Climate Change Adaptation and Mitigation in the Kenyan Coffee Sector

Final Report
Cali, Colombia: January, 2010

CIAT
Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture
Consultative Group on International Agricultural Research

Table of Contents

Table of Figures

Index of Tables

1 Executive summary

This document reports on the methods and results of a consultancy with the title "Climate Change Adaptation and Mitigation in the Kenyan Coffee Sector" conducted for Sangana Commodities Ltd. and the German technical cooperation (GTZ.). Further partners of this project are the World-bank (WB) and Coffee community 4C Association.

The methodology applied was based on the combination of current climate data with future climate change predictions from 4 models for 2020 and 20 models for 2050. The data of the current climate and the climate change was used as input to Maxent, a crop prediction model. The evidence data used for Maxent were collected by GPS through field work in Kenya.

The analysis focused on the specific municipalities that were of interest to the client and provide predictions of the future climate and predictions of the suitability of current coffee-growing areas to continue growing coffee by 2020 and 2050.

The results show that the change in suitability as climate change occurs is site-specific. There will be areas that become unsuitable for coffee, where farmers will need to identify alternative crops. There will be areas that remain suitable for coffee, but only when the farmers adapt their agronomic management to the new conditions the area will experience. Finally, there will be areas where today no coffee is grown but which in the future will become suitable. These areas will require strategic investments to enable them to develop for production of coffee. Climate change brings not only bad news but also a lot of potential. The winners will be those who are prepared for change and know how to adapt.

In Kenya the yearly and monthly rainfall will increase and the yearly and monthly minimum and maximum temperatures will increase by 2020 and progressively increase by 2050. The overall climate will become less seasonal in terms of variation through the year in temperature with temperature in specific districts increasing by about 1 ºC by 2020 and 2.3 ºC by 2050 and more seasonal in precipitation with the maximum number of cumulative dry month staying constant at 4 months.

The implications are that the distribution of suitability's within the current coffee-growing areas in Kenya for coffee production in general will decrease quite seriously by 2050. The suitable areas will migrate up the altitudinal gradient. Areas that retain some suitability will see decreases to between 60 and 70%, compared with suitability's today of 60 - 80%.

The optimum coffee-producing zone is currently at an altitude between 1400 and 1600 masl and will by 2050 increase to an altitude between 1600 and 1800 masl. Increasing altitude compensates for the increase in temperature. Compared with today, by 2050 areas at altitudes between 1000 and 1400 masl will suffer the highest decrease in suitability and the areas around 2000 masl the highest increase in suitability.

2 Authors

The analyses presented here were conducted by the Decision and Policy Analyses DAPA group at CIAT under the leadership of Dr. Peter Laderach, with the collaboration of Anton Eitzinger, Oriana Ovalle, Julian Ramírez and Dr. Andy Jarvis. For further information please contact:

Dr. Peter Laderach
Centro Internacional de Agricultura Tropical (CIAT)
A.A. 6713, Cali, Colombia
Email: p.laderach@cgiar.org

3 Introduction

This document reports on the methods and results of a consultancy with the title "Climate Change Adaptation and Mitigation in the Kenyan Coffee Sector" conducted for Sangana Commodities Ltd. and the German technical cooperation (GTZ). The document includes climate predictions, crop suitability predictions and detailed analysis for the Kenyan coffee growing areas (Figure 1).

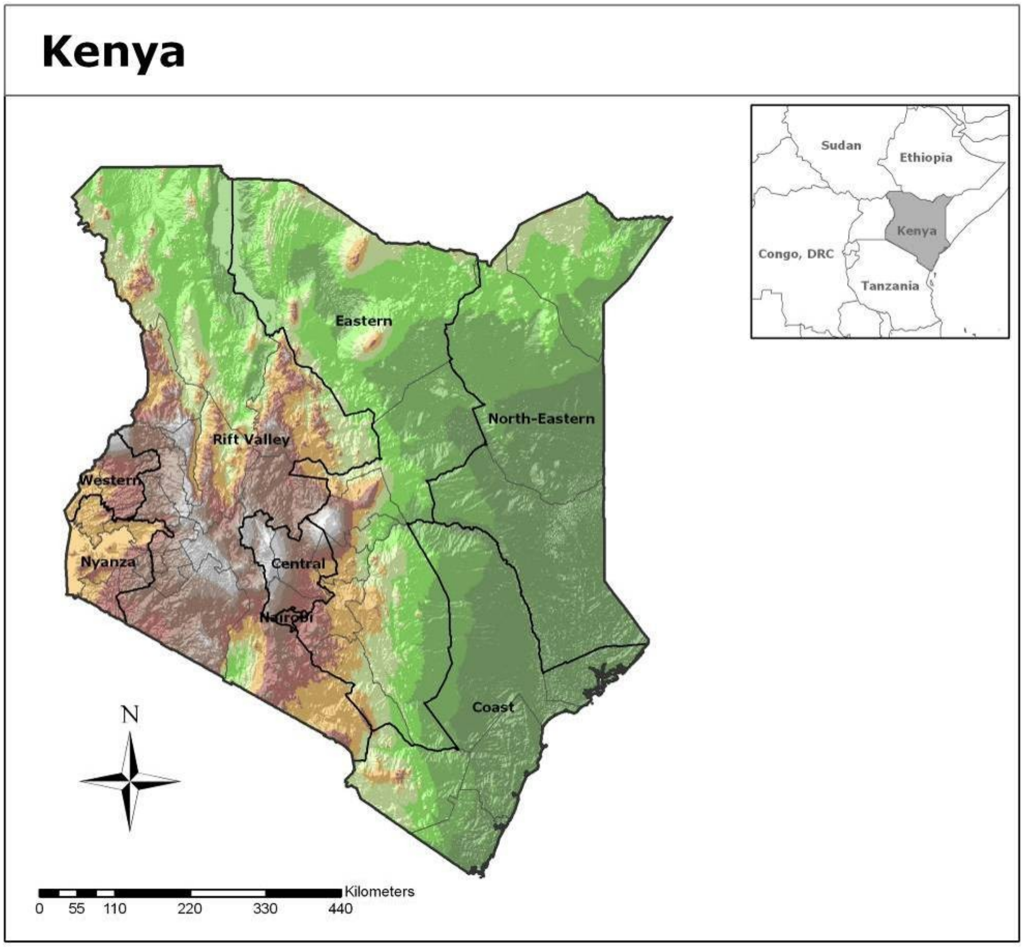

Figure 1: Location of the study areas analyzed for the project.

4 Study objective

Elaboration of future climate scenarios to indicate the impact of climate change on adaptability of coffee in Kenya which will be accessible and available for international and regional organizations such as the Coffee Research Foundation and the 4C Association.

5 Key questions

The present report sets out to answer the following key questions.

1. How will the climate in the project areas change by the year 2020 and 2050?
2. What impact will the climate change have for the suitability of current areas to grow coffee and how will the coffee areas change?
3. What are the environmental variables that drive the suitability of an area to grow coffee?

6 Methods and data generation

6.a Historical climate generation

We obtained the historical climate data from www.worldclim.org database (Hijmans et al, 2005). The WorldClim data were generated through interpolation of average monthly climate data from weather stations on a 30 arc-second resolution grid (often referred to as "1 km" resolution). Variables included are monthly total precipitation, and monthly mean, minimum and maximum temperature, and 19 derived bioclimatic variables. (Hijmans et al. 2005)

In the WorldClim database, climate layers were interpolated using:

- Major climate databases compiled by the Global Historical Climatology Network (GHCN), the FAO, the WMO, the International Center for Tropical Agriculture (CIAT), R-HYdronet, and a number of additional minor databases for Australia, New Zealand, the Nordic European Countries, Ecuador, Peru, Bolivia, amongst others.
- The SRTM elevation database (aggregated to 30 arc-seconds, "1 km")
- The ANUSPLIN software. ANUSPLIN is a program for interpolating noisy multi-variate data using thin plate smoothing splines. We used latitude, longitude, and elevation as independent variables.

For stations for which there were records for multiple years, the averages were calculated for the 1960-90 period. Only records for which there were at least 10 years of data were used. In some cases the time period was extended to the 1950-2000 period to include records from areas for which there were few recent records available (e.g., DR Congo) or predominantly recent records (e.g., Amazonia).

After removing stations with errors, the database consisted of precipitation records from 47,554 locations, mean temperature from 24,542 locations, and minimum and maximum temperature for 14,835 locations.

The data on which WorldClim is based in Kenya are from 736 stations with precipitation data, 708 stations with mean temperature, and 61 stations with minimum and maximum temperatures.

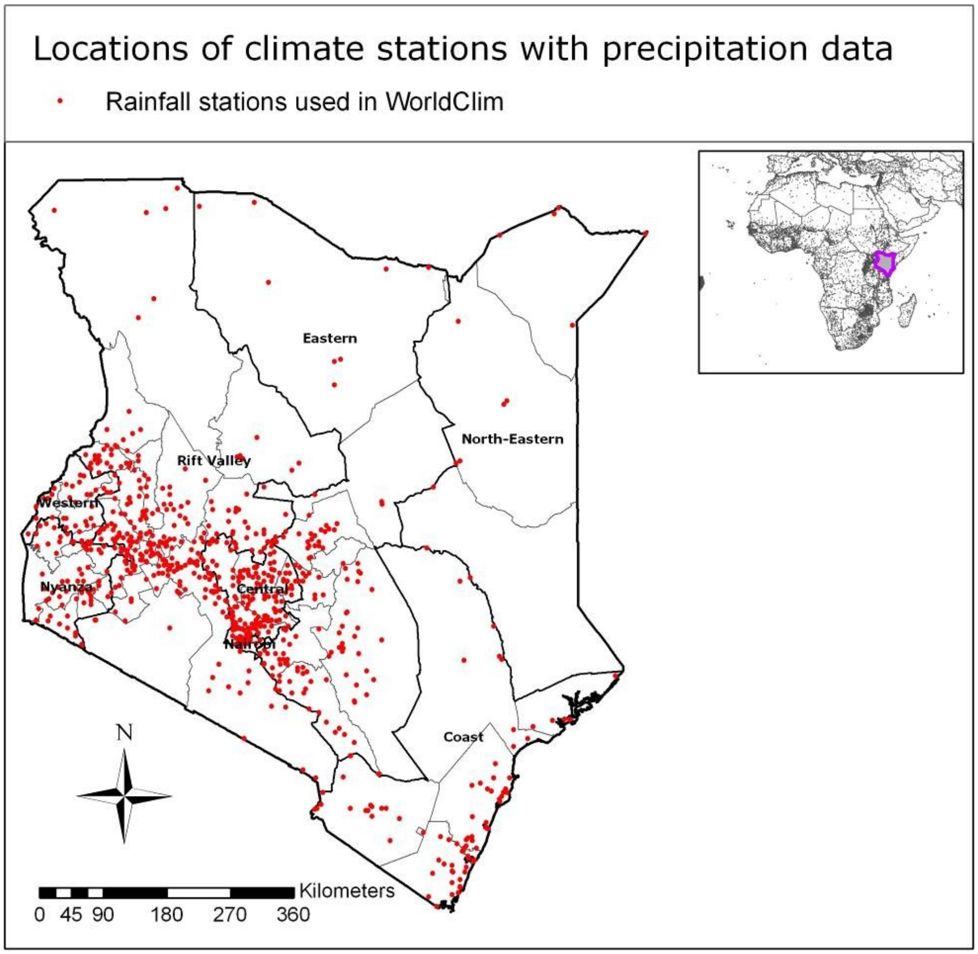

Figure 2: Locations of climate stations in Kenya with precipitation data, which were used in the WorldClim dataset.

Within the WorldClim database, there are bioclimatic variables that were derived from the monthly temperature and rainfall values to generate more biologically meaningful variables, which are often used in ecological niche modeling (e.g., BIOCLIM, GARP). The bioclimatic variables represent annual trends (e.g., mean annual temperature, annual precipitation) seasonality (e.g., annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wettest and driest quarters). A quarter is a period of three months (1/4 of the year).

The derived bioclimatic variables are:

Bio1 = Annual mean temperature
Bio2 = Mean diurnal range (Mean of monthly (max temp - min temp))
Bio3 = Isothermality (Bio2/Bio7) (* 100)
Bio4 = Temperature seasonality (standard deviation *100)
Bio5 = Maximum temperature of warmest month
Bio6 = Minimum temperature of coldest month
Bio7 = Temperature Annual Range (Bio5 – Bi06)
Bio8 = Mean Temperature of Wettest Quarter
Bio9 = Mean Temperature of Driest Quarter
Bio10 = Mean Temperature of Warmest Quarter
Bio11 = Mean Temperature of Coldest Quarter
Bio12 = Annual Precipitation
Bio13 = Precipitation of Wettest Month
Bio14 = Precipitation of Driest Month
Bio15 = Precipitation Seasonality (Coefficient of Variation)
Bio16 = Precipitation of Wettest Quarter
Bio17 = Precipitation of Driest Quarter
Bio18 = Precipitation of Warmest Quarter
Bio19 = Precipitation of Coldest Quarter

6.b Future climate

6.b.i Global circulation models

A global circulation model (GCM) is a computer-based model that calculates and predicts what climate patterns will be in a number of years in the future. GCMs use equations of motion as a numerical weather prediction (NWP) model, with the purpose of numerically simulating changes in the climate as a result of slow changes in some boundary conditions (such as the solar constant) or physical parameters (such as the concentration of greenhouse gases). The model focuses on each grid cell and the transfer of energy between grid cells. Once the simulation is calculated a number of climate patterns can be determined; from ocean and wind currents to patterns in precipitation and rates of evaporation rates that affect, for example, lake-levels and growth of agricultural plants. The GCMs are run in a number of specialized computer laboratories around the world. We used data in our analyses from these laboratories. The twenty models are summarized in Table 1.

