000 plants/ha to 60,000 plants/ha depending on the potential of the area to grow maize and inputs used. Accordingly, a plant population of 20,000-30,000 plants/ha was assigned to farmers using seed rates lower than 15 kg/ha, 40,000 plants/ha for those using 15-20 kg/ha and 50,000 -60,000 plants/ha for those using more than 20 kg/ha. In case of Uganda we used higher plant population as is the practice with farmers in that area. The distribution of farmers in these groups is presented in Table 19. Majority of the farmers were found to be using 30,000 or less plants/ha.

Table 19: Number of farmers using different plant populations under the five agro-ecologies

Plant population (plants/ha)	**Number of farmers in each agro-ecological zone**					
Ethiopia						
Kenya						
	UM2	**UM3**	**LM3**	**LM4**	**LM5**	**Total**
30,000	31	55	50	69	63	268
40,000	39	27	48	18	18	150
50,000	3	5	8	4	1	21

Tanzania			
	LH1	**LH2**	**Total**
20,000	39	49	87
30,000	20	31	51
40,000	17	1	18
50,000	7	5	12

Uganda				
	Acric Ferralsols	**Petric Plinthisols**	**Dystric Regosols**	**Total**
40,000	60	69	53	162
50,000	18	16	32	66
60,000	20	18	21	59

Large differences existed in the amount of fertilizer used by farmers in different countries and in different AEZs within the country (Table 20). Similar differences were also observed in the use of manures. In general use of fertilizes by smallholder farmers is low and limited to some high potential environments. In Uganda none of the farmers covered by the survey used fertilizers. Here, farmers rely on crop rotation, manure and other organic residues to replenish soil fertility. While setting up the simulations for individual farmers, we used the actual amounts reported by farmers. The type of fertilizer used by farmers also varied from one country to the other but the fertilizers are all ammonical (Calcium Ammonium Nitrate, Di-Ammonium Phosphate and NPK complex). A uniform depth of 5 cm was used for placing the fertilizer and the entire amount was applied once at the time of sowing.

Table 20: Fertilizer use by farmers in the four countries under different agro-ecologies

Fertilizer use by farmers in Adama, Ethiopia						
Fertilizer (kg/ha)	SA2	SM2	SM3	Total		
<10	56	53	81	190		
10-20	3	3	1	7		
20-30	6	8	7	21		
30-40	2	3	2	7		
40-50	3	1	1	5		
>50	9	1		10		
Fertilizer use by farmers in Embu county Kenya						
Fertilizer (kg/ha)	UM2	UM3	LM3	LM4	LM5	Total
<10	10	7	16	20	47	100
10-25	25	12	14	27	24	102
25-50	30	24	32	43	25	154
>50	21	38	34	19	5	117
Fertilizer use by farmers in Wami basin Tanzania						
	LHZ 1	LHZ 2	Total			
0	62	73	135			
10-50	18	10	28			

>50	3	2	5			

5.4 Crop Model calibration and validation

Model calibration was carried out for a total of ten maize varieties that are relevant for the target locations with data collected from various trials conducted with in the target countries (Table 21).

Table 21: Details of maize varieties calibrated in the four target countries

Country	Variety	Data source
Ethiopia	Melkasa 1 and Melkasa 2	Experimental data from EIAR Melkassa research station
Kenya	Katumani, H511 and H513	Experimental data from KARI Embu research station from a trial conducted over three seasons SR seasons of 2000 and 2001 and LR season of 2001
Tanzania	Stuka, Staha	Mourice,. S. K., Rweyemamu, C. L., Tumbo, S. D. and Amuri, N. (2014) Maize cultivar specific parameters for Decision Support System for Agrotechnology Transfer (DSSAT) application in Tanzania. American Journal of Plant Science, vol. 5, 821-833
Uganda	Longe 5, Longe 9 and Uganda Tradn	Experimental data from Bulindi Zonal Agricultural Research Institute in Hoima (Kaizzi et al., 2012).

Varieties were calibrated for four main parameters - days to flowering, days to maturity, grain and biomass yields at harvest. For some varieties such as Katumani, default parameters that are available with APSIM and DSSAT models needed no further adjustments. For other varieties, parameters were derived by manipulating the thermal time required to complete various growth stages until the simulated phenology matched the observed phenology. Simulations with final set of parameters by both the models indicated a good relationship between observed and simulated days to flowering and days to maturity (Figures 26 and 27). However, the model-simulated biomass and grain yield are related poorly with the observed data. This is mainly due to lack of information regarding the management practices employed in these trials and lack of data on initial soil moisture and fertility conditions. DSSAT simulated days to flowering, days to maturity and biomass yields correlated with observed data better than those simulated with APSIM. However, in case of grain yield the relationship was better between observed and APSIM simulated yields.

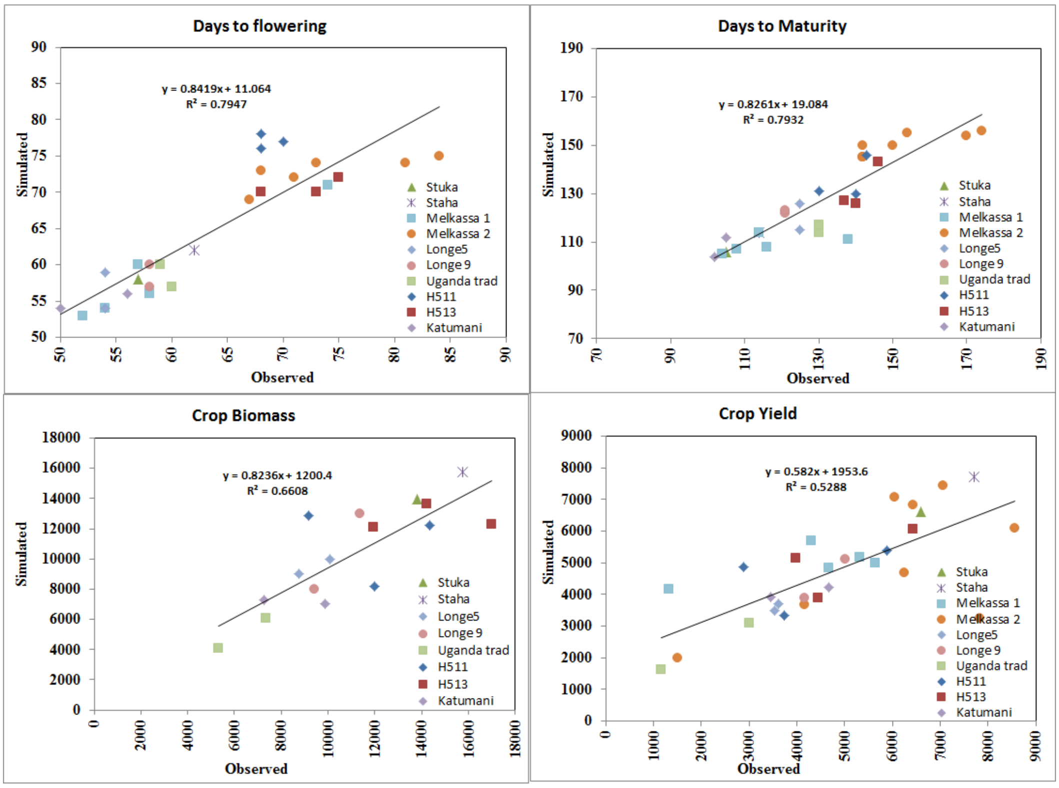


Figure 26: Relationship between observed and DSSAT simulated characteristics of maize varieties

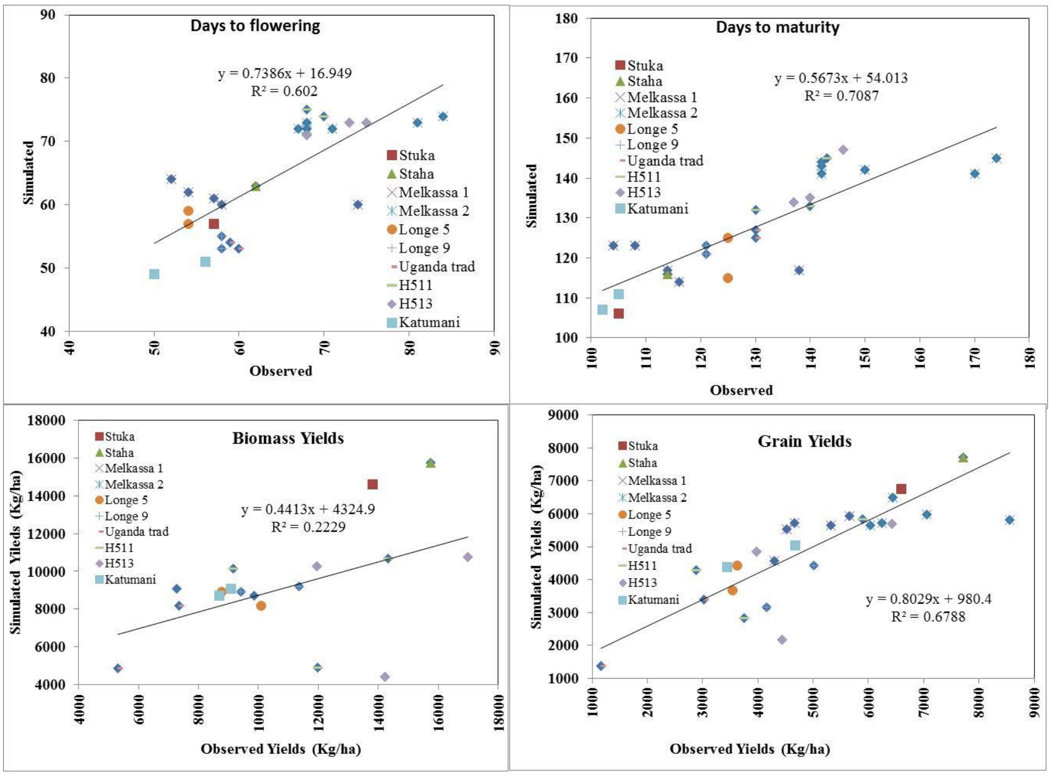


Figure 27: Relationship between observed and APSIM simulated characteristics of maize varieties

5.5 Sensitivity analysis

Model sensitivity to various environmental parameters was examined by conducting a matrix of simulations designed to understand the response of DSSAT and APSIM crop models to changes in maximum and minimum temperatures, precipitation and atmospheric CO_2 concentrations. Embu climate data for 30 years (1980-2010) was used for the sensitivity analysis. Table 22 compares the average maize yields simulated by the two models under different climatic conditions. In general, APSIM simulated higher biomass yield compared to DSSAT under all conditions. While both models simulated fairly similar responses to changes in temperature and rainfall in case of grain yield, they differed in the way total biomass was estimated. Simulations with APSIM indicated a decline in the total biomass and those by DSSAT indicated an increase. While a reduction in the crop growing period is considered as the main reason for reduced biomass production in APSIM simulations, the CO_2 effect is considered as the main contributor for higher biomass production with DSSAT. APSIM is insensitive to changes in atmospheric CO_2.

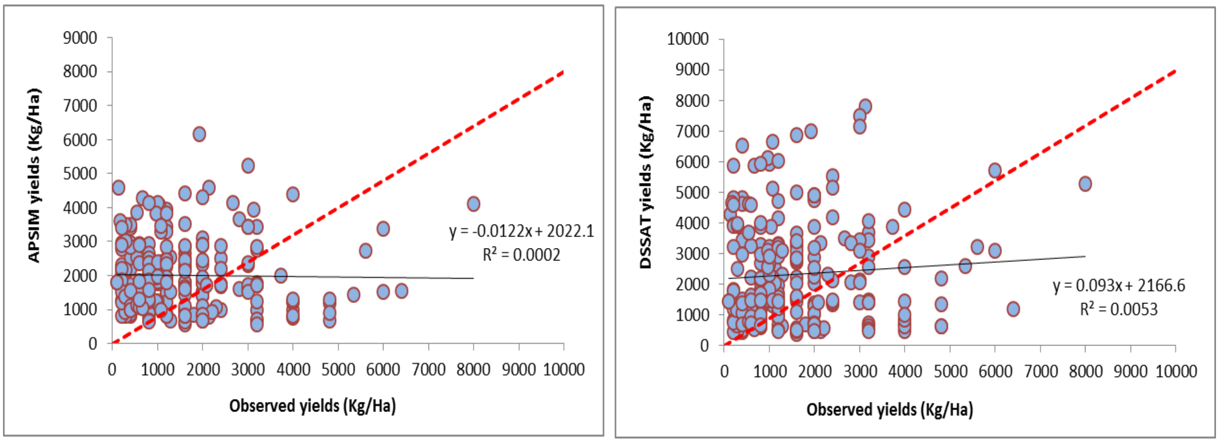
Table 22: Response of maize to changes in management and climatic conditions

Treatment	**APSIM**		**DSSAT**	
	Biomass Yield (kg/ha))	**Grain Yield (kg/ha**	**Biomass Yield (kg/ha))**	**Grain Yield (kg/ha**
Effect of temperature and rainfall				
Base Climate	9525	2207	4468	2450
Base+1^{0}C	9181 (-4%)	2326 (+5%)	6711 (50%)	2461 (0%)
Base+3^{0}C	8617 (-10%)	2593 (+17%)	7398 (66%)	2690 (10%)
Base+5^{0}C	8001 (-16%)	2697 (+22%)	7788 (74%)	2811 (15%)
Base+1^{0}C+10%RF	9364 (-2%)	2473 (+12%)	6383 (43%)	2343 (-4%)
Base+3^{0}C+10%RF	8753 (-8%)	2681 (+21%)	7038 (57%)	2549 (4%)
Base+5^{0}C+10%RF	8155 (-14%)	2814 (+27%)	7381 (65%)	2657 (8%)
Base+1^{0}C-10%RF	9021 (-5%)	2187 (-1%)	6992 (56%)	2562 (5%)
Base+3^{0}C-10%RF	8463 (-11%)	2424 (+10%)	7723 (73%)	2842 (16%)
Base+5^{0}C-10%RF	7811 (-18%)	2628 (+19%)	8117 (82%)	2958 (21%)

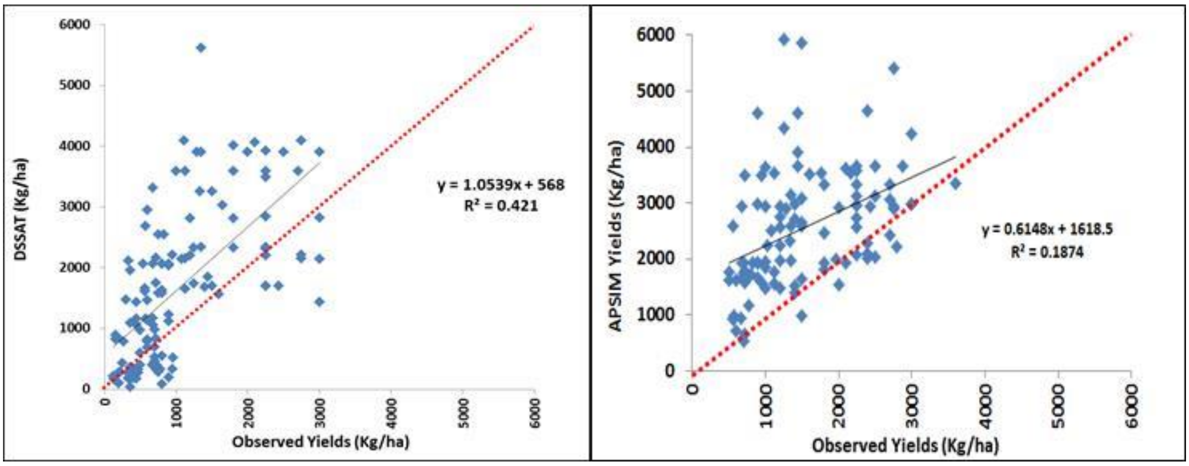
5.6 Model validation

After the calibration, the models were used to simulate farmer yields after setting up simulations for each farmer. The simulated yields are generally higher than the yields reported by farmers (Figure 28) in case of Ethiopia and Kenya. The relationship between simulated and farmer reported yields is very poor in case of Ethiopia and very good in case of Tanzania. The differences between simulated and observed yields varied from as little as 20 Kg/ha to as high as 4000 kg/ha. A number of factors may have contributed to this mismatch. These include differences in interpreting and translating farmer description of soil and other resources into quantitative model parameters, inability of the models to capture the effects of biotic stresses such as pests, diseases and weeds, inaccuracies in estimating yields especially in the mixed/intercropping systems which are widely practiced and inaccuracies in defining the initial conditions.

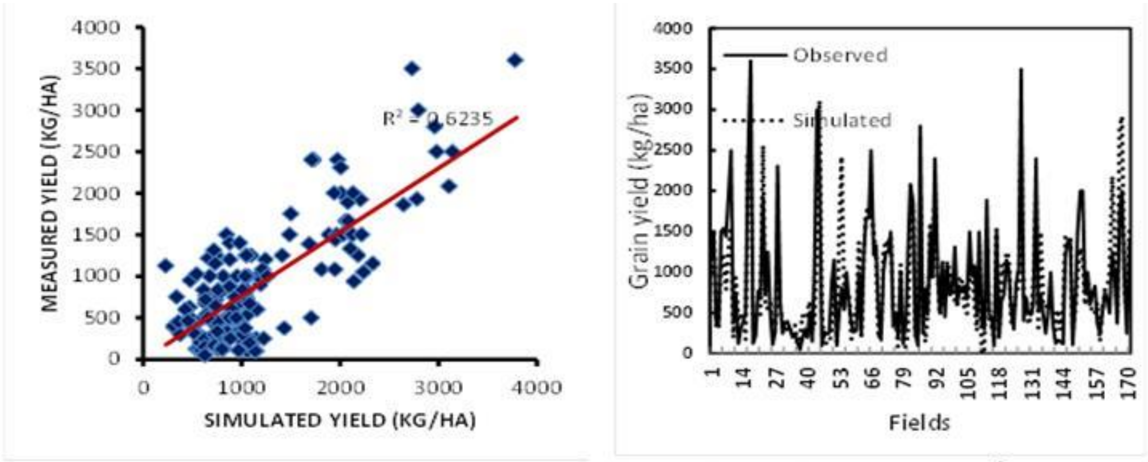
a. Ethiopia



b. Kenya



c. Tanzania



DSSAT Model calibration results

Apsim Model calibration results (R^2=0.658)

Figure 28: Relationship between DSSAT and APSIM simulated yields and farmer reported yields

However, simulated yields reflected the trends in the yields reported by farmers from different agro-ecologies fairly well in all countries. In case of Kenya, agro-ecologies UM2, UM3 and LM3 are high potential areas compared to LM4 and LM5. The simulated yields captured these differences in yields achieved by farmers in different agro-ecologies well (Figure 29). The difference between simulated and reported yields tends to be lower in case of low potential environments such as LM4 and LM5. In these environments, moisture stress is the most dominant yield determining factor.

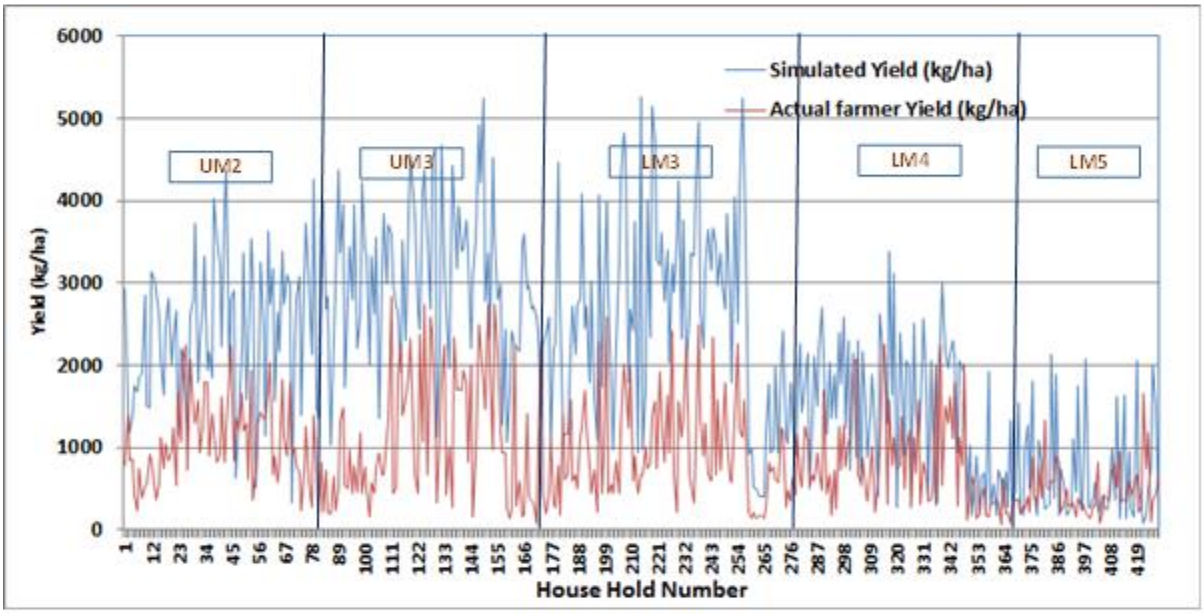


Figure 29: Trends in farmer achieved and simulated yields across five agro-ecologies in Kenya.

6. Integrated Assessment Results

6.1 Sensitivity of current agricultural production systems to climate change:

Simulations were carried out with both DSSAT and APSIM to assess performance of maize under baseline and climate change scenarios for all combinations of RCPs 4.5 and 8.5, time periods mid and end centuries and 20 AOGCMs in all the four countries. The simulation results showed both positive and negative impacts of climate change on maize yields depending on the existing baseline climatic conditions at that location and the management employed. The large number of farm conditions setup for this simulation has helped us to conduct a detailed assessment of how different crop production factors are responding to projected changes in climatic conditions under a range of agro-ecologies in the four countries.

Ethiopia:

In Ethiopia, simulations were carried out for 240 farms representing a unique combination of soil, climate and management conditions across three AEZs in Adama district. Among the AEZs, yields are relatively high in the SA2 and low in the SM3 with SM2 falling in between. Simulated long-term average yields under baseline conditions varied from 2413 kg/ha in SA2 to 2024 kg/ha in SM2 and 1977 kg/ha in SM3. Since, no major differences were observed in the management of farms by farmers across the three AEZs, much of the difference in yields is attributed to differences in the climatic conditions. These yields are in agreement

Small positive (<10%) changes were indicated in maize yields by both DSSAT and APSIM for all AEZs in Adama under most climate change scenarios to mid and end-century periods. However, there are some differences in the way APSIM and DSSAT simulated these changes. APSIM simulations indicate higher increase with 4.5 end and 8.5 mid-century scenarios (Figure 30) while DSSAT simulations indicate higher yield increases with 8.5 mid and end-century scenarios. APSIM predicted higher increase in SM2 while DSSAT predicts higher gains in SA2. The increase in yield is attributed to the general increase in Rainfall predicted by most GCMs for Nazreth and Wonji met stations.

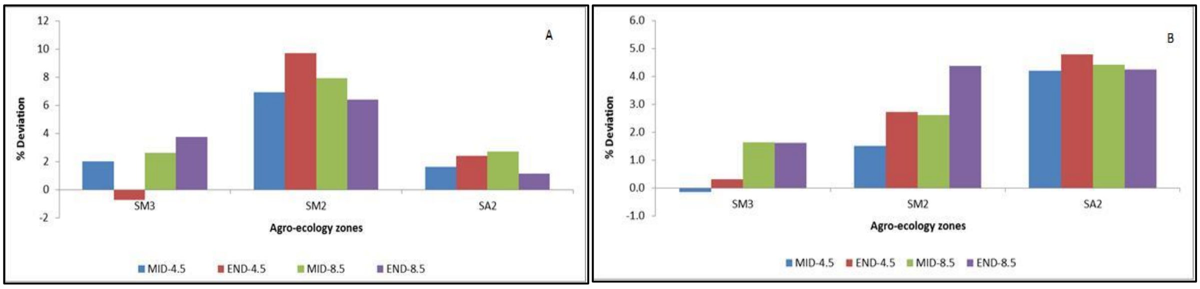


Figure 30: Effect of climate change on performance of maize as simulated by A. DSSAT and B. APSIM at Adama, Ethiopia

Among the Agro-ecologies, some negative or marginal increases were observed in SM3 while SM2 showed higher variability. In general DSSAT simulated yields are slightly higher than those simulated by APSIM which is attributed to the CO_2 effect that is absent in simulations by APSIM.

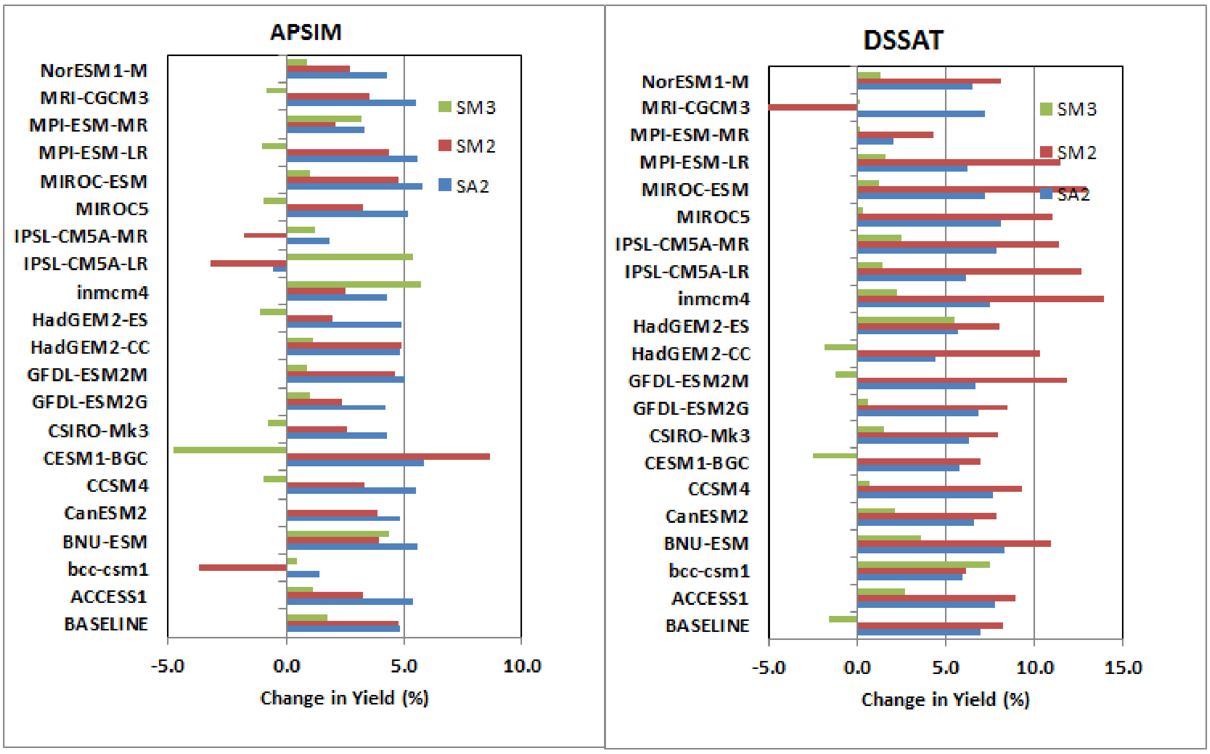


Figure 31: Changes in maize yields simulated by APSIM DSSAT in response to changes in climatic conditions predicted by different GCMs under RCP 8.5 to mid-century

Kenya:

In case of Kenya, where differences in biophysical conditions between AEZs is high and where two distinct cropping seasons exist, impacts of climate change varied from one AEZ to the other and from one season to the other. To represent the diversity in AEZs and capture the full range of management practices employed by farmers in different AEZs, simulation runs were set up for 440 farmers. Both DSSAT and APSIM predicted that the impact of climate change will be more positive in case of SR season compared to LR season (Figure 32). Results from APSIM simulations projected that maize yields are marginally increasing in the AEZs UM2, UM3 and LM3 and are declining in LM4 and LM5. In all AEZs the projected changes are within ± 10% range compared to yields simulated with baseline climate. In case of DSSAT except for LR season in LM4, maize yields increased by more than 10%, mostly in 20-30% range, across all AEZs and in both seasons. Highest increase is predicted in LM3 followed by LM5 and UM3. Though the percent increase is high in LM5 the yields are very low in this AEZ. Compared to LR season the increase is higher during the SR season. The changes in crop yields varied from –27 to +79 % in LR season and from -36 to +80% in SR season. LM3 represented by

Karurumo weather station showed the highest increase. In both seasons, simulated maize yields showed a gradual increase in the order 4.5 MID, 4.5 END, 8.5 MID and 8.5 END as displayed in 32.

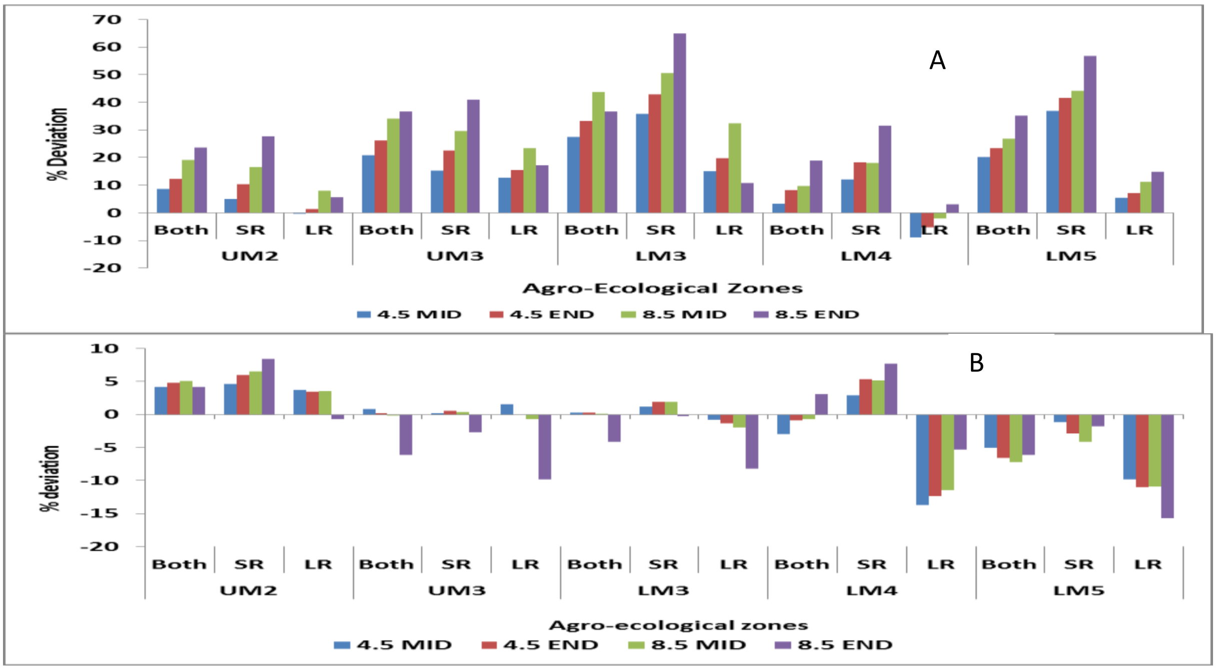


Figure 32: Projected changes in maize yields during short and long rain seasons in different agro-ecologies of Embu county, Kenya in response to changes in climate under RCPs 4.5 and 8.5 by (A) DSSAT and (B) APSIM to mid and end-century periods

Tanzania:

In Tanzania, climate change is expected to have a negative impact on maize yields under both the livelihood zones to both mid and end-century periods under RCP 4.5 and 8.5. A progressive increase in the magnitude of this decline in maize yields is observed from 4.5 mid, 4.5 end, 8.5 mid and 8.5 end-century scenarios (Figure 33). The impact is less in zone 1 compared to zone 2.