Table 1. Summary chart of the Global Circulation Models GCM's from which data were used for the analyses

Originating Group(s)	Country	MODEL ID	OUR ID	GRID	Year
Bjerknes Centre for Climate Research	Norway	BCCR-BCM2.0	BCCR_BCM2	128x64	2050
Canadian Centre for Climate Modelling & Analysis	Canada	CGCM2.0	CCCMA_CGCM2	96x48	2020 2050
		CGCM3.1(T47)	CCCMA_CGCM3_1	96x48	2050
		CGCM3.1(T63)	CCCMA_CGCM3_1_T63	128x64	2050
Météo-France Centre National de Recherches Météorologiques	France	CNRM-CM3	CNRM_CM3	128x64	2050
CSIRO Atmospheric Research	Australia	CSIRO-Mk3.0	CSIRO_MK3	192x96	2050
		CSIRO-MK2.0	CSIRO_MK2	56x64	2020 2050
Max Planck Institute for Meteorology	Germany	ECHAM5/MPI-OM	MPI_ECHAM5	N/A	2050
Meteorological Institute of the University of Bonn Meteorological Research Institute of KMA	Germany Korea	ECHO-G	MIUB_ECHO_G	96x48	2050
LASG / Institute of Atmospheric Physics	China	FGOALS-g1.0	IAP_FGOALS_1_0_G	128x60	2050
US Dept. of Commerce NOAA Geophysical Fluid Dynamics Laboratory	USA	GFDL-CM2.0	GFDL_CM2_1	144x90	2050
NASA / Goddard Institute for Space Studies	USA	GISS-AOM	GISS_AOM	90x60	2050
Institut Pierre Simon Laplace	France	IPSL-CM4	IPSL_CM4	96x72	2050
Center for Climate System Research National Institute for Environmental Studies Frontier Research Center for Global Change (JAMSTEC)	Japan	MIROC3.2(hires)	MIROC3_2_HIRES	320x160	2050
	Japan	MIROC3.2(medres)	MIROC3_2_MEDRES	128x64	2050
Meteorological Research Institute	Japan	MRI-CGCM2.3.2	MRI_CGCM2_3_2a	N/A	2050
National Center for Atmospheric Research	USA	PCM	NCAR_PCM1	128x64	2050
Hadley Centre for Climate Prediction and Research Met Office	UK	UKMO-HadCM3	HCCPR_HADCM3	96x73	2020 2050
Centre for Climate System Research (CCSR), and National Institute for Environmental Studies (NIES)	Japan	CCSR/NIES99	NIES-99	64x64	2020 2050

6.b.ii Generation of future climate

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report was based on the results of 21 global climate models (GCMs), data for which are available through an IPCC interface, or directly from the institutions that developed each individual model. The spatial resolution of the GCM results is inappropriate for analyzing the impacts on agriculture as in almost all cases the grid cells measure more than 100 km a side. This is especially a problem in heterogeneous landscapes such as those of the Andes, where, in some places, one cell can cover the entire width of the range.

Downscaling is therefore needed to provide higher-resolution surfaces of expected future climates if the likely impacts of climate change on agriculture are to be forecast. Two approaches are available for downscaling; 1) re-modeling of impacts using regional climate models (RCMs) based on boundary conditions provided by the GCMs, or 2) statistical downscaling whereby resolution is reduced using interpolation and explicit knowledge of the distribution of climate at a fine-scale. Whilst the use of RCMs is more robust from the perspective of climate science, it requires large amount of re-processing, and moreover, RCMs are only available for a limited number of GCM models. Because of the heavy data-processing requirements, it is only realistic to include one or two RCMs in any analysis. In the context of this project, the use of RCMs for only one or two GCMs would make it impossible for us to quantify uncertainty in the analysis, which we believe is inappropriate. We have therefore used statistically-downscaled data derived from a larger set of GCMs.

CIAT downloaded and re-processed the climate change data from the 20 most reputable GCMs that were used in the IPCC Fourth Assessment Report (http://www.ipcc-data.org). The models are listed above in section 6b (i). A statistical downscaling method was applied to these data to produce 10km, 5km and 1km resolution surfaces for 2020 (4 GCMs) and 2050 (20 GCMs) of the monthly means of maximum and minimum temperature and monthly precipitation. In all cases, IPCC scenario A2a (“business as usual”) was used.

Specifically, the centroid of each GCM grid cell was calculated, and the anomaly in climate was assigned to that point. The statistical downscaling was then applied to interpolate between the points to the desired resolution using the same spline interpolation method used to produce the WorldClim dataset for current climates (Hijmans et al. 2005). The anomaly for the higher-resolution was then added to the current distribution of climate (derived from WorldClim) to produce a surface of future climate. The method assumes that the current meso- distribution of climate will remain the same, but that regionally there is a change in the baseline. Whilst in some specific cases this assumption may not hold true, for the great majority of sites it is unlikely that there will be a fundamental change in meso-scale climate variability.

6.c Suitability prediction

We reviewed several prediction models such as ECOCROP, DOMAIN, BIOCLIM, and MAXENT in order to select the most appropriate model to use in the present analysis.

6.c.i Ecocrop

ECOCROP, developed by the FAO (http://ecocrop.fao.org/ecocrop/srv/en/home) is a crop database, with a description of the growing environment and use of various crops. There is also a crop prediction model with the same name (Hijmes et al., 2005b) that uses parameters in the FAO database to predict areas suitable for specific crops. ECOCROP is a very useful model for situations where there are no evidence data available for specific crops and one is forced to use environmental ranges instead. The results, however, are of very general in nature and they can only be used to describe overall trends.

6.c.ii Bioclim

BIOCLIM utilizes a boxcar environmental envelope algorithm to identify locations that have environmental conditions that fall within the range over which a given element is known to occur. Specifically, the minimum and maximum values for each environmental predictor are identified and used to define the multidimensional environmental box where the element is known to occur. Study area sites that have environmental conditions within the boundaries of the multi-dimensional box are predicted as potential sites of occupancy of the element. Since this method is known to be sensitive to outliers, often the predicted distribution is calculated by disregarding 5% of the lower and higher values for each environmental predictor variable and is termed the “core bioclimate”.

6.c.iii Domain

The DOMAIN algorithm calculates the Gower distance statistic between each cell on the map and each point, using the values of the climate variables. The distance between point A and cell B for a single climate variable is calculated as the absolute difference in the values of that variable divided by the range across all points, The Gower distance is then the mean over all climate variables:

$$d_{AB} = \frac{1}{p} \sum_{k=1}^{p} \frac{| A_k - B_k |}{range(k)}$$

Where d_{AB} = Gower distance

p = Total number of climatic variables

A_k = Value of point k in point A

B_k = Value of variable k in cell B

range (k) = Range of variable k across all the points present.

The Gower similarity indicator is calculated as:

$$D = 1 - d_{AB}$$

The similarity between each pixel of the layer and the presence points is mapped. The higher the value of D for one pixel, the more similar are the climatic variables of this cell to the presence point data. The pixel has similar conditions to the presence data. Predictions are not to be interpreted as predictions of probability of occurrence but as a measure of classification confidence. (Carpenter et al., 1993; Hijmans et al., 2005a)

DOMAIN and BIOCLIM are fairly good models for conditions where evidence data are available. The algorithms used for both models are simple and tend to reduce and average the evidence information. The results are much more specific than the results for ECOCROP but are still rather general.

6.c.iv Maxiumum Entropy

Maximum entropy (MAXENT) is a general-purpose method for making predictions or inferences from incomplete information. The idea is to estimate a target probability distribution by finding the probability distribution of maximum entropy, subject to a set of constraints that represent (one's) incomplete information about the target distribution. The information available about the target distribution often presents itself as a set of real-valued variables, called 'features', and the constraints are that the expected value of each feature should match its empirical average ("average value for a set of sample points taken from the target distribution", Phillips et al., 2006). Similar to logistic regression, MAXENT weights each environmental variable by a constant. The probability distribution is the sum of each weighed variable divided by a scaling constant to ensure that the probability value ranges from 0 to 1. The program starts with a uniform probability distribution and iteratively alters one weight at a time to maximize the likelihood of reaching the optimum probability distribution.

MAXENT is generally considered to be the most accurate model (Elith et al. 2006) and was selected for the analyses of the present study after an initial iteration of analysis in the study region using all four models.

6.c.v Summary prediction method applied

A total of 19 bioclimatic variables were generated by each GCM, describing the mean and extreme conditions of the future climate (Hijmans et al. 2005; Table 1). Each variable was averaged over the final analysis 4 GCMs for 2020 and 20 GCMs for 2050 to generate a mean climatic scenario as input to the software MAXENT (Philipps et al. 2006) in order to predict the shift in suitability for coffee production in the Kenya resulting from climate change. The use of average predictions over several models, as in this paper, has been found to reduce uncertainty due to the cancellation of offsetting errors in the individual GCMs (Pierce et al. 2009). One variable, the precipitation of the driest month, was excluded because of its very high CV among GCMs, and because another variable, the precipitation of the driest quarter, is likely to contain very similar climatic information for the study region (Table 1). Although the remaining 17 bioclimatic variables are not independent of each other, we used the complete set of variables in the analysis because (1) they are useful to provide the best possible description of the climatic requirements of coffee over the year, (2) some authors have indicated that MAXENT reduces the risk of overfitting through variable weighting as explained below (Phillips et al. 2006; Phillips and Dudik 2008; Hijmans and Graham 2006), and (3) the alternative approach of reducing the set of 17 bioclimatic descriptors to a set of orthogonal variables (Dormann 2006) might lead to loss of information and would have complicated the interpretation of the results. Future suitability predictions were then assessed through each of the 4 GCMs for 2020 and 20 GCMs for 2050 via the software MAXENT (Phillips et al. 2006) and three measurements of uncertainty were computed: (1) the agreement among models calculated as percentage of models predicting changes in the same direction as the average of all models at a given location; (2) the upper and lower 95% confidence intervals (C.I.) around the mean suitability change using all models; and (3) the coefficient of variation (CV) among models. To assure coherence plausibility we applied the Tukey's (1977) outlier test to see if all models pretending similar predictions and no model were removed in Kenya after these initial runs.

In order to understand the relative importance of different climatic drivers, we then carried out a forward, step-wise regression analysis with the suitability shift per data point as the dependent variable and the model-average changes in the bioclimatic variables between the present and future as the independent variables, and calculating the relative contribution of each variable to the total predicted suitability shift in terms of the proportion of R-square explained when adding each variable to the linear regression model. This analysis was carried out separately for the data points showing positive and negative shifts in suitability.

7 Results I: Evidence Data

For the coffee-growing areas in Kenya we used 805 current locations of Arabica coffee farms in Kenya. 644 of this locations where collected during field work using global positioning system (GPS) within a precision of 10 to 30 meters and 161 of the sites where collected by desk studies from on-line mapping resources. To exclude Robusta coffee (*Coffea canephora*), which replaces Arabica coffee at lower altitudes, only sites with an altitude above 500 m.a.s.l. where used.

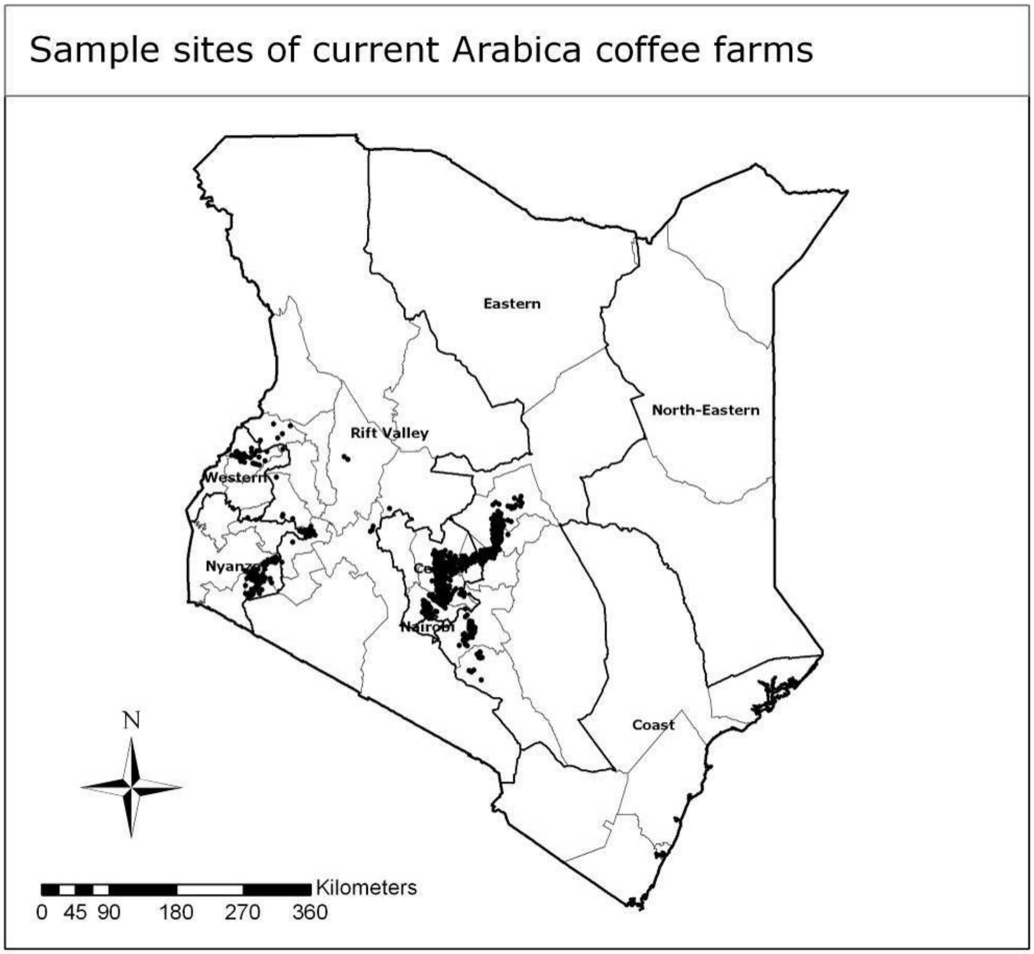

Figure 3: Summary of the sample sites in the coffee growing districts of Kenya.