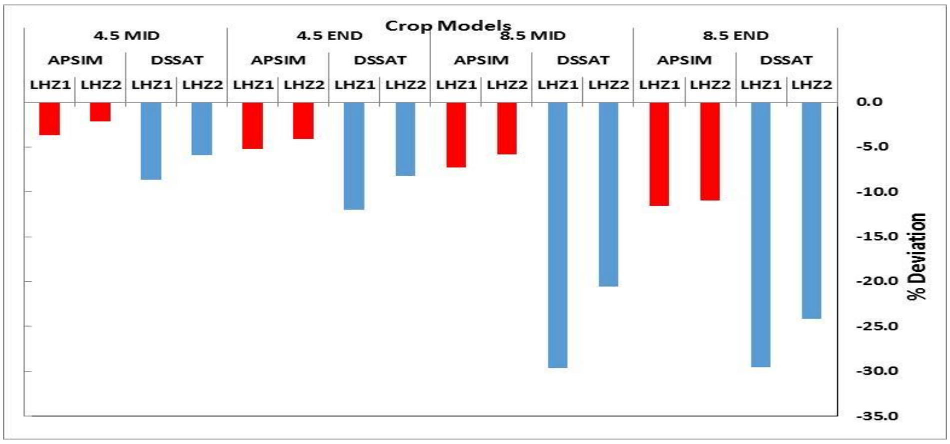


Figure 33: Changes in Maize yields in Wami basin, Tanzania in response to changes in climate under RCPs 4.5 and 8.5 to mid and end-century periods

Both DSSAT and APSIM simulated maize yields indicate a decline in both livelihood zones under climatic conditions predicted by all GCMs. However, DSSAT simulations show a higher decline than simulations by APSIM. For example, in Zone 1 under HADGEM2–ES 1 scenario a 27% decline was predicted by DSSAT while APSIM shows only 9% decline (Figure 34). There are also differences among the five GCMs as indicated by the median yields, with highest crop yields under CCSM4 and lowest under HADGEM2-ES. According to the data set, evidence suggests that maize yields in zone 1 will be variably distributed above the median. In case of APSIM, though the median yields in zone 2 are slightly higher than that in zone 1, maize yields in many farms in zone 2 are below the median level. The opposite is true in case of DSSAT simulated yields, in which more farms are above the median value. Overall, the projected decline in maize grain yield in the livelihood zone varied from 5.3 to 40.7%.

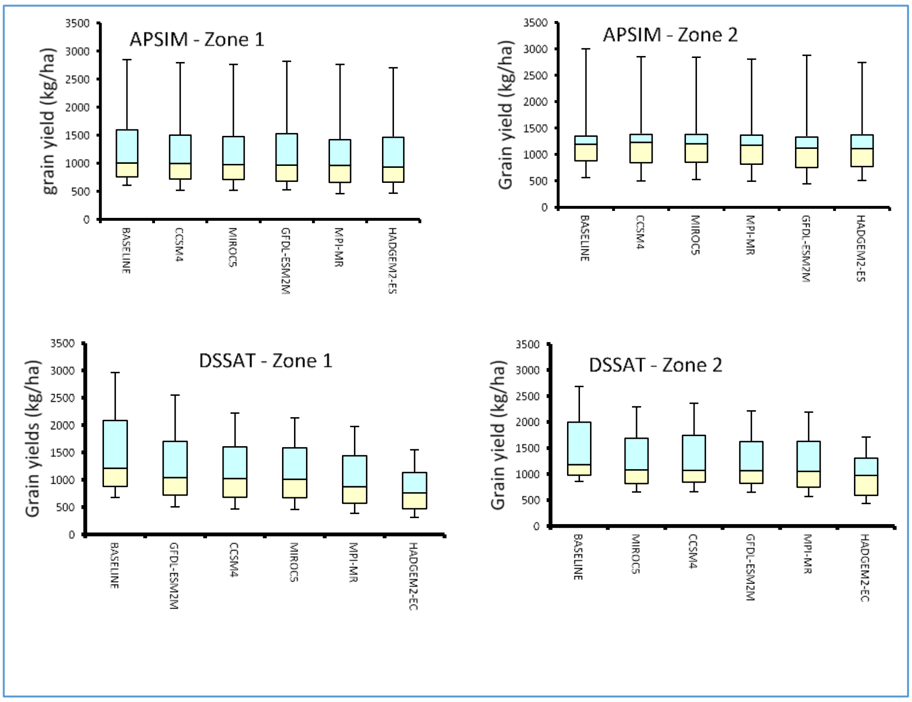


Figure 34: Variability in the yields simulated by DSSAT and APSIM using climate change projections by five GCMs to mid-century under RCP 8.

Uganda:

In the Hoima and Masindi districts of Uganda, a significant decline in maize yields was simulated in all agro-ecologies by both APSIM and DSSAT as shown in Figure 35. While APSIM simulated yields show a higher decline in SR season for all scenarios, DSSAT simulated yields show higher decline in LR seasons. The magnitude of decline in DSSAT simulated yields is much higher with 8.5 end-century projections compared with projections for other periods. Except for Petric Plinthosols region, APSIM simulations show a higher negative impact of climate change on maize yields compared to yields from DSSAT simulation.

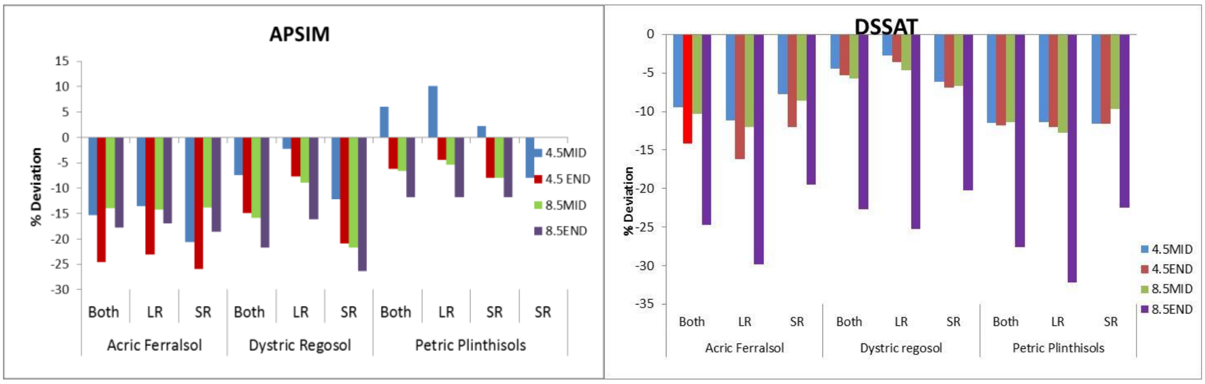


Figure 35: Projected changes in maize yields in the three agro-ecological zones of Hoima and Masindi districts in Uganda

Overall, the analysis indicates that the impacts of climate change depends on a number of factors including differences in the projected climatic conditions by different GCMs. The predicted increase in maize yields in Ethiopia and Kenya is mainly attributed to the general increase in rainfall and temperatures remaining within the optimal range for maize production even with an increase of 2.5 to 4.8°C. The higher increase in yields observed during the SR season compared to LR season in Kenya is due to distribution of rainfall over a longer period and higher number of rainy days. The average number of rainy days in LR season is 40 while in SR it is 58 days as shown in Figure 36.The less number of rainy days and shorter duration of the LR season have exposed maize to water stress especially during the critical stages of flowering and grain filling. Also most AOGCMs projected considerably higher increase in rainfall during SR season compared to LR season. In the SR season projected changes in maize yields are as high as +60% and that during LR season are up to a maximum of +30% except for LM4 where yields declined under future climate scenarios.

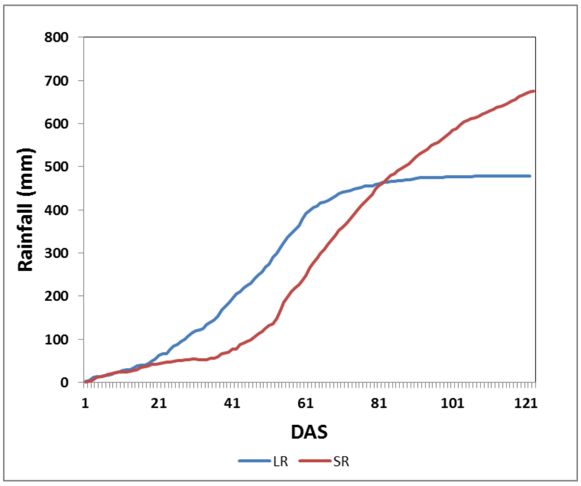


Figure 36: Average cumulative rainfall for SR and LR seasons

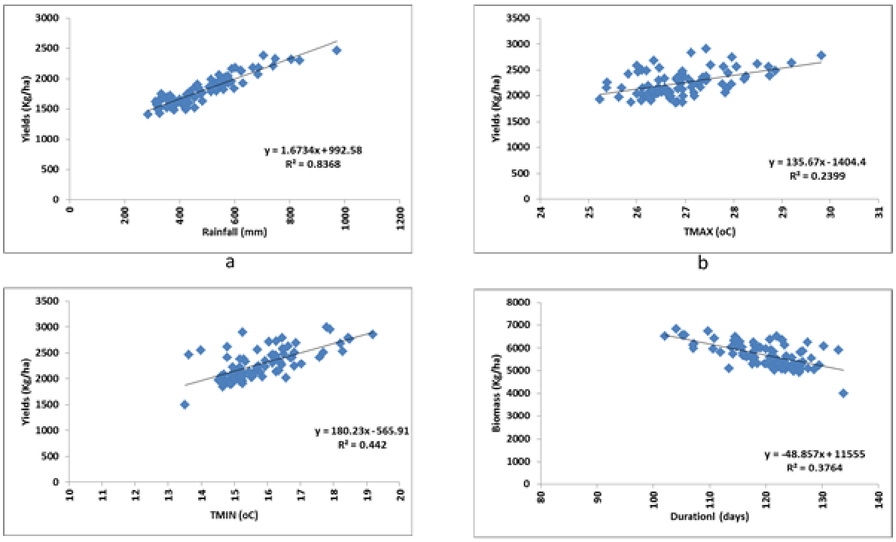
In general, DSSAT simulated yields are slightly higher than those simulated by APSIM. This difference is mainly due to the CO_2 fertilization effect which is considered by DSSAT in these assessments. The APSIM version that we have used in this assessment is insensitive to changes in CO_2 concentration (refer to section 9.1). In addition to CO_2 effect, the models also differed in the way they simulated the effects of various production factors (Table 23). While both models produced comparable results for AEZs UM2 and LM5, APSIM yields are higher by about 800 kg for AEZs UM3 and LM3 and lower by about 500 kg for LM4. The models differed in simulating the performance of different varieties. APSIM simulated yields for extensively grown local variety Katumani are much higher than those by DSSAT. Both models simulated a decline in yield with delayed planting. However, the yields by APSIM are higher for early and normal planting and the decline in yield with delayed planting is also higher compared to DSSAT. Though, both models simulated higher yields with increasing plant population, APSIM response to increased plant population is much higher than that by DSSAT. Most significant difference between the models is in simulating the response to fertilizers. Under no fertilizer, DSSAT simulated yields are double to those by APSIM. Also, APSIM simulations showed higher response to small amounts of fertilizers. Under all conditions, the response to changes in climatic conditions is very small in case of APSIM while DSSAT simulations showed a response that ranged from 100-600 kg/ha.

Table 23: Differences in APSIM and DSSAT simulated yields under baseline and climate change scenarios in response to various production factors

Type of variable	Variable	Grain Yield (Kg/ha)			
		DSSAT		APSIM	
	Climate	Baseline	AOGCMs	Baseline	AOGCMs
Agro-ecological zone	UM2	2201.5	2555.2	2195.9	2295.9
	UM3	2056.8	2675.5	2866.0	2829.0
	LM3	1549.4	2160.3	2476.9	2455.1
	LM4	1549.8	1702.7	1020.4	1016.9
	LM5	708.3	895.0	763.5	712.1
Variety	Katumani	1224.2	1512.2	2120.8	2140.5
	Deka_lb	1959.3	2409.6	2461.9	2502.7
	H_511	1696.3	2154.7	1965.5	2031.2
	H_513	1949.1	2422.3	1353.0	1270.1
Planting	Early	1846.4	2420.4	2287.7	2276.6
	Normal	1396.0	1689.5	1610.0	1609.1
	Late	1279.0	1387.8	1163.0	1211.1
Plant population (plants/ha)	30,000	1664.7	1829.6	1535.2	1534.6
	40,000	1786.4	1991.7	2219.8	2209.5
	50,000	1833.8	2044.7	2618.3	2608.9
Fertilizer (kg/ha)	0	1059.4	1246.1	450.5	590.8
	20	1563.1	1704.0	1246.8	1283.5

	40	1828.6	1961.5	1953.8	1917.2
	80	2034.6	2241.8	2914.3	2806.7

Further analysis of results have clearly indicated a significant relationship between simulated maize yield and rainfall, maximum and minimum temperatures, evapotranspiration and crop duration in all countries. In the water limiting AEZs of LM4 and LM5 in Kenya, maize yields increased linearly with increase in seasonal rainfall up to 700 mm (Figure 37a). Further increase in seasonal rainfall has no effect. Maize yields also showed a linear relationship with increase in seasonal maximum temperature between 25 and 30^{0}C (Figure 37b) and minimum temperature between 14 and 19^{0}C (Figure 37c). Increased temperatures lead to faster growth and reduced duration of the crop which showed a negative impact on the total biomass produced. The biomass yields declined linearly as the duration of the crop increased from 100-130 days (Figure 37d).



a

b

c

d

Figure 37**:** Crop and climate interactions, a: between rainfall and DSSAT simulated maize yields in LM4, b: maximum temperature and yields in LM3, c: minimum temperature and maize yields in LM 5 and d: biomass yield and crop duration in UM2 and UM3

The impact of climate change on performance of maize was also influenced by the management practices adopted by farmers such as crop variety used, planting time, plant population and amount of fertilizer applied and these effects varied from one AEZ to the other. Local variety Katumani which is widely used by the farmers in the study area is most vulnerable to projected changes in future climate (Figure 38). Both APSIM and DSSAT simulations clearly indicate that the variety Katumani is more vulnerable to climate change and more so during LR season. Katumani is a short duration variety and further reduction in the growing period has adversely affected its performance. In addition, it is a drought tolerant variety and hence did not respond to the projected increase in rainfall.

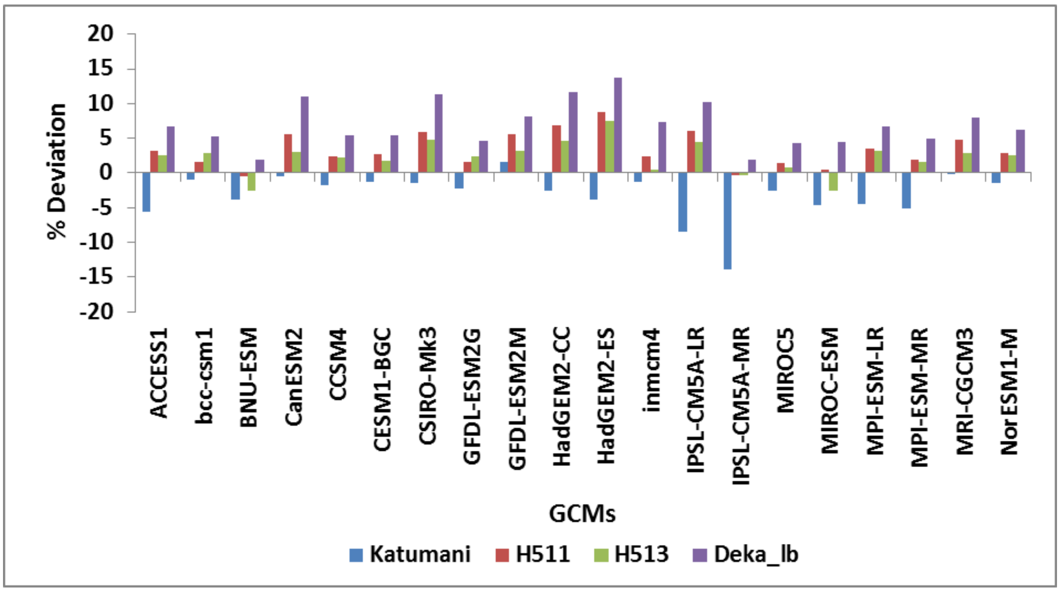


Figure 38: Impact of climate change on crop varieties cultivated in Embu county of Kenya

Farmers using low input production systems were found to be less affected due to changing climate compared to farmers with high input systems. Adverse impacts of climate change were also observed in the case of farmers planting late and using low plant population. Use of higher plant population seems to be an important option in adapting to climate change in the study area since it is able to compensate the impacts of reduced crop duration and capitalize on the increased moisture availability.

6.2 Economic impacts of climate change:

In order to examine the sensitivity of the current production system to climate change, potential impacts of climate change were evaluated on net farm returns, per capita income and poverty using economic model TOA-MD. To assess the sensitivity system to climate change we considered two systems:

- System 1 = current climate-current technology
- System 2 = future climate-current technology

This implies that the current production system under current climate and current technology (system 1) is shocked with climate change (system 2) to determine how it responds to such a shock. Technology has been held constant but we introduced future climate into this system. Climate change in this case includes a combination of rainfall and climate loadings.

Based on results from maize simulation, historical data and expert opinion, we made some assumptions on expected changes in crops which have not been simulated. For instance in Kenya with climate change, beans production is expected to increase by 10% in UM2, UM3, LM3 and LM4, but decline by 20% in LM5. Coffee is grown in UM2 and UM3, both of which gain from climate change, hence its production is expected to go up by 20% in both AEZs. Pigeon pea and sorghum are drought tolerant crops grown in marginal areas and are not expected to be adversely affected by climate change. In fact, the increment in rainfall and temperature simultaneously in the region is expected to boost production of these crops by 40% and 20% in LM4 and LM5 respectively. Dairy production is also expected to increase by 20%. Output prices—both for crops and dairy--were also held constant, but production costs are expected to change as production changes. Other household characteristics such as farm size, herd size, non-agricultural income, etc. are assumed to remain constant. Any change between the two systems is therefore purely the effect of climate on the current system.

Tables 24 and 25 illustrates the maize simulated yields with APSIM and DSSAT for the 5 GCMS (CCSM4, GFDL-ESM2M, HadGEM2-ES, MIROC-5 and MPI-ESM-MR). It is expected that introduction of climate change in the current system will cause varied responses to maize sub-system and even the other sub-systems based on the different GCMs. The mean for all GCMs according to APSIM model indicate gains in UM2 and UM3 and LM3 and losses in LM4 and LM5 (Table 24). In case of Tanzania and Uganda losses are expected in all AEZs. Note that this simulation only illustrates how maize responds to climate change. On average, DSSAT model indicates that all AEZs in Ethiopia and Kenya will gain from climate change (Table 25), but the gains will be lower in LM4 and LM5 compared to other AEZs in Kenya and in all AEZs in Ethiopia. In case of Tanzania a general reduction is simulated, but the magnitude of this reduction is lower compared to APSIM simulated yields.

Table 25: APSIM Simulated and observed maize yields in different AEZs

AEZ	**Observed mean maize yield (Kg/ha)**	**Scenario 1: Sensitivity of current agricultural production systems**					**Mean**
		APSIM Time averaged Relative yield (%)					
		CCSM4	**GFDL**	**HadGEM_2ES**	**MIROC-5**	**MPI_ESM_MR**	
Ethiopia							
SA2	445.08	8.37	8.76	11.20	4.36	11.38	8.814
SM2	379.41	7.07	5.40	8.86	-0.23	7.95	5.81
SM3	544.20	6.16	6.44	11.21	6.54	8.41	7.752
Kenya							
UM2	2191.20	-4.70	12.10	3.29	16.58	5.01	6.456
UM3	2273.20	-2.10	34.88	-0.08	38.58	-3.79	13.498
LM3	1830.48	2.17	31.99	1.98	51.33	0.34	17.562
LM4	1675.40	-29.81	-2.23	-3.38	12.25	-1.00	-4.834
LM5	877.04	-25.14	13.08	-19.95	27.05	-23.38	-5.668
Tanzania							
LH1	987.72	-19.0	-16.0	-40.0	-21.0	-30.0	-26.75
LH2	891.90	-17.0	-21.0	-43.0	-20.0	-25.0	-25.2
Agg	939.81	-18.0	-14.0	-42.0	-20.0	-27.0	-24.2

Uganda							
ACRIC	1613.09	-11.24	-12	-16.05	-11.56	-13.14	-12.79
DYSTRIC	2203.72	-15.94	-13.6	-17.79	-13.20	-12.62	-14.63
PETRIC	1783.16	-5.31	-5.42	-6.98	-3.38	-4.64	-5.15
Agg	1893.98	-12.13	-11.30	-14.78	-10.41	-10.35	-11.79

Table 25**:** DSSAT Simulated and observed maize yields in different AEZs

AEZ	**Observed mean maize yield (Kg/ha)**	**Scenario 1: Sensitivity of current agricultural production systems**					**Mean**
		DSSAT Time averaged Relative yield (%)					
		CCSM4	**GFDL**	**HadGEM_2ES**	**MIROC-5**	**MPI_ESM_MR**	
Ethiopia							
SA2	445.08	3.0	4.0	4.0	1.0	-3.0	**1.8**
SM2	379.41	13.0	8.0	14.0	11.0	-6.0	**8.0**
SM3	544.20	1.0	4.0	3.0	1.0	6.0	**3.0**
Kenya							
UM2	2191.20	12.10	3.29	16.58	5.01	6.77	8.75
UM3	2273.20	34.88	-0.08	38.58	-3.79	26.88	19.294
LM3	1830.48	31.99	1.98	51.33	0.34	63.16	29.76
LM4	1675.40	-2.23	-3.38	12.25	-1.00	30.28	7.184
LM5	877.04	13.08	-19.95	27.05	-23.38	26.93	4.746
Tanzania							
ZONE1	987.72	-5.0	-6.0	-10.0	-6.0	-1.0	-5.6
ZONE 2	891.90	-2.0	-8.0	-5.0	-1.0	-3.0	-3.8
AGG	939.81	-3.0	-7.0	-7.0	-3.0	-6.0	-5.2
Uganda							
ACRIC	1613.09	-13.70	-8.32	-16.59	-9.01	-17.14	-12.95
DYSTRIC	2203.72	-18.01	15.58	10.79	15.48	7.86	-5.85
PETRIC	1783.16	-31.30	3.00	-4.66	0.85	-4.30	-17.21
Agg	1893.98	-20.42	4.31	-2.42	3.44	-3.64	-11.30

If the current production system in the target locations is subjected to climate change, all GCMs show number of losers is varied but are comparable in both models (Table 26). As expected, the number of losers is much higher in Tanzania and Ugandan locations compared to Kenyan and Ethiopian locations.

Table 26**:** Losers from climate change in scenario 1

AEZ	**APSIM**					**DSSAT**				
	CCSM4	**GFDL**	**HadGEM_2ES**	**MIROC-5**	**MPI-ESM**	**CCSM4**	**GFDL**	**HadGEM_2ES**	**MIROC-5**	**MPI-ESM**
Ethiopia										
WO	23.30	23.13	22.35	24.87	23.30	25.98	26.1	25.16	26.94	28.83
MK	33.85	34.46	33.23	36.59	33.85	32.34	33.40	31.83	32.62	38.86
ME	26.32	26.24	24.71	26.11	26.32	28.48	27.65	27.92	28.50	26.55
Agg	26.49	26.55	25.61	28.33	26.49	27.93	27.21	27.72	28.66	31.67

Kenya										
UM2	30.14	27.36	26.76	27.10	27.67	25.43	24.23	26.78	28.13	23.09
UM3	27.40	25.21	28.91	25.40	28.36	14.14	13.10	15.89	16.88	14.05
LM3	22.06	23.03	23.39	22.67	23.31	17.37	15.62	14.97	19.85	16.19
LM4	36.02	12.41	10.77	19.60	18.29	21.13	17.71	13.68	24.45	18.73
LM5	29.63	24.17	30.41	25.95	30.72	18.89	15.81	20.53	28.46	17.21
Agg	30.81	20.57	23.59	23.70	26.05	19.38	16.45	17.86	25.94	17.58
Tanzania										
ZONE 1	53.57	53.36	55.48	53.93	56.03	65.29	62.25	69.86	65.86	68.46
ZONE 2	54.16	62.58	56.53	51.76	55.28	76.89	79.55	89.88	78.06	82.52
Agg	53.78	56.65	55.86	53.16	55.76	69.44	68.43	77.02	70.22	73.49
Uganda										
ACRIC	52.95	53.28	54.66	52.88	53.49	53.68	51.23	54.61	51.77	55.10
DYSTRIC	50.49	49.19	51.40	49.08	50.17	55.82	42.51	43.51	42.57	44.23
PETRIC	49.61	49.63	50.43	48.83	49.41	62.45	51.57	54.43	52.08	54.29
Agg	51.04	50.55	52.18	50.19	51.01	56.69	47.28	49.44	47.59	49.90

Climate change is expected to increase net farm returns in Kenya and Tanzania as can be seen by comparison between net returns with and without climate change for the different GCMs. In some GCMs and in Tanzania, we recorded decline in maize production, and the positive incomes could be explained by increases in returns from other crops (coffee, beans, pigeon peas and sorghum), which are expected to increase in yields due to climate change. The gains in net returns are highest in UM3 and LM3 and least in LM5. This is true both for APSIM and DSSAT (Figure 39). The observed net farm returns are are highest in LM3, UM3 and LM4, and least in LM5. With climate change, these returns increase as indicated in

Figure 39 for DSSAT and APSIM, depending on the GCM. The increments range from Ksh. 4,900 ($57) to Ksh. 21,000 ($246) per annum for APSIM, and from Ksh. 7,500 ($88) to 46,500 ($547) per annum for DSSAT. In case of Ethiopia they are in the range of EBr 2,236 ($ 115) to EBtr 4,521 ($ 232) with highest gains in SM2 under HadGEM_2ES projections. In case of Tanzania net returns declined by about $100 in all AEZs with DSSAT while the change is negligible with APSIM. Similar trends were also observed in case of Uganda, except under DYSTRIC soil scenario and the reduction in net returns is higher with yields simulated by APSIM under all GCMs.

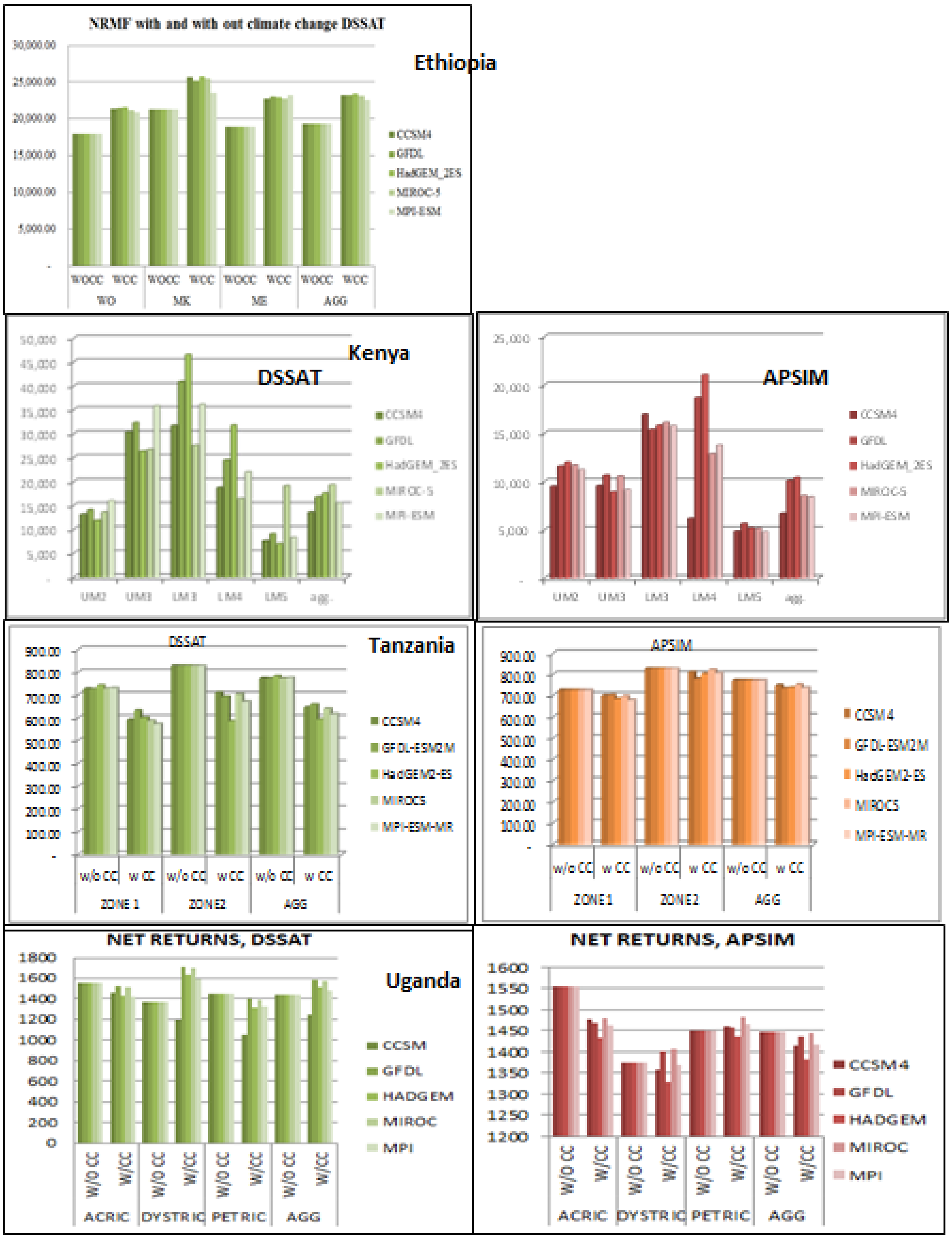


Figure 39: Net return changes with climate change (DSSAT on left and APSIM on right). The units are EBr for Ethiopia, KSh for Kenya and USD for Tanzanian and Uganda

Furthermore, the sensitivity of per capita income to climate change is calculated by taking the difference in per capita income with and without climate change. Figure 40 shows that climate change will lead to an increase in per capita income at varying degrees depending on the GCMs. Thye changes in per capita income in Ethiopia is generally in the range of 15% except for GCM MPI-ESM which showed lower increases in all AEZs. In Kenya, the changes in per capita income range from Ksh 804

(USD 9.5) to over Ksh 3798 (USD 44.7) per annum based on APSIM simulations, and from Ksh. 1163 (USD 13.7) to over 7619 (USD 89.6) per annum as per DSSAT estimations. In Tanzania and Uganda they are less than the observed incomes.