8 Results II: Regional changes

8.a Regional changes in the mean annual precipitation

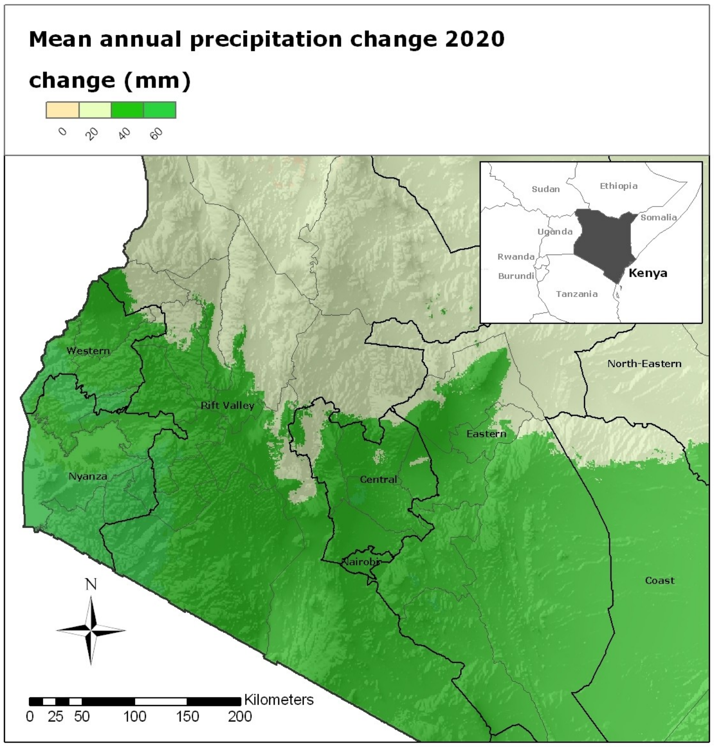

Figure 4: Mean annual precipitation changes 2020 for Kenya.

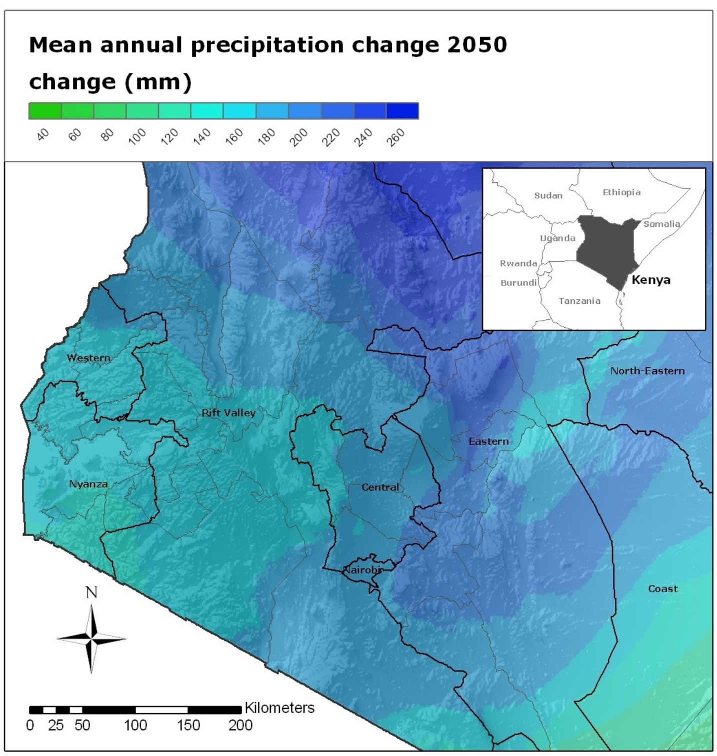

Figure 5: Mean annual precipitation changes 2050 for Kenya.

The mean annual precipitation increases in 2020 in average by 30 mm and in 2050 by 170 mm (Figures 4 and 5). The municipalities Machakos, Meru and Nithi will have larger increase in precipitation than others and Kisii, Nyamira and Kericho will have the smallest increase in precipitation by 2050. The variability in precipitation between the sites within a district is largest in Meru and Embu and smallest in Bungoma and Nyeri in 2050 (Figure 5).

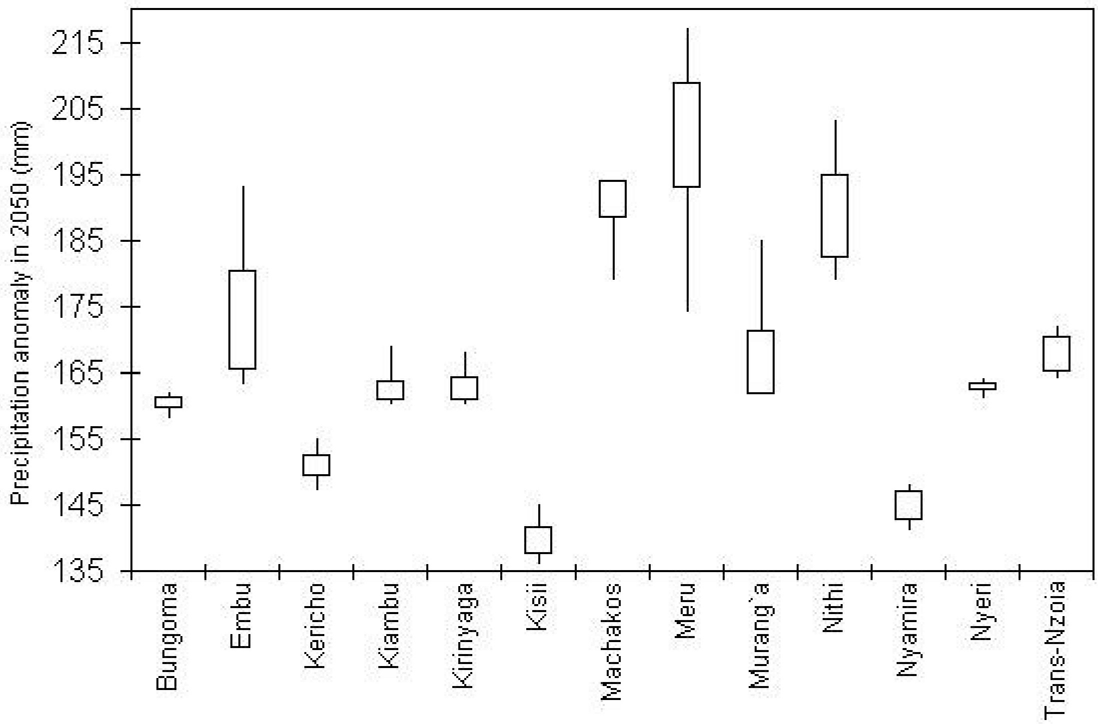

Figure 6: Mean annual precipitation change by 2050 for 13 coffee-growing municipalities of Kenya. The edges of the boxes indicate the mean maximum and mean minimum values and the ends of the line the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation.

8.b Changes in the mean annual temperature

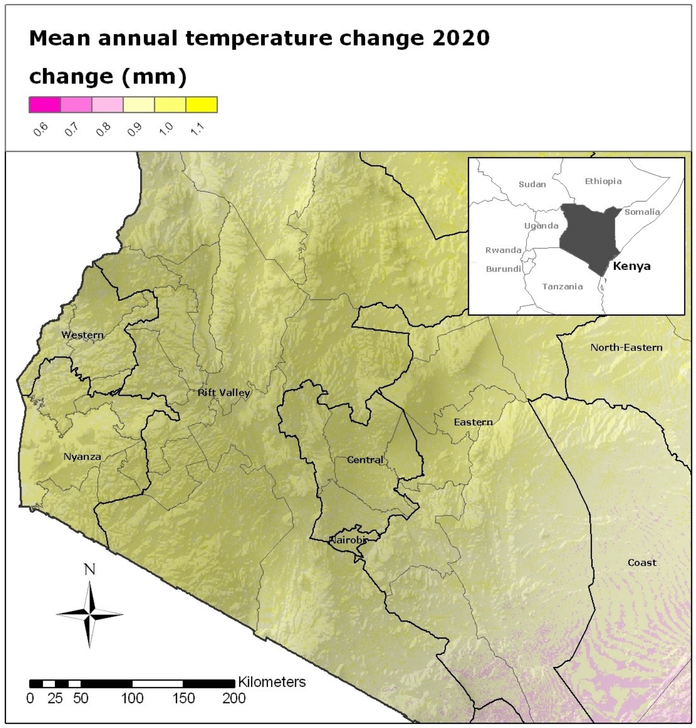

Figure 7: Mean annual temperature change in 2020 for Kenya.

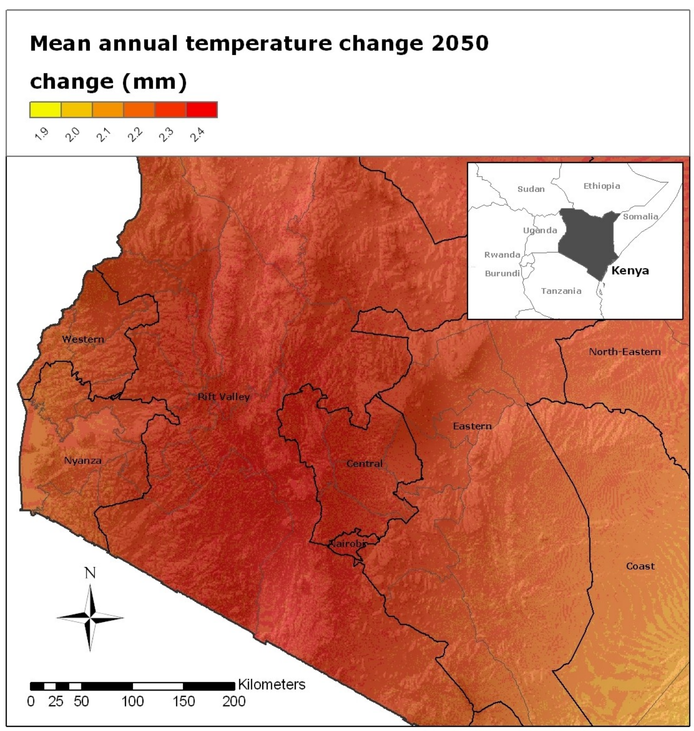

Figure 8: Mean annual temperature change in 2050 for Kenya.

The mean annual temperature will increase progressively. The increase by 2050 is between 1.9 and 2.4 ºC (Figures 8). The districts on lower altitude and closer to the sea will experience a somewhat smaller increase in temperature in 2050 than the remaining districts. There is less variability in temperature between the sites in each district for temperature as it is for precipitation (Figure 9).

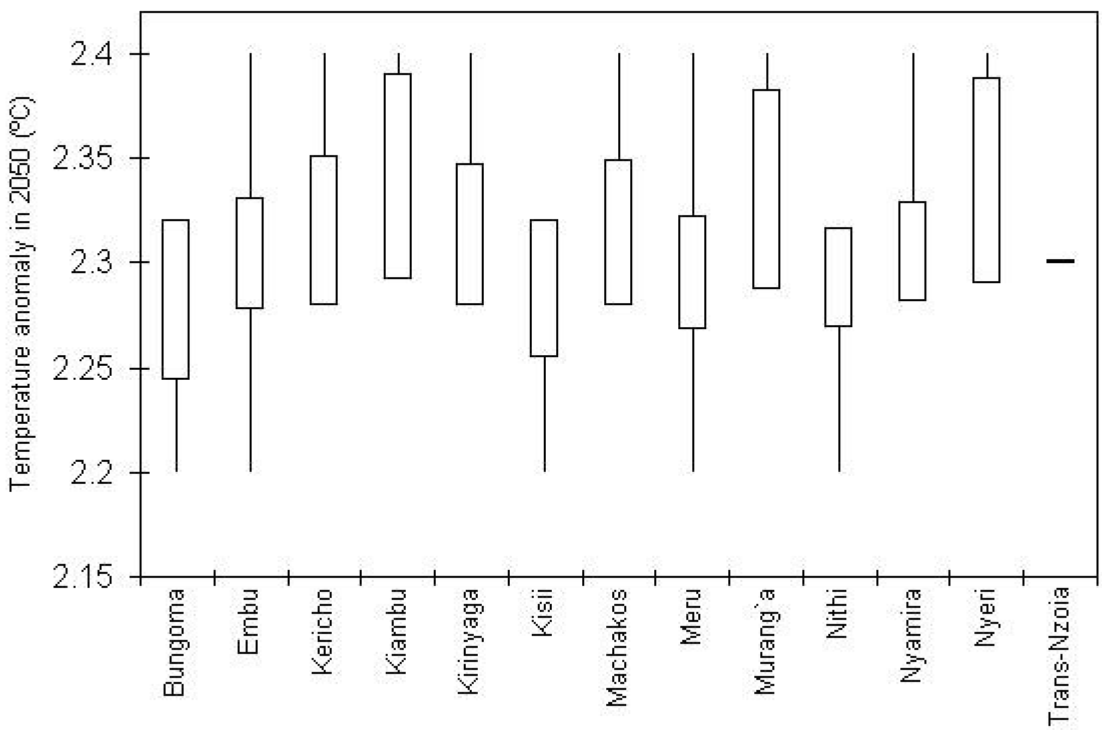

Figure 9: Mean annual temperature change by 2050 for 13 coffee-growing districts of Kenya. The edges of the boxes indicate the mean maximum and mean minimum values and the ends of the line the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation.

8.c Climate change summery of coffee production sites

The summary climate characteristics for all points of the entire Kenya

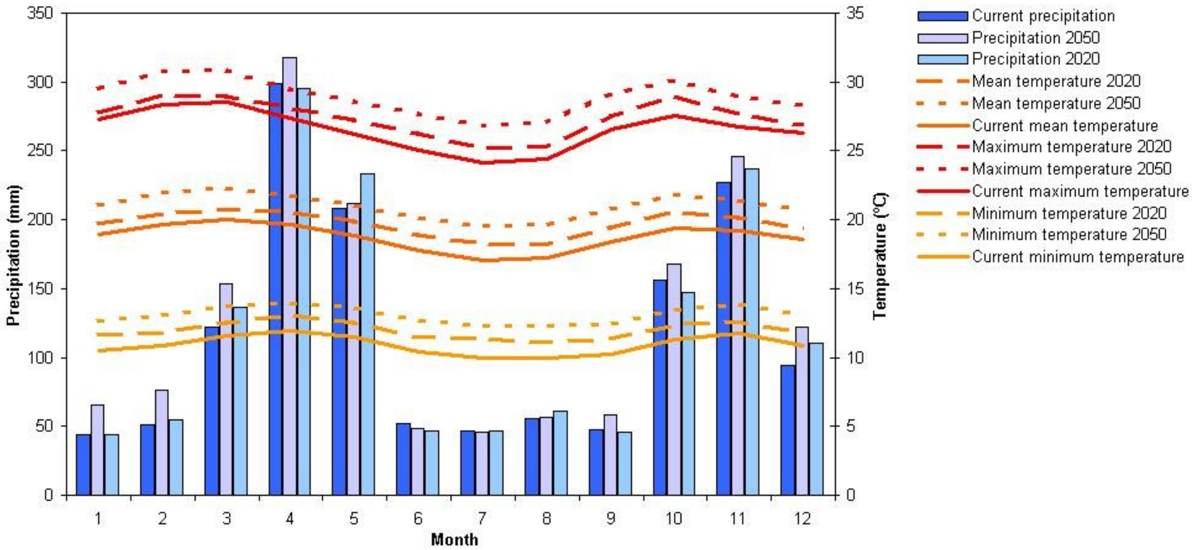

Figure 10: Climate trend summary 2020 and 2050 for sample sites.

General climatic characteristics

- The rainfall increases from 1405 millimeters to 1575 millimeters in 2050 passing through 1435 in 2020
- Temperatures increase and the average increase is 2.3 ºC passing through an increment of 1.0 ºC in 2020
- The mean daily temperature range increases from 15.6 ºC to 15.9 ºC in 2050
- The maximum number of cumulative dry months keeps constant in 4 months

Extreme conditions

- The maximum temperature of the year increases from 28.6 ºC to 31.2 ºC while the warmest quarter gets hotter by 2.3 ºC in 2050
- The minimum temperature of the year increases from 9.8 ºC to 12.0 ºC while the coldest quarter gets hotter by 2.4 ºC in 2050
- The wettest month gets wetter with 330 millimeters instead of 305 millimeters, while the wettest quarter gets wetter by 60 mm in 2050
- The driest month keeps constant with 30 millimeters while the driest quarter gets wetter by 10 mm in 2050

Climate Seasonality

- Overall this climate becomes less seasonal in terms of variability through the year in temperature and less seasonal in precipitation

Variability between models

- The coefficient of variation of temperature predictions between models is 5.9%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 10.2%
- Precipitation predictions were uniform between models and thus no outliers were detected

8.d Suitability of coffee production areas

Currently, the main coffee-producing areas in Kenya are located in two areas, the central region around Mount Kanya and in the Rift Valley in the west (Figure 11). According to the MAXENT model, the most suitable of them are concentrated in the higher areas of Bungoma, Embu, Kericho, Kiambu, Kirinyaga, Kisii, Machakos, Meru, Muranga, Nithi, Nyamira, Nyeri and Trans-Nzoia. The remaining districts are in general rather less suitable.

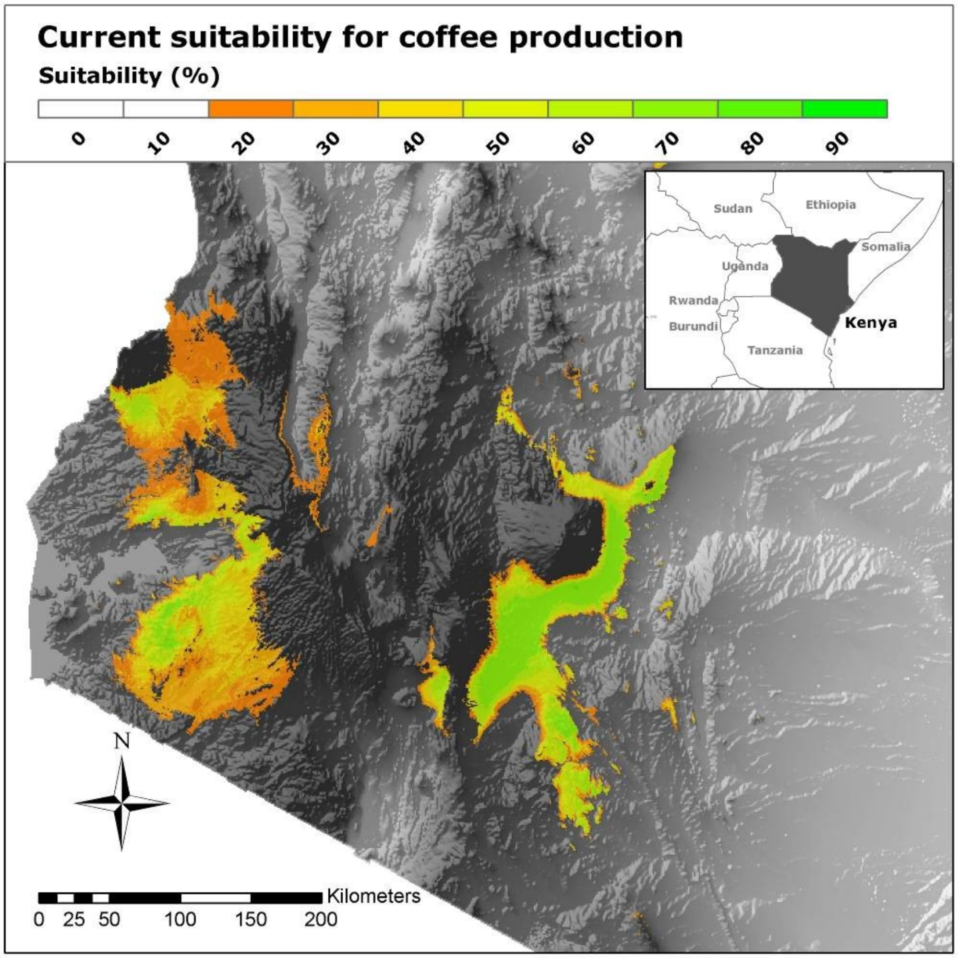

Figure 11: Current suitability for coffee production within coffee-growing districts of Kenya.

By 2050 the suitability of the thirteen municipalities in Kenya for coffee production in general decreases quite seriously (Figure 12). The CV for 2020 and 2050 ranges between 0 and 20 % for coffee-growing areas and may therefore be accepted as reliable. The areas that still show some suitability to produce coffee are all located in the central region south of Mount Kenya. The average suitability of these areas decreases to between 30 and 50%, whereas today they have suitabilities of 60 - 80%. The majority of areas lose suitability and only some restricted areas in Rift Valley where today there is no coffee planting are gaining suitability from 20 – 30% (Figure 13).

With progressive climate change, areas at higher altitudes become suitable for producing coffee (Figure 14). Altitude was not used in the suitability modeling and is therefore independent of the other variables. Altitude is however very much correlated with temperature-related variables. The optimum coffee-producing zone is currently at an altitude between 1400 and 1600 masl and will by 2050 increase to an altitude between 1600 and 1800 masl. Increasing altitude compensates for the increase in temperature (Figure 12).

Compared with today, by 2050 areas at altitudes around 1200 masl will suffer the highest decrease in suitability and the areas around 2000 masl the highest increase in suitability (Figure 14).

The Measure of agreement of models predicting changes in the same direction as the average of all models at a given location is between 70% - 100% in coffee growing areas (Figure 13).

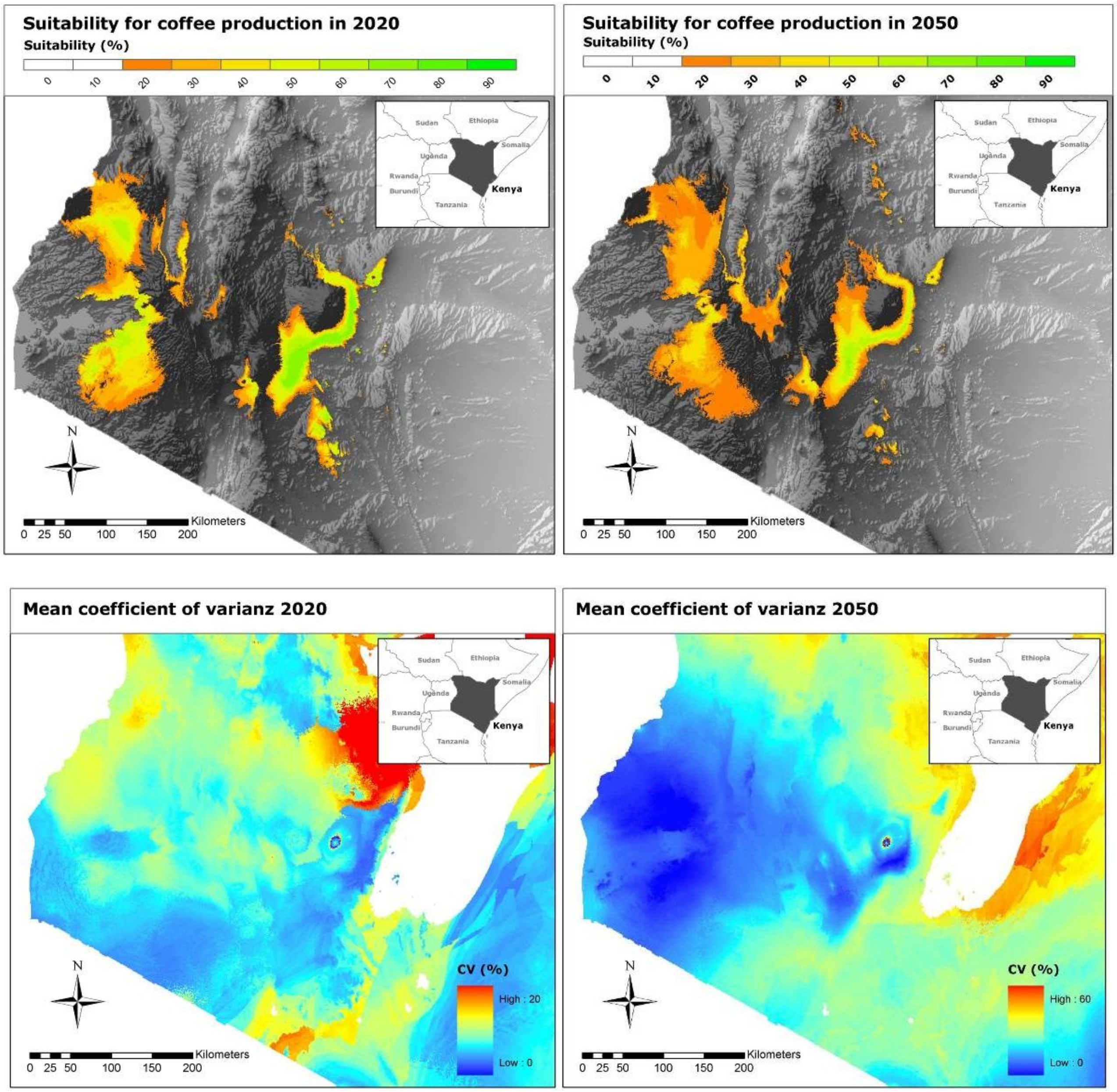

Figure 12: Suitability for coffee production in 2020 and 2050 (above) and mean coefficient of variance of bioclimatic variables in 2020 and 2050 (below) in Kenya.

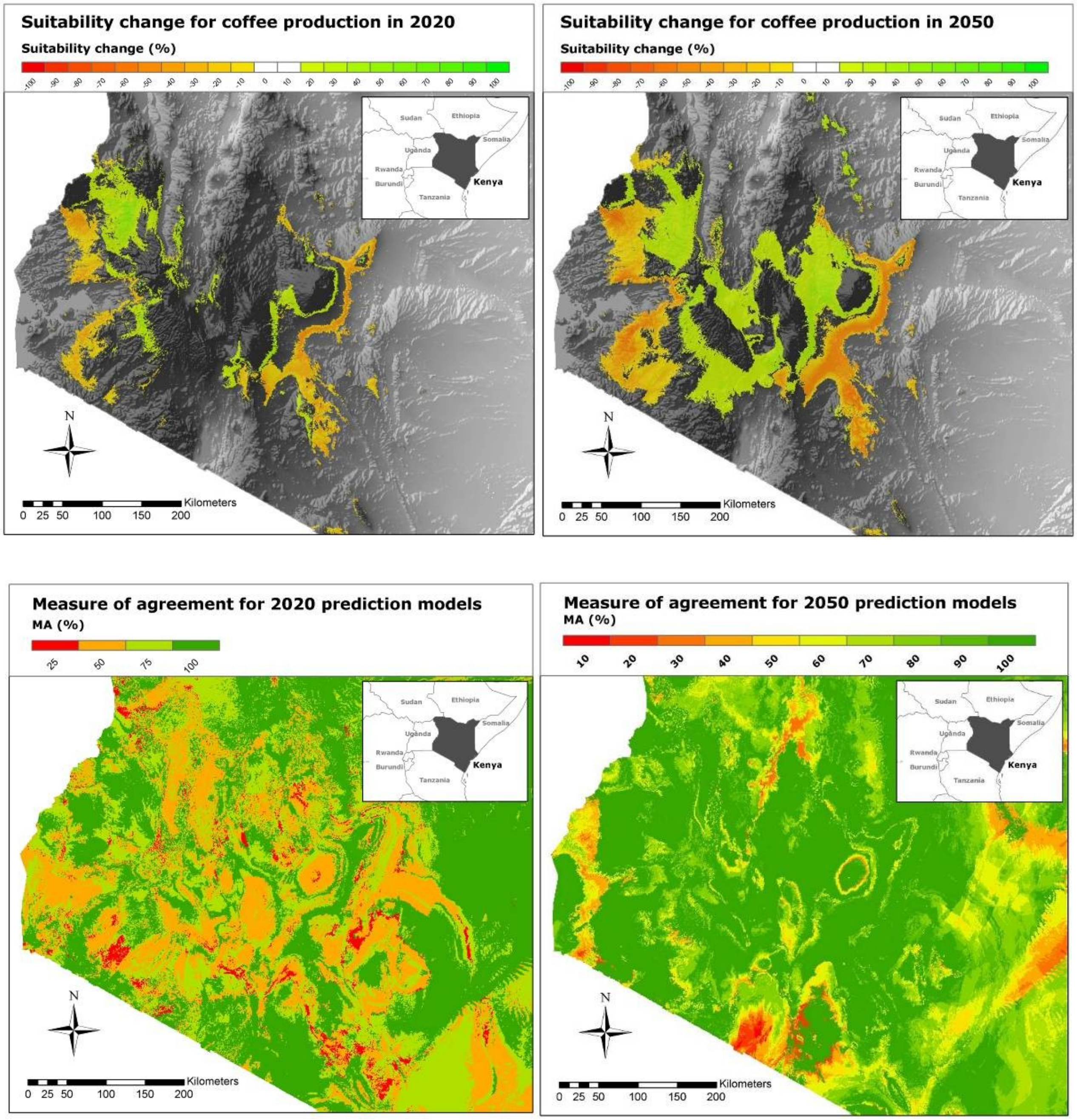

Figure 13: Suitability change for coffee production in 2020 and 2050 (above) and Measure of agreement of models predicting changes in the same direction as the average of all models at a given location (below) in Kenya.