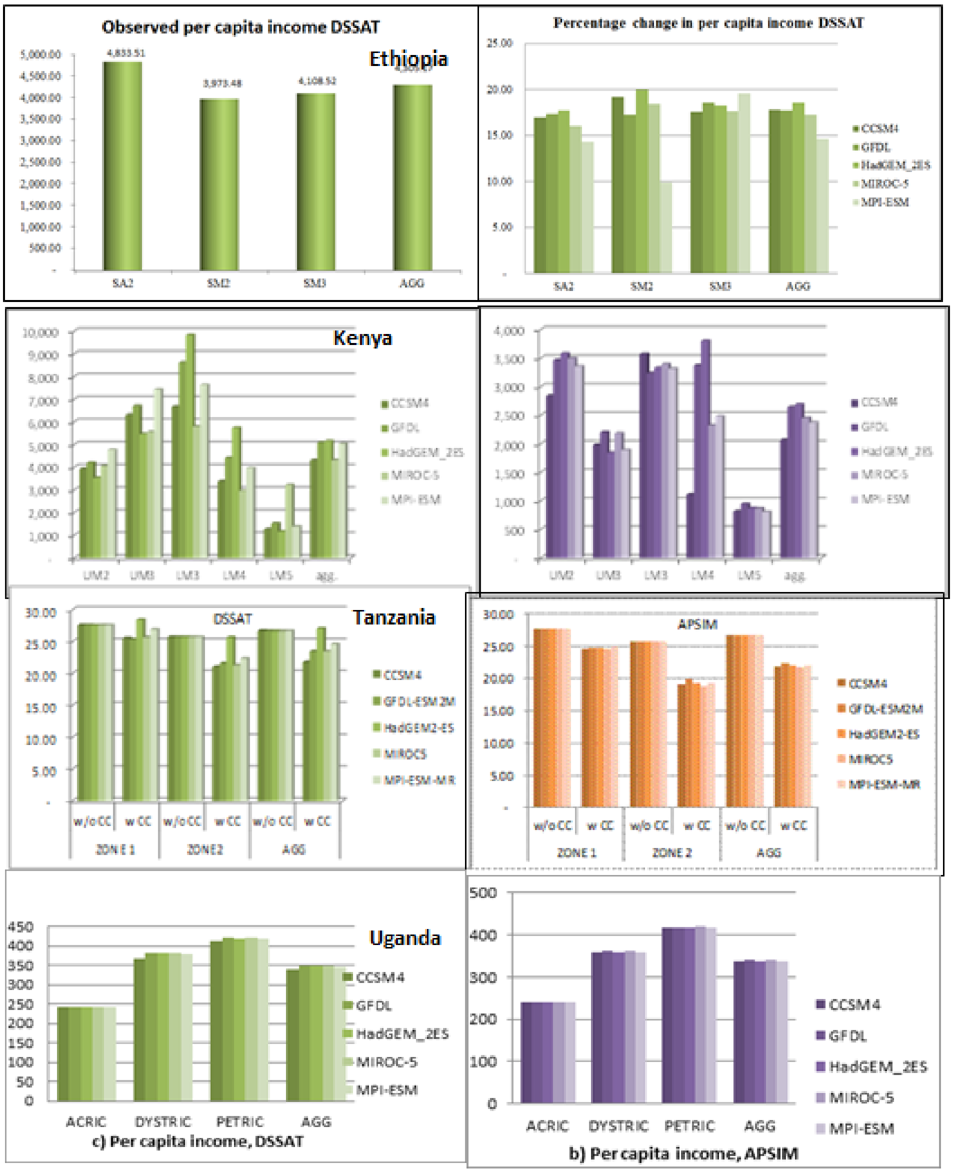


Figure 40: *Change in per capita income with climate change scenario 1 (DSSAT on left and APSIM on right)*

Another important indicator of farmers' welfare is the poverty level. In Ethiopia the observed poverty rates varied from 39.15% in SA2 to 47.57 in SM2 agro-ecologies. These are rates are projected to decline by up to 16% with climate change. The decline is high in SA2 compared to SM2 and SM3. Among the GCMs, the least decline is expected with the climate projected by MPI-ESM and highest decline under the climate projected by HadGEM-2ES. In Kenya, the observed poverty rates range from 33.5% in UM2 to 64.51% in LM5. With climate change, the change in poverty levels indicates that poverty will decline in all AEZ for all GCMs based on both models. However, the levels do vary as seen from AEZs. The highest reduction in poverty rate is in UM3, where APSIM records declines of over 3.3% in all GCMs, while DSSAT records declines of over 9.6% in all GCMs (Figure 41). The least reduction in poverty rates were recorded in LM5 in both APSIM and DSSAT, with minimal declines of 1.44% (APSIM) and 2.1% according to DSSAT. Overall, the mean reduction in poverty rate in all the AEZs with climate change is 2.6% (APSIM) and 5.3% (DSSAT). In Kenya and Tanzania poverty rates are projected to increase under climate change. Current poverty rates in Tanzania are very high ranging from 60-80% in different livelihood zones. Highest poverty rates were observed in case of Zone 2. These rates will increase by up to 10% under climate change. Higher increase will be occurring in Zone 1 compared to Zone 2. The increase is similar under all the 5 GCMs but higher with DSSAT simulated maize yields. In Uganda, poverty rates varied from 47.8 in PETRIC to 66.64 in ACRIC zones. These are expected to increase further under climate change. Highest increase will occur in ACRIC zone where poverty rates are expected to increase by up to 16%. The lowest increase is observed with PETRIC zone where the projected increase is about 8%. No major differences were observed in the projections by different GCMs. Both DSSAT and APSIM results indicate similar increases. The difference between APSIM and DSSAT projections is about 1-2% in different agro-ecologies.

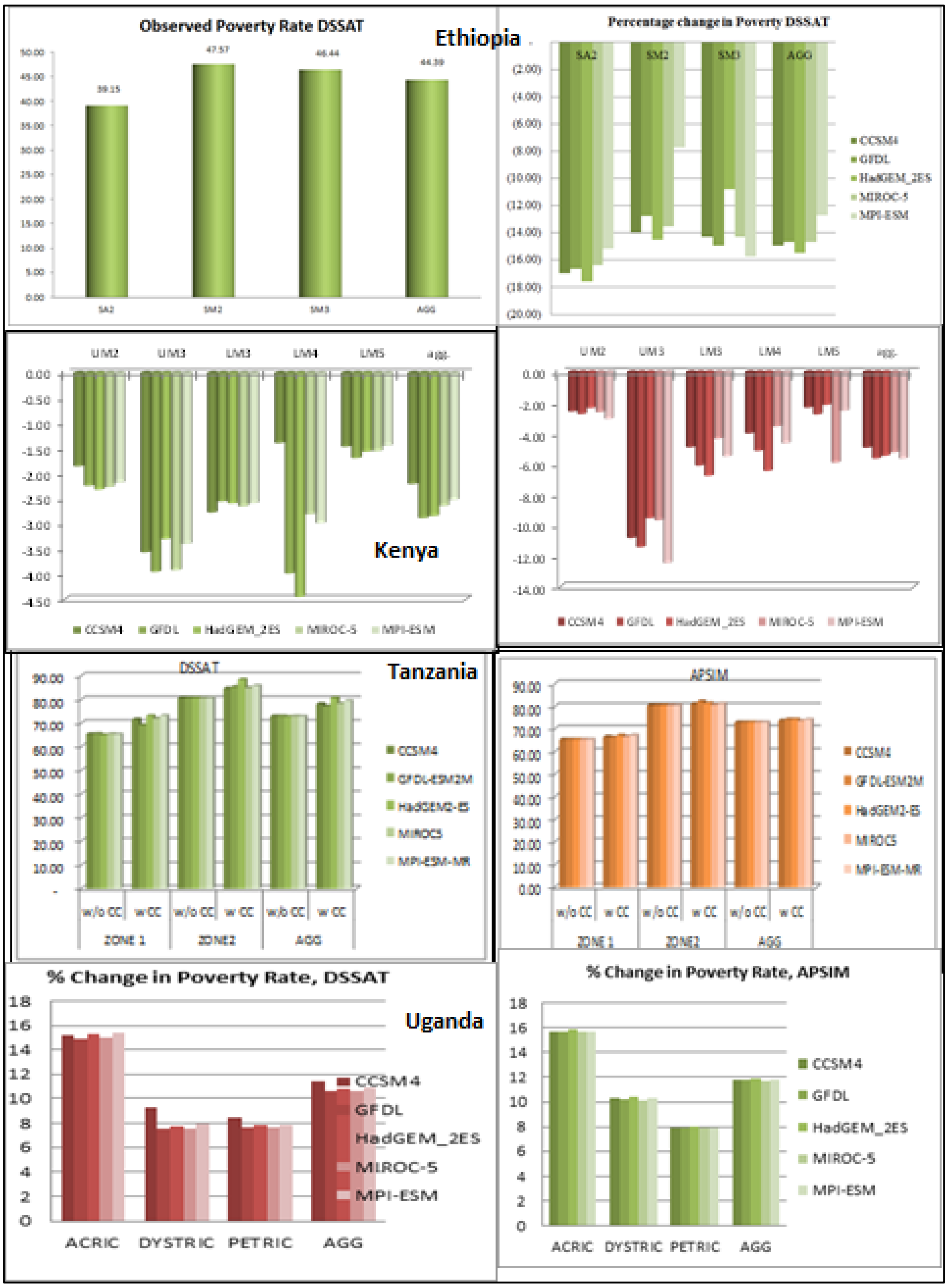


Figure 41: Percent decline in Poverty levels (a: APSIM and b: DSSAT)

6.3 Benefits of climate change adaptations

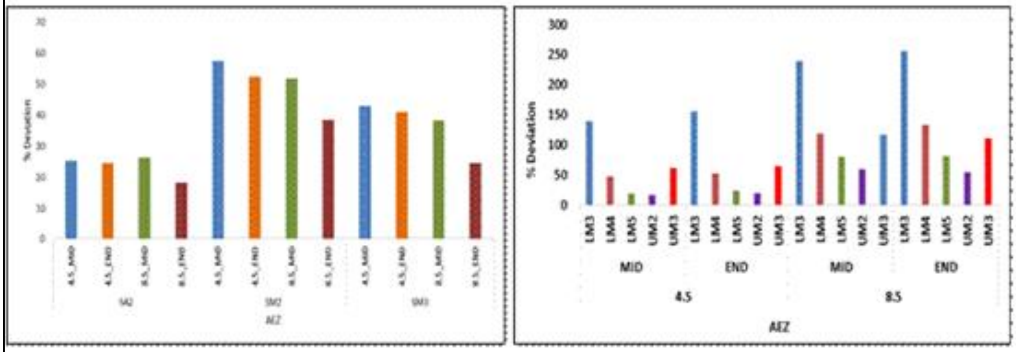
Strong trends in climate change showed increasing scale of potential climate impacts on local crop varieties and crop management practices in the study area. Potential adaptation options vary with the scale of projected impacts. Since, maize crop yields are marginally increasing or decreasing in the future projected climate change scenario, we show the implementation of better performing crop varieties with best crop management practices can cope with harsh and highly variable climate. Developing adaptation measures based on the best performing crop variety, crop management practices and suitable planting date is likely to have substantial benefits under moderate climate change scenarios.

Adaptation planning incorporates scientific information both from projections of climate and its impacts on crop productivity. There is a high diversity of agricultural practices in the study region because of the range of climate and other environmental variables and economic factors. Here we present a framework of adaption options based on the performance of crop varieties, crop management practices and planting window in the study areas. From the above crop simulation results it is evident that both the crop models APSIM and DSSAT show marginal changes in maize crop yields in the future projected climate changes scenarios. Local crop varieties with current management practices showed decreased crop yields, based on the above analysis the better performing crop varieties along with sustainable crop management practices were picked as shown in Table 27.

Table 27: Identified maize varieties and corresponding crop management practices for adaptation under climate change in different countries.

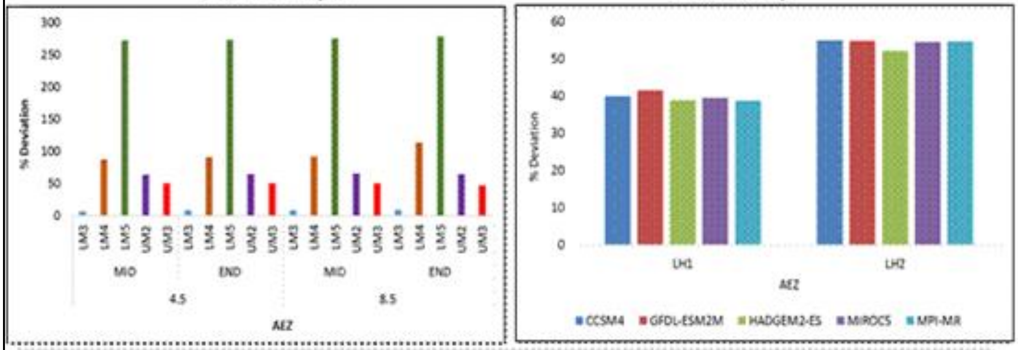
AEZ	**Adaptation strategy for LR season**				**Adaptation strategy for SR season**			
	Planting Time	**Plant pop.**	**Variety**	**Fertilizer**	**Planting Time**	**Variety**	**Plant Pop.**	**Fertilizer**
				Ethiopia				
SA2	Late	44	Melkassa2	50	No second season			
SM2	Normal	44	Melkassa2	50				
SM3	Early	53	Melkassa2	50				
				Kenya				
LM3	15-30 Mar	50	H513	60	1-15 Oct	Deka_lb	50	80
LM4	15-30 Mar	50	Deka_lb	60	15-30 Oct	H511	50	70
LM5	15-30 Mar	50	H511	60	1-15 Nov	Deka_lb	40	60
UM2	15-30 Mar	50	H513	80	1-15 Nov	H511	40	70
UM3	15-30 Mar	50	H513	70	1-15 Oct	H513	40	60
				Tanzania				
LH1 and 2	Late	40	Kilima	60	No second season			
				Uganda				
Masindi	Normal	50	Longe9	40	Late	Longe9	40	50
Kyangwe	Normal	50	Longe9	40	Late	Longe9	40	50

Simulation analysis was carried out with both APSIM and DSSAT with identified management strategies and selected varieties using baseline and the downscaled CMIP5 AOGCMs future climate projections. DSSAT simulated maize yields with adapted technology show that crop yields are significantly increasing across all AEZs under both 4.5 and 8.5 RCPs and in all countries (Figure 42 and Table 28). Increase in crop yields is comparatively high under RCP 8.5 in case of Kenya and RCP 4.5 in case of Ethiopia. Even though projected atmospheric temperatures are higher than 4.5 RCP, maize crop yields are considerably increasing in 8.5 RCP in Kenya because of current low temperatures in that location. With adaptation, yields in the AEZ LM5 in Kenya recorded the highest increase. This is one of the low potential environment



DSSAT-Ethiopia

DSSAT-Kenya



APSIM-Kenya

APSIM-Tanzania

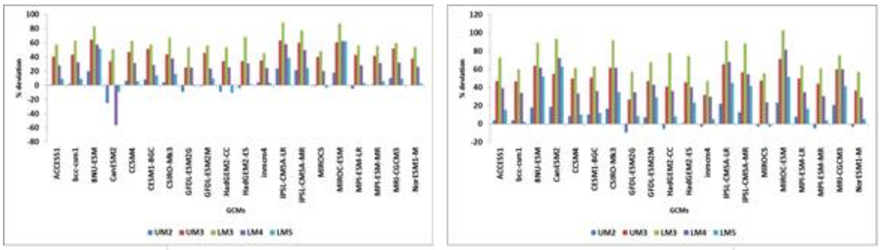
Figure 42: Projected response to adaptation by DSSAT and APSIM in different countries.

Table 28: Simulated maize yields under current climate with current management and future climate with adaptation. Adaptation is average of all GCMs for RCP 8.5 mid-century period

		DSSAT			APSIM		
Country	**AEZ**	**Baseline**	**Adapted**	**%Dev**	**Baseline**	**Adapted**	**%Dev**
Kenya	UM2	2215.9	3324.6	50.0	2195.9	3606.9	64.3
	UM3	2010.5	4101.6	104.0	2866.0	4273.4	49.1
	LM3	1556.1	4426.5	184.5	2476.9	2690.1	8.6
	LM4	1556.8	3066.1	97.0	1020.4	1954.6	91.5
	LM5	712.6	1948.3	173.4	763.5	2875.2	276.6
Ethiopia	SA2	2752.1	3191.6	16.0	2349.4	4008.7	70.6

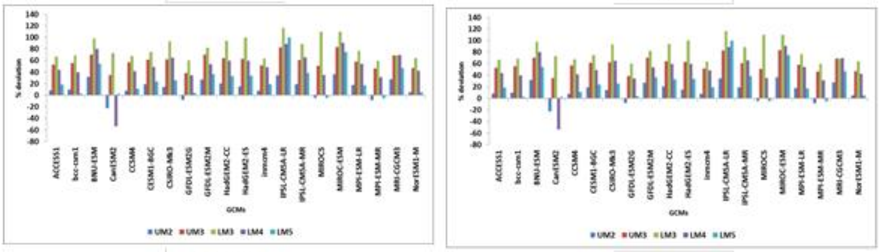
	SM2	2319.5	3177.8	37.0	1955.7	4044.3	106.8
	SM3	2242.2	2986.0	33.2	1746.7	4194.2	140.1
Tanzania	LH1	1507.64	2422.42	60.7	1371.1	2273.5	65.8
	LH2	1552.53	2262.07	45.7	1401.6	3063.2	118.5
Uganda	ACRIC	2295.2	5727.1	149.5	2543.4	4440.3	74.6
	DYSTRIC	2185.0	6033.9	176.1	1586.1	3195.4	101.5
	PETRIC	1287.4	5659.3	339.6	1708.9	3304.7	93.4

This increase is observed across all the GCMs. Detailed analysis of Kenya results indicate that yields with adaptation are low for only one GCM in one of the AEZ. Maize crop yields were decreasing in AEZ LM4 in both 4.5 MID and 8.5 MID projected climate by global climate model CanESM2. This GCM predicts that maximum and minimum temperatures are increasing by 3.5 and 4.2 °C and 4.0 and 4.8 °C respectively and precipitation amounts during the cropping season are decreasing in both 4.5 MID and 8.5 MID RCP by -12 % and -7% This decline in rainfall is mainly responsible for low yields under adaptation in LM4 as displayed in Figure 43.



4.5 MID

4.5 END



8.5 MID

8.5 END

Figure 43: DSSAT projected changes in maize crop yields for two RCPs and time periods in Embu County

Using TOA-MD, impact of these adaptations to climate change on the indicators of per capita income, net farm returns and poverty were assessed. The assessment also determined the percentage of farmers in each AEZ who gain from climate change adaptations. This scenario compares a future climate with future technology against a future climate-future technology with adaptations i.e.

- System 1 = Future climate-future technology with RAPs and Trends
- System 2 = future climate-future technology with Adaptation, RAPs and Trends

Here we present a detailed analysis of Kenya case. In other countries very similar results were observed, the adaptation package described above involves higher utilization of fertilizer and higher seeding rates both of which imply increases cost of production to the farmer. For this reason, the total variable cost of production was increased by 10%. All the other variables in the other sub-systems were held constant. From Tables 29 and 30, adaptation to climate change is expected to increase maize yields in all AEZs, with LM5 gaining the most from adaptations. APSIM simulations show that this adaptation strategy will increase projected maize yields by between 10% (LM3) and 219% (LM5). DSSAT simulations indicate that this adaptation strategy will rise yields by between 58% (UM2) and 253% (LM5). This is an indication that farmers from LM5 will gain most from adaptation to climate change.

Table 29: APSIM Projected maize yields in different AEZs

AEZ	Projected mean maize yield (Kg/ha)	Scenario 3: Benefits of climate change adaptation					Mean
		APSIM Time averaged Relative yield (%)					
		CCSM4	GFDL	HadGEM_2ES	MIROC-5	MPI_ESM_MR	
UM2	2815.00	59.08	57.30	66.18	58.71	53.67	58.99
UM3	2938.50	49.13	47.72	48.44	49.38	46.95	48.32
LM3	2806.50	10.10	8.73	10.20	9.14	9.19	9.47
LM4	2218.50	62.85	88.17	86.38	48.35	58.98	68.94
LM5	1060.85	194.43	219.16	213.15	183.74	190.53	200.20

Table 30: DSSAT Projected maize yields in different AEZs

AEZ	Projected mean maize yield (Kg/ha)	Scenario 3: Benefits of climate change adaptation					Mean
		DSSAT Time averaged Relative yield (%)					
		CCSM4	GFDL	HadGEM_2ES	MIROC-5	MPI_ESM_MR	
Ethiopia							
SA2	600.85	121.99	122.40	122.40	121.75	130.19	124,19
SM2	783.68	174.05	172.29	172.29	161.47	172.57	170.53
SM3	764.06	268.94	265.34	265.34	268.55	260.03	265.64
Kenya							
UM2	2815.00	57.66	76.67	69.20	89.57	69.64	72.55
UM3	2938.50	91.95	106.12	100.34	123.93	93.15	103.10
LM3	2806.50	84.47	104.39	113.90	136.32	96.77	107.17
LM4	2218.50	93.32	104.79	112.79	140.80	104.44	111.23
LM5	1060.85	141.17	185.78	182.69	253.54	160.89	184.81

We expect the high potential gains in yields to be matched by high percentages of adopters in all GCMs. APSIM projects the adopters of the adaptation package at between 52% and 72% depending on the GCM (Figure 44a), while DSSAT predicts adoption levels of between 66% and 76% also depending on the GCM (Figure 44b). These high adaptation levels are expected given the potential gains in maize yields of the adaptation package.

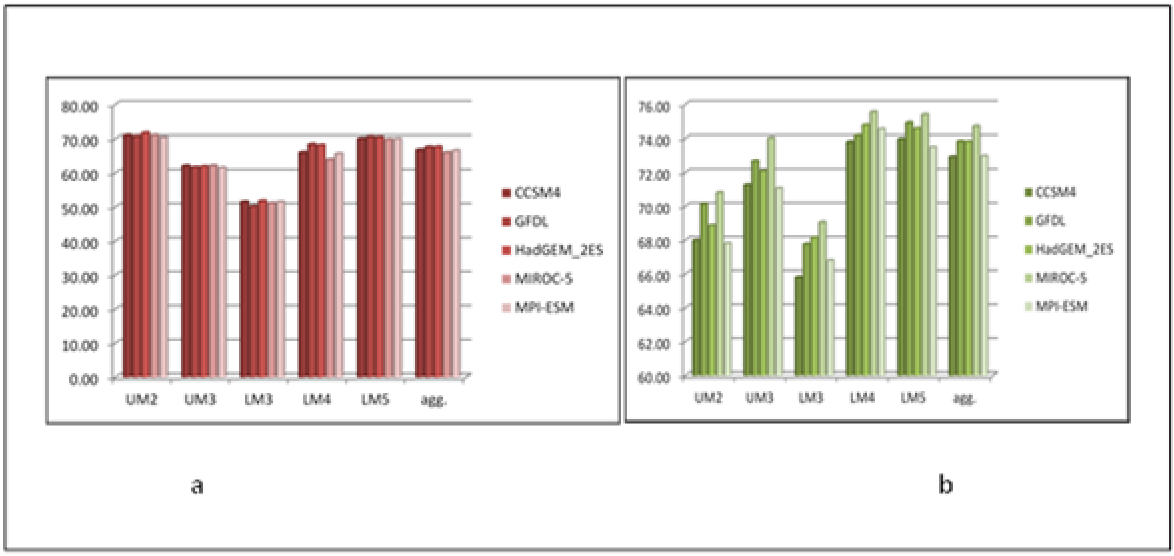


Figure 44: Adoption rates of the climate change adaptation package (%) scenario 3 (a: APSIM and b: DSSAT)

The indicator for net returns shows that there are substantial increases in net farm returns after the adoption of this package. This is evident in both DSSAT and APSIM simulations. APSIM results indicate that most of the gains in net farm returns will be in LM4 and LM5. Results from DSSAT indicate that the gains from adaptation will be mostly concentrated in UM3 to LM5 (Figure 45).

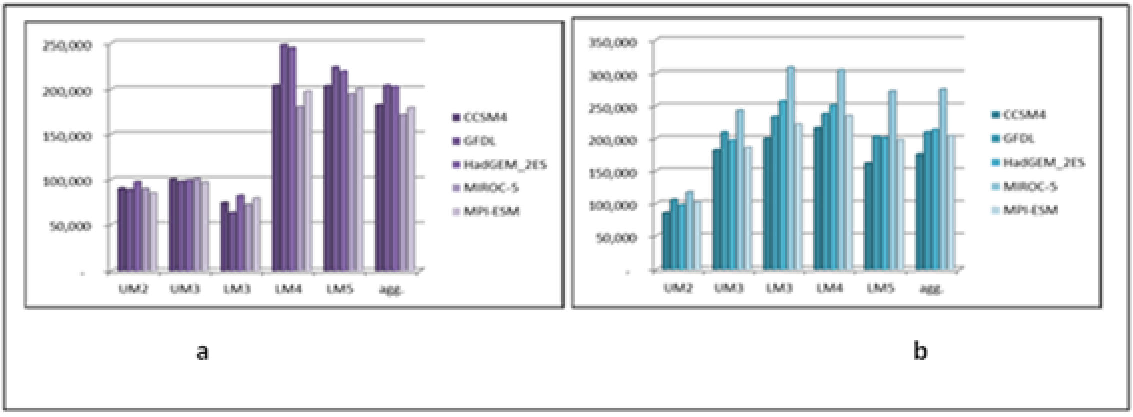


Figure 45: Changes in net farm returns scenario 3 (a: APSIM and b: DSSAT)

Per capita income indicator also increases with increase in the net farm returns. Adaptation is also expected to reduce the poverty rates. This is noticeable especially in LM5 where poverty levels declines are highest in both models (Figure 46). In this AEZ, adaptation to climate change decreases poverty by over 4% for all GCMs. This is an indication that adaptation to climate change is key especially for LM5.

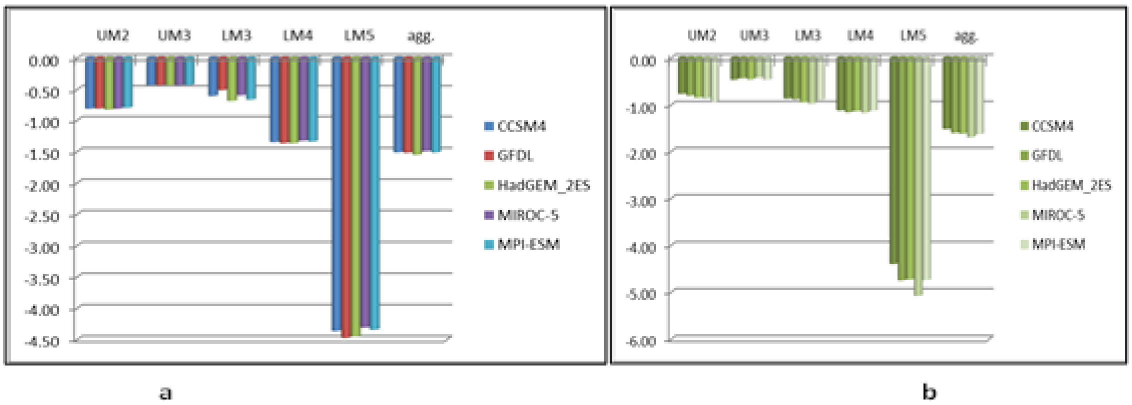


Figure 46: Change in Poverty rate with adaptation scenario 3 (a: APSIM, b: DSSAT)

7. Stakeholder engagement

From the beginning, the project has identified and engaged stakeholders while implementing various activities. The stakeholders that the project has engaged can be broadly grouped into three categories. These include policy and decision makers including the Climate Change Secretariats in the participating countries, research and developmental agents including meteorological departments that have interest in understanding the climate change impacts on smallholder agriculture and involved with developing and promoting adaptation strategies and students and others whose skills and understanding of climate impacts is crucial for continued research and development on an emerging topic like this which is highly dynamic and is subjected to rapid developments.

In Ethiopia, the organizations involved are Agricultural Transformation Agency (ATA) the main policy advisory arm of the Government of Ethiopia on issues related to agricultural research, Ethiopian Institute of Agricultural Research (EIAR), National Meteorological Agency (NMA), academic institutions including Mekelle University and Addis Ababa University and NGOs IDE and CARE. Fifteen MSc students were benefitted directly by the project (see ANNEX 2). These students used the protocols, methods and data developed by the project in their theses research and were benefitted by the training received in using the climate, crop and economic modelling tools. The country now has a core group of researchers with skills and capacities to undertake comprehensive assessment of climate change impacts on agricultural systems.

In Kenya, extensive efforts were made to engage stakeholders and conducted a stakeholder consultation meeting to present the approach and results used in this assessment. The stakeholder meeting was attended by a twenty seven people representing various government departments, NGOs, national and regional research institutions and donor agencies (see ANNEX 2). All the project staff received extensive training in the use of climate, crop and economic models and the training was followed by hands on work and refresher courses which ensured that the acquired skills are applied and confidence of the team members in use of these tools was enhanced. The program interacted with various regional bodies such as Association for Strengthening Agricultural Research in East and Central Africa (ASARECA) and East Africa office of CGIAR research Program on Climate Change Agriculture and Food Security (CCAFS). CCAFS Eastern Africa Program has supported some of the training and data collection efforts and closely associated with the implementation of research activities across all the four countries. The sites selected for this assessment are also benchmark locations for CCAFS research in the region. The project methods and results were presented in the conference organized by the Soil Science Society of Eastern Africa in Nakuru and NASA supported SERVIR program stakeholder workshop in Nairobi. The project methodology is also adopted by a project currently being implemented in Eastern Africa through WMO regional office in Nairobi with funding support from UNECA.