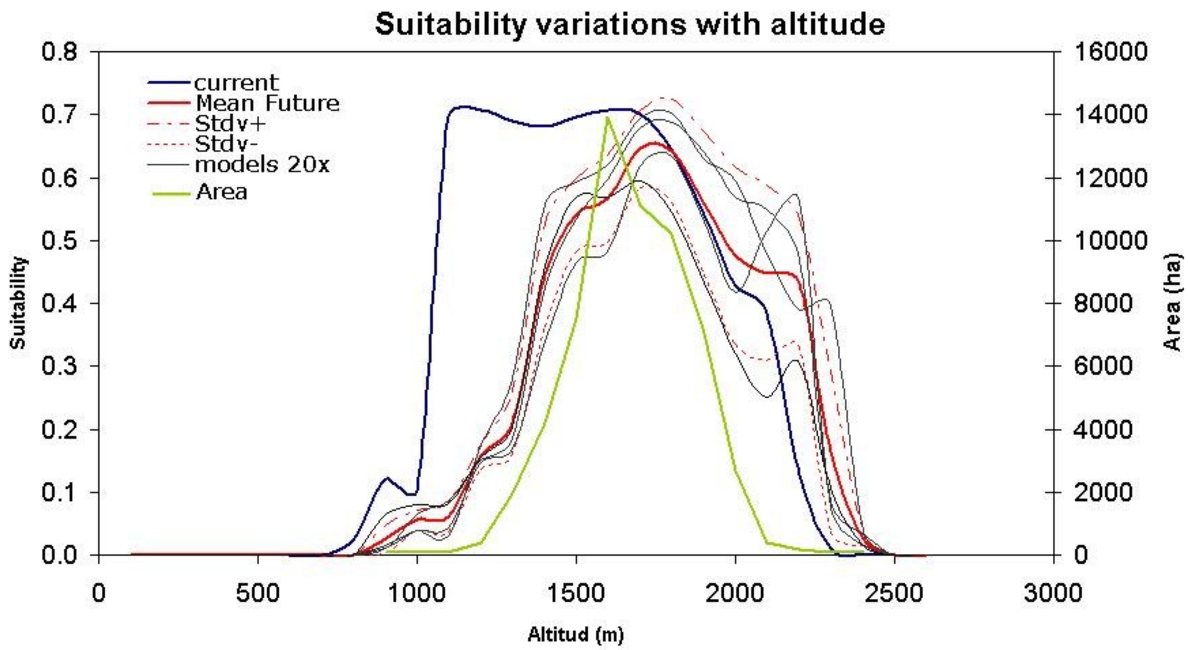

Figure 14: The relation between the suitability of areas for coffee production and altitude for current climates, and predicted for 2020 and 2050 in Kenya.

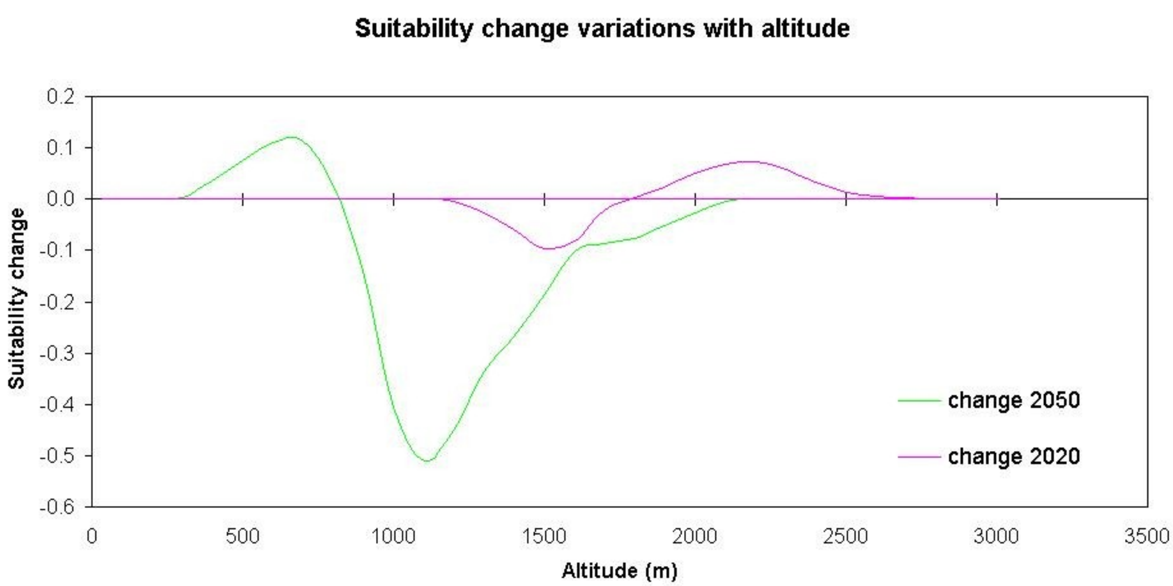

Figure 15: The relation between the change in suitability of areas for coffee production and altitude for 2050 compared with current suitability.

The regression analysis identified primarily the bioclimatic variables related to precipitation increase and general increasing temperature as drivers of the predicted negative suitability shifts (Table 2). The increases in min temperature of coldest month and precipitation of driest month explained together 64% of the negative suitability shifts and increasing precipitation of the coldest quarter explained another 20% of the negative suitability shifts, suggesting that the general increase of rainfall would lead to decrease in suitability.

Table 2: Contribution of different bioclimatic variables to the predicted shift in suitability for *Coffea arabica* in Kenya, between the present and the 2050s, separating locations with decreasing and increasing suitability[a]

Variable	Adjusted R2	R2 due to variable	% of total variability	Present mean	Change by 2050s
Locations with decreasing suitability (n=803, 100% of all observations)					
BIO14 – Precipitation of driest month	0.1913	0.1913	38.5	32 mm	- 3 mm
BIO6 – Min temperature of coldest month	0.3191	0.1278	25.7	9.8 °C	+ 2.1 °C
BIO19 – Precipitation of coldest quarter	0.4180	0.0989	19.9	154 mm	+ 18 mm
BIO13 – Precipitation of wettest month	0.4505	0.0325	6.5	305 mm	+ 24 mm
others	0.4900	0.0020	4.4		

[a]Variables explaining less than 5% of total variability are not listed.

9 Results III: Site-specific changes

9.a Average climate change trends Bungoma (Kenya)

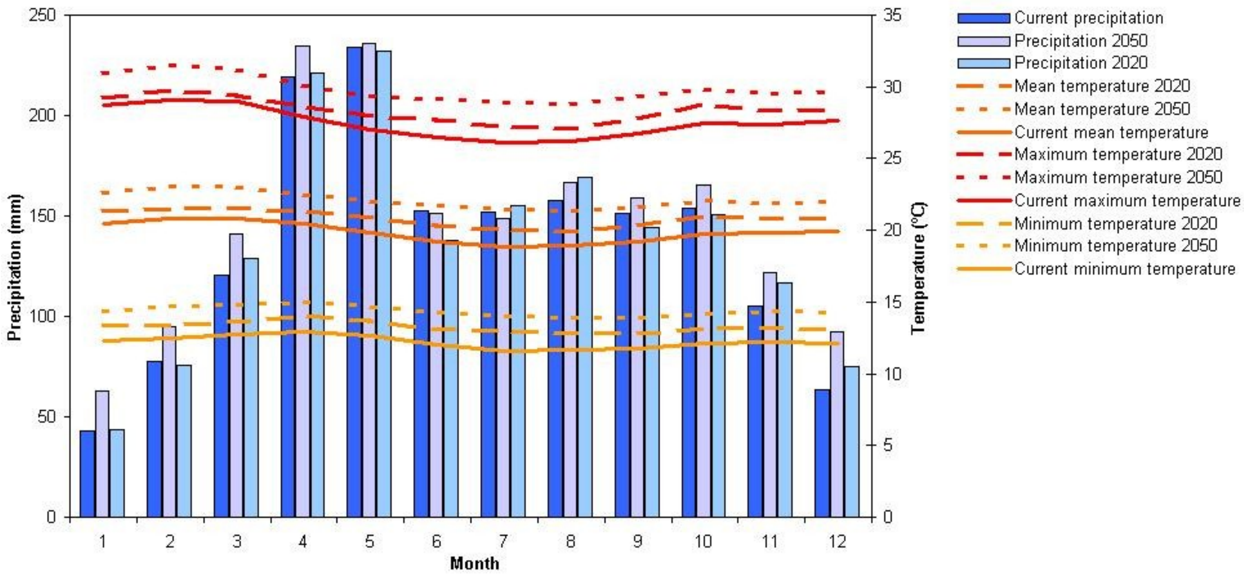

Figure 16.: Climate trend summary 2020 and 2050 for sample sites in Bungoma.

General climatic characteristics

- The rainfall increases from 1630 millimeters to 1790 millimeters in 2050 passing through 1660 in 2020
- Temperatures increase and the average increase is 2.3 ºC passing through an increment of 1 ºC in 2020
- The mean daily temperature range increases from 15.3 ºC to 15.5 ºC in 2050
- The maximum number of cumulative dry months decreases from 3 months to 2 months

Extreme conditions

- The maximum temperature of the year increases from 29.1 ºC to 31.6 ºC while the warmest quarter gets hotter by 2.3 ºC in 2050
- The minimum temperature of the year increases from 11.6 ºC to 13.7 ºC while the coldest quarter gets hotter by 2.4 ºC in 2050
- The wettest month gets wetter with 255 millimeters instead of 235 millimeters, while the wettest quarter gets wetter by 35 mm in 2050
- The driest month gets wetter with 60 millimeters instead of 45 millimeters while the driest quarter gets wetter by 65 mm in 2050

Climate Seasonality

- Overall this climate becomes less seasonal in terms of variability through the year in temperature and less seasonal in precipitation

Variability between models

- The coefficient of variation of temperature predictions between models is 5.1%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 9.4%
- Precipitation predictions were uniform between models and thus no outliers were detected

9.b Average climate change trends Embu (Kenya)

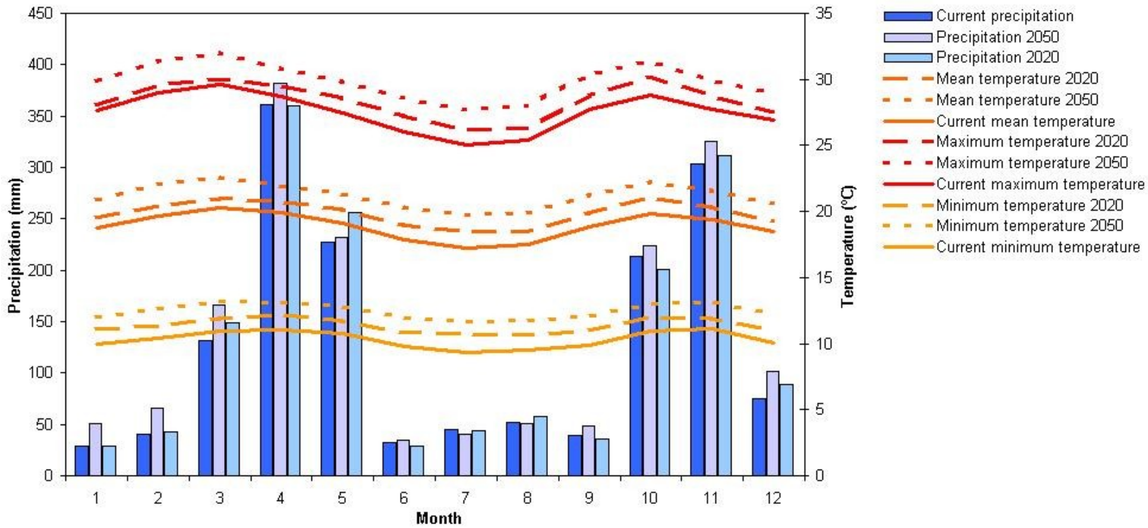

Figure 17: Climate trend summary 2020 and 2050 for sample sites in Embu.

General climatic characteristics

- The rainfall increases from 1550 millimeters to 1720 millimeters in 2050 passing through 1575 in 2020
- Temperatures increase and the average increase is 2.3 ºC passing through an increment of 1 ºC in 2020
- The mean daily temperature range increases from 17.2 ºC to 17.4 ºC in 2050
- The maximum number of cumulative dry months keeps constant in 4 months

Extreme conditions

- The maximum temperature of the year increases from 29.7 ºC to 32.2 ºC while the warmest quarter gets hotter by 2.4 ºC in 2050
- The minimum temperature of the year increases from 9.4 ºC to 11.5 ºC while the coldest quarter gets hotter by 2.4 ºC in 2050
- The wettest month gets wetter with 390 millimeters instead of 360 millimeters, while the wettest quarter gets wetter by 60 mm in 2050
- The driest month keeps constant with 25 millimeters while the driest quarter gets wetter by 5 mm in 2050

Climate Seasonality

- Overall this climate becomes more seasonal in terms of variability through the year in temperature and less seasonal in precipitation

Variability between models

- The coefficient of variation of temperature predictions between models is 5.9%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 10%

Precipitation predictions were uniform between models and thus no outliers were detected

9.c Average climate change trends Kericho (Kenya)

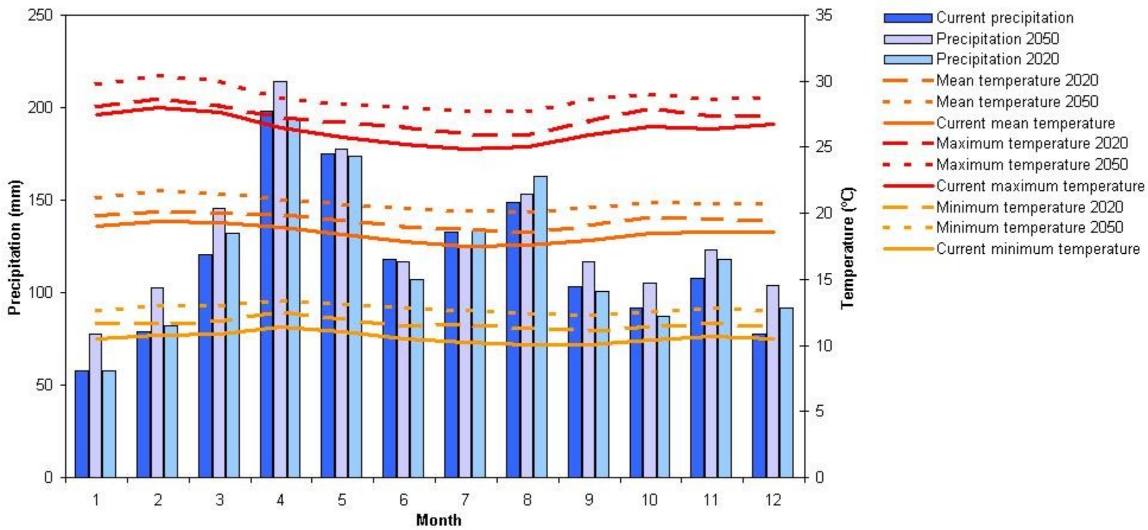

Figure 18: Climate trend summary 2020 and 2050 for sample sites in Kericho.

General climatic characteristics

- The rainfall increases from 1410 millimeters to 1560 millimeters in 2050 passing through 1440 in 2020
- Temperatures increase and the average increase is 2.3 ºC passing through an increment of 1 ºC in 2020
- The mean daily temperature range increases from 15.8 ºC to 16 ºC in 2050
- The maximum number of cumulative dry months decreases from 4 months to 2 months

Extreme conditions

- The maximum temperature of the year increases from 28 ºC to 30.6 ºC while the warmest quarter gets hotter by 2.3 ºC in 2050
- The minimum temperature of the year increases from 10 ºC to 12.1 ºC while the coldest quarter gets hotter by 2.4 ºC in 2050
- The wettest month gets wetter with 220 millimeters instead of 200 millimeters, while the wettest quarter gets wetter by 45 mm in 2050
- The driest month gets wetter with 70 millimeters instead of 60 millimeters while the driest quarter gets wetter by 55 mm in 2050

Climate Seasonality

- Overall this climate becomes less seasonal in terms of variability through the year in temperature and less seasonal in precipitation

Variability between models

- The coefficient of variation of temperature predictions between models is 6%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 10%
- Precipitation predictions were uniform between models and thus no outliers were detected

9.d Average climate change trends Kiambu (Kenya)

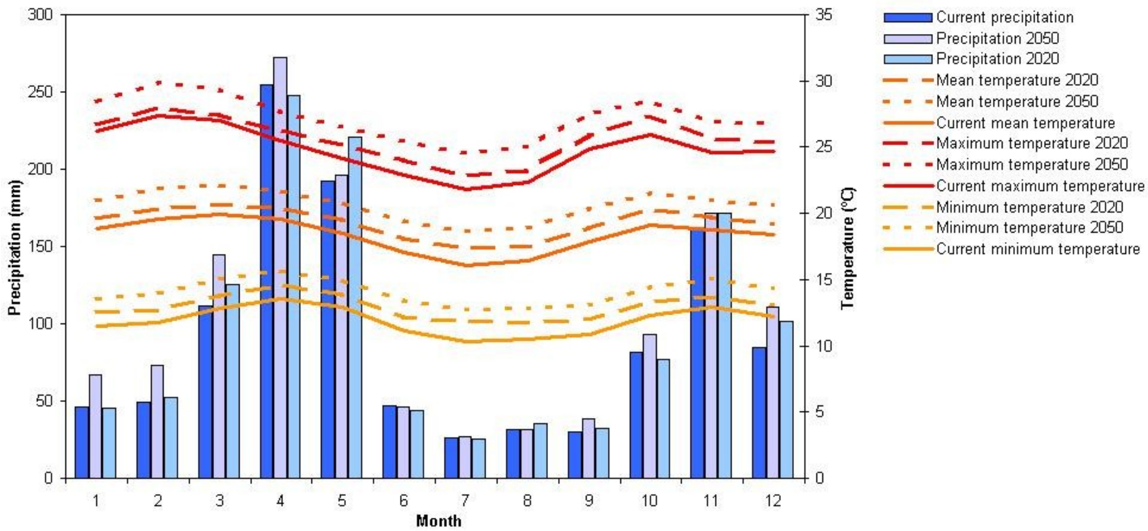

Figure 19: Climate trend summary 2020 and 2050 for sample sites in Kiambu.

General climatic characteristics

- The rainfall increases from 1120 millimeters to 1280 millimeters in 2050 passing through 1150 in 2020
- Temperatures increase and the average increase is 2.3 ºC passing through an increment of 1 ºC in 2020
- The mean daily temperature range decreases from 12.9 ºC to 12.6 ºC in 2050
- The maximum number of cumulative dry months keeps constant in 5 months

Extreme conditions

- The maximum temperature of the year increases from 27.4 ºC to 30 ºC while the warmest quarter gets hotter by 2.3 ºC in 2050
- The minimum temperature of the year increases from 10.4 ºC to 12.6 ºC while the coldest quarter gets hotter by 2.5 ºC in 2050
- The wettest month gets wetter with 275 millimeters instead of 255 millimeters, while the wettest quarter gets wetter by 55 mm in 2050
- The driest month gets drier with 20 millimeters instead of 25 millimeters while the driest quarter keeps constant in 2050

Climate Seasonality

- Overall this climate becomes less seasonal in terms of variability through the year in temperature and less seasonal in precipitation

Variability between models

- The coefficient of variation of temperature predictions between models is 6.1%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 12.7%
- Precipitation predictions were uniform between models and thus no outliers were detected

9.e Average climate change trends Kirinyaga (Kenya)

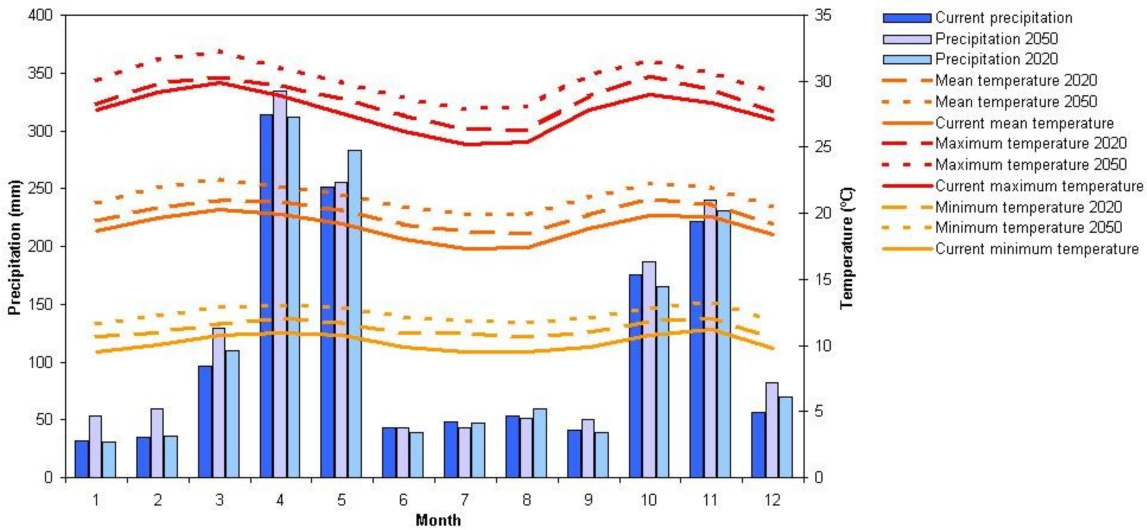

Figure 20: Climate trend summary 2020 and 2050 for sample sites in Kirinyaga.

General climatic characteristics

- The rainfall increases from 1365 millimeters to 1530 millimeters in 2050 passing through 1390 in 2020
- Temperatures increase and the average increase is 2.3 ºC passing through an increment of 1 ºC in 2020
- The mean daily temperature range increases from 17.5 ºC to 17.7 ºC in 2050
- The maximum number of cumulative dry months keeps constant in 4 months

Extreme conditions

- The maximum temperature of the year increases from 29.9 ºC to 32.5 ºC while the warmest quarter gets hotter by 2.4 ºC in 2050
- The minimum temperature of the year increases from 9.4 ºC to 11.5 ºC while the coldest quarter gets hotter by 2.4 ºC in 2050
- The wettest month gets wetter with 335 millimeters instead of 315 millimeters, while the wettest quarter gets wetter by 60 mm in 2050
- The driest month gets drier with 25 millimeters instead of 30 millimeters while the driest quarter gets wetter by 5 mm in 2050

Climate Seasonality

- Overall this climate becomes more seasonal in terms of variability through the year in temperature and less seasonal in precipitation

Variability between models

- The coefficient of variation of temperature predictions between models is 5.9%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 11.2%
- Precipitation predictions were uniform between models and thus no outliers were detected

9.f Average climate change trends Kisii (Kenya)

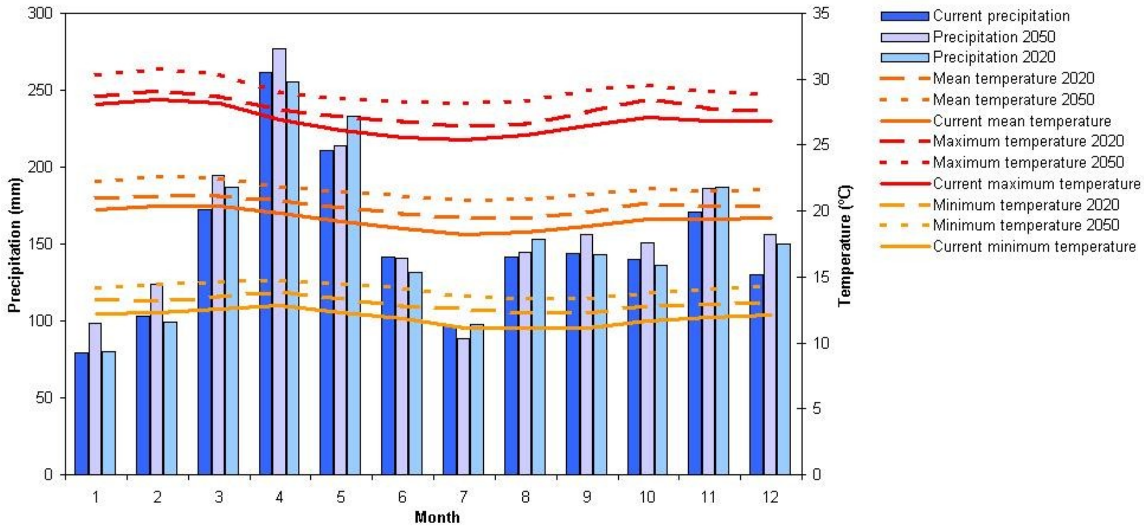

Figure 21: Climate trend summary 2020 and 2050 for sample sites in Kisii.