In Tanzania, the team interacted with a number of stakeholders mainly policy makers at the Ministry of Agriculture, Food Security and Cooperatives especially from the divisions of Environment that hosts the climate change secretariat, Food Security, Irrigation and Technical services and Land use planning, and Mechanization. The team actively participated in and contributed to various workshops including the international workshop on climate change held in Morogoro, Tanzania and presented the results from the assessment. AgMIP tools have been utilized by the graduate students (two PhD and 1 MSc) and their publications are under way. Undergraduate students doing BSc Irrigation Degree at Sokoine University of Agriculture, Morogor are being introduced to AgMIP tools. The country now has a team of researchers, three meteorologists, four crop modelers and four economic modelers who have received training under the project and also got an opportunity to apply the skills gained through project work. This team of researchers is using the project developed protocols in two other projects funded by IDRC and GIZ. The tools and methods were also integrated with relevant courses offered by Sokoine University in its Irrigation department.

In Uganda, the team members interacted with officials from key ministries including agriculture and environment which have the main responsibility of developing national adaptation plans and programs for the country. The team presented the research results in various meeting that are organized by Climate change unit (Uganda), IUCN-Uganda, African Crop Science Conference in Uganda (October, 2013), and WWF-D.R. Congo. The team is now planning a stakeholder consultation during the month of May, 2014 to present the results of the assessment and receive feedback. A total of 10 researchers and students were benefitted by the various formal and informal capacity building activities conducted by the project.

Currently, we are developing a data visualization tools (http://dmu.icrisat.ac.in/agmip.aspx) with which stakeholders can compare and assess the changes in climate and its impacts on crop performance and economic indicators. The economic component is still under development.

8. Data collected and shared

One of the significant outcomes of this project is the data collected. In most African countries availability of data is a major problem. There are no archiving systems in practice and the only source of data is the published reports. The teams made extensive efforts to collect the required data from various sources that included formal and informal publications and farmer surveys. All the data, except observed climatic data, collected and used in this assessment is uploaded and made available through AGMIP FTP site (ftp://data.agmip.org/). Due to restrictions imposed by the national meteorological agencies, access to observed climate data is restricted. Table 31 below summarizes the status of the data available at the AgMIP FTP site.

Table 31: Data available through AgMIP web site

Data type	**Country**	**Location**	**Variables**	**Comments**
Climate	Kenya	Embu	Precipitation, Tmax, Tmin and Solar radiation	Baseline data and CCSM4 8.5 END data are provided. All climate scenarios are available on request.
	Ethiopia	Melkassa	Precipitation, Tmax, Tmin and Solar radiation	
	Uganda	Masindi	Precipitation, Tmax, Tmin and Solar radiation	
Crop	Kenya	Embu	Crop cultivar coefficients, Farmers survey data, DSSAT seasonal files (*.SHX), Soil data	DSSAT files for 10 farmers for each location are uploaded. All other files are available on request.
	Ethiopia	Melkassa	Crop cultivar coefficients, Farmers survey data, DSSAT seasonal files (*.SHX), Soil data	
	Uganda	Masindi	Crop cultivar coefficients, Farmers survey data, DSSAT seasonal files (*.SHX), Soil data	
Economic	Kenya			Economic data is currently being compiled and will be uploaded soon
	Ethiopia			
	Uganda			

9. Additional Studies

During this assessment we have conducted a number of other studies to fully evaluate and confirm model simulations of the impact of important variables on the performance and growth of maize.

Among them are assessing the CO2 effect and evaluating climate change impacts on wheat are the important ones.

9.1 Carbon dioxide Effect

To assess the effect of atmospheric CO_2 concentration on growth and yields of maize, simulations were carried out with DSSAT with and without changing CO_2 under projected climates from all the 20 AOGCMs. In the without scenario, the atmospheric concentration of CO_2 was set to 380 ppm and in the with scenario it was set to 450 ppm for RCP 4.5 and 850 ppm for RCP 8.5 scenarios. Maize yields showed higher increase in the scenario in which CO_2 concentration was changed compared to the unchanged scenario. The increase is fairly small in UM2 and UM3 represented by Embu climate compared to other AEZs. The CO_2 effect on maize yields was found to be much higher in case of Ishiara and Kindaruma compared to Embu and Karuromo. In case of LM4 represented by Ishiara, maize yields declined without CO_2 effect (Figure 47 and Annex 14) but increased when CO_2 effect is included. The climate at Ishiara and Kindaruma sites is warmer by 2-3^{0}C compared to that in Embu and Karuromo and use of inputs such as fertilizer is very low.

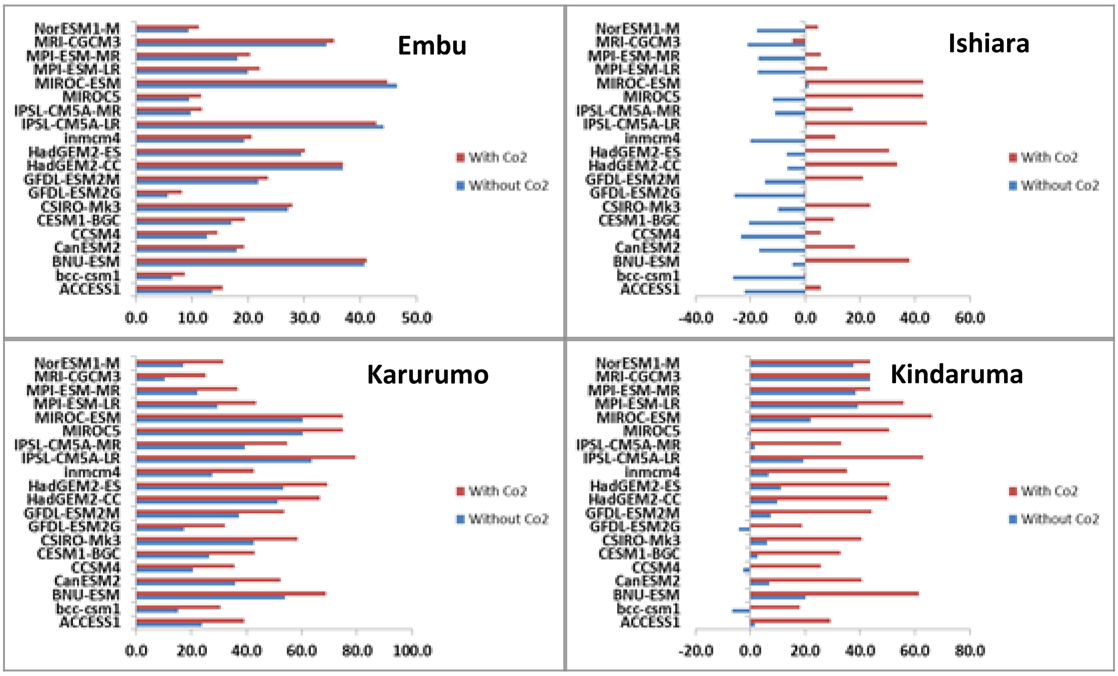


Figure 47: Comparison of projected changes in maize yields (percent deviation from baseline) with and without CO_2 fertilization effect under RCP 8.5 mid-century scenario

DSSAT simulated future maize crop yields for both the RCPs 4.5 and 8.5 and time periods MID and END century show that future maize crop yields are in general increasing across all the agro ecological zones except for LR season in LM4 (Figure 48). Though both the simulations (with and without CO_2)

followed similar trends across all the agro ecological zones, yields increased by about 20 % when elevated CO_2 concentrations are incorporated.

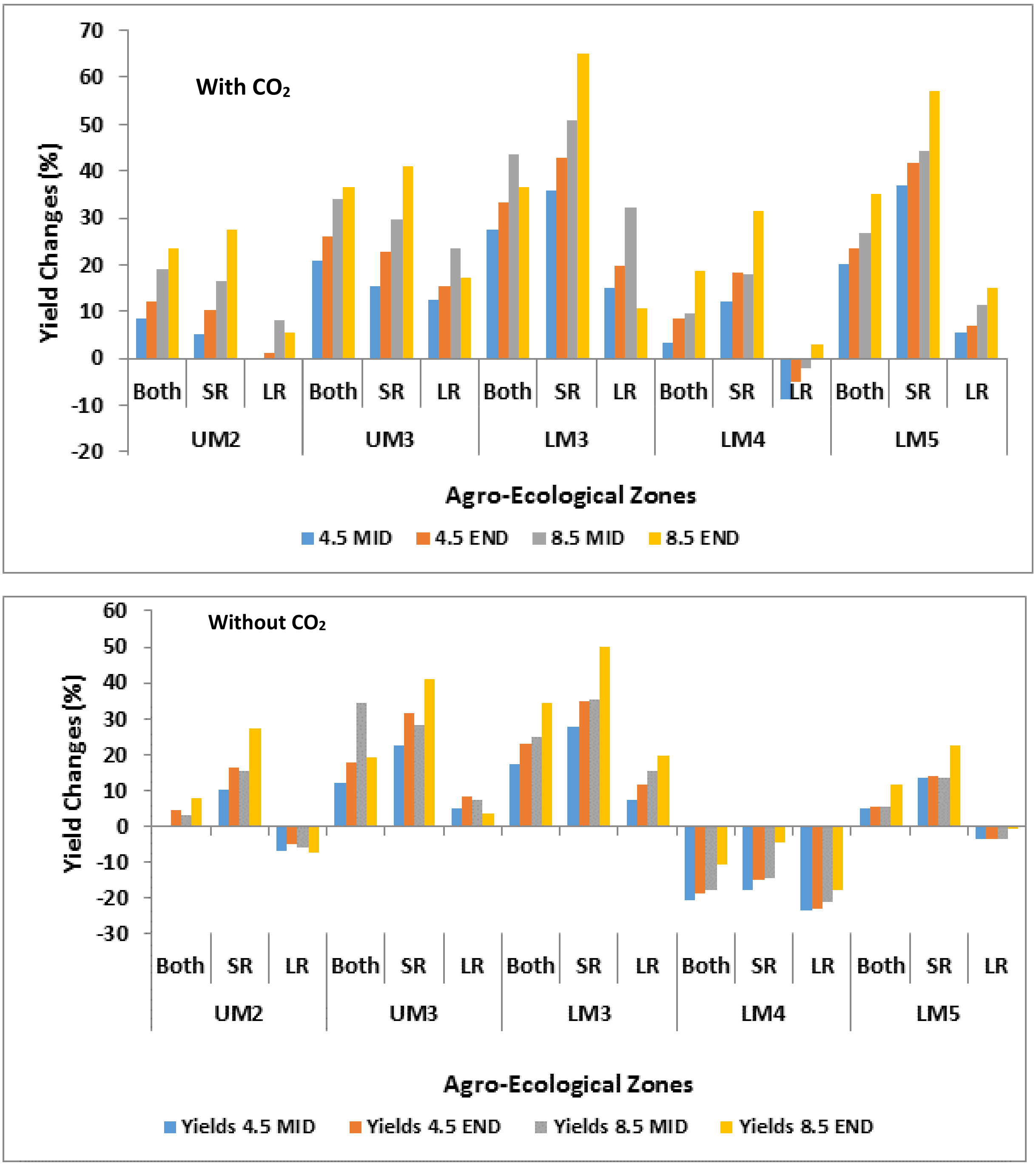
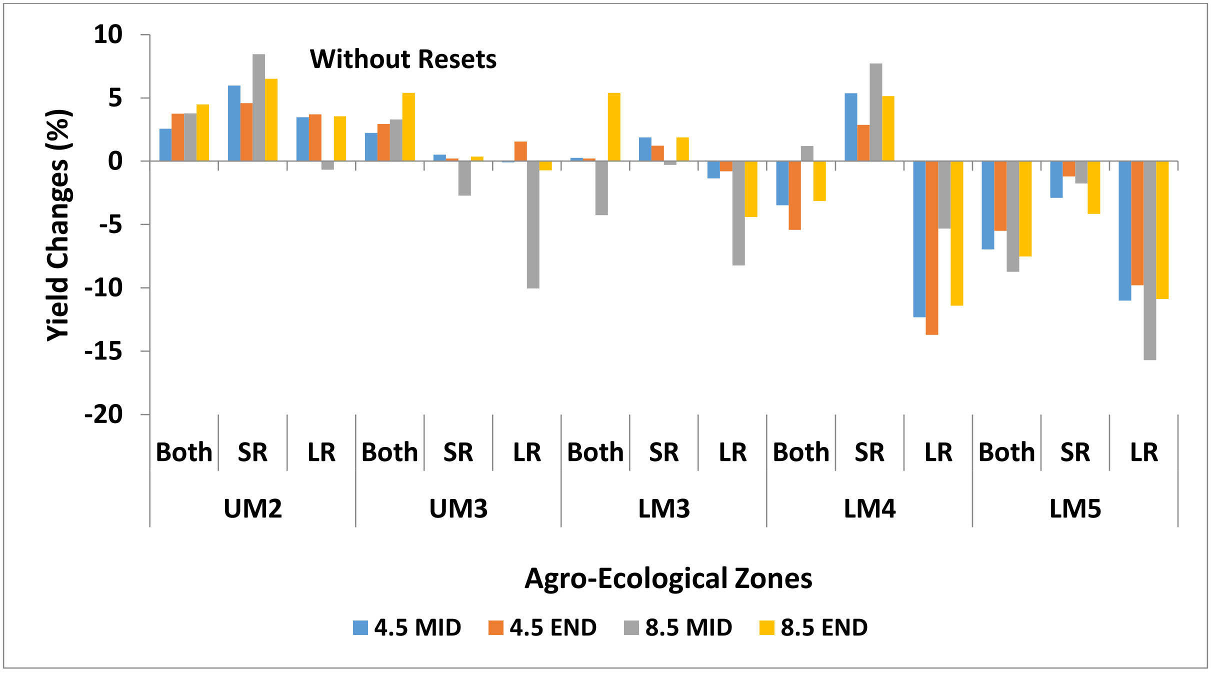


Figure 48: Changes in maize productivity under different agroecologies with and without changes in CO_2 concentration under different climate change scenarios

9.1 Effect of resetting initial conditions

In this assessment initial conditions defining soil water and nitrogen were reset one month before start of the simulations with APSIM and DSSAT every season. This was done to eliminate the carry over effects of moisture and soil fertility (nitrogen) and rundown in soil organic carbon on crop yields and measure effect of climate variability and change alone on crop performance. However, under low input systems the carry over effect of soil moisture and fertility can have significant effect on the performance of the crop in the following season. To assess this effect simulations were carried out with APSIM with and without resetting initial soil moisture and soil nitrogen. In the without scenario, initial conditions were set at the start of simulations in year 1 only. Figure 49 presents the changes in maize yields under both the scenarios while actual yields are summarized in Annex 15.



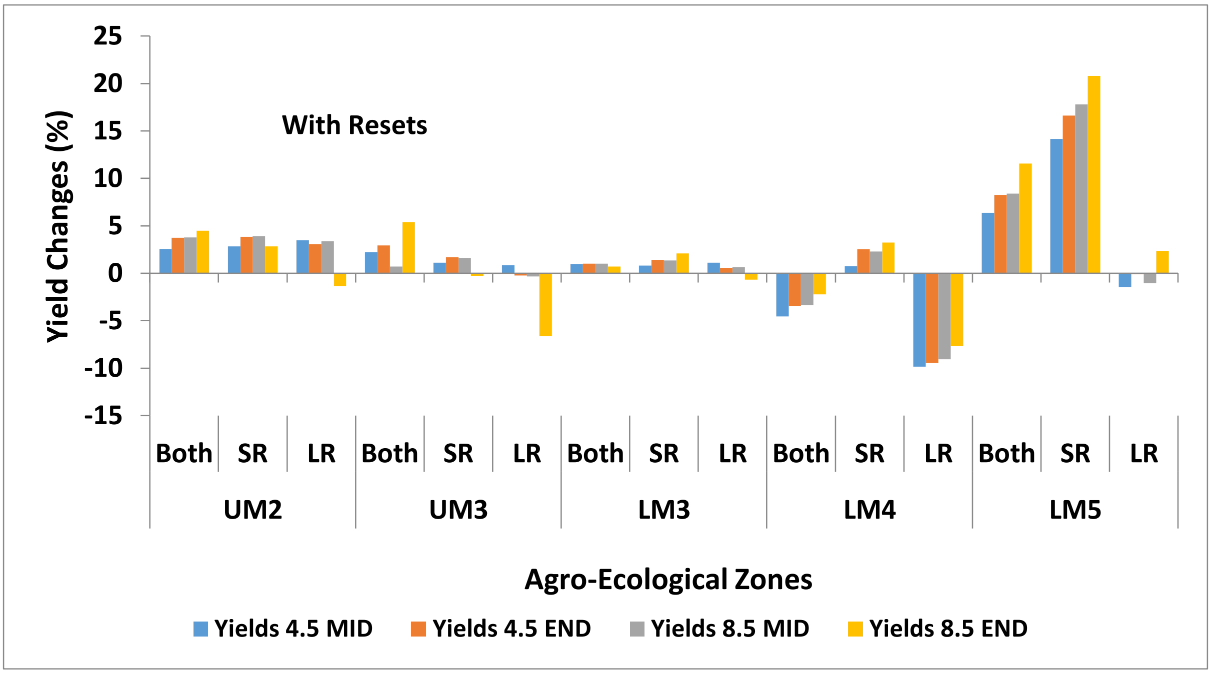


Figure 49: Changes in maize productivity under different agro-ecologies with and without resetting initial water and nitrogen contents under different climate change scenarios

Results indicate that the effect of resets varied from one AEZ to the other. The differences are more conspicuous in the water stressed and warmer AEZs of LM4 and LM5. In LM 5, the yields increased under climate change when the initial conditions were reset while declined in continuous simulations. For example, under RCP 8.5 to end-century period maize yields during SR season increased by about 20.8% and declined by 4.1% in the continuous runs. In case of LM4, yields increased marginally during SR season and decline in LR season under both scenarios but the magnitude of the change is much higher in case of continuous simulations. In case of high potential UM2, UM3 and LM3 the differences are marginal. This is attributed to the differences in plant available moisture at the start of the season. In the with reset scenario, moisture at the start of the season was set to 50% of the total plant available water which seems to be on higher side. Since the seasonal rainfall in LM4 and LM5 is low this contributed to the higher plant available water.

9.2 Climate change impacts on Wheat in Ethiopia

In Ethiopia wheat is the second most important food crop. Wheat grows at altitude from less than 2000 m to greater than 2300 m above sea level and with rainfall from less than 300 to greater than 1000 mm. Variability in rainfall is the most wheat yield limiting factor especially in medium to low rainfall areas. This study was carried out as a part of AgMIP Eastern Africa project to assess how the performance of wheat is going to be influenced under different climate change scenarios in Hintalo-Wajerate areas of northern Ethiopia (Figure 1). The methods followed are similar to those described earlier.

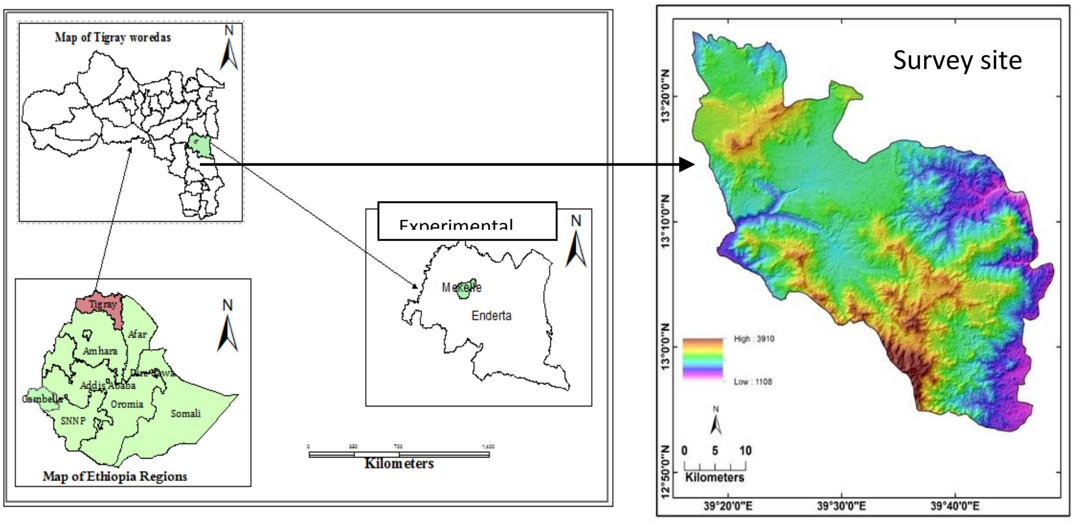


Figure 1: Map showing the location of the target area

Climate, soil and crop data:

Wheat variety HAR2501was calibrated using the data collected from a field experiment that was carried out during the cropping season in 2011 at Wukro (lat. and long.) and in 2012 and 2013 at Mekelle (lat. 13. 28 and long. 39. 3) sites, northern Ethiopia. Available data includes information on phenology (days to emergence, days to flowering and days to maturity) and yield of the wheat cultivar. Data on household and farm characteristics was from a survey that was carried out in 2012 at Hintalo-Wajrate area (Adigudom) covering 197 farmers. Data collected includes crop and crop management information such as planting date, planting depth, harvesting date, planting density, cultivar, fertilizer and manure applied and yield. Information on soil properties was collected by collecting and analyzing samples from two representative sites in the target area. Tables 1-4 present a summary of the physical and chemical properties of the two soil profiles used in the simulations.

Table 1: Soil chemical properties of the two experimental sites at Mekelle

Location	Soil depth (cm)	pH	E.C	%C	% Om	Avail. P(ppm)	Avail. K(ppm)	CEC (meq/ 100g)	% TN
Endayesus	0-20	6.75	0.47	0.7	1.21	3.41	272.47	43.3	0.08
	20-40	6.67	0.17	0.67	1.165	2.77	212.55	42.6	0.07
	40-60	7.15	0.15	0.55	0.935	2.11	195.08	39.9	0.06
Industry kebele	0-20	7.98	0.15	1.45	2.49	1.74	1196.15	49.6	0.147
	20-40	8.02	0.12	2.02	3.48	2.6	1940.08	48.2	0.18
	40-60	8.00	0.31	1.43	2.47	0.48	1006.42	51.2	0.15
	60-80	7.72	0.86	1.38	2.39	1.32	1246.08	53.0	0.15
	80-100	7.78	0.79	1.61	2.77	2.18	886.59	51.2	0.16

Source: Abadi, (2012)

Table 2: Soil physical characteristics of the two experimental sites at Mekelle

Location	Depth (cm)	FC Vol%	PWP Vol%	Sand %	Silt %	Clay %	Texture
Endayesus	0-20	32.04	14.28	55	24	21	SCL
	20-40	37.45	19.33	50	26	24	SCL
	40-60	30.62	19.01	64	20	16	SL
Industry kebele	0-20	50	20.14	19	35	46	C
	20-40	54	23.42	21	33	46	C
	40-60	50	35.36	13	31	56	C

SCL, sandy clay loam; SL, sandy loam; C, clay; FC, field capacity; PWP, permanent wilting point

Source: Abadi, (2012)

Table 3: Soil chemical properties of the Adigudom survey sites

Depth (cm)	Ph	EC	%OC	%OM	%TN	Avail. P (ppm)	CEC meq/100g
0 - 4	8.00	0.17	1.77	3.06	0.14	8.60	42.6
4-80	8.26	0.37	1.84	3.17	0.09	4.60	26.2
80 - 125	7.82	2.17	1.55	2.68	0.10	3.24	47.2
125 - 200	8.33	0.24	0.74	1.28	0.06	2.88	41.6

Table 4: Soil physical properties of the Adigudom survey sites

Depth (cm)	BD g/cm^3	DUL mm/mm	LL mm/mm	Sand %	Silt %	Clay %	Texture
0 - 4	1.21	0.50	0.32	9	41	50	SC
4 - 80	1.19	0.54	0.39	21	13	66	C
80 - 125	1.19	0.54	0.39	19	19	62	C
125 - 200	1.32	0.39	0.27	49	17	34	SCL

SC, silt clay; C, clay; SCL, sandy clay loam; DUL and LL are upper and lower limit soil water and BD, is bulk density

The long-term climate data (1980 – 2009) for three locations, Adigudom, Adimeasanu and Hintalo, that includes daily maximum and minimum temperature, rainfall and solar radiations were obtained from the National Metrological Agency. Long-term climatic conditions are presented in Figure 2. Climate change scenarios for mid and century periods were generated under RCP 4.5 and 8.5 as per the methods described earlier using delta method for 20 AOGCMs.

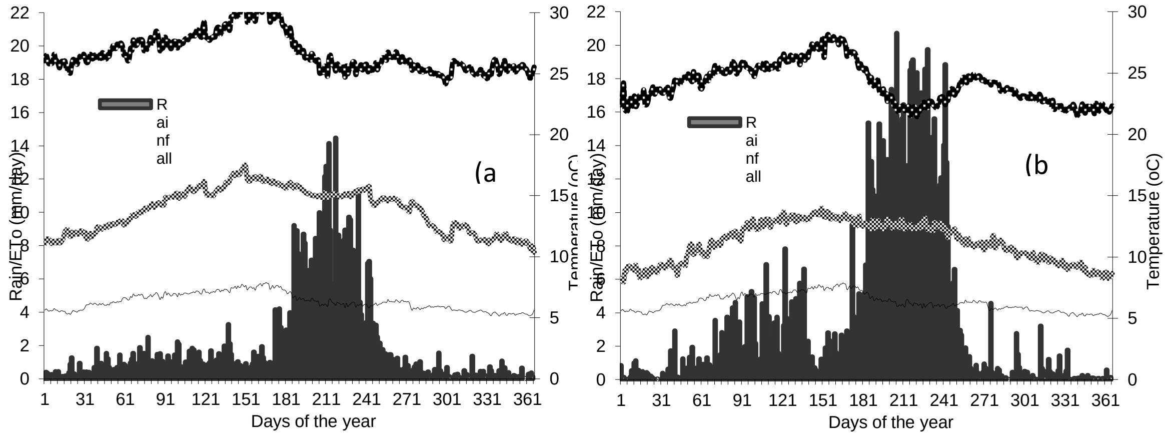


Figure 2: Long-term (1980 – 2009) mean daily rainfall, reference evapotranspiration and temperature data of Adigudom (a) and Mekelle (b)

Model calibration

The wheat module in APSIM v7.4 was calibrated using the available climate, soil and crop information in the experimental sites. The phenology was matched by changing the thermal times required to match the simulated phenology with the observed. The variety Kotuku available with the model was used as the base for further changes. Model evaluation was carried out using both experimental and survey data. The observed days to emergence, days to flowering and days to maturity obtained at the experimental sites were compared with the espective predicted data for the growing seasons in 2011, 2012 and 2013. Table 5 shows the good relationship achieved between the observed and simulated data while figures 3a and 3b compare the farmer reported yields with model simulated yields for the survey season 2012.

Table 5: Statistical evaluation for phenological observations

Year	Days to emergence		Days to flowering		Days to maturity	
	Obs	Sim	Obs	Sim	Obs	Sim
2011	6	6	65	65	101	103
2012	6	6	60	63	90	98
2012	6	6	68	70	103	111
2012	6	6	68	70	103	111
2013	6	6	69	71	104	112
R2		1.0		0.91		0.81
RMSE		0.0		2.0		7.2

IA	1.0	0.90	0.54
D%	0.0	2.8	6.8

IA, index of agreement; D%, percentage of deviation from the mean; RMSE, root means square of error; Obs, observed; Sim, simulated;

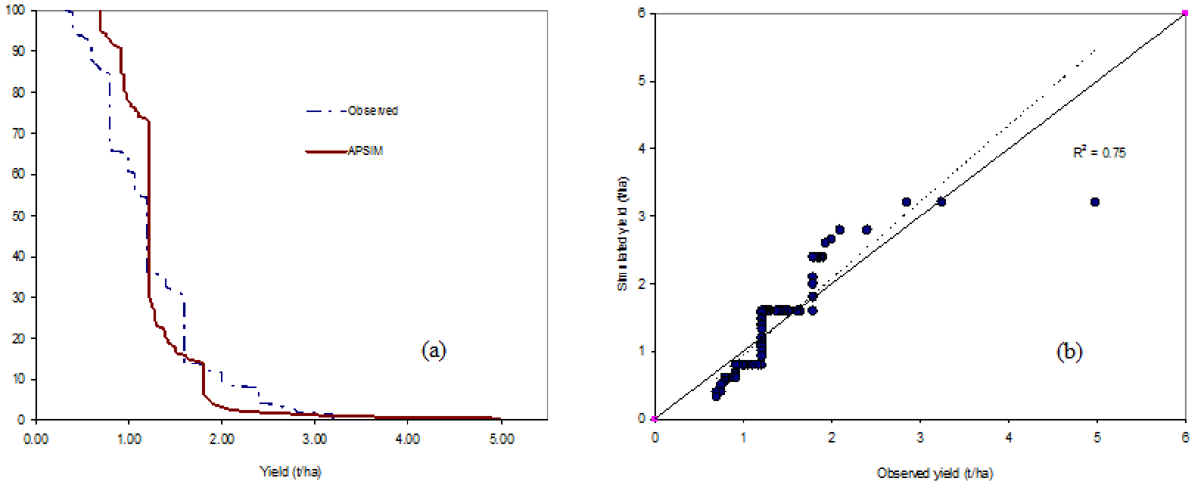


Figure 3: a. The probability of exceedance of the simulated and observed yields and b. The relationship between farmer and simulated yields.

Sensitivity analysis

Results of the sensitivity analysis indicated that the APSIM-wheat module was moderately responsive to nitrogen application, temperature and planting date but was less responsive to plant population (Figures 4a-d).