General climatic characteristics

- The rainfall increases from 1792.1 millimeters to 1931.7 millimeters in 2050 passing through 1841.78 in 2020
- Temperatures increase and the average increase is 2.28 ºC passing through an increment of 0.97 ºC in 2020
- The mean daily temperature range increases from 14.89 ºC to 15.14 ºC in 2050
- The maximum number of cumulative dry months keeps constant in 1 months

Extreme conditions

- The maximum temperature of the year increases from 28.4 ºC to 31 ºC while the warmest quarter gets hotter by 2.2 ºC in 2050
- The minimum temperature of the year increases from 11 ºC to 13.2 ºC while the coldest quarter gets hotter by 2.4 ºC in 2050
- The wettest month gets wetter with 280 millimeters instead of 260 millimeters, while the wettest quarter gets wetter by 45 mm in 2050
- The driest month keeps constant with 80 millimeters while the driest quarter gets wetter by 30 mm in 2050

Climate Seasonality

- Overall this climate becomes less seasonal in terms of variability through the year in temperature and more seasonal in precipitation

Variability between models

- The coefficient of variation of temperature predictions between models is 5.3%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 8.2%
- Precipitation predictions were uniform between models and thus no outliers were detected

9.g Average climate change trends Machakos (Kenya)

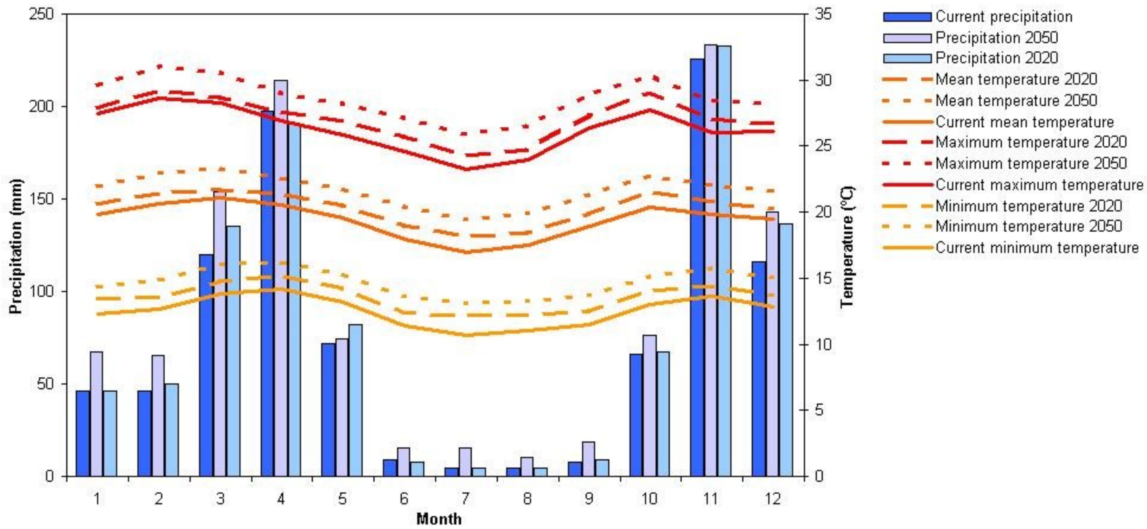

Figure 22: Climate trend summary 2020 and 2050 for sample sites Machakos.

General climatic characteristics

- The rainfall increases from 915 millimeters to 1105 millimeters in 2050 passing through 950 in 2020
- Temperatures increase and the average increase is 2.3 ºC passing through an increment of 0.9 ºC in 2020
- The mean daily temperature range decreases from 13.8 ºC to 13.4 ºC in 2050
- The maximum number of cumulative dry months keeps constant in 6 months

Extreme conditions

- The maximum temperature of the year increases from 28.7 ºC to 31.2 ºC while the warmest quarter gets hotter by 2.3 ºC in 2050
- The minimum temperature of the year increases from 10.7 ºC to 13 ºC while the coldest quarter gets hotter by 2.4 ºC in 2050
- The wettest month gets wetter with 255 millimeters instead of 230 millimeters, while the wettest quarter gets wetter by 85 mm in 2050
- The driest month keeps constant with 5 millimeters while the driest quarter gets wetter by 20 mm in 2050

Climate Seasonality

- Overall this climate becomes less seasonal in terms of variability through the year in temperature and less seasonal in precipitation

Variability between models

- The coefficient of variation of temperature predictions between models is 5.6%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 12.7%
- Precipitation predictions were uniform between models and thus no outliers were detected

9.h Average climate change trends Meru (Kenya)

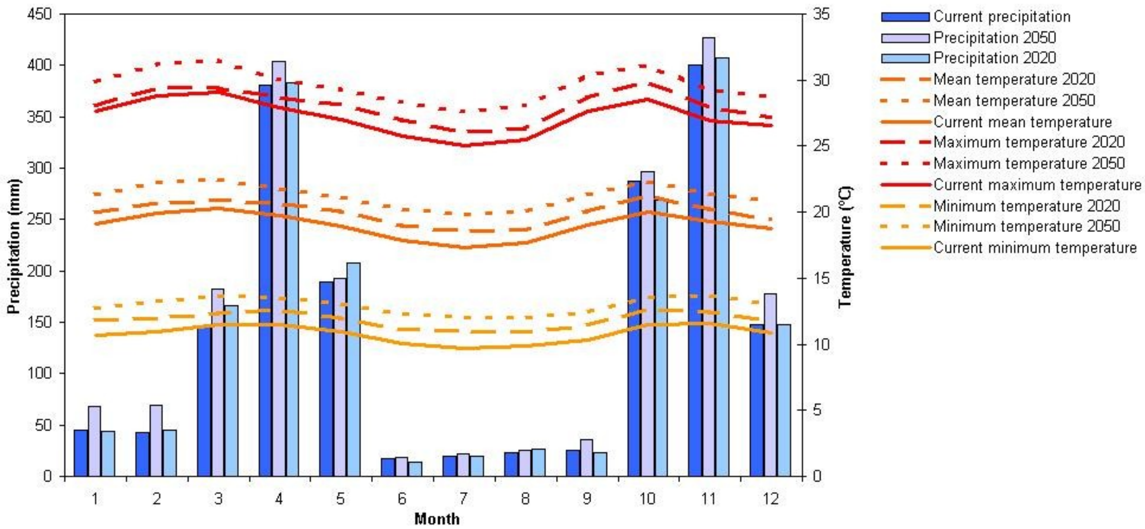

Figure 23: Climate trend summary 2020 and 2050 for sample sites in Meru.

General climatic characteristics

- The rainfall increases from 1720 millimeters to 1925 millimeters in 2050 passing through 1750 in 2020
- Temperatures increase and the average increase is 2.3 ºC passing through an increment of 1 ºC in 2020
- The mean daily temperature range increases from 16.4 ºC to 16.7 ºC in 2050
- The maximum number of cumulative dry months keeps constant in 4 months

Extreme conditions

- The maximum temperature of the year increases from 29.1 ºC to 31.8 ºC while the warmest quarter gets hotter by 2.4 ºC in 2050
- The minimum temperature of the year increases from 9.7 ºC to 11.8 ºC while the coldest quarter gets hotter by 2.4 ºC in 2050
- The wettest month gets wetter with 445 millimeters instead of 405 millimeters, while the wettest quarter gets wetter by 75 mm in 2050
- The driest month keeps constant with 15 millimeters while the driest quarter gets wetter by 5 mm in 2050

Climate Seasonality

- Overall this climate becomes less seasonal in terms of variability through the year in temperature and less seasonal in precipitation

Variability between models

- The coefficient of variation of temperature predictions between models is 5.9%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 9.5%
- Precipitation predictions were uniform between models and thus no outliers were detected

9.i Average climate change trends Murang`a (Kenya)

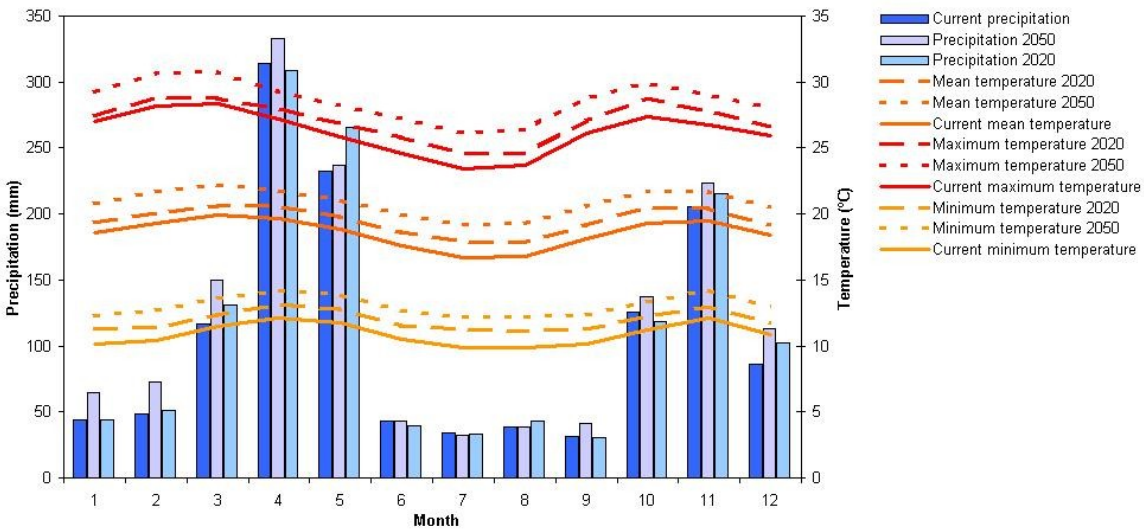

Figure 24: Climate trend summary 2020 and 2050 for sample sites in Murang'a.

General climatic characteristics

- The rainfall increases from 1320 millimeters to 1485 millimeters in 2050 passing through 1350 in 2020
- Temperatures increase and the average increase is 2.3 ºC passing through an increment of 1 ºC in 2020
- The mean daily temperature range increases from 15.3 ºC to 15.6 ºC in 2050
- The maximum number of cumulative dry months keeps constant in 4 months

Extreme conditions

- The maximum temperature of the year increases from 28.4 ºC to 31 ºC while the warmest quarter gets hotter by 2.4 ºC in 2050
- The minimum temperature of the year increases from 9.8 ºC to 11.9 ºC while the coldest quarter gets hotter by 2.5 ºC in 2050
- The wettest month gets wetter with 335 millimeters instead of 315 millimeters, while the wettest quarter gets wetter by 60 mm in 2050
- The driest month gets drier with 25 millimeters instead of 30 millimeters while the driest quarter gets drier by 2.7 mm in 2050

Climate Seasonality

- Overall this climate becomes less seasonal in terms of variability through the year in temperature and less seasonal in precipitation

Variability between models

- The coefficient of variation of temperature predictions between models is 6%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 11.4%
- Precipitation predictions were uniform between models and thus no outliers were detected

9.j Average climate change trends Nithi (Kenya)

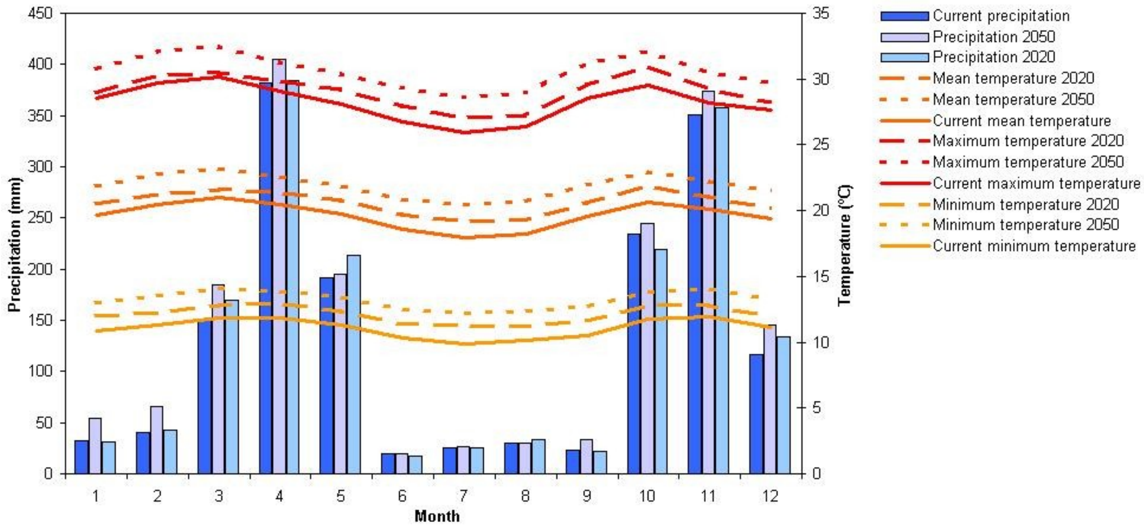

Figure 25: Climate trend summary 2020 and 2050 for sample sites in Nithi.

General climatic characteristics

- The rainfall increases from 1595 millimeters to 1785 millimeters in 2050 passing through 1625 in 2020
- Temperatures increase and the average increase is 2.3 ºC passing through an increment of 1 ºC in 2020
- The mean daily temperature range increases from 17.1 ºC to 17.4 ºC in 2050
- The maximum number of cumulative dry months keeps constant in 4 months

Extreme conditions

- The maximum temperature of the year increases from 30.1 ºC to 32.8 ºC while the warmest quarter gets hotter by 2.4 ºC in 2050
- The minimum temperature of the year increases from 9.9 ºC to 12.1 ºC while the coldest quarter gets hotter by 2.4 ºC in 2050
- The wettest month gets wetter with 420 millimeters instead of 385 millimeters, while the wettest quarter gets wetter by 85 mm in 2050
- The driest month gets drier with 15 millimeters instead of 20 millimeters while the driest quarter gets drier by 5 mm in 2050

Climate Seasonality

- Overall this climate becomes less seasonal in terms of variability through the year in temperature and less seasonal in precipitation

Variability between models

- The coefficient of variation of temperature predictions between models is 5.6%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 9.9%
- Precipitation predictions were uniform between models and thus no outliers were detected

9.k Average climate change trends Nyamira (Kenya)

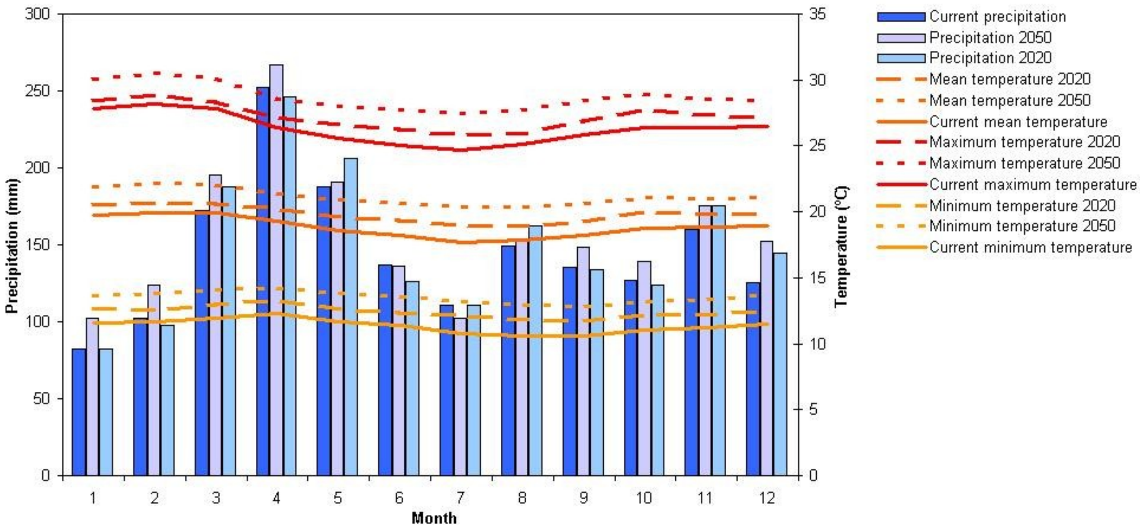

Figure 26: Climate trend summary 2020 and 2050 for sample sites in Nyamira.