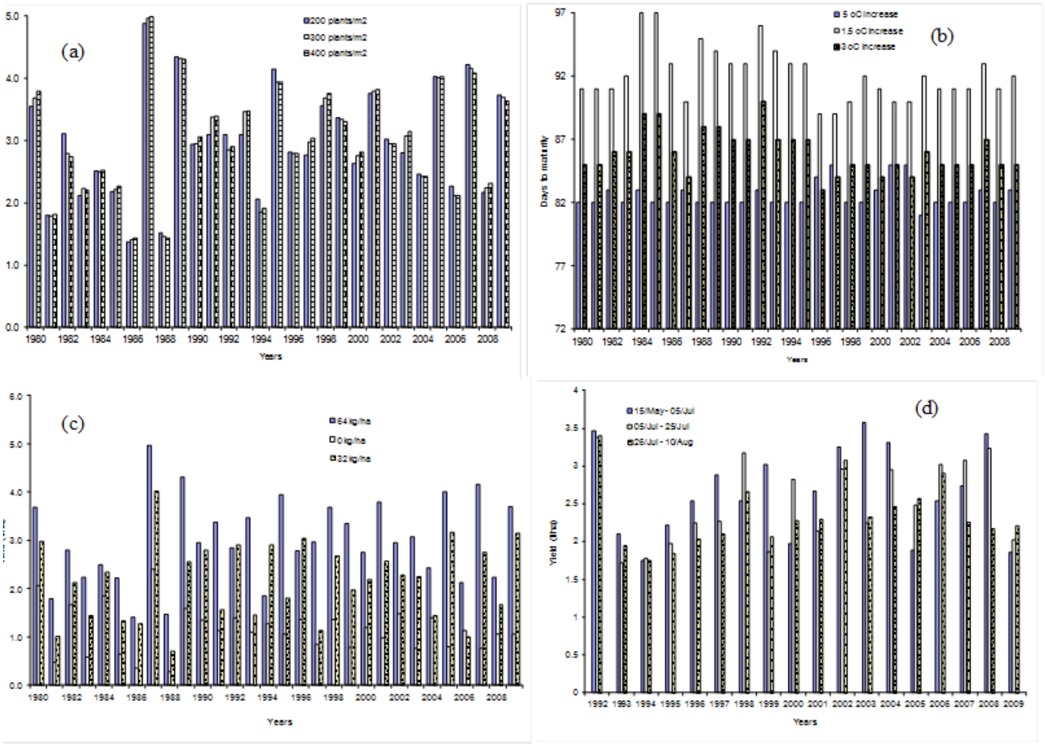


Figure 4: Response of wheat yield to a. plant population, b. effect of temperature on length of growing period, c. response to nitrogen application and d. effect of planting date on yield

Sensitivity of wheat to climate change:

In general, wheat yields declined from the current level under future climate projections by all GCMs. Decline in yield to near term and mid-term were more or less similar but are less than the current yields. However, substantial reduction in yield was observed for the end-century scenario (Figure 5) and the extent of yield reduction varied from GCM to GCM. The yield reduction varied from – 21.8% to – 1.87% during the near term and from –32.67% to –1% to mid-century periods, depending on the GCM used (Figures 5 and 6). Among the GCMs, highest reduction in wheat yield was observed with climate projections from IPSL-CM5A-MR for mid-century (-32.67%) and IPSL-CM5A-LR for end-century (-60.5%) period. The differences between RCP 4.5 and 8.5 are not as high as those observed with maize crop.

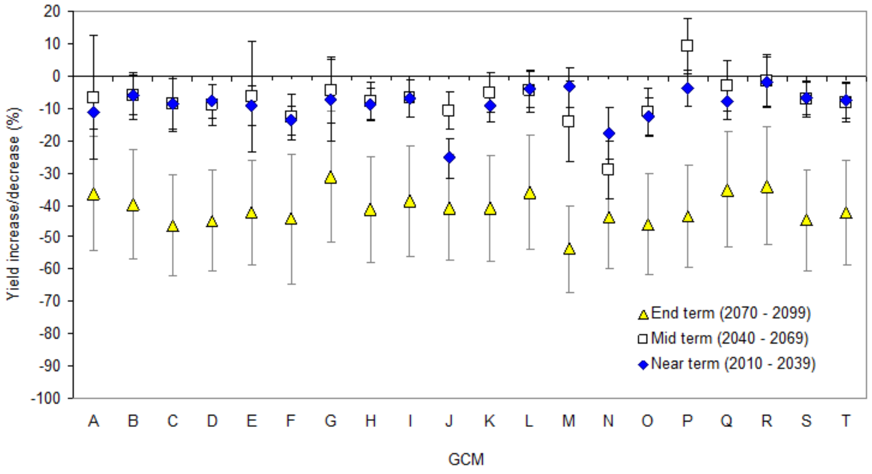


Figure 5: Change in wheat yield (%) as simulated by APSIM based on 20 GCM with RCP4.5 for near, mid and end-century. Vertical bars indicate error bars

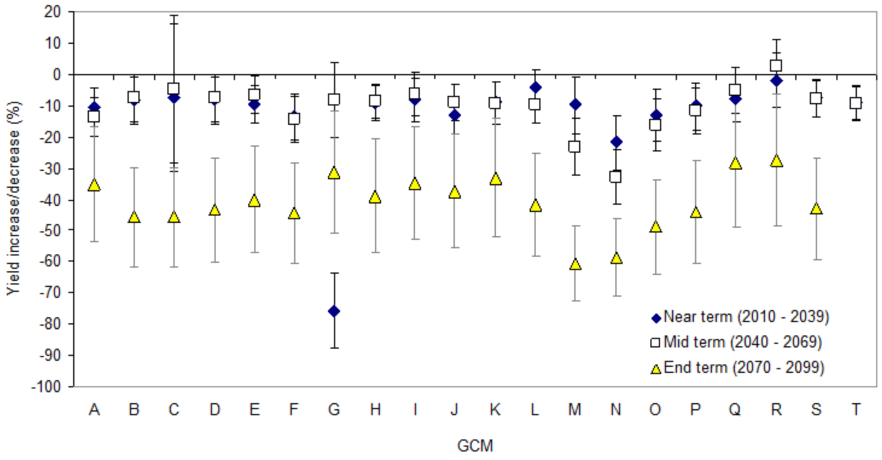


Figure 6: Change in wheat yield (%) as simulated by APSIM based on 20 GCM with RCP8.5 for near, mid and end-century. Vertical bars indicate error bars

Adaptation options to climate change:

Results of the sensitivity analysis in Figures 5a to 5d indicated that use of optimal fertilizer and planting time could increase wheat yield. Hence, simulations were carried out by changing these two inputs. The results indicate substantial gap in yield between the ones obtained with current management and those obtained with adaptation to mid-century period (Figure 7). Average wheat yield simulated based on five selected GCM showed an increase between 154% and 161% over the one without adaptation measures.

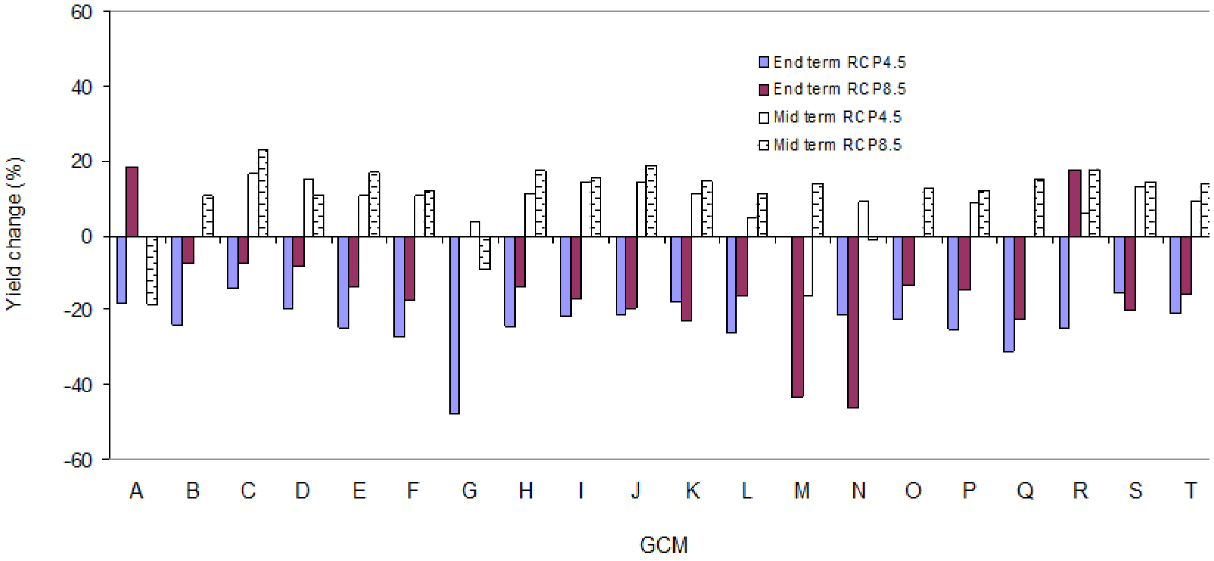


Figure 7: Changes in wheat yield with changes predicted by five GCMs with and without climate change adaptation for mid and end-century periods under RCP 4.5 and 8.5.

10. Conclusions and Next Steps

Realistic assessment of impacts of climate change on smallholder agriculture is a challenging exercise. Crop productivity in smallholder agricultural systems is a function of complex interactions of various sub-optimal resources with large variations between fields partly from inherent differences in soil types and partly due to differences in management. To estimate crop productivity under such circumstances, models must be sensitive enough to simulate the effects of biophysical heterogeneity and management strategies. Crop simulation models such as DSSAT and APSIM have the capabilities to capture these differences but require detailed data on climate, soil and management. An additional challenge is to translate these impacts on productivity into socio-economic impacts on poor small holder farmers deriving their livelihoods form these systems. This assessment addressed this complexity in a comprehensive way by integrating best available knowledge and modelling tools in the areas of climate, crop and socio-economics. This probably is one of the first attempts in the region to assess the impacts of climate change on smallholder farming systems in a holistic and systematic way.

Despite data constraints and limitations, this assessment has demonstrated that it is possible to make more reliable and credible assessment of impacts of climate variability and change on smallholder farming systems that can aid in planning for adaptation. The analysis provided good insights into the climate sensitivity of the various components under a range of agro-ecologies that are representative of the Eastern Africa region and identify components of the system that are going to be impacted by the projected changes in climate. It highlighted the differential impacts of the changes in climate can have on different AEZs within a small area which cannot be captured in the large scale assessments made using aggregated empirical models. The assessment further highlights the fact that impacts of climate change will not be uniform and there will be losers and gainers depending on the environment they are operating in and management employed. The assessment also reveals that to a large extent the negative effects of climate change can be minimized and benefits from the positive impacts can be maximized by making simple adjustments to the existing practices such as changing a variety, changing plant density and changing fertility management. The planning and effectiveness of adaptation strategies can be greatly enhanced by this type of information which helps in identifying the most appropriate interventions and also in targeting the most vulnerable AEZs and people.

The methods and tools developed under this project proved to be extremely valuable in understanding and characterizing how smallholder agriculture in developing countries is going to be impacts by the projected changes in climate and in developing more appropriate site specific adaptation strategies. Efforts however, are required to define the resource endowment and management employed by the farmers as accurately as possible to capture the diversity that exists between the farms. Once established, this will serve as a valuable platform to assess impacts of current as well as future climates. The framework will also serve as means to develop climate-based agricultural forecasting and early warning systems that can enable governments and humanitarian organizations to protect rural communities from the impacts of adverse extremes with appropriate responses. Current assessment is limited to assess the impacts of maize only. However, this can be extended easily to cover most other enterprises that the farmers are involved with and make more comprehensive assessment of the system. There is a need to create awareness amongst the policy makers and decision makers about this and to ensure that the relevant departments get and utilize this information in planning various interventions from adapting to impacts of climate change to food security assessment and early warning.

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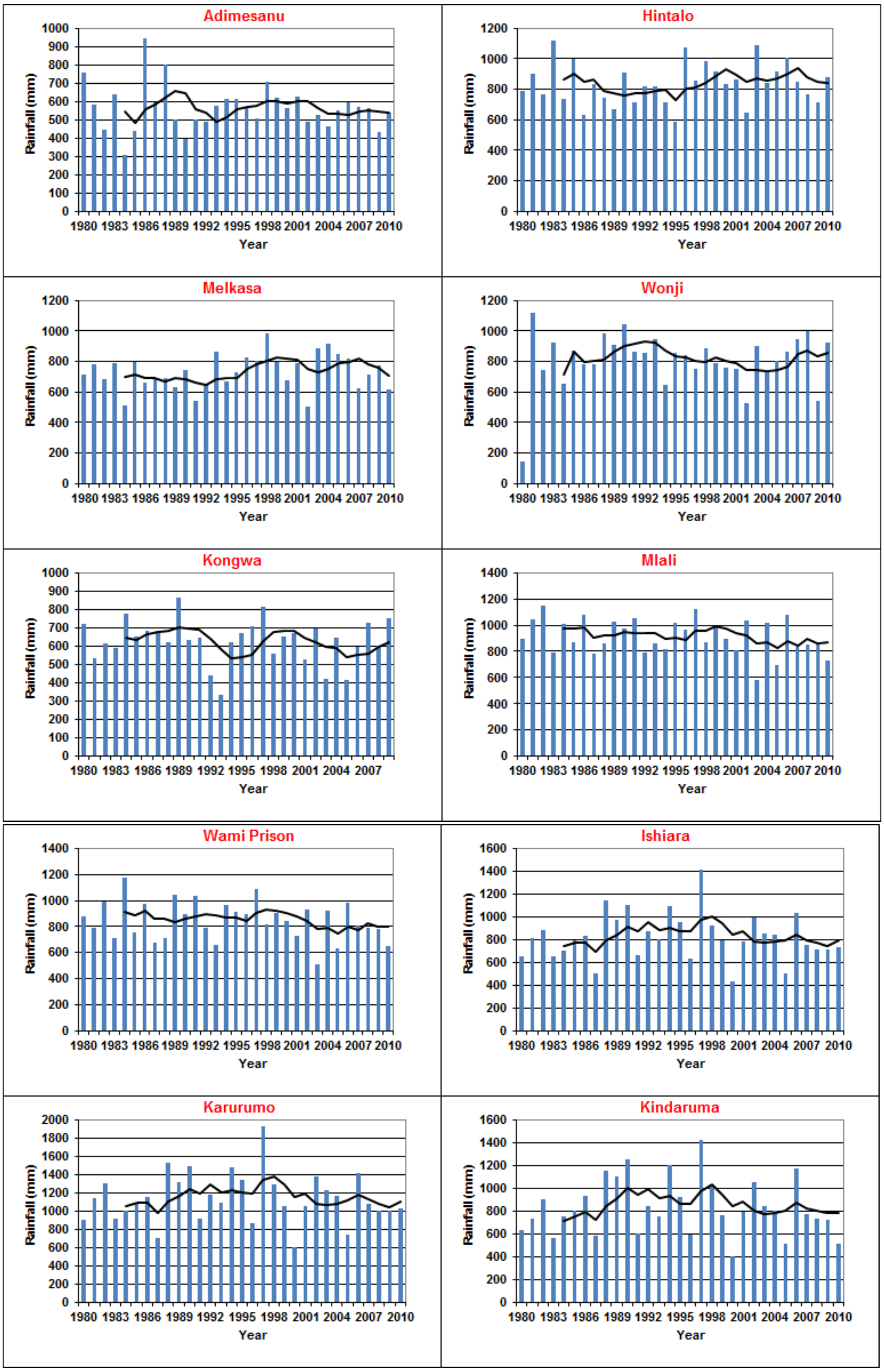
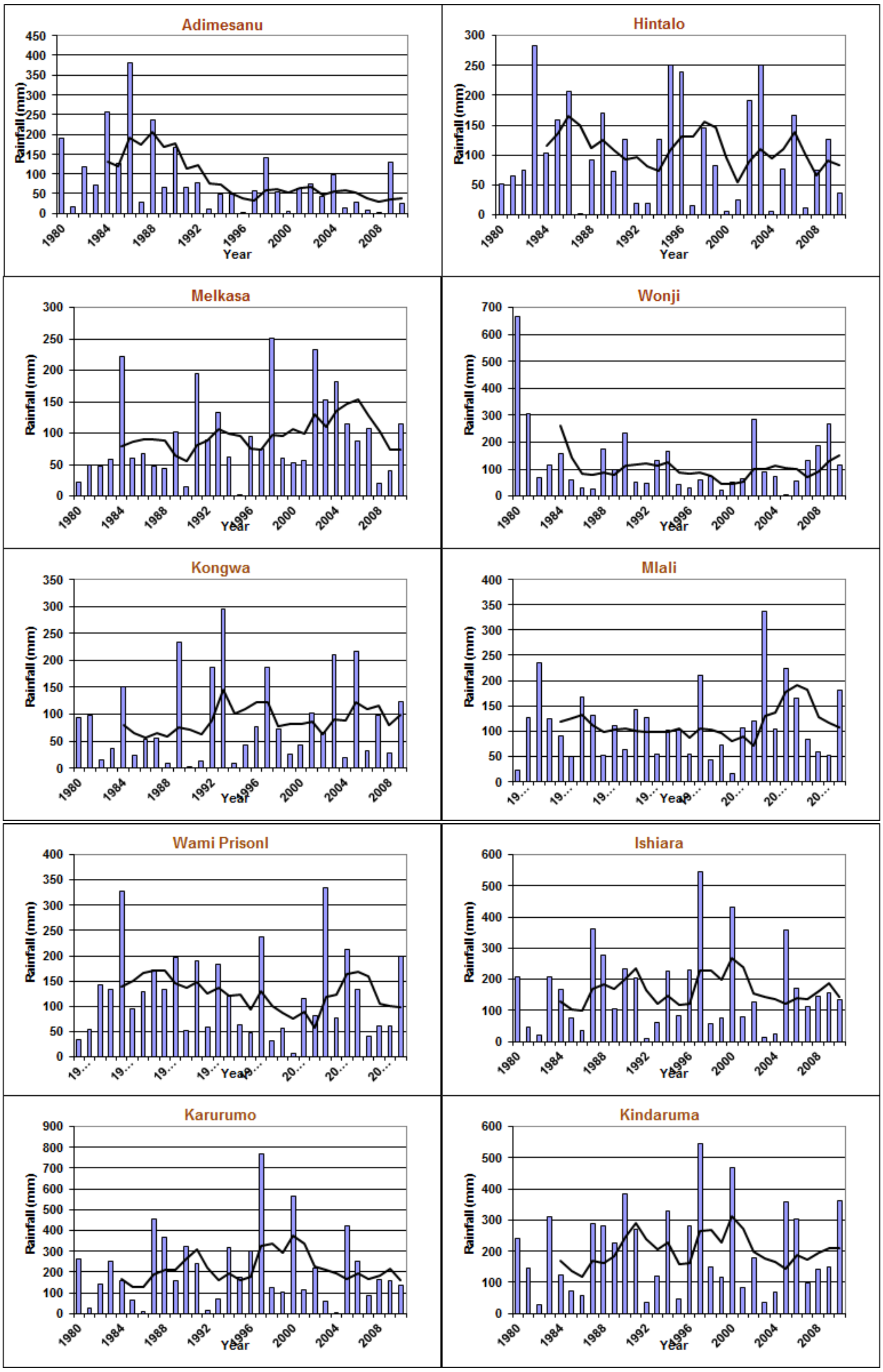
ANNEXES

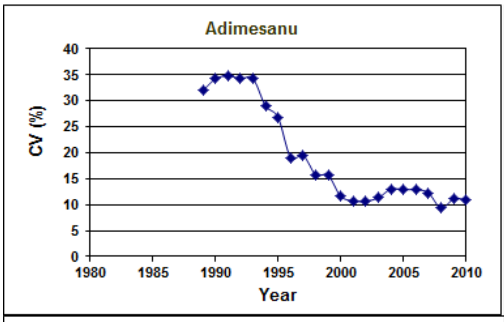
Annex 1: Trends in annual rainfall (solid line is the five year moving average)

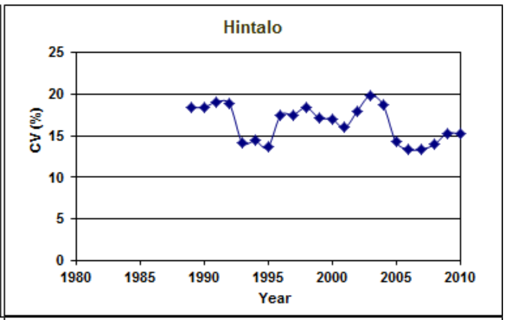


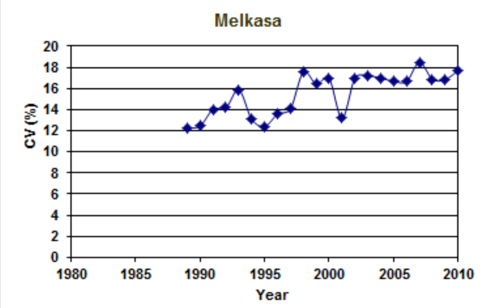
Annex 2: Trends in annual rainfall anomalies (absolute) with five year moving average

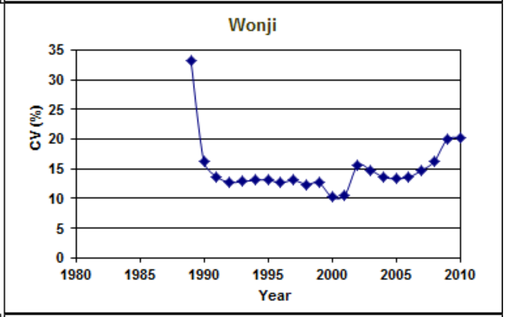


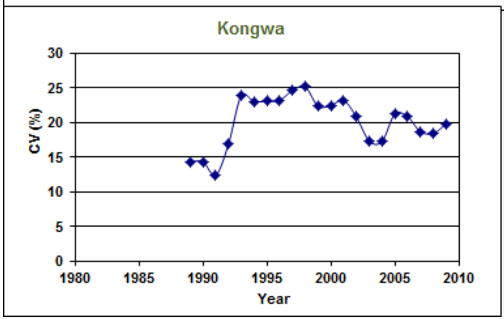
Annex 3: Trends in ten year moving coefficient of variation in annual rainfall

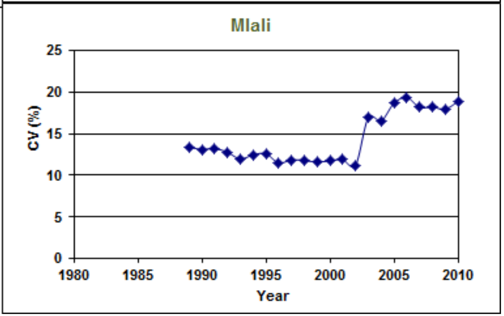


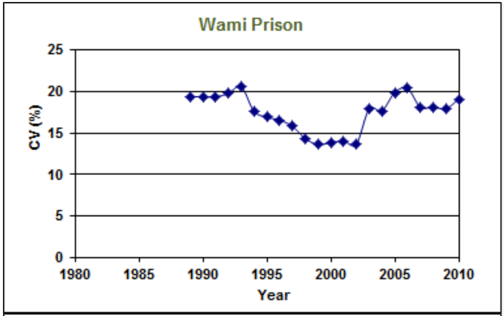


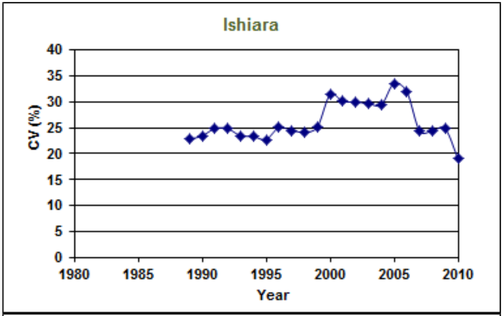


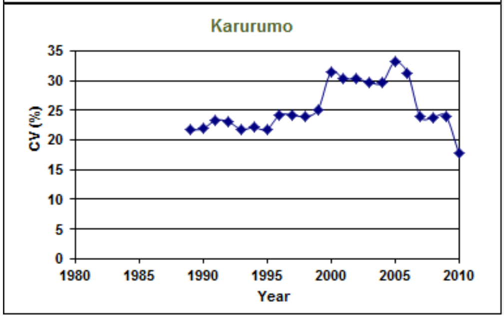


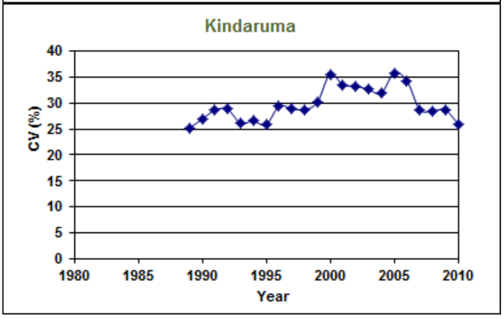












Annex 4: Absolute changes in the projected minimum temperature at different locations under RCPs 4.5 and 8.5 for mid (2040-2070) and end (2070-2100) periods

GCMS	4.5 MID								4.5 END								8.5 MID								8.5 END							
	Locations								**Locations**								**Locations**								**Locations**							
	Ethiopia				**Tanzania**			**Uganda**	**Ethiopia**				**Tanzania**			**Uganda**	**Ethiopia**				**Tanzania**			**Uganda**	**Ethiopia**				**Tanzania**			**Uganda**
	Wonji	**Melkasa**	**Adimesanu**	**Hintalo**	**Wami Prison**	**Mlali**	**Kongwa**	**Masandi**	**Wonji**	**Melkasa**	**Adimesanu**	**Hintalo**	**Wami Prison**	**Mlali**	**Kongwa**	**Masandi**	**Wonji**	**Melkasa**	**Adimesanu**	**Hintalo**	**Wami Prison**	**Mlali**	**Kongwa**	**Masandi**	**Wonji**	**Melkasa**	**Adimesanu**	**Hintalo**	**Wami Prison**	**Mlali**	**Kongwa**	**Masandi**
ACCESS1	2.0	1.4	2.1	2.1	1.3	1.8	1.9	2.3	2.9	2.2	2.9	2.9	2.1	2.5	2.7	3.1	2.6	2.5	3.2	3.2	2.2	2.6	1.9	3.3	5.2	4.6	5.3	5.3	3.9	4.4	4.8	5.2
bcc-csm1	1.3	0.5	1.6	1.6	1.2	1.5	1.6	2.2	1.6	0.6	2.0	2.0	1.7	2.0	2.0	2.5	1.5	1.0	2.3	2.3	1.8	2.1	1.6	2.9	3.5	2.8	4.1	4.1	3.5	3.8	3.9	4.4
BNU-ESM	1.4	0.5	1.6	1.6	1.1	1.4	1.4	2.1	1.7	0.6	2.0	2.0	1.4	1.7	1.8	2.6	1.6	1.0	2.3	2.3	1.8	2.2	1.4	4.4	3.7	2.8	4.1	4.1	3.2	3.6	3.6	4.4
CanESM2	3.0	1.5	2.8	2.8	1.4	1.7	1.8	2.3	3.5	2.1	3.4	3.4	1.7	2.0	2.0	2.7	3.8	2.6	4.2	4.2	2.1	2.4	1.8	2.2	6.8	4.8	6.6	6.6	3.7	4.1	4.1	5.1
CCSM4	1.5	0.8	1.3	1.5	0.5	0.5	1.0	0.6	1.8	1.1	1.6	1.8	0.7	0.7	1.3	0.8	1.5	1.4	2.0	2.1	1.2	1.6	1.0	1.1	3.2	2.5	3.6	3.8	2.5	2.7	3.0	2.4
CESM1-BGC	1.4	0.7	1.4	1.5	0.6	0.5	1.1	0.6	1.6	0.9	1.5	1.7	0.7	0.7	1.3	0.8	1.3	1.1	2.0	2.1	1.1	1.5	1.1	2.2	2.9	2.2	3.5	3.7	2.6	2.8	3.2	3.4
CSIRO-Mk3	2.7	2.0	2.8	2.5	1.7	2.0	2.0	2.6	3.5	2.9	3.7	3.3	2.4	2.7	2.7	3.3	2.7	2.6	3.4	3.2	2.1	2.4	2.0	3.1	5.7	5.1	5.9	5.5	4.0	4.3	4.3	5.2
GFDL-ESM2G	1.2	0.5	1.0	1.0	0.9	1.2	1.1	1.8	1.6	1.0	1.2	1.2	1.1	1.4	1.4	1.8	1.4	1.3	1.9	1.9	1.4	1.7	1.1	3.5	3.4	2.8	3.5	3.5	2.9	3.2	2.9	3.9
GFDL-ESM2M	1.3	0.6	1.3	1.3	0.8	1.1	1.1	1.9	1.8	1.2	2.0	2.0	0.9	1.3	1.4	2.1	1.6	1.5	2.5	2.5	1.4	1.7	1.1	3.5	3.5	2.9	3.8	3.8	2.5	2.9	2.8	3.7
HadGEM2-CC	2.9	2.2	2.3	2.3	1.7	2.1	2.1	2.6	3.7	3.1	3.0	3.3	2.0	2.5	2.5	3.1	3.3	3.2	3.6	3.8	2.5	2.9	2.1	2.2	6.6	6.0	6.0	5.8	4.6	5.0	5.3	5.8
HadGEM2-ES	3.0	2.3	2.7	2.9	1.7	2.1	2.2	2.7	4.0	3.4	3.4	3.7	2.5	2.9	2.9	3.4	3.2	3.1	3.5	3.9	2.4	2.7	2.2	3.5	6.6	5.9	6.1	6.1	4.5	4.7	5.1	5.9
inmcm4	1.2	0.6	1.3	1.3	0.5	0.8	0.8	1.3	1.5	0.9	1.5	1.5	0.7	1.1	1.1	1.8	1.6	1.5	2.3	2.3	1.0	1.3	0.8	2.1	3.7	3.0	4.1	4.1	2.1	2.4	2.6	3.6
IPSL-CM5A-LR	2.3	1.7	2.3	1.9	1.9	2.2	2.2	2.5	3.0	2.3	3.0	2.5	2.3	2.6	2.6	3.1	3.0	2.9	3.3	2.8	2.6	2.9	2.2	3.4	5.9	5.2	5.9	5.3	4.7	5.0	5.0	5.7
IPSL-CM5A-MR	2.8	2.1	3.5	3.5	1.6	1.9	1.9	2.0	3.6	3.0	5.3	5.3	2.4	2.7	2.8	3.4	3.3	3.2	4.2	4.2	2.5	2.8	1.9	2.3	7.0	6.3	7.7	7.7	4.9	5.2	5.2	6.0
MIROC5	1.4	0.7	1.4	1.4	1.5	1.8	1.8	2.5	1.8	1.1	1.7	1.7	2.0	2.3	2.3	2.0	1.5	1.3	1.6	1.6	1.7	2.0	1.8	2.4	3.2	2.6	2.9	2.9	3.8	4.1	4.1	3.6

MIROC-ESM	1.8	1.1	1.7	1.7	1.0	1.4	1.6	1.7	2.4	1.6	2.1	2.1	1.4	1.8	2.1	2.6	1.8	1.5	1.9	1.9	1.4	1.7	1.6	3.1	4.3	3.4	3.9	3.9	2.7	3.0	3.5	4.1
MPI-ESM-LR	1.9	1.3	2.0	1.9	1.2	1.5	1.7	1.9	2.3	1.7	2.5	2.4	1.5	1.8	2.0	2.2	2.4	2.2	2.9	2.9	1.8	2.1	1.7	2.1	4.9	4.3	5.1	5.1	3.4	3.7	4.1	4.9
MPI-ESM-MR	2.0	1.4	2.1	2.2	1.3	1.6	1.7	2.0	2.5	1.8	2.6	2.6	1.7	2.0	2.1	2.3	2.2	2.0	2.8	2.9	1.9	2.2	1.7	3.2	4.9	4.3	5.0	5.1	3.4	3.7	4.1	5.0
MRI-CGCM3	1.6	1.0	1.6	1.6	0.9	1.2	1.3	2.0	2.2	1.5	2.1	2.1	1.2	1.6	1.6	2.4	2.0	1.8	2.4	2.4	1.5	1.8	1.3	2.8	4.3	3.7	4.1	4.1	2.7	3.1	3.1	6.1
NorESM1-M	1.3	0.7	1.3	1.5	0.3	0.7	0.7	1.0	1.7	1.1	1.7	1.9	0.7	1.0	1.0	1.4	1.4	1.3	2.0	2.1	1.1	1.4	0.7	2.7	3.0	2.4	3.5	3.8	2.2	2.6	2.6	1.8
Average	**1.9**	**1.2**	**1.9**	**1.9**	**1.1**	**1.5**	**1.6**	**1.9**	**2.4**	**1.7**	**2.5**	**2.5**	**1.6**	**1.9**	**2.0**	**2.4**	**2.2**	**1.9**	**2.7**	**2.7**	**1.8**	**2.1**	**1.6**	**2.8**	**4.6**	**3.9**	**4.7**	**4.7**	**3.4**	**3.7**	**3.9**	**4.5**
Median	**1.7**	**1.0**	**1.7**	**1.7**	**1.2**	**1.5**	**1.6**	**2.0**	**2.2**	**1.6**	**2.1**	**2.1**	**1.6**	**1.9**	**2.0**	**2.4**	**1.9**	**1.7**	**2.5**	**2.5**	**1.8**	**2.1**	**1.6**	**2.9**	**4.3**	**3.6**	**4.1**	**4.1**	**3.4**	**3.7**	**4.0**	**4.6**

Annex 5: Absolute changes in the projected maximum temperature at different locations under RCPs 4.5 and 8.5 for mid (2040-2070) and end (2070-2100) periods

GCMS	4.5 MID								4.5 END								8.5 MID								8.5 END							
	Ethiopia				**Tanzania**			**Uganda**	**Ethiopia**				**Tanzania**			**Uganda**	**Ethiopia**				**Tanzania**			**Uganda**	**Ethiopia**				**Tanzania**			**Uganda**
	Wonji	**Melkasa**	**Adimesanu**	**Hintalo**	**Wami Prison**	**Mlali**	**Kongwa**	**Masandi**	**Wonji**	**Melkasa**	**Adimesanu**	**Hintalo**	**Wami Prison**	**Mlali**	**Kongwa**	**Masandi**	**Wonji**	**Melkasa**	**Adimesanu**	**Hintalo**	**Wami Prison**	**Mlali**	**Kongwa**	**Masandi**	**Wonji**	**Melkasa**	**Adimesanu**	**Hintalo**	**Wami Prison**	**Mlali**	**Kongwa**	**Masandi**
ACCESS1	**1.9**	**2.5**	**2.5**	**2.5**	**1.9**	**2.0**	**2.2**	**1.8**	**2.7**	**3.3**	**3.3**	**3.2**	**2.8**	**2.9**	**3.0**	**2.4**	**2.7**	**3.3**	**3.1**	**3.1**	**2.7**	**2.6**	**2.2**	**2.8**	**4.4**	**5.0**	**5.1**	**5.0**	**4.3**	**4.4**	**4.6**	**4.4**
bcc-csm1	**1.5**	**1.9**	**1.7**	**1.7**	**1.4**	**1.2**	**1.5**	**1.5**	**1.8**	**2.2**	**2.1**	**2.1**	**1.6**	**1.4**	**1.7**	**1.8**	**2.1**	**2.4**	**2.3**	**2.3**	**2.1**	**1.9**	**1.5**	**2.0**	**3.8**	**4.0**	**4.1**	**4.1**	**3.2**	**3.0**	**3.3**	**3.5**
BNU-ESM	**1.1**	**1.9**	**1.7**	**1.7**	**1.5**	**1.4**	**1.7**	**0.3**	**0.9**	**2.2**	**2.1**	**2.1**	**2.0**	**1.8**	**2.1**	**0.5**	**1.4**	**2.4**	**2.3**	**2.3**	**2.2**	**2.0**	**1.7**	**1.1**	**2.7**	**4.0**	**4.1**	**4.1**	**3.7**	**3.5**	**3.8**	**1.8**
CanESM2	**1.6**	**1.7**	**1.8**	**1.8**	**1.5**	**1.3**	**1.6**	**1.5**	**2.0**	**1.9**	**2.3**	**2.3**	**1.7**	**1.5**	**1.8**	**2.0**	**2.4**	**2.5**	**2.7**	**2.7**	**2.4**	**2.2**	**1.6**	**2.7**	**3.6**	**3.6**	**4.0**	**4.0**	**4.1**	**3.9**	**4.2**	**4.8**
CCSM4	**1.4**	**2.0**	**1.5**	**1.4**	**1.6**	**1.3**	**1.8**	**0.7**	**1.7**	**2.2**	**1.7**	**1.7**	**1.9**	**1.6**	**2.1**	**1.1**	**1.9**	**2.4**	**2.1**	**2.0**	**2.2**	**2.0**	**1.8**	**1.7**	**3.4**	**4.0**	**3.7**	**3.6**	**3.7**	**3.5**	**3.7**	**2.7**
CESM1-BGC	**1.4**	**2.0**	**1.6**	**1.6**	**1.5**	**1.3**	**1.7**	**0.8**	**1.8**	**2.3**	**1.7**	**1.7**	**1.8**	**1.6**	**2.0**	**1.1**	**1.8**	**2.4**	**2.0**	**1.9**	**2.1**	**1.8**	**1.7**	**1.8**	**3.2**	**3.8**	**3.5**	**3.4**	**3.6**	**3.4**	**3.6**	**2.9**
CSIRO-Mk3	**2.6**	**3.1**	**2.3**	**2.1**	**1.9**	**1.8**	**2.3**	**2.3**	**3.2**	**3.8**	**3.1**	**2.8**	**2.7**	**2.5**	**3.2**	**2.8**	**3.0**	**3.5**	**2.8**	**2.6**	**2.4**	**2.2**	**2.3**	**2.6**	**5.3**	**5.8**	**5.1**	**4.8**	**4.0**	**3.8**	**4.6**	**4.3**
GFDL-ESM2G	**1.4**	**2.0**	**1.4**	**1.4**	**1.7**	**1.5**	**1.6**	**0.9**	**1.1**	**1.6**	**1.5**	**1.5**	**1.9**	**1.8**	**1.9**	**1.0**	**2.1**	**2.7**	**2.2**	**2.2**	**1.9**	**1.7**	**1.6**	**2.2**	**3.6**	**4.1**	**3.8**	**3.8**	**3.4**	**3.3**	**3.5**	**3.2**
GFDL-ESM2M	**1.1**	**1.7**	**1.5**	**1.5**	**1.2**	**1.0**	**1.4**	**1.1**	**1.3**	**1.9**	**2.3**	**2.3**	**1.2**	**1.0**	**1.6**	**1.2**	**1.9**	**2.5**	**2.5**	**2.5**	**1.4**	**1.2**	**1.4**	**1.7**	**3.2**	**3.8**	**3.8**	**3.8**	**2.5**	**2.3**	**2.8**	**2.7**

HadGEM2-CC	2.2	2.8	2.4	2.4	2.4	2.2	2.5	2.3	2.8	3.4	3.2	3.1	2.4	2.4	2.7	2.9	2.8	3.3	3.2	3.2	3.1	3.0	2.5	3.0	4.8	5.4	5.6	5.7	4.9	5.0	5.2	5.3
HadGEM2-ES	2.5	3.0	2.8	2.6	2.3	2.3	2.4	2.5	3.1	3.6	3.6	3.5	3.2	3.2	3.0	2.9	3.1	3.6	3.5	3.4	3.0	3.1	2.4	3.3	4.8	5.4	5.6	5.6	4.9	5.0	5.1	5.3
inmcm4	1.0	1.5	1.1	1.1	1.0	0.8	1.1	0.8	1.5	2.0	1.7	1.7	1.4	1.3	1.7	1.2	1.0	1.5	1.3	1.3	1.4	1.3	1.1	1.0	2.2	2.8	2.7	2.7	2.5	2.4	2.8	2.2
IPSL-CM5A-LR	2.0	2.5	1.7	1.8	1.8	1.7	2.0	1.6	2.4	3.0	2.3	2.3	2.5	2.4	2.7	2.1	2.5	3.1	2.4	2.5	2.7	2.5	2.0	2.2	4.3	4.9	4.3	4.6	4.7	4.5	4.8	4.0
IPSL-CM5A-MR	1.5	2.0	1.7	1.7	2.0	1.8	2.1	1.3	2.7	3.3	2.5	2.5	2.5	2.4	2.7	2.2	2.4	2.9	2.9	2.9	2.8	2.7	2.1	2.2	4.0	4.6	4.9	4.9	4.7	4.6	4.9	3.9
MIROC5	1.6	2.1	1.4	1.4	1.5	1.3	1.6	1.5	1.9	2.4	1.7	1.7	1.6	1.5	1.8	1.8	1.9	2.5	1.4	1.4	1.4	1.2	1.6	2.0	2.9	3.6	2.4	2.4	3.7	3.6	3.9	3.5
MIROC-ESM	2.0	2.2	1.5	1.5	1.5	1.4	2.1	1.7	2.3	2.6	1.7	1.7	2.0	1.8	2.7	2.4	1.8	2.2	1.3	1.3	1.7	1.5	2.1	1.8	3.5	3.8	3.0	3.0	2.8	2.6	3.9	3.3
MPI-ESM-LR	2.0	2.6	2.0	1.9	1.5	1.3	1.8	1.4	2.3	2.9	2.5	2.4	1.8	1.6	2.2	1.8	2.7	3.3	2.7	2.8	2.0	1.8	1.8	2.2	4.7	5.3	4.9	4.8	3.4	3.2	4.0	4.0
MPI-ESM-MR	2.1	2.7	2.1	2.1	1.5	1.3	1.7	1.7	2.5	3.0	2.5	2.4	2.1	1.9	2.4	2.0	2.8	3.3	2.7	2.8	2.2	2.1	1.7	2.6	4.8	5.4	4.7	4.7	3.5	3.3	4.2	4.3
MRI-CGCM3	1.4	1.9	1.4	1.4	1.5	1.4	1.8	1.3	1.6	2.2	1.7	1.7	1.7	1.7	2.1	1.7	1.9	2.5	2.0	2.0	1.8	1.8	1.8	2.4	3.1	3.7	3.1	3.1	3.1	3.3	3.6	4.0
NorESM1-M	1.1	1.7	1.2	1.2	1.5	1.4	1.7	1.2	1.6	2.2	1.6	1.8	2.0	1.8	2.1	1.5	1.7	1.0	1.8	1.9	2.1	2.0	1.7	1.6	2.8	3.3	3.0	3.2	3.7	3.5	3.8	2.5
Average	1.7	2.2	1.8	1.7	1.6	1.5	1.8	1.4	2.1	2.6	2.2	2.2	2.0	1.9	2.3	1.8	2.2	2.7	2.4	2.4	2.2	2.0	1.8	2.1	3.8	4.3	4.1	4.1	3.7	3.6	4.0	3.6
Median	1.5	2.0	1.7	1.7	1.5	1.4	1.7	1.4	2.0	2.4	2.2	2.2	2.0	1.8	2.1	1.8	2.1	2.5	2.4	2.4	2.1	2.0	1.7	2.2	3.6	4.0	4.0	4.0	3.7	3.5	3.9	3.7

Annex 6: Projected changes in the rainfall during season 1 (Mar-May) for selected locations under RCPs 4.5 and 8.5 for mid (2040-2070) and end (2070-2100) periods

GCMS	4.5 MID				4.5 END				8.5 MID				8.5 END			
	Adi-gudom	Nazeret	Embu	Dodoma	Adi-gudom	Nazeret	Embu	Dodoma	Adi-gudom	Nazeret	Embu	Dodoma	Adi-gudom	Nazeret	Embu	Dodoma
ACCESS1	-8.3	7.5	3.6	7.5	-9.9	10.9	11.6	-8.6	7.6	24.1	8.0	3.9	22.0	39.4	20.9	7.9
bcc-csm1	6.5	-6.9	-18.5	-2.0	-22.2	-13.9	-1.6	-4.9	-6.7	8.6	-2.4	-10.4	-7.9	7.8	-1.6	11.2
BNU-ESM	48.0	86.2	141.7	35.3	42.4	97.3	116.4	38.6	55.9	104.3	107.9	21.5	38.6	106.8	170.6	12.0
CanESM2	4.7	31.9	29.6	34.0	9.6	26.8	37.9	63.1	31.5	50.4	17.8	39.7	56.9	88.9	41.2	42.5
CCSM4	-15.2	-25.1	6.5	-0.3	-1.2	-6.1	3.8	-0.3	-25.5	-20.8	4.2	-1.5	-33.6	-11.4	20.9	6.3
CESM1-BGC	-19.3	-9.0	20.2	12.8	-19.1	-18.2	19.2	3.8	-7.0	12.0	20.6	-3.5	-38.5	-0.9	29.6	3.5
CSIRO-Mk3	83.1	18.9	3.7	7.4	24.4	31.5	27.0	12.9	29.2	40.9	2.5	4.8	21.0	29.8	15.3	14.4
GFDL-ESM2G	33.3	37.6	-13.7	-20.0	-1.9	20.0	-10.2	-23.1	-45.4	-22.6	-13.9	-8.5	-16.4	5.5	-9.4	-23.7
GFDL-ESM2M	11.3	1.8	2.8	-7.4	-0.4	19.3	9.5	14.6	6.9	7.0	-0.9	-8.3	-28.0	-12.0	-5.3	4.0
HadGEM2-CC	5.3	-1.4	-15.4	-10.2	-5.3	-11.1	-12.0	-26.9	40.3	20.7	14.8	-7.5	71.2	34.0	9.7	-20.9
HadGEM2-ES	-8.2	-7.6	-16.4	-16.8	-27.0	-11.9	15.1	1.3	-3.3	11.5	1.0	-6.8	26.9	28.5	19.0	-13.9
inmcm4	-4.2	-9.6	14.6	11.9	17.9	-0.9	4.3	16.2	-25.2	3.4	26.5	16.4	1.6	0.9	17.1	20.4
IPSL-CM5A-LR	67.8	84.5	28.5	-17.6	149.0	121.5	25.9	-20.7	88.4	99.2	25.9	-28.4	126.7	155.9	58.5	-37.4
IPSL-CM5A-MR	51.8	56.8	36.6	9.3	30.6	31.3	28.4	23.1	82.4	92.4	48.3	6.5	113.5	103.9	116.9	48.3
MIROC5	-10.6	-11.7	3.7	38.1	3.2	-12.6	-0.8	50.4	0.1	-8.7	8.5	49.9	12.9	-8.8	8.4	30.6
MIROC-ESM	-37.8	-20.8	65.4	-11.0	-44.0	-21.6	81.5	0.0	-41.7	-31.3	87.7	3.2	-48.5	-40.3	60.4	-13.4
MPI-ESM-LR	23.8	-2.6	9.5	16.0	9.8	-10.4	10.7	10.8	-3.8	-10.8	0.3	-2.8	14.7	-9.9	26.9	25.1
MPI-ESM-MR	9.8	16.6	20.0	27.8	-8.1	13.8	31.5	15.4	-0.2	15.3	11.0	4.9	-8.9	-12.6	2.2	4.0
MRI-CGCM3	12.6	5.5	12.2	7.5	31.4	41.0	11.3	6.6	32.5	50.4	13.1	0.7	72.0	83.3	45.2	12.8
NorESM1-M	30.5	42.2	-5.3	7.3	-14.6	11.7	-2.9	3.6	-18.3	-4.7	-2.6	3.3	-6.2	10.3	-0.7	11.8
Average	**14.2**	**14.7**	**16.5**	**6.5**	**8.2**	**15.9**	**20.3**	**8.8**	**9.9**	**22.1**	**18.9**	**3.8**	**19.5**	**29.9**	**32.3**	**7.3**
Median	**8.2**	**3.6**	**8.0**	**7.4**	**-0.8**	**11.3**	**11.5**	**5.2**	**0.0**	**11.7**	**9.7**	**2.0**	**13.8**	**9.0**	**20.0**	**9.6**

Annex 7: Projected changes in the rainfall during season 2 (Oct-Dec) for selected locations under RCPs 4.5 and 8.5 for mid (2040-2070) and end (2070-2100) period

GCMS	4.5 MID				4.5 END				8.5 MID				8.5 END			
	Adi-gudom	Nazeret	Embu	Dodoma	Adi-gudom	Nazeret	Embu	Dodoma	Adi-gudom	Nazeret	Embu	Dodoma	Adi-gudom	Nazeret	Embu	Dodoma
ACCESS1	-3.6	-5.9	4.4	-3.8	-0.8	-3.8	40.2	1.7	18.0	-5.3	38.5	8.9	5.9	-1.5	138.5	31.3
bcc-csm1	-8.8	0.4	18.0	11.0	-5.7	4.3	1.5	-2.0	-2.5	5.3	9.5	6.7	11.7	10.6	83.5	4.3
BNU-ESM	28.5	10.9	34.3	-13.6	44.5	18.4	28.6	-10.2	22.7	14.1	33.7	-8.2	54.9	22.7	147.0	-14.6
CanESM2	12.5	4.9	45.8	7.3	14.7	7.7	76.3	16.4	8.1	4.9	82.6	24.2	32.4	20.6	240.7	34.6
CCSM4	7.6	-3.3	1.5	2.1	10.1	-2.4	-4.6	-6.8	8.1	-7.5	-13.1	-12.1	15.7	1.8	138.5	4.3
CESM1-BGC	25.9	0.5	14.5	3.8	20.9	-2.1	10.5	8.7	33.1	-6.7	13.1	-3.1	32.4	6.7	80.9	3.3
CSIRO-Mk3	-10.1	-18.7	-1.2	12.7	-42.7	-16.7	16.5	9.0	-18.7	-10.8	24.4	10.4	-16.2	-24.1	112.6	21.7
GFDL-ESM2G	4.0	2.3	-19.8	-0.7	-0.8	-0.9	-27.5	-1.8	7.2	-8.1	-27.4	-5.3	3.4	-2.1	-15.8	-10.5
GFDL-ESM2M	0.3	-0.6	-7.5	-8.8	-4.9	2.4	23.7	2.7	-4.9	-5.3	16.2	4.4	-12.4	5.3	40.3	-1.8
HadGEM2-CC	10.7	-0.4	-18.5	-11.7	1.1	1.3	-28.8	15.5	11.1	0.0	7.4	-3.6	18.5	8.3	72.8	1.5
HadGEM2-ES	-9.3	-5.2	-14.3	15.6	0.1	1.1	-12.3	13.5	1.1	-4.6	14.1	5.4	12.9	5.5	76.7	14.1
inmcm4	-9.0	-4.9	-2.2	-4.3	-16.2	-4.8	4.5	-7.1	8.7	5.0	-1.8	-3.9	6.6	6.2	55.8	1.7
IPSL-CM5A-LR	28.7	17.5	36.0	4.2	83.6	18.3	59.6	2.8	90.0	25.3	39.3	8.2	190.1	39.6	181.0	3.1
IPSL-CM5A-MR	121.8	48.5	21.1	-1.5	3.3	8.1	29.0	31.1	151.1	77.4	38.6	14.4	188.3	135.7	150.2	28.4
MIROC5	20.4	17.9	-9.1	44.4	25.6	21.5	-19.9	52.1	44.6	30.1	-31.6	60.8	54.0	59.6	18.7	49.8
MIROC-ESM	3.4	-6.7	26.4	-9.8	11.9	-9.3	34.3	-16.3	22.1	1.2	47.5	-22.5	30.9	4.2	150.3	-8.2
MPI-ESM-LR	-14.7	9.6	-12.6	-11.4	-21.1	17.5	0.6	0.2	-4.8	10.2	2.7	6.5	-25.9	35.1	53.0	24.6
MPI-ESM-MR	-17.1	10.0	-9.1	-3.0	-20.0	22.5	-10.7	11.9	-15.9	17.4	-14.1	6.9	-25.3	21.0	33.4	46.5
MRI-CGCM3	1.2	-2.5	30.9	9.4	20.2	-8.1	34.0	2.3	-1.2	-7.8	20.1	19.2	9.3	-14.2	130.4	-0.3
NorESM1-M	7.0	-6.1	-5.3	-7.8	6.8	-8.8	-15.1	0.8	11.4	-9.2	-19.7	5.3	12.7	-1.4	22.8	-7.9
Average	**10.0**	**3.4**	**6.7**	**1.7**	**6.5**	**3.3**	**12.0**	**6.2**	**19.5**	**6.3**	**14.0**	**6.1**	**30.0**	**17.0**	**95.6**	**11.3**
Median	**3.7**	**0.0**	**0.2**	**-1.1**	**2.2**	**1.2**	**7.5**	**2.5**	**8.4**	**0.6**	**13.6**	**5.9**	**12.8**	**6.5**	**82.2**	**3.8**

Annex 8: Projected changes in annual rainfall at other locations under RCPs 4.5 for mid (2040-2070) and end-century (2070-2100) periods

GCMS	4.5 MID											4.5 END										
	Wonji	**Melkasa**	**Adimesanu**	**Hintalo**	**Wami Prison**	**Mlali**	**Kongwa**	**Masandi**	**Ishiara**	**Karurumo**	**Kindaruma**	**Wonji**	**Melkasa**	**Adimesanu**	**Hintalo**	**Wami Prison**	**Mlali**	**Kongwa**	**Masandi**	**Ishiara**	**Karurumo**	**Kindaruma**
ACCESS1	-1.9	-2.1	-8.3	-5.2	2.6	-26.4	-11.8	0.8	9.8	6.2	4.3	2.6	1.6	-6.3	-2.8	-5.4	-33.5	-9.7	4.3	32.8	28.4	32.6
bcc-csm1	0.8	-5.0	-4.4	-5.1	9.6	-11.7	-3.3	0.8	-1.8	-1.8	-3.5	2.1	-2.1	-7.0	-7.3	8.2	-15.2	-1.0	-1.0	-1.2	-0.2	-3.5
BNU-ESM	41.8	-5.0	-4.4	-5.1	10.2	-17.5	3.9	38.5	102.1	96.0	98.3	52.2	-2.1	-7.0	-7.3	12.6	-15.1	5.2	37.7	88.4	83.4	84.7
CanESM2	16.9	25.7	14.2	14.4	24.8	-5.8	18.0	12.8	35.8	36.6	33.3	20.5	33.1	18.5	17.5	42.3	5.6	36.8	16.2	54.2	54.3	51.3
CCSM4	-2.9	-3.8	2.4	4.4	2.9	-20.0	0.0	12.4	7.7	5.6	5.5	6.3	4.6	10.7	8.7	1.4	-19.7	-3.9	11.1	0.9	-0.3	-0.5
CESM1-BGC	-4.0	-4.3	18.0	16.7	7.0	-15.9	3.4	14.0	17.5	17.8	15.0	-5.6	-5.9	7.8	13.2	6.3	-14.9	0.6	12.1	16.4	15.7	14.1
CSIRO-Mk3	-6.8	-7.7	-17.2	5.2	2.2	-20.6	-8.6	-7.0	14.6	9.1	11.8	1.1	-1.1	-20.9	-29.1	6.0	-18.1	-6.9	-2.5	35.7	30.1	32.2
GFDL-ESM2G	11.9	10.3	8.5	8.9	-7.9	-26.6	-3.5	15.0	0.1	-1.4	-2.0	4.6	4.0	-1.0	-0.7	-8.2	-27.7	1.5	13.9	-1.4	-3.3	-3.5
GFDL-ESM2M	1.3	1.6	4.6	5.5	3.7	-19.7	-8.0	0.0	1.5	0.0	0.2	8.5	8.8	-1.2	-1.6	20.9	-10.1	16.7	45.0	17.2	14.6	14.4
HadGEM2-CC	1.5	1.1	3.3	8.6	-9.2	-27.2	-10.3	-0.9	-10.8	-12.2	-12.4	0.5	-0.2	-0.7	-1.5	3.8	-22.0	-2.7	-0.1	-2.7	-8.3	-0.4
HadGEM2-ES	-4.3	-4.4	-7.0	-9.1	0.9	-21.8	-4.9	-0.9	-2.0	-4.2	-7.6	1.0	0.5	-3.2	-4.5	-7.2	-28.9	0.1	7.6	16.6	12.3	9.8
inmcm4	-5.9	-6.1	-8.5	-8.2	3.2	-19.5	-4.2	1.2	8.9	7.2	6.9	-4.4	-4.1	-10.4	-9.8	1.4	-21.0	-3.2	-0.1	6.5	5.4	3.9
IPSL-CM5A-LR	43.8	42.8	36.6	78.2	8.6	-14.2	-1.9	23.1	40.2	37.7	36.8	56.6	55.4	94.1	145.2	1.0	-21.2	-7.3	27.9	54.7	49.2	49.9
IPSL-CM5A-MR	57.6	58.2	106.4	109.3	6.1	-19.9	0.3	23.7	31.8	31.9	15.2	17.6	18.2	11.0	13.2	14.8	-11.2	5.9	18.4	32.4	31.7	27.9
MIROC5	9.4	3.6	13.5	13.9	43.1	11.4	31.6	-5.9	-3.0	-2.6	-4.9	9.5	4.9	19.7	19.3	55.0	21.6	40.7	-5.9	-9.6	-10.5	-10.7
MIROC-ESM	-8.8	-3.0	-0.8	-0.6	8.7	-13.7	-11.8	-9.6	57.5	51.9	54.4	-9.2	-6.9	5.2	5.2	-2.7	-24.4	-19.4	0.1	68.7	64.3	66.0
MPI-ESM-LR	8.4	8.4	-13.1	-4.5	28.0	-6.4	-0.1	23.9	5.4	2.4	4.1	11.5	11.6	-14.9	-11.9	26.3	-6.8	1.5	27.9	13.6	11.1	11.8
MPI-ESM-MR	11.5	11.3	-2.7	-11.2	31.7	-1.3	4.8	17.5	15.6	10.7	14.0	24.7	23.0	-3.8	-13.7	26.2	-3.0	5.7	25.6	13.3	11.9	11.9
MRI-CGCM3	-0.9	-1.3	2.7	1.0	2.7	-21.9	-5.3	3.7	3.1	18.0	1.8	4.0	4.3	20.9	20.9	12.2	-14.7	-3.9	4.4	24.2	24.1	21.5
NorESM1-M	9.8	8.4	11.3	11.9	0.7	-22.2	-7.1	14.6	-2.1	-3.0	-3.8	-0.2	-0.9	3.9	-0.2	0.2	-22.1	-7.8	20.7	-4.1	-5.1	-5.7
Average	**9.0**	**6.4**	**7.8**	**11.5**	**9.0**	**-16.0**	**-0.9**	**8.9**	**16.6**	**15.3**	**13.4**	**10.2**	**7.3**	**5.8**	**7.6**	**10.8**	**-15.1**	**2.4**	**13.2**	**22.8**	**20.4**	**20.4**
Median	**1.4**	**-0.1**	**2.5**	**4.8**	**4.9**	**-19.6**	**-3.4**	**8.1**	**8.3**	**6.7**	**4.9**	**4.3**	**2.8**	**-0.9**	**-1.1**	**6.1**	**-16.6**	**-0.4**	**11.6**	**16.5**	**13.4**	**13.0**

Annex 9: Projected changes in annual rainfall at other locations under RCPs 8.5 for mid (2040-2070) and end-century (2070-2100) periods