General climatic characteristics

- The rainfall increases from 1740 millimeters to 1885 millimeters in 2050 passing through 1790 in 2020
- Temperatures increase and the average increase is 2.3 ºC passing through an increment of 1 ºC in 2020
- The mean daily temperature range increases from 14.9 ºC to 15.2 ºC in 2050
- The maximum number of cumulative dry months keeps constant in 1 months

Extreme conditions

- The maximum temperature of the year increases from 28.1 ºC to 30.6 ºC while the warmest quarter gets hotter by 2.3 ºC in 2050
- The minimum temperature of the year increases from 10.6 ºC to 12.7 ºC while the coldest quarter gets hotter by 2.4 ºC in 2050
- The wettest month gets wetter with 270 millimeters instead of 250 millimeters, while the wettest quarter gets wetter by 45 mm in 2050
- The driest month gets wetter with 85 millimeters instead of 80 millimeters while the driest quarter gets wetter by 40 mm in 2050

Climate Seasonality

- Overall this climate becomes less seasonal in terms of variability through the year in temperature and more seasonal in precipitation

Variability between models

- The coefficient of variation of temperature predictions between models is 5.6%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 8.4%
- Precipitation predictions were uniform between models and thus no outliers were detected

9.I Average climate change trends Nyeri (Kenya)

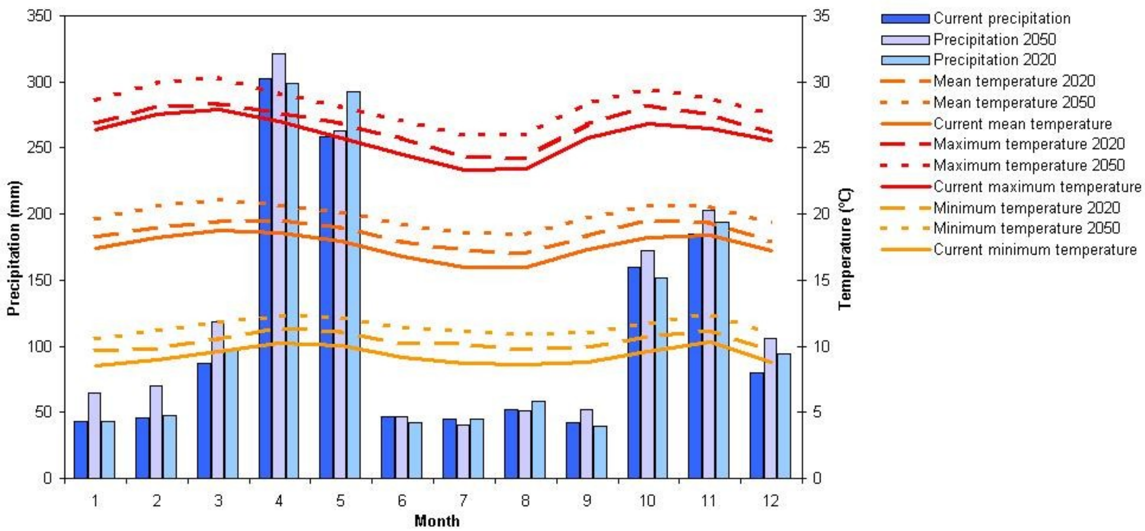

Figure 27: Climate trend summary 2020 and 2050 for sample sites in Nyeri.

General climatic characteristics

- The rainfall increases from 1345 millimeters to 1510 millimeters in 2050 passing through 1370 in 2020
- Temperatures increase and the average increase is 2.3 ºC passing through an increment of 1 ºC in 2020
- The mean daily temperature range increases from 16.6 ºC to 16.8 ºC in 2050
- The maximum number of cumulative dry months keeps constant in 4 months

Extreme conditions

- The maximum temperature of the year increases from 27.9 ºC to 30.5 ºC while the warmest quarter gets hotter by 2.4 ºC in 2050
- The minimum temperature of the year increases from 8.5 ºC to 10.5 ºC while the coldest quarter gets hotter by 2.5 ºC in 2050
- The wettest month gets wetter with 325 millimeters instead of 300 millimeters, while the wettest quarter gets wetter by 55 mm in 2050
- The driest month gets drier with 30 millimeters instead of 40 millimeters while the driest quarter gets drier by 10 mm in 2050

Climate Seasonality

- Overall this climate becomes more seasonal in terms of variability through the year in temperature and less seasonal in precipitation

Variability between models

- The coefficient of variation of temperature predictions between models is 6.4%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 11.5%
- Precipitation predictions were uniform between models and thus no outliers were detected

9.m Average climate change trends Trans-Nzoia (Kenya)

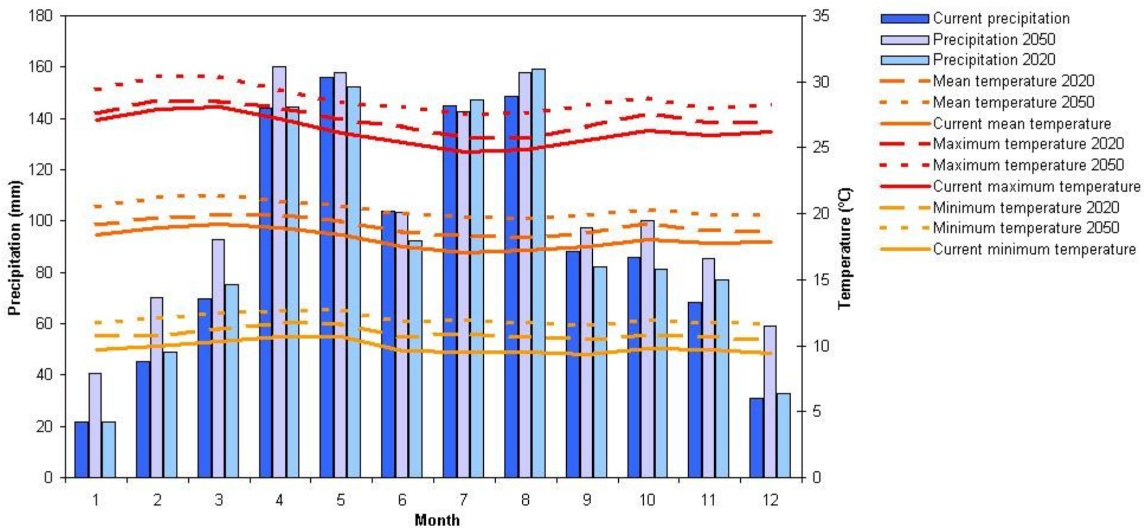

Figure 28: Climate trend summary 2020 and 2050 for sample sites in Trans-Nzoia.

General climatic characteristics

- The rainfall increases from 1110 millimeters to 1275 millimeters in 2050 passing through 1125 in 2020
- Temperatures increase and the average increase is 2.3 ºC passing through an increment of 1 ºC in 2020
- The mean daily temperature range increases from 16.4 ºC to 16.7 ºC in 2050
- The maximum number of cumulative dry months decreases from 7 months to 5 months

Extreme conditions

- The maximum temperature of the year increases from 28.1 ºC to 30.6 ºC while the warmest quarter gets hotter by 2.3 ºC in 2050
- The minimum temperature of the year increases from 9.3 ºC to 11.3 ºC while the coldest quarter gets hotter by 2.4 ºC in 2050
- The wettest month gets wetter with 180 millimeters instead of 155 millimeters, while the wettest quarter gets wetter by 45 mm in 2050
- The driest month gets wetter with 35 millimeters instead of 20 millimeters while the driest quarter gets wetter by 60 mm in 2050

Climate Seasonality

- Overall this climate becomes less seasonal in terms of variability through the year in temperature and less seasonal in precipitation

Variability between models

- The coefficient of variation of temperature predictions between models is 5.9%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 12.8%
- Precipitation predictions were uniform between models and thus no outliers were detected

10 Conclusions

10.a Overall conclusions

- The changes in suitability of a particular area to grow coffee are site-specific because each site or area has its own very specific environmental conditions.
- The solution to site-specific changes is site-specific management, this is different sites and areas will need interventions tailored to their biophysical conditions.
- There will be sites and areas:
  - That will become unsuitable to grow coffee, where farmers will need to identify alternative crops;
  - That will remain suitable for coffee, but only when the agronomic management is adapted to the changed conditions of the particular site or area;
  - Where coffee is not grown today but in future will become suitable for coffee. These areas need strategic investments to develop coffee production;
- Climate change will bring not only bad news but also a lot of new potential.
- The winners will be those who are prepared for change and know how to adapt.

10.b Specific conclusions

10.b.i How will the climate in the project area change by the year 2050?

- The yearly and monthly rainfall will increase progressively by 2050.
- The yearly and monthly minimum and maximum temperatures will increase progressively by 2050.
- The overall climate will become less seasonal in terms of variability through the year in temperature and less seasonal in precipitation.
- The maximum number of cumulative dry month will stay constant at 4 months.
- Precipitation for specific districts will increase by 135 to 205 mm by 2050.
- The increase of temperatures for specific districts by 2050 is between 2.2 and 2.4 °C by 2050.

10.b.ii What impact will climate change have for suitability of coffee and how will coffee areas change?

- By 2050 the suitability of the thirteen municipalities in Kenya for coffee production in general decreases quite seriously.
- The suitability of the areas that still are suitable decreases to between 30 and 60%, compared with their suitability today of 50-70%.

- The optimum coffee-producing zone is currently an altitude of 1600 masl, by 2050 it increases further to 1700 masl. Increasing altitude compensates for the increase in temperature.
- Between today and 2050 areas at altitudes around 1300 masl will suffer the highest decrease in suitability and the areas around 2200 masl the highest increase in suitability

10.b.iii What are the climatic factors that determine the suitability for coffee?

- By 2050, the decrease of precipitation of driest month and increase of minimum temperature of the coldest month are main negative factors driving suitability together with increasing precipitation of the coldest quarter, which, however, has less weight, suggesting that the decrease in dry season rainfall combined with higher evaporative demand would lead to drought stress at lower altitudes.
- The positive suitability shifts at the highest altitudes of the present growth range of coffee, on the other hand, were mostly driven by increasing temperatures.

11 Recommendations

- This report is the results of a desk study and does not include local expert knowledge.
- It would be possible to make much more precise predictions of the effects of climate change in the specific growing-regions by using expert knowledge to refine the results presented here.
- Local experts and community leaders in each administrative unit need to be made aware of the results of this study and the likely effects on livelihoods.
- Road maps for each specific areas should be defined, taking account of the needs of each individual area e.g.:
    - Identification of alternative crops;
    - Adaptation of agronomic management such as shade, varieties, irrigation, etc.; and
    - Strategic planning for areas with new potential for coffee production.

References

Carpenter, G., A.N. Gillison, and J. Winter. 1993. DOMAIN: a flexible modelling procedure for mapping potential distributions of plants and animals. Biodiversity and Conservation 2:667.

Dormann C.F. (2006) Promising the future? Global change projections of species distributions. Basic and Applied Ecology 8: 387-397.

Elith, J., Graham, C.H., Anderson, R.P., Dudík, M., Ferrier, S., Guisan, A., Hijmans, R.J., Huettmann, F., Leathwick, R., Lehmann, A., Li, J., Lohmann, L.G., Loiselle, B.A., Manion, G., Moritz, C., Nakamura, M., Nakazawa,Y., Overton, J.McC., Peterson, A.T., Phillips, J., Richardson, K., Scachetti-Pereira, R., Schapire, E., Soberon, J., Williams, S., Wisz, M., Zimmermann, E. 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography* 29:129-151.

Hijmans R.J., Cameron S.E., Parra J.L., Jones P.G., and Jarvis, A. (2005) Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978.

Hijmans, R.J., L. Guarino, A. Jarvis, R. O'Brien, P. Mathur, C. Bussink, M. Cruz, I. Barrantes, and E. Rojas. 2005a. DIVA-GIS Version 5.2, Manual.

Hijmans R.J. and Graham C. (2006) The ability of climate envelope models to predict the effect of climate change on species distributions. Global Change Biology 12: 2272-2281.

Phillips, S.J., R.P. Anderson, and R.E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling* 190:231-259.

Phillips S.J. and Dudik M. (2008) Modeling of Species Distributions with Maxent: New Extensions and Comprehensive Evaluation. Ecography 31: 161-175.

Pierce D.W., Barnetta T.P., Santerb B.D. and Gleckler P.J. (2009) Selecting global climate models for regional climate change studies. PNAS 106: 8441–8446.

Tukey J.W. (1977) Exploratory data analysis. Addison-Wesley Publishing Co., Reading, MA.