GCMS	8.5 MID											8.5 END										
	Wonji	**Melkasa**	**Adimesanu**	**Hintalo**	**Wami Prison**	**Mlali**	**Kongwa**	**Masandi**	**Ishiara**	**Karurumo**	**Kindaruma**	**Wonji**	**Melkasa**	**Adimesanu**	**Hintalo**	**Wami Prison**	**Mlali**	**Kongwa**	**Masandi**	**Ishiara**	**Karurumo**	**Kindaruma**
ACCESS1	3.1	2.1	3.8	14.0	-0.5	-25.6	-11.8	-0.5	29.0	26.3	24.4	10.7	8.9	-1.1	7.2	0.8	-27.7	2.2	4.3	51.5	46.5	38.8
bcc-csm1	7.0	7.2	-1.7	-1.9	6.0	-14.7	-3.3	5.0	0.0	1.6	-2.2	11.9	10.8	9.8	9.6	12.1	-13.7	1.9	-1.0	11.2	11.5	8.0
BNU-ESM	52.3	7.2	-1.7	-1.9	7.9	-17.8	3.9	0.7	79.5	78.0	75.4	57.1	10.8	9.8	9.6	4.6	-20.0	-7.1	37.7	131.0	126.9	125.9
CanESM2	26.2	32.5	17.1	15.4	39.4	6.9	18.0	-2.6	45.5	47.9	42.0	54.8	52.5	44.7	44.0	54.0	14.4	54.6	16.2	79.8	81.6	75.4
CCSM4	-1.3	-1.8	3.6	3.6	0.1	-20.8	0.0	4.8	-1.5	-2.8	-3.1	11.5	10.2	5.0	8.1	9.8	-15.1	-31.3	11.1	9.5	8.8	7.4
CESM1-BGC	2.3	2.0	16.3	24.9	4.2	-15.6	3.4	-10.8	19.5	18.7	16.8	16.9	15.4	12.5	20.0	14.2	-10.5	1.0	12.1	29.9	29.1	26.7
CSIRO-Mk3	6.2	3.8	-14.1	-10.4	0.4	-23.2	-8.6	4.3	23.7	19.1	19.6	-2.0	-4.6	-17.5	-8.6	24.1	-5.8	-4.6	-2.5	49.7	41.9	44.3
GFDL-ESM2G	-11.2	-11.4	-2.6	-1.7	0.4	-24.2	-3.5	31.3	-12.1	-13.9	-13.7	1.7	1.0	0.3	1.3	-7.0	-30.1	54.8	13.9	-13.8	-17.2	-16.0
GFDL-ESM2M	1.1	0.7	0.4	0.3	12.7	-12.9	-8.0	18.4	13.5	11.2	11.3	4.1	4.3	-10.5	-9.1	20.6	-11.6	-13.1	45.0	8.1	5.4	5.8
HadGEM2-CC	10.3	8.9	10.6	14.4	-11.7	-30.0	-10.3	7.5	30.3	25.0	15.6	17.8	16.4	13.8	23.7	-11.7	-37.2	-27.7	-0.1	34.1	27.2	15.7
HadGEM2-ES	0.6	0.5	-2.1	0.5	-7.4	-30.6	-4.9	0.8	22.6	19.3	12.3	14.4	13.3	8.8	15.1	-12.5	-34.9	-0.7	7.6	41.7	35.8	17.0
inmcm4	5.8	5.8	3.1	3.8	1.0	-22.1	-4.2	9.2	17.8	14.7	15.6	6.4	6.6	5.9	7.5	2.3	-21.1	8.4	-0.1	14.0	12.7	11.5
IPSL-CM5A-LR	55.7	55.3	88.8	19.9	2.4	-18.7	-1.9	4.5	44.3	39.6	148.2	81.8	81.1	175.4	170.4	-0.5	-21.4	-12.9	27.9	86.7	81.2	80.7
IPSL-CM5A-MR	87.6	84.6	135.8	134.6	1.3	-22.9	0.3	30.8	50.1	48.2	32.2	126.5	128.0	168.5	170.3	18.7	-13.5	29.6	18.4	102.8	97.4	58.1
MIROC5	19.0	7.0	34.3	34.5	53.4	20.7	31.6	6.4	-8.8	-10.6	-9.8	41.2	19.6	45.9	47.1	36.4	11.9	-0.1	-5.9	-2.9	-4.5	-4.4
MIROC-ESM	-3.6	1.8	14.4	14.5	6.0	-19.6	-11.8	-1.0	75.2	70.7	73.0	-1.4	-0.9	24.0	23.9	6.1	-18.4	-22.0	0.1	62.1	62.5	61.2
MPI-ESM-LR	7.7	7.1	-6.6	-2.0	18.3	-11.7	-0.1	9.5	10.3	7.8	8.3	22.6	23.2	-12.5	-10.9	61.5	20.2	29.1	27.9	28.7	22.8	26.1
MPI-ESM-MR	17.7	16.6	-3.3	-8.6	14.4	-13.4	4.8	19.4	4.5	0.5	2.4	16.4	14.7	-7.8	-15.1	39.8	5.4	-5.6	25.6	9.0	1.9	6.4
MRI-CGCM3	8.1	7.3	4.5	4.6	12.9	-13.1	-5.3	31.7	26.8	21.8	24.1	14.7	13.2	20.6	18.4	16.0	-16.1	-12.4	4.4	64.6	57.1	60.7
NorESM1-M	-3.4	-4.5	6.4	3.1	-3.8	-24.8	-7.1	2.8	-6.9	-7.9	-8.2	8.4	7.6	13.5	17.1	-4.4	-27.6	-7.5	20.7	-5.1	-6.7	-6.4
Average	**14.6**	**11.6**	**15.4**	**13.1**	**7.9**	**-16.7**	**-0.9**	**8.6**	**23.2**	**20.8**	**24.2**	**25.8**	**21.6**	**25.5**	**27.5**	**14.2**	**-13.6**	**1.8**	**13.2**	**39.6**	**36.1**	**32.1**
Median	**6.6**	**6.4**	**3.7**	**3.7**	**3.3**	**-19.1**	**-3.4**	**4.9**	**21.1**	**18.9**	**15.6**	**14.5**	**12.0**	**9.8**	**12.3**	**10.9**	**-15.6**	**-2.6**	**11.6**	**32.0**	**28.1**	**21.5**

Annex 10: Projected changes in season 1 (Oct-Dec) rainfall at other locations under RCPs 4.5 for mid (2040-2070) and end-century (2070-2100) periods

GCMS	4.5 MID											4.5 END										
	Wonji	**Melkasa**	**Adimesanu**	**Hintalo**	**Wami Prison**	**Mlali**	**Kongwa**	**Masandi**	**Ishiara**	**Karurumo**	**Kindaruma**	**Wonji**	**Melkasa**	**Adimesanu**	**Hintalo**	**Wami Prison**	**Mlali**	**Kongwa**	**Masandi**	**Ishiara**	**Karurumo**	**Kindaruma**
ACCESS1	8.2	7.8	-3.6	-9.1	32.8	-25.2	10.8	4.0	9.6	5.9	22.8	14.4	11.1	0.0	-11.5	4.6	-41.5	-1.1	-3.6	16.9	13.5	39.5
bcc-csm1	-5.4	-3.3	6.6	3.5	3.5	-35.2	1.1	2.7	-16.1	-17.7	-10.0	-13.1	-8.7	-22.4	-24.3	3.2	-33.8	-0.6	3.9	-4.5	-2.4	1.5
BNU-ESM	91.9	-3.3	6.6	3.5	42.6	-11.2	39.6	24.6	142.8	141.9	159.9	100.9	-8.7	-22.4	-24.3	44.4	-10.5	42.2	33.1	117.0	116.5	132.1
CanESM2	31.4	40.2	4.7	6.1	44.1	-9.3	39.7	12.9	30.3	30.1	39.1	30.2	53.3	9.2	7.5	74.0	9.3	69.3	17.4	42.6	40.2	52.2
CCSM4	-11.8	-13.9	-26.4	-18.4	9.4	-29.2	4.8	2.3	11.7	9.1	19.0	21.9	17.0	-0.1	-2.4	8.1	-29.4	4.7	6.0	6.4	4.9	13.8
CESM1-BGC	-6.4	-7.1	-23.2	-22.6	16.2	-27.4	18.1	4.0	18.5	19.8	26.2	-15.4	-15.9	-19.9	-21.6	10.4	-28.5	9.7	1.3	20.0	19.8	28.0
CSIRO-Mk3	21.8	19.6	58.9	67.1	12.8	-33.8	8.5	-9.0	15.7	8.7	24.2	36.8	32.5	32.0	8.2	17.2	-30.9	16.1	-4.4	39.4	32.6	49.0
GFDL-ESM2G	44.5	38.4	33.3	31.7	-16.6	-48.4	5.9	10.4	-7.0	-9.1	-0.2	23.9	20.7	-2.2	-3.9	-22.8	-53.1	8.7	23.9	-6.3	-8.9	0.3
GFDL-ESM2M	-0.5	1.6	11.3	18.0	-1.5	-38.0	10.7	12.5	9.0	7.0	16.8	18.1	19.9	-0.9	1.3	15.6	-29.6	24.2	24.6	13.9	11.7	22.0
HadGEM2-CC	0.2	-1.1	2.9	-0.3	-14.9	-41.0	-10.7	-4.3	-14.6	-15.0	-10.2	-9.8	-10.9	-5.4	-11.5	-8.9	-48.4	-25.8	-7.4	-3.8	-8.1	4.0
HadGEM2-ES	-8.3	-7.6	0.1	-10.6	-16.3	-46.9	-14.9	-7.6	-15.9	-16.0	-9.5	-12.3	-11.9	-19.8	-26.6	2.3	-39.5	3.3	-2.9	21.9	18.4	22.2
inmcm4	-8.6	-9.6	-4.2	-5.7	18.9	-24.3	16.9	-2.8	16.0	14.8	24.6	-1.2	-0.6	17.6	18.1	20.8	-22.7	22.2	-0.7	4.9	4.6	12.2
IPSL-CM5A-LR	89.9	85.9	67.8	175.3	-13.4	-45.8	-15.2	30.1	33.5	30.7	42.8	127.1	123.9	148.2	163.2	-17.3	-48.5	-18.7	33.9	40.4	32.7	49.8
IPSL-CM5A-MR	58.1	57.5	51.8	48.5	8.5	-32.6	6.6	33.2	33.0	35.1	20.2	32.0	32.0	30.0	34.5	17.7	-27.8	17.2	21.5	26.9	28.2	20.8
MIROC5	-10.7	-6.3	-10.6	-13.3	34.1	-20.1	36.6	-4.8	1.3	2.8	8.2	-11.7	-12.2	2.8	-1.9	48.0	-11.6	49.9	-6.0	1.1	0.0	8.2
MIROC-ESM	-25.8	-12.1	-37.8	-32.9	2.5	-33.8	-7.0	-11.1	74.1	69.1	86.4	-23.7	-10.4	-44.2	-41.7	2.3	-35.6	-7.1	-0.1	89.2	85.0	102.3
MPI-ESM-LR	-3.3	-2.6	7.9	33.2	61.5	4.3	23.9	3.8	13.3	10.4	22.1	-12.0	-10.6	-10.1	16.5	56.9	2.2	18.1	3.3	15.7	12.0	24.8
MPI-ESM-MR	20.4	17.2	14.3	11.4	59.1	0.5	33.8	-2.7	28.0	23.0	37.6	19.4	14.5	-7.4	-10.0	44.7	-6.7	23.4	-4.2	30.3	30.9	39.4
MRI-CGCM3	6.8	5.3	12.6	10.8	22.7	-28.0	9.6	5.3	1.3	12.3	8.0	41.5	41.3	31.1	30.0	22.7	-33.5	9.4	13.5	14.1	12.5	22.2
NorESM1-M	47.5	43.1	30.5	9.7	-2.7	-39.7	-4.1	-15.7	-3.0	-4.7	3.7	16.1	12.4	-14.8	-16.9	-5.0	-40.4	-7.3	-10.9	-0.7	-2.2	6.1
Average	**17.0**	**12.5**	**10.2**	**15.3**	**15.2**	**-28.3**	**10.7**	**4.4**	**19.1**	**17.9**	**26.6**	**19.1**	**14.4**	**5.1**	**4.1**	**17.0**	**-28.0**	**12.9**	**7.1**	**24.3**	**22.1**	**32.5**
Median	**3.5**	**0.3**	**6.6**	**4.8**	**11.1**	**-30.9**	**9.1**	**3.2**	**12.5**	**9.7**	**21.2**	**17.1**	**11.8**	**-1.5**	**-3.2**	**13.0**	**-30.2**	**9.5**	**2.3**	**16.3**	**13.0**	**22.2**

Annex 11: Projected changes in season 1 (Oct-Dec) rainfall at different locations under RCPs 8.5 for mid (2040-2070) and end-century (2070-2100) periods

GCMS	8.5 MID											8.5 END										
	Wonji	**Melkasa**	**Adimesanu**	**Hintalo**	**Wami Prison**	**Mlali**	**Kongwa**	**Masandi**	**Ishiara**	**Karurumo**	**Kindaruma**	**Wonji**	**Melkasa**	**Adimesanu**	**Hintalo**	**Wami Prison**	**Mlali**	**Kongwa**	**Masandi**	**Ishiara**	**Karurumo**	**Kindaruma**
ACCESS1	27.2	24.4	12.5	5.3	18.2	-32.7	10.8	-4.2	10.4	8.7	26.9	43.7	40.0	26.8	18.1	19.0	-32.9	13.3	-3.6	30.1	25.0	48.2
bcc-csm1	10.3	13.8	-6.7	-6.6	-3.3	-38.3	1.1	1.1	-5.1	-3.4	1.1	11.0	17.7	-8.1	-11.2	15.3	-28.7	0.4	3.9	-2.5	-1.3	4.0
BNU-ESM	111.8	13.8	-6.7	-6.6	28.5	-19.4	39.6	-3.1	99.0	104.5	112.0	109.5	17.7	-8.1	-11.2	21.1	-23.0	2.9	33.1	170.2	172.7	187.8
CanESM2	58.9	73.3	31.5	23.6	48.3	-7.1	39.7	-5.2	19.2	18.8	27.0	97.6	93.4	56.2	50.9	62.3	6.4	30.7	17.4	45.3	44.2	54.8
CCSM4	-10.4	-9.9	-23.6	-23.8	11.4	-25.6	4.8	-8.7	6.9	5.5	14.2	7.3	4.1	-36.9	-39.6	16.4	-26.7	-27.9	6.0	16.7	17.2	24.1
CESM1-BGC	21.1	21.5	-1.8	-10.3	6.7	-31.7	18.1	-9.2	20.6	21.0	28.4	11.4	9.0	-35.8	-42.0	19.3	-24.6	-0.7	1.3	30.1	31.2	38.3
CSIRO-Mk3	46.3	41.8	48.5	12.0	9.0	-36.8	8.5	-12.1	13.0	7.6	20.3	34.3	30.7	49.3	3.0	18.0	-33.2	3.2	-4.4	32.0	23.7	40.9
GFDL-ESM2G	-22.9	-22.8	-45.4	-45.2	-12.9	-49.0	5.9	36.6	-13.6	-16.6	-7.3	7.4	5.9	-16.7	-14.8	-29.0	-58.8	20.6	23.9	-20.4	-25.1	-14.9
GFDL-ESM2M	6.6	7.1	6.9	8.3	-3.0	-39.6	10.7	28.5	16.0	13.8	24.0	-15.2	-12.4	-28.5	-20.8	2.8	-38.5	-10.6	24.6	4.8	2.1	12.1
HadGEM2-CC	24.1	21.3	34.1	27.5	-10.3	-44.5	-10.7	-1.8	22.9	18.6	13.4	36.5	34.8	55.5	59.7	-20.1	-53.6	-35.7	-7.4	23.2	16.4	17.6
HadGEM2-ES	11.1	11.8	4.7	-1.7	-8.0	-43.8	-14.9	-3.0	6.1	3.8	15.0	28.6	29.1	39.0	27.5	-16.4	-53.1	9.3	-2.9	31.8	25.5	24.6
inmcm4	3.9	3.5	-25.2	-27.1	19.1	-24.5	16.9	-3.7	31.2	28.3	40.6	2.7	1.3	1.4	0.9	22.8	-22.4	45.5	-0.7	19.1	18.6	27.3
IPSL-CM5A-LR	100.5	100.8	88.3	175.4	-20.9	-49.1	-15.2	5.0	35.6	30.6	127.7	158.0	158.0	125.8	174.0	-29.5	-54.4	-46.3	33.9	68.1	64.2	79.0
IPSL-CM5A-MR	98.4	93.3	82.4	83.4	-6.8	-42.8	6.6	42.9	47.8	46.8	32.8	110.8	104.2	112.6	112.7	7.9	-35.7	63.6	21.5	122.5	119.2	62.9
MIROC5	-8.3	-10.6	0.1	-1.8	43.6	-15.5	36.6	8.5	10.4	9.2	18.2	-8.1	-8.2	12.5	8.6	23.1	-28.6	16.5	-6.0	11.0	10.2	18.7
MIROC-ESM	-35.0	-23.3	-41.7	-36.7	22.8	-24.4	-7.0	-7.1	98.3	91.9	112.7	-43.6	-30.8	-48.8	-44.8	8.0	-29.2	-21.5	-0.1	70.9	65.9	82.7
MPI-ESM-LR	-10.7	-11.1	-11.8	-1.8	17.1	-29.6	23.9	-0.2	6.6	2.3	14.9	-10.4	-10.0	-12.9	26.7	82.1	12.3	31.0	3.3	36.4	30.8	47.1
MPI-ESM-MR	22.0	15.7	-4.4	-0.6	39.2	-12.7	33.8	23.3	16.1	12.8	24.7	-10.6	-12.5	-23.8	-5.1	48.7	-6.6	-17.9	-4.2	14.2	7.5	22.9
MRI-CGCM3	53.1	50.8	32.5	31.1	31.0	-27.4	9.6	22.8	24.7	15.9	33.2	86.2	84.2	71.5	70.3	29.7	-35.5	4.8	13.5	69.8	54.8	81.4
NorESM1-M	-0.9	-4.5	-18.3	-21.3	-10.9	-43.6	-4.1	17.7	-0.7	-2.2	6.3	10.9	10.5	-6.5	-19.7	-6.0	-43.5	-15.8	-10.9	3.4	1.2	10.7
Average	**25.4**	**20.5**	**7.8**	**9.2**	**10.9**	**-31.9**	**10.7**	**6.4**	**23.3**	**20.9**	**34.3**	**33.4**	**28.3**	**16.2**	**17.2**	**14.8**	**-30.5**	**3.3**	**7.1**	**38.8**	**35.2**	**43.5**
Median	**16.1**	**13.8**	**-0.9**	**-1.7**	**10.2**	**-32.2**	**9.1**	**-1.0**	**16.0**	**13.3**	**24.3**	**11.2**	**14.1**	**-2.6**	**2.0**	**17.2**	**-31.0**	**3.0**	**2.3**	**30.1**	**24.4**	**32.8**

Annex 12: Projected changes in season 2 (Mar-May) rainfall at different locations under RCPs 4.5 for mid (2040-2070) and end-century (2070-2100) periods

GCMS	4.5 MID											4.5 END										
	Wonji	**Melkasa**	**Adimesanu**	**Hintalo**	**Wami Prison**	**Mlali**	**Kongwa**	**Masandi**	**Ishiara**	**Karurumo**	**Kindaruma**	**Wonji**	**Melkasa**	**Adimesanu**	**Hintalo**	**Wami Prison**	**Mlali**	**Kongwa**	**Masandi**	**Ishiara**	**Karurumo**	**Kindaruma**
ACCESS1	-5.7	-5.9	-9.3	-3.9	-10.0	-17.8	-15.2	-7.6	10.1	6.5	-15.7	-3.4	-3.7	-8.5	-1.1	-8.0	-22.4	-9.5	-4.5	51.7	44.9	31.6
bcc-csm1	-0.1	-6.0	-8.8	-9.1	12.0	11.7	-1.1	-5.4	11.7	12.4	4.8	4.1	-2.1	-5.6	-5.4	-1.7	-2.3	-12.7	-8.0	1.2	1.1	-5.9
BNU-ESM	11.2	-6.0	-8.8	-9.1	-13.9	-16.5	-20.9	24.0	42.0	38.5	30.9	18.9	-2.1	-5.6	-5.4	-9.7	-12.0	-18.0	23.4	37.3	33.2	26.4
CanESM2	5.1	19.3	12.5	12.9	2.0	-1.2	-3.6	13.0	39.0	41.4	30.3	7.8	24.2	14.7	14.7	8.7	4.5	4.8	11.1	64.4	67.9	54.6
CCSM4	-3.3	-3.4	7.4	8.6	-4.0	-11.4	-7.1	17.2	1.6	0.3	-5.6	-2.4	-2.5	12.6	11.0	-10.8	-14.3	-14.9	11.8	-8.6	-8.5	-14.5
CESM1-BGC	-7.5	-7.0	27.0	25.5	-4.1	-5.1	-5.3	15.3	15.0	14.6	6.9	-5.1	-4.8	13.1	20.3	1.8	-2.5	-1.2	7.6	12.4	11.5	4.3
CSIRO-Mk3	-19.1	-19.1	-35.3	-6.6	5.6	1.1	0.8	-7.4	4.3	2.2	-3.8	-17.2	-17.1	-37.1	-40.9	8.2	2.6	-2.0	-10.2	20.9	19.6	11.8
GFDL-ESM2G	2.4	2.1	4.0	4.9	-3.0	-5.5	-5.8	12.7	-0.1	-1.5	-7.4	-0.9	-0.8	-0.8	-0.4	-5.4	-8.4	-0.1	8.4	-1.5	-2.5	-8.9
GFDL-ESM2M	-0.6	-0.5	0.3	0.9	-7.4	-8.9	-35.7	-23.2	-14.9	-14.0	-20.5	2.5	2.8	-4.9	-4.3	-1.3	-5.0	-6.2	73.7	13.4	12.0	4.7
HadGEM2-CC	-0.5	-0.7	2.2	10.6	-11.7	-13.7	-19.3	-6.9	-15.5	-17.7	-14.0	1.2	1.1	-1.3	1.7	1.8	-4.5	4.0	-8.3	-24.9	-27.0	-18.9
HadGEM2-ES	-5.1	-5.2	-9.5	-9.1	9.8	0.2	4.0	-7.5	-8.2	-10.3	-12.3	1.0	0.6	-2.3	-0.3	-7.0	-13.7	2.3	-0.8	-3.9	-6.7	-8.5
inmcm4	-5.1	-4.8	-9.0	-8.4	-6.2	-8.1	-13.6	3.6	0.0	-0.6	-7.3	-5.6	-5.1	-16.2	-15.6	-7.7	-10.3	-15.6	-0.8	9.0	7.2	0.7
IPSL-CM5A-LR	17.2	18.3	28.7	57.0	7.2	5.7	-4.9	12.2	38.1	37.2	28.1	18.3	19.6	83.8	146.1	0.6	-3.1	-6.0	17.2	71.0	66.6	57.4
IPSL-CM5A-MR	48.5	49.5	121.8	124.7	-12.4	-14.9	-19.6	18.0	18.8	19.5	9.1	7.6	8.7	3.4	5.0	4.9	3.1	-4.8	12.6	33.7	32.1	37.0
MIROC5	18.1	8.0	20.4	21.0	41.2	37.6	30.3	-3.3	-8.5	-8.5	-15.0	20.8	12.7	25.7	26.3	52.6	50.5	36.9	-6.9	-23.8	-22.7	-28.6
MIROC-ESM	-6.9	-2.1	3.4	3.5	18.0	10.7	-8.7	-8.3	30.2	28.3	20.5	-9.4	-8.4	12.0	12.0	-7.2	-10.6	-28.5	-3.2	35.1	34.4	25.5
MPI-ESM-LR	9.2	9.8	-18.3	-13.5	-12.0	-16.2	-19.5	24.4	-8.0	-9.7	-15.1	17.1	17.5	-18.7	-20.2	-12.8	-16.7	-10.4	10.9	4.3	3.4	-3.5
MPI-ESM-MR	9.1	9.9	-4.5	-16.4	10.9	4.1	-11.8	26.4	-3.6	-7.1	-11.2	21.6	21.9	-7.7	-17.3	14.4	8.0	2.6	57.0	-9.1	-12.0	-15.8
MRI-CGCM3	-2.4	-2.6	1.2	-0.9	-2.5	-9.0	-1.0	-18.0	7.7	30.7	1.9	-8.8	-8.1	20.3	20.3	2.7	4.2	-7.3	-17.7	35.0	34.3	26.4
NorESM1-M	-6.3	-5.8	7.0	11.4	-5.7	-8.8	-12.3	28.0	-4.5	-4.7	-11.2	-8.9	-8.1	6.8	2.6	-3.0	-6.9	-7.8	35.2	-13.9	-14.0	-20.0
Average	**2.9**	**2.4**	**6.6**	**10.2**	**0.7**	**-3.3**	**-8.5**	**5.4**	**7.8**	**7.9**	**-0.3**	**3.0**	**2.3**	**4.2**	**7.5**	**1.1**	**-3.0**	**-4.7**	**10.4**	**15.2**	**13.8**	**7.8**
Median	**-0.5**	**-2.4**	**1.7**	**2.2**	**-3.5**	**-6.8**	**-7.9**	**7.9**	**2.9**	**1.2**	**-6.4**	**1.1**	**-1.4**	**-1.1**	**0.7**	**-1.5**	**-4.7**	**-6.1**	**8.0**	**10.7**	**9.4**	**2.5**

Annex 13: Projected changes in season 2 (Mar-May) rainfall at different locations under RCPs 8.5 for mid (2040-2070) and end-century (2070-2100) periods

GCMS	8.5 MID											8.5 END										
	Wonji	**Melkasa**	**Adimesanu**	**Hintalo**	**Wami Prison**	**Mlali**	**Kongwa**	**Masandi**	**Ishiara**	**Karurumo**	**Kindaruma**	**Wonji**	**Melkasa**	**Adimesanu**	**Hintalo**	**Wami Prison**	**Mlali**	**Kongwa**	**Masandi**	**Ishiara**	**Karurumo**	**Kindaruma**
ACCESS1	-4.9	-5.3	3.0	17.5	-6.1	-11.3	-15.2	-7.0	54.0	48.0	28.9	-1.4	-2.2	-8.1	5.7	-4.0	-13.6	15.2	-4.5	72.1	66.4	32.5
bcc-csm1	4.7	4.4	-2.5	-2.6	6.0	5.9	-1.1	-4.7	6.6	7.5	-0.4	9.9	7.4	11.7	12.4	1.1	-1.3	-18.5	-8.0	28.1	26.2	18.4
BNU-ESM	14.2	4.4	-2.5	-2.6	-8.8	-11.4	-20.9	-27.1	42.5	39.2	31.2	22.8	7.4	11.7	12.4	-12.6	-14.5	-16.6	23.4	72.8	68.6	59.6
CanESM2	5.3	16.7	8.1	8.9	19.2	17.4	-3.6	-2.0	75.8	79.0	64.5	20.8	30.2	32.4	34.4	20.0	13.0	55.0	11.1	119.7	122.3	105.5
CCSM4	-2.1	-2.0	8.7	8.8	-13.6	-17.2	-7.1	4.7	-14.1	-14.4	-20.0	6.3	6.6	12.4	17.3	-5.1	-9.7	-21.6	11.8	-2.5	-3.2	-9.2
CESM1-BGC	-9.4	-9.2	20.5	32.7	-1.9	-0.8	-5.3	-10.5	17.2	15.2	8.4	10.4	11.0	22.3	33.0	-0.7	-3.8	-0.5	7.6	27.0	24.7	17.2
CSIRO-Mk3	-11.3	-11.7	-29.9	-15.5	3.4	-2.9	0.8	10.7	33.9	30.0	23.1	-24.7	-24.8	-35.6	-12.7	21.4	16.1	14.3	-10.2	56.4	51.6	43.4
GFDL-ESM2G	-7.7	-8.3	7.2	7.7	-8.2	-11.5	-5.8	17.8	-10.7	-11.6	-17.0	-2.0	-2.2	3.5	4.3	-15.0	-18.3	-3.9	8.4	-21.3	-22.2	-27.2
GFDL-ESM2M	-5.0	-5.2	-4.9	-4.4	3.3	0.9	-35.7	4.4	2.6	2.2	-4.5	5.5	5.2	-12.3	-11.3	-5.3	-9.6	4.4	73.7	3.0	1.9	-4.6
HadGEM2-CC	0.1	-0.3	4.1	11.3	-19.1	-18.9	-19.3	12.0	15.2	12.8	5.4	8.3	7.4	4.6	18.6	-19.6	-31.6	-14.3	-8.3	23.9	19.7	0.3
HadGEM2-ES	-4.4	-4.6	-3.8	1.1	-6.2	-15.4	4.0	-7.4	25.3	22.4	5.0	5.5	4.8	0.0	12.8	-12.9	-20.1	10.1	-0.8	29.2	26.9	-5.9
inmcm4	4.7	5.3	8.7	9.8	-11.1	-13.8	-13.6	10.6	2.9	1.1	-5.0	5.2	6.3	6.6	8.4	-7.9	-11.3	-9.8	-0.8	10.3	8.5	1.7
IPSL-CM5A-LR	25.4	26.6	90.0	-12.7	5.9	2.5	-4.9	-4.5	43.6	41.7	185.1	39.9	41.9	190.3	175.7	1.2	-2.0	1.8	17.2	104.4	98.7	87.7
IPSL-CM5A-MR	76.4	75.2	151.0	147.9	-9.5	-12.5	-19.6	19.5	47.0	44.7	31.8	134.3	137.0	188.5	188.5	-10.5	-13.7	-10.5	12.6	73.2	70.9	54.1
MIROC5	30.2	13.1	44.6	44.6	58.0	54.2	30.3	9.4	-33.9	-33.5	-38.2	58.2	28.2	54.1	55.9	55.4	55.5	59.8	-6.9	-22.5	-22.5	-27.6
MIROC-ESM	1.0	7.6	22.1	22.0	-2.1	-7.8	-8.7	-7.6	42.3	43.3	33.1	3.7	6.1	30.9	31.5	-2.0	-7.4	-40.0	-3.2	51.2	57.3	43.0
MPI-ESM-LR	10.0	10.2	-8.2	-4.0	3.4	-2.5	-19.5	13.4	6.6	6.2	-1.4	33.7	34.2	-15.3	-24.2	33.7	27.3	38.1	10.9	13.6	9.1	4.0
MPI-ESM-MR	16.6	17.0	-4.3	-13.1	1.2	-5.3	-11.8	11.4	-6.6	-10.7	-14.2	20.0	19.6	-9.5	-21.4	28.4	17.7	17.9	57.0	1.0	-5.6	-7.9
MRI-CGCM3	-7.6	-7.6	-1.2	-0.9	4.4	6.5	-1.0	23.8	17.3	21.5	9.5	-14.3	-13.7	9.3	7.1	2.6	2.1	-30.7	-17.7	58.5	56.0	47.7
NorESM1-M	-9.2	-8.9	11.4	9.3	-8.8	-11.1	-12.3	-11.0	-19.9	-19.2	-25.4	-1.8	-1.3	12.7	21.6	-14.8	-18.0	-12.1	35.2	-19.7	-19.0	-24.9
Average	**6.3**	**5.9**	**16.1**	**13.3**	**0.5**	**-2.8**	**-8.5**	**2.8**	**17.4**	**16.3**	**15.0**	**17.0**	**15.5**	**25.5**	**28.5**	**2.7**	**-2.2**	**1.9**	**10.4**	**33.9**	**31.8**	**20.4**
Median	**0.6**	**2.0**	**5.7**	**8.2**	**-2.0**	**-6.6**	**-7.9**	**4.6**	**16.2**	**14.0**	**5.2**	**7.3**	**7.0**	**10.5**	**12.6**	**-3.0**	**-8.5**	**-2.2**	**8.0**	**27.5**	**25.5**	**10.6**

Annex 14: Performance of identified adaptation strategies under current and future climatic conditions expected under RCP 4.5 and 8.5 to mid and end century

Country	**AEZ**		**DSSAT**					**APSIM**				
			Baseline	**4.5**		**8.5**		**Baseline**	**4.5**		**8.5**	
				MID	**END**	**MID**	**END**		**MID**	**END**	**MID**	**END**
Kenya	**UM2**	**Climate Change**	2201.5	2395.3	2475.3	2625.6	2724.7	2195.9	2287.4	2301.2	2308.2	2286.9
		Adaptation	2419.4	2493.3	2588.1	2720.6	2777.9	2195.9	3593.8	3613.4	3632.3	3617.1
	UM3	**Climate Change**	2056.8	2498.1	2606.6	2771.8	2825.5	2866.0	2889.7	2872.7	2862.0	2691.6
		Adaptation	2184.5	3165.2	3272.4	3469.9	3567.7	2866.0	4313.8	4313.6	4315.1	4216.0
	LM3	**Climate Change**	1549.4	1974.1	2065.9	2226.9	2374.4	2476.9	2483.1	2484.8	2477.9	2374.7
		Adaptation	1697.1	2431.9	2580.8	2721.2	3008.0	2476.1	2646.9	2691.3	2695.7	2717.6
	LM4	**Climate Change**	1549.8	1597.7	1675.3	1698.0	1839.8	1020.4	990.2	1011.6	1013.5	1052.3
		Adaptation	1630.0	2117.6	2364.3	2443.2	2799.2	1011.2	1899.1	1929.3	1940.5	2164.5
	LM5	**Climate Change**	708.3	851.4	873.8	897.5	957.3	763.5	724.7	713.3	708.6	701.9
		Adaptation	1293.4	1444.5	1583.2	1631.5	1748.9	774.8	2882.5	2892.3	2906.2	2932.6
Ethiopia	**SA2**	**Climate Change**	2635.5	2812.5	2814.3	2875.4	2896.0	2242.2	2336.1	2349.2	2341.4	2337.2
		Adaptation	3176.0	3248.8	3228.7	3219.3	3069.9	2520.1	3956.2	4008.0	4023.4	4087.8
	SM3	**Climate Change**	2220.5	2276.1	2234.5	2218.4	2266.7	1741.4	1738.6	1746.7	1769.9	1769.4
		Adaptation	3357.7	3066.0	3113.6	3132.2	2772.3	2556.1	4277.1	4268.5	4270.9	4127.1
	SM2	**Climate Change**	2175.1	2366.1	2394.2	2482.7	2469.0	1903.8	1932.8	1955.6	1953.8	1986.9
		Adaptation	3605.7	3252.4	3267.7	3354.0	2986.5	1761.6	4053.6	4083.7	4068.0	4055.7
Uganda	**Petric**	**Climate Change**	1287.4	1278.7	1271.2	1274.7	1144.1	1586.1	1487.5	1464.7	1459.7	1462.5
		Adaptation	5651.8	5670.9	5616.8	5659.3	4944.7	3305.2	3307.0	3302.8	3304.7	3263.6
	Dystric	**Climate Change**	2185.0	2161.9	2108.1	2176.2	1889.5	1708.9	1644.2	1638.4	1631.3	1658.0
		Adaptation	6017.5	6009.8	5951.5	6033.9	5226.7	3274.7	3218.8	3218.1	3195.4	3093.9
	Acric	**Climate Change**	2295.2	2113.1	2055.3	2133.0	1758.7	2543.4	2430.3	2401.6	2394.0	2394.6
		Adaptation	6226.4	6055.7	6043.7	5727.1	5102.3	4526.7	4464.5	4484.4	4440.3	4320.8

Annex 15: Changes in grain yield with and without CO2 effect in different agroecological zones of Kenya under projected changes in climate to mid and end century periods by 20 GCMs under RCPs 4.5 and 8.5

GCMs		4.5 MID					4.5 END					8.5 MID					8.5 END				
		UM2	UM3	LM3	LM4	LM5	UM2	UM3	LM3	LM4	LM5	UM2	UM3	LM3	LM4	LM5	UM2	UM3	LM3	LM4	LM5
Without CO_2	ACCESS1	1945.6	1627.5	1737.5	921.2	461.1	2228.7	2420.2	1941.3	965.4	485.9	2078.7	2237.7	1844.2	944.6	488.4	2360.5	2513.7	2197.1	1098.9	509.1
	bcc-csm1	2121.4	2281.1	1751.3	909.4	461.2	2170.2	2308.9	1746.3	900.7	452.6	2127.1	2347.0	1779.0	925.4	449.4	2188.8	2372.7	1937.6	958.2	496.2
	BNU-ESM	2420.0	2690.1	2031.2	1043.2	549.1	2419.6	2699.3	2109.1	896.8	535.2	2447.4	2687.7	2120.6	1062.3	537.2	2629.6	2902.4	2392.1	1225.5	606.4
	CanESM2	2490.9	2630.9	2035.4	1052.0	537.0	2592.2	2767.3	2225.6	1152.3	577.5	2532.7	2617.6	2178.0	1120.4	564.6	2583.7	2739.5	2407.3	1258.6	852.0
	CCSM4	2209.0	2393.4	1895.6	942.6	482.5	2244.9	2402.6	1756.1	885.7	473.5	2149.2	2345.3	1761.8	876.5	473.8	2360.4	2549.4	1605.8	959.8	490.5
	CESM1-BGC	2245.9	2404.8	1733.0	895.5	500.8	2293.8	2451.2	1856.1	926.7	484.9	2291.7	2430.2	1876.4	945.4	474.8	2351.9	2519.7	2121.2	1046.8	513.6
	CSIRO-Mk3	2100.2	2323.1	1835.4	937.8	481.4	2353.4	2571.2	2041.0	1004.5	512.5	2156.7	2409.6	1964.7	1011.1	501.6	2346.6	2119.4	1960.5	1118.7	472.8
	GFDL-ESM2G	1855.6	1979.3	1675.3	881.8	454.2	1896.1	2030.4	1724.7	915.8	461.4	1840.2	2027.1	1654.0	866.8	447.4	1878.1	1976.6	1799.3	911.7	454.5
	GFDL-ESM2M	2046.9	2254.2	1691.8	880.7	481.5	2138.5	2278.0	1818.4	932.5	504.9	2386.8	2517.2	1891.3	964.6	494.3	2195.6	2331.9	1946.5	962.9	478.5
	HadGEM2-CC	2054.0	2185.9	1703.8	851.5	458.0	2086.9	2244.9	1858.8	953.5	484.7	2291.5	2466.1	2006.1	996.8	503.6	2336.2	2475.3	2185.8	1055.1	475.5
	HadGEM2-ES	2033.1	2180.8	1810.8	920.0	477.3	2194.3	2319.0	1914.1	937.6	481.8	2230.8	2409.3	2058.4	1010.5	513.3	2379.1	2530.7	2190.3	1055.6	480.1
	inmcm4	2024.9	2210.1	1620.0	841.9	461.0	1918.4	2079.4	1615.2	859.2	471.3	2047.3	2208.4	1710.3	894.3	471.7	2059.4	2199.1	1812.8	883.3	463.3
	IPSL-CM5A-LR	2462.4	2652.3	2064.6	1040.1	547.8	2494.1	2726.0	2142.0	1108.4	571.4	2567.7	2793.2	2307.2	1141.8	611.4	2638.4	2727.1	2491.1	1245.9	573.9
	IPSL-CM5A-MR	2445.4	2137.5	1995.7	1018.8	668.7	2575.2	2586.8	2084.1	1125.5	522.4	2283.6	1973.8	2009.6	1049.6	506.9	2522.6	2254.3	2390.6	1224.9	544.9
	MIROC5	2024.0	2202.2	1646.6	906.1	460.1	2128.4	2280.0	1703.9	883.3	467.2	2026.7	2160.3	2262.1	985.2	447.1	2257.4	2354.7	1805.4	960.4	603.9
	MIROC-ESM	2395.5	2674.8	2091.6	1058.9	578.2	2627.1	2818.1	2263.6	1138.7	574.2	2620.6	2840.7	2262.1	1167.0	577.0	2809.9	2977.3	2503.9	1278.6	594.7
	MPI-ESM-LR	2247.3	2342.1	1763.0	926.7	609.9	2435.3	2421.9	1813.1	970.4	627.1	2414.2	2427.0	1884.3	952.1	624.1	2348.0	2375.6	1968.8	1003.6	631.1
	MPI-ESM-MR	2327.7	2341.9	1731.9	925.5	642.1	2273.1	2352.8	1767.7	961.6	624.7	2098.9	2179.3	1661.2	896.0	602.3	2105.3	2174.8	1763.7	962.6	593.2
	MRI-CGCM3	2499.6	2519.6	1814.7	1201.2	644.7	2672.8	2676.1	1948.9	1048.8	689.7	2610.0	2596.1	1810.2	990.9	687.6	2876.8	2892.5	2286.9	1206.7	745.7
	NorESM1-M	2326.2	2345.9	1677.6	920.8	608.6	2291.6	2297.1	1753.8	942.3	613.6	2313.1	2256.6	1713.3	940.9	624.8	2288.8	2296.6	1844.9	964.3	621.5
With CO_2	ACCESS1	2297.4	1980.6	1887.3	1509.0	765.7	2390.9	2584.4	2093.0	1661.7	829.3	2423.7	2617.5	2137.9	1581.0	834.1	2706.4	2867.1	2487.0	1892.9	909.4
	bcc-csm1	2295.1	2450.5	1911.5	1553.7	772.5	2343.4	2478.9	1899.0	1524.7	756.0	2456.9	2708.4	2063.6	1563.3	778.9	2529.3	2735.4	2228.4	1655.2	841.3
	BNU-ESM	2612.4	2872.8	2200.8	1799.6	942.5	2611.6	2889.8	2283.0	1864.0	942.8	2796.9	3076.2	2415.8	1882.4	956.0	2980.4	3269.1	2670.0	2151.6	1086.6

	CanESM2	2671.2	2804.2	2199.4	1815.1	903.7	2780.1	2946.0	2403.6	2012.9	994.2	2860.3	2948.9	2467.4	1949.1	981.8	2905.8	3058.7	2673.9	2199.7	1310.7
	CCSM4	2383.2	2559.4	2059.6	1690.7	815.3	2419.6	2573.6	1912.4	1522.4	790.2	2479.1	2716.2	2049.6	1530.4	803.3	2712.9	2906.5	1881.1	1656.3	855.0
	CESM1-BGC	2424.0	2583.8	1886.5	1516.4	809.1	2470.6	2620.8	2016.9	1602.0	811.5	2638.5	2815.7	2175.3	1638.0	833.2	2712.6	2898.4	2417.9	1817.0	912.2
	CSIRO-Mk3	2285.0	2505.0	2008.5	1640.9	816.7	2554.6	2758.1	2241.6	1800.7	894.0	2509.2	2797.2	2268.4	1715.7	873.7	2704.5	2472.6	2417.9	1940.6	937.2
	GFDL-ESM2G	2011.2	2140.3	1830.9	1489.8	754.7	2047.2	2195.4	1880.3	1532.0	767.4	2158.6	2406.1	1930.9	1436.4	745.1	2203.9	2331.4	2096.1	1560.6	780.7
	GFDL-ESM2M	2220.9	2416.3	1847.5	1484.2	785.8	2310.9	2441.7	1980.8	1621.3	844.6	2727.4	2894.0	2192.9	1675.2	867.1	2552.4	2715.0	2242.0	1701.9	851.9
	HadGEM2-CC	2207.4	2346.3	1862.2	1479.8	754.7	2248.0	2398.2	2018.9	1664.8	825.8	2656.7	2841.6	2298.8	1763.4	891.5	2671.5	2841.1	2483.9	1871.4	881.5
	HadGEM2-ES	2189.6	2345.4	1964.2	1558.0	798.7	2364.2	2485.4	2072.3	1686.5	840.3	2583.3	2787.3	2355.8	1759.7	902.8	2718.3	2896.2	2470.6	1863.0	886.3
	inmcm4	2192.3	2382.3	1769.2	1453.2	755.7	2083.9	2240.0	1758.7	1435.6	756.8	2388.5	2591.4	1985.6	1503.2	796.9	2394.5	2565.8	2090.0	1547.6	801.0
	IPSL-CM5A-LR	2650.3	2830.4	2236.6	1811.0	924.7	2678.8	2909.9	2310.9	1890.4	958.5	2920.7	3171.7	2618.7	2044.9	1055.0	2967.7	3067.1	2777.1	2188.9	1040.6
	IPSL-CM5A-MR	2621.4	2299.5	2160.2	1774.9	1018.1	2751.2	2767.8	2252.2	1838.6	898.0	2641.6	2323.2	2304.0	1727.9	873.8	2863.0	2578.0	2651.1	2132.0	997.1
	MIROC5	2186.6	2365.2	1794.2	1456.2	743.4	2290.8	2446.4	1852.3	1474.1	766.8	2363.5	2554.6	2542.5	2042.2	900.3	2645.3	2762.3	2096.8	1592.0	938.6
	MIROC-ESM	2586.0	2863.5	2255.8	1870.5	977.3	2817.2	2998.8	2435.3	2007.3	1009.4	2961.0	3190.9	2542.5	2042.2	1024.7	3118.4	3306.1	2775.9	2265.3	1080.8
	MPI-ESM-LR	2410.9	2515.8	1917.9	1527.6	904.8	2602.2	2586.3	1968.3	1587.3	933.8	2797.7	2827.2	2164.7	1591.4	965.9	2731.3	2752.5	2269.7	1657.4	982.8
	MPI-ESM-MR	2492.9	2514.5	1889.3	1510.6	943.6	2442.5	2521.9	1926.0	1596.2	933.7	2464.2	2565.5	1934.7	1461.2	915.8	2471.9	2555.6	2049.5	1526.8	911.8
	MRI-CGCM3	2675.6	2683.3	1968.8	1569.1	947.0	2861.1	2845.9	2111.4	1702.8	1022.7	3020.6	2993.2	2099.8	1569.1	1019.2	3266.4	3271.5	2575.2	2029.9	1184.3
	NorESM1-M	2496.2	2508.4	1834.1	1503.1	901.2	2452.7	2460.4	1903.7	1556.6	914.7	2679.2	2635.0	1991.4	1538.0	943.2	2660.7	2668.1	2136.8	1593.9	964.0

Annex 16: Changes in grain yield with and without resetting initial conditions in different agroecological zones of Kenya under projected changes in climate to mid and end century periods by 20 GCMs under RCPs 4.5 and 8.5

GCMs		4.5 MID					4.5 END					8.5 MID					8.5 END				
		UM2	UM3	LM3	LM4	LM5	UM2	UM3	LM3	LM4	LM5	UM2	UM3	LM3	LM4	LM5	UM2	UM3	LM3	LM4	LM5
Without Resets	**ACCESS1**	2653.3	3419.1	3035.6	1939.1	905.0	2653.3	3419.1	3035.6	1939.1	905.0	2597.4	3392.0	2991.4	1894.9	906.6	2567.7	3330.0	3064.2	1965.2	905.4
	bcc-csm1	2732.4	3554.1	3102.9	1913.1	917.4	2732.4	3554.1	3102.9	1913.1	917.4	2671.3	3506.3	3090.0	1894.9	914.4	2681.1	3467.4	3100.1	1949.0	949.9
	BNU-ESM	2324.5	3160.4	2788.2	1814.5	793.9	2324.5	3160.4	2788.2	1814.5	793.9	2343.4	3170.3	2825.6	1843.5	816.5	2181.5	3015.7	2729.8	1790.5	783.4
	CanESM2	2426.6	3289.9	2918.1	1968.6	910.1	2426.6	3289.9	2918.1	1968.6	910.1	2493.5	3328.1	2981.0	1991.5	936.2	2367.8	3169.3	2885.8	1972.5	918.1
	CCSM4	2725.1	3539.0	3108.0	1853.9	883.8	2725.1	3539.0	3108.0	1853.9	883.8	2759.6	3536.4	3110.9	1847.5	895.2	2571.6	3328.5	3130.5	1920.5	934.5
	CESM1-BGC	2645.3	3468.2	3033.2	1895.0	897.1	2645.3	3468.2	3033.2	1895.0	897.1	2647.0	3450.2	3035.6	1906.7	895.2	2637.8	3402.3	3048.6	1945.0	937.7
	CSIRO-Mk3	2631.5	3422.1	3034.1	1949.9	929.0	2631.5	3422.1	3034.1	1949.9	929.0	2681.7	3467.7	3055.8	1913.3	852.4	2638.1	3395.1	3018.7	1984.8	958.9
	GFDL-ESM2G	2731.0	3551.4	3087.9	1842.7	882.5	2731.0	3551.4	3087.9	1842.7	882.5	2734.9	3556.5	3119.8	1793.6	868.1	2805.7	3548.5	3181.9	1813.8	893.1
	GFDL-ESM2M	2480.8	3378.1	3013.4	1914.4	899.0	2480.8	3378.1	3013.4	1914.4	899.0	2645.4	3510.9	3082.7	1962.0	930.6	2779.1	3567.8	3119.8	1968.2	949.3
	HadGEM2-CC	2934.7	3663.9	3203.4	1954.5	945.8	2934.7	3663.9	3203.4	1954.5	945.8	2704.4	3474.9	3048.7	1955.0	946.7	2782.1	3464.9	3112.2	1965.7	973.6
	HadGEM2-ES	2777.6	3525.8	3069.7	1894.9	936.0	2777.6	3525.8	3069.7	1894.9	936.0	2759.0	3520.8	3094.3	1977.1	957.0	2701.6	3397.5	3022.8	1947.9	963.4
	inmcm4	2613.9	3455.4	3012.8	1875.1	881.0	2613.9	3455.4	3012.8	1875.1	881.0	2640.5	3438.4	2986.1	1903.0	888.4	1964.5	2327.8	3037.5	1944.5	931.1
	IPSL-CM5A-LR	2498.7	3366.1	2950.6	1859.4	887.5	2498.7	3366.1	2950.6	1859.4	887.5	2609.4	3412.3	3053.1	1976.6	898.7	2377.9	3162.5	2901.5	1896.4	891.3
	IPSL-CM5A-MR	2571.8	3383.0	3026.6	1942.8	884.3	2571.8	3383.0	3026.6	1942.8	884.3	2410.3	3226.7	2897.4	1841.6	898.7	2207.0	3020.3	2773.4	1831.0	924.5
	MIROC5	2768.7	3575.9	3127.9	1826.7	878.8	2768.7	3575.9	3127.9	1826.7	878.8	2765.8	3567.9	3095.5	1767.6	848.6	2781.9	3557.9	3138.1	1874.4	913.7
	MIROC-ESM	2421.3	3235.9	2905.3	1899.2	868.9	2421.3	3235.9	2905.3	1899.2	868.9	2319.3	3182.1	2842.8	1864.9	839.9	2460.7	3233.9	2969.7	1966.1	927.1
	MPI-ESM-LR	2676.3	3466.3	3046.4	1866.2	882.1	2676.3	3466.3	3046.4	1866.2	882.1	2729.8	3503.3	3092.3	1886.5	904.9	2677.6	3386.7	3012.1	1890.7	907.8
	MPI-ESM-MR	2695.8	3451.1	3068.8	1844.2	866.9	2695.8	3451.1	3068.8	1844.2	866.9	2732.2	3499.3	3064.2	1800.8	879.4	2800.2	3500.3	3107.6	1813.4	899.5
	MRI-CGCM3	2574.1	3412.7	3017.8	1918.2	909.1	2574.1	3412.7	3017.8	1918.2	909.1	2706.7	3502.8	3069.0	1974.0	932.3	2536.6	3323.3	2963.7	1979.5	941.0
	NorESM1-M	2782.8	3572.5	3130.9	1874.7	916.2	2782.8	3572.5	3130.9	1874.7	916.2	2804.9	3596.9	3144.3	1872.7	895.0	2824.8	3578.2	3190.1	1897.9	922.7
With Re-sets	**ACCESS1**	2312.9	2837.5	2462.8	1041.4	705.1	2339.3	2871.3	2330.3	1068.3	752.9	2270.1	2673.2	2345.3	1091.0	669.5	2270.6	2806.2	2424.9	1007.4	696.1
	bcc-csm1	2328.8	2929.0	2527.3	980.1	725.4	2272.2	2908.9	2534.1	971.8	740.0	2290.8	2752.8	2450.8	1025.4	688.8	2290.0	2891.8	2507.9	976.4	715.2
	BNU-ESM	2207.9	2798.4	2375.1	1013.0	702.4	2162.4	2786.6	2335.5	980.8	705.9	2160.0	2648.5	2299.9	1077.2	657.6	2234.6	2805.3	2391.3	1028.8	697.2
	CanESM2	2295.7	2853.3	2436.7	1103.0	727.7	2299.8	2868.5	2458.8	1054.1	736.0	2252.8	2640.7	2335.9	1134.0	679.6	2319.6	2843.9	2457.1	1104.3	722.2
	CCSM4	2316.1	2925.3	2533.1	974.9	725.7	2305.6	2928.3	2518.6	972.6	735.2	2273.2	2664.4	2484.3	1043.7	690.4	2332.0	2914.0	2522.9	969.3	714.9
	CESM1-BGC	2301.1	2914.8	2497.2	988.2	721.1	2268.0	2904.4	2493.7	984.5	729.8	2302.4	2776.2	2456.5	1063.5	682.5	2300.9	2896.4	2492.7	1002.3	714.3
	CSIRO-Mk3	2327.2	2832.8	2457.2	1078.9	694.4	2334.5	2894.0	2488.6	1015.7	710.8	2294.7	2680.1	2359.9	1126.8	680.6	2333.7	2867.6	2480.4	1044.0	710.9
	GFDL-ESM2G	2284.9	2898.3	2530.2	971.3	727.1	2258.6	2888.9	2524.5	965.0	732.6	2312.1	2756.8	2501.1	1010.9	708.8	2288.4	2871.8	2524.1	935.7	714.3
	GFDL-ESM2M	2225.2	2858.9	2496.9	1018.5	722.2	2238.0	2884.9	2520.1	979.5	737.8	2328.8	2813.0	2499.3	1079.1	702.8	2322.2	2930.1	2525.4	1048.8	730.0
	HadGEM2-CC	2419.5	2870.7	2537.1	1032.0	723.1	2352.3	2908.6	2535.2	928.9	719.7	2327.5	2692.4	2382.5	1122.2	703.0	2341.7	2826.1	2465.5	1082.2	713.4
	HadGEM2-ES	2345.7	2834.7	2473.7	1029.4	709.8	2379.5	2893.0	2539.0	1034.1	719.5	2311.1	2671.7	2353.2	1105.6	686.0	2360.9	2822.2	2485.4	1085.9	707.5
	inmcm4	2246.4	2889.9	2482.9	950.9	724.5	2261.0	2894.2	2480.8	946.5	729.9	2278.9	2760.7	2458.7	1006.5	684.9	2311.2	2894.0	2469.6	987.6	710.2

	IPSL-CM5A-LR	2252.4	2853.6	2456.0	1030.4	702.0	2275.6	2874.7	2471.5	1040.3	709.6	2364.0	2295.8	1794.1	908.6	1045.0	2328.9	2823.8	2469.7	1102.2	702.6
	IPSL-CM5A-MR	2290.1	2822.9	2463.7	1066.1	705.0	2278.8	2875.0	2475.2	1036.4	715.7	2145.9	2508.5	2187.4	1043.9	670.4	2210.2	2737.6	2393.3	978.6	679.6
	MIROC5	2342.3	2930.2	2536.6	958.1	718.1	2275.7	2921.5	2506.4	928.0	715.0	2341.0	2834.5	2509.3	970.6	691.4	2335.0	2923.6	2516.6	899.2	700.3
	MIROC-ESM	2277.9	2789.1	2407.1	1090.0	680.0	2267.8	2838.6	2427.2	1065.5	699.0	2267.8	2659.9	2353.8	1145.1	677.9	2253.3	2808.4	2399.1	1075.7	696.0
	MPI-ESM-LR	2306.9	2887.4	2495.0	983.6	699.1	2320.5	2908.3	2505.7	939.9	708.6	2263.2	2683.4	2372.6	1016.1	655.5	2328.9	2872.8	2499.0	1002.3	697.6
	MPI-ESM-MR	2303.2	2880.4	2492.2	934.0	695.6	2300.0	2898.4	2486.0	961.0	711.9	2290.9	2711.1	2405.3	949.0	670.7	2294.8	2842.9	2479.9	916.7	687.5
	MRI-CGCM3	2291.7	2903.8	2494.3	1031.7	730.2	2245.2	2899.9	2485.3	978.7	745.5	2309.1	2793.4	2425.0	1119.0	692.9	2344.1	2920.4	2508.5	1060.6	737.4
	NorESM1-M	2347.5	2944.0	2541.6	956.7	727.8	2312.8	2946.1	2545.5	952.1	737.9	2353.5	2814.4	2518.6	1008.3	698.8	2362.5	2942.3	2544.2	961.0	724.4

ANNEX 17: Capacities developed in the participating countries.

S. N	MSc researchers	Organization	Level	Skill area
1	Kiros Wolday	Tigray Agric. Res. Center	MSC researcher	Crop modeling
2	Yaynemusa G/tsadikan	Tigray Vocational Training Center	MSC researcher	Crop modeling
3	Aklilu Afewerk	Tigray Vocational Training Center	MSC researcher	Crop modeling
4	Tsedale Demelash	National Meteorological Agency	MSC researcher	Crop modeling and climate modeling
5	Tesfaye Mekonnen	National Meteorological Agency	MSC researcher	Crop modeling and climate modeling
6	Solomon Takele	National Meteorological Agency	MSC researcher	Crop modeling and climate modeling
7	Redae Tadesse	Mekelle University	MSC researcher	Crop modeling and climate modeling
8	Tesfaye Kidanemariam	Minstry of Agriculture	MSC researcher	Crop modeling
9	Kidist	National Meteorological Agency	MSC researcher	Crop modeling and climate modeling
10	Weldebirhan	National Meteorological Agency	MSC researcher	Crop modeling and climate modeling
11	Mengesha	Melkasa Agr. Res. Center (EIAR)	MSC researcher	Crop modeling and climate modeling
12	Yibrah	Tigray Agric. Res. Center	MSC researcher	Crop modeling and climate modeling
13	Kahsay G/Michael	Minstry of Agriculture	MSC researcher	Economic modeling
14	Haylay Haileslasie	Relief society of Tigray	MSC researcher	Crop modelling
15	Yemane Kahsay	Mekelle University	MSC researcher	Economic modeling
Project members				
1	Girma mamo	Melkasa Agr. Res. Center (EIAR)	Member	Crop modeling
2	Araya Alemie	Mekelle University	PI-AgMIP-Ethiopia	Crop modeling
3	Girmay Gebru	Mekelle University	Member	Crop modeling
4	Fekadu Getachew	Melkasa Agr. Res. Center (EIAR)	Member	Crop modeling
5	Atkilt Girma	Mekelle University	Member	Climate modeling
6	Robel Takele	Melkasa Agr. Res. Center (EIAR)	Member	Climate modeling

7	Henok Shiferaw	Mekelle University	Member	Climate modeling
8	Fredu Nega	Mekelle University	Member	Economic modeling
9	Kebede Manjur	Mekelle University	Member	Economic modeling
10	Tedros Taddesse	Mekelle University	Member	Economic modeling
Training of trainers				
1	Shiferaw Tadess	Bakor Research Center	Trainers and knowledge desiminatores	Crop modeling
2	Azeb Hailu Kassa	Tigray Agricultural Research Center	Trainers and knowledge desiminatores	Crop modeling
3	Nuguse	Kulumsa Agric. Research Center	Trainers and knowledge desiminatores	Crop modeling

S.N	Name	Institution	Level	Area
1	Fiseha Baraki	Tigray Agric. Res. Center	MSC researcher	Crop modeling
2	Yeabyo G/Selasie	Minstry of Agriculture	MSC researcher	Crop modeling
3	Mebrahtom G/kidan	Minstry of Agriculture	MSC researcher	Crop modeling
4	SSemwanga Mohammed	Makerere University, Uganda	MSC researcher	Crop modeling and climate modeling
5	Fasil Mequannint	Melkasa Agr. Res. Center (EIAR)	MSC researcher	Crop modeling and climate modeling
6	Haile Kebede	Minstry of Agriculture	MSC researcher	Crop modeling and climate modeling
7	Abadi Berhane	Axum University	MSC researcher	Crop modeling and climate modeling
8	Abebe Tesfay	Minstry of Agriculture	MSC researcher	Crop modeling
9	Alemat Embaye	Tigray Agric. Res. Center	MSC researcher	Crop modeling
10	Birhanu Amere	Tigray Agric. Res. Center	MSC researcher	Crop modeling
11	Kiros Gebretsadikan	Tigray Agric. Res. Center	MSC researcher	Crop modeling
12	Niguse Abebe	Tigray Agric. Res. Center	MSC researcher	Crop modeling
13	Teka Solomon	Tigray Agric. Res. Center	MSC researcher	Crop modeling
14	Jonatan	Tanzania	MSC researcher	Crop modeling and climate modeling
15	Mantu	Liberia	MSC researcher	Crop modeling and climate modeling
16	Amdom	Minstry of Agriculture	MSC researcher	Crop modeling and climate modeling
17	Yemane Nega Kebede	Tigray Vocational Training Center	MSC researcher	Crop modeling

Annex 18: Stakeholders participated in the consultation meetings and discussions in Kenya

Sl No	Name	Designation/Company	Email Address
1	Emma Bowa	Head, Climate Change Advocacy, CARE International, P.O.Box 43864 – 00100, Nairobi, Kenya	emmabowa@care.or.ke
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9	Evans Kituyi	Senior Programme Specialist, CARIAA International Development Research Centre	ekituyi@idrc.or.ke
10	Ada Mwangola	V2030 Secretariat; Ministry of Devolution & Planning	amwangola@vision2030.go.ke
11	Dr Paul Muoria	Nature Kenya/Community Based Adaptation	species@naturekenya.org; office@naturekenya.org
12	Dr. Elijah Mukhala	WMO Representative for Eastern and Southern Africa I World Meteorological Organization	emukhala@wmo.int
13	Mr. Nicholas Maingi	WMO	
14	Mr. Joshua Ngaina	WMO	
15	Valerian Micheni	Drought Information Manager, National Drought Management Aurthority	valerian.micheni@ndma.go.ke
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17	Anthony Esilaba	Kenya Agricultural Research Institute	aesilaba@gmail.com
18	Patricio Njiru	Embu county officials	patnjiru@gmail.com
19	Michael Okumu	– Climate Change Unit – Ministry of Agriculture, Livestock and Fisheries MoALFD)	ochiengokumu@gmail.com

20	Dr. Phillip Omondi	Senior Climate Research Scientist/Modeller – ICPAC, IGAD Climate Prediction and Applications Center, P.O. Box 10304 -00100 Nairobi, KENYA	philip.omondi@gmail.com
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22	Ms Edith Adera	Senior Program Specialist, Climate Change and Water, Agriculture and Environment Program International Development Research Centre, Regional Office for Sub-Saharan Africa	eadera@idrc.ca
23	Mary Kilavi	Kenya Meteorological department	
24	Richard Mulwa	University of Nairobi	
25	Elijah Muli	Kenya RED Cross	elijah.muli@kenyaredcross.org
26	Emmanuel Cyoy	Practical Action	emmanuel.cyoy@practicalaction.or.ke
26	Peter Ambenje	Kenya Meteorological Department	ambenje@meteo.go.ke
27	Jens Ryder	Sector Coordination Advisor, Agriculture Sector Coordination Unit (ASCU), Ministry of Agriculture, Livestock and Fisheries, Kilimo House, Catheral Road, P.O. Box 30028 -00100 Nairobi, KENYA	info@ascu.go.ke

Annex 19: Researchers received training in using AgMIP tools in Uganda

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1	Esther Sebuliba	Research assistant at Geography, geo-informatics and climatic sciences	essey@gmail.com
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10	Gabirye Geofrey	PhD student in Germany	geofreygabiri@gmail.com