Predictions of Land Use Changes under Progressive Climate Change in Coffee Growing Regions of the AdapCC Project

Final Report Piura, Peru

Cali, Colombia: October, 2008

Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture

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1. Executive summary

This document reports on the methods and results of a consultancy with the title "Prediction of land-use changes in the coffee-growing regions of the AdapCC project under progressive climate change". The consultancy aimed to provide the scientific bases for the implementation of a private-public partnership project called AdapCC (www.adapCC.org) of the "Deutsche Gesellschaft fuer Technische Zusammenarbeit" (GTZ) and Cafedirect, a UK-based fair-trade hot-drink company. The outputs of the consultancy consist of four reports, one for each of the four coffee-production areas included in the AdapCC project (Piura in Peru, Nicaragua, Chiapas and Veracruz in Mexico).

The methodology applied was based on the combination of current climate data with future climate change predictions from 4 global circulation models for 2020 and 18 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 compiled from existing databases, scientific publications, expert knowledge, and Google Earth.

The analysis focused on the specific municipalities that were of interest to the regional project partners and provide predictions of the future climate and predictions of the suitability of current coffee-growing areas to continue growing coffee by 2020 and by 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 Piura the yearly and monthly rainfall, minimum temperature, and maximum temperature will all increase progressively by 2020 and by 2050. The overall climate will become more seasonal in terms of variation of temperature throughout the year with temperatures in specific districts increasing by about 0.9°C by 2020 and by about 2.2°C by 2050. In contrast, the climate will become less seasonal in precipitation, with the maximum cumulative number of dry month decreasing from 4 to 3 months. Precipitation in specific districts will increase 20 to 50 mm by 2020 and 100 to 150 mm by 2050.

The implications are that the current coffee-growing areas will remain suitable for production by 2020 and in some areas will become even more suitable. By 2050, however, most areas will become less suitable for coffee production. Only Huarmaca Department will become more suitable by 2050.

Increasing altitude compensates for the increases in temperature, with progressive climate change, higher altitudes will become suitable to produce coffee. The optimum coffee-producing zone is currently at an altitude of 1320 masl. By 2020 the optimum altitude will increase to 1470 masl, and by 2050 to 1720 masl. Between today and 2020, areas at around 1000 masl will become unsuitable, while areas around 1500 masl will become more suitable. By 2050 areas up to 1200 masl will become unsuitable and areas up to 1750 masl will benefit.

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2. Authors

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3. Project Background

This document reports on the methods and results of a consultancy with the title "Prediction of land use changes in the coffee growing regions of the AdapCC project under progressive climate change". The consultancy aims to provide the scientific bases for the implementation of a private-public partnership project called AdapCC (www.adapCC.org) of the Deutsche Gesellschaft fuer Technische Zusammenarbeit (GTZ) and Cafedirect, a UK based fair-trade hot-drink company. The AdapCC project focuses on several key coffee (*Coffea arabica*) and tea producing countries; the present consultancy only focuses on the coffee-producing regions, which are the Departments of Chiapas and Veracruz in Mexico, several Departments in Nicaragua and the Department of Piura in Peru (Figure 1). The outputs of the consultancy consist of four reports, one for each coffee-production area. The analysis furthermore focuses on the specific municipalities that are of interest to the regional project partners. The consultancy provides predictions of climate and predictions of the suitability of current coffee-growing areas to continue growing coffee by 2020 and by 2050.

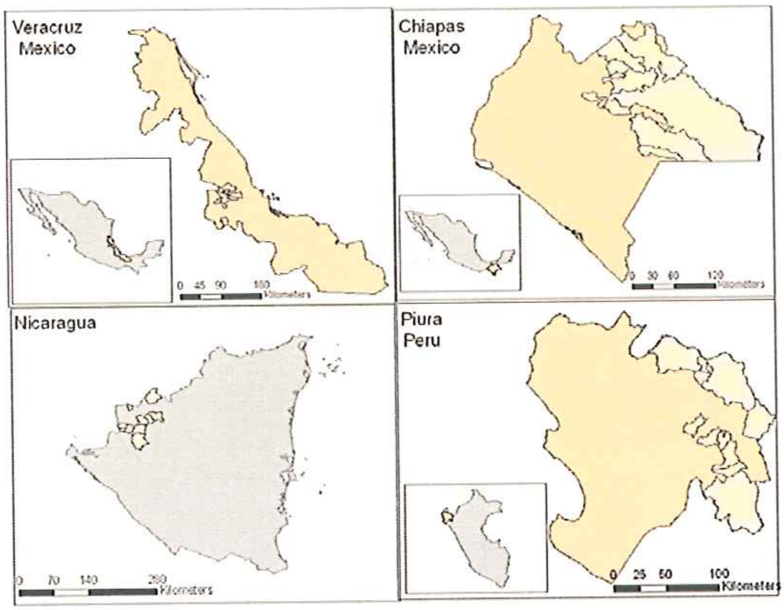


Figure 1. Location of the study areas analyzed for the AdapCC project.

4. Study objective

To predict the impact of climate change on coffee suitability and adaptability for the AdapCC project regions as the knowledge bases to improve adaptation and/or transformation strategies in the production system and subsequently in the entire supply chain.

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 years 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

6a. Sampling and Sampling Design

Ideally one would have wished to apply some kind of probability sampling with which to implement the selection of sites in the exploratory study, using either a model-based or a design-based approach (Brus and De Gruijter, 1997; Dobermann and Oberthur, 1997). Probability sampling means that every element, or sampling unit, of a population has a known probability of being included in the survey sample, so that once the population is defined, sampling sites can be selected randomly. However due to the absence of field data we could not follow such an approach here.

There are two broad non-probabilistic sampling methods. The first is accidental sampling, typified by the "man in the street" opinion seeking, the second is purposive sampling, where the need is for a targeted sample and where sampling for strict proportionality is not the primary concern. Because the objectives of this study were well defined, we used purposive sampling. There are several strategies on which to base purposive sampling including modal instance, expert opinion, quota, heterogeneity, and snowball sampling.

Proportional quota sampling, which we used here, attempts to represent the major characteristics of the population by sampling proportional numbers of each category. In contrast, in non-proportional quota sampling, one specifies the minimum number of sampled units required in each category. In this study, the purpose was not to have numbers in each category that exactly matched their proportions in the whole population, but to have enough samples to ensure that the most important groups in the population, identified by expert opinion, were represented. This method is the non-probabilistic analogue of stratified random sampling, which is typically used to assure that smaller groups are adequately represented in a sample.

The major difference between non-probabilistic and probabilitistic sampling is that non-probabilitic sampling does not involve random selection. But this does not necessarily mean that non-probability samples are not representative of the population. It does imply, however, that non-probabilistic samples cannot depend upon the rationale of probability theory, and we therefore must find other ways to show that the population was adequately sampled. Traditionally, researchers prefer probabilistic or random sampling methods over non-probabilistic methods, considering them to be more accurate and rigorous. However, in much applied research, such as the project that we report here, there are often circumstances where it is neither feasible nor it is theoretically necessary to undertake random sampling.

The difficult issue in purposive quota sampling, as used here, is to decide upon the specific characteristics on which the quota will be based. The following methods were employed to identify the sample farms;

1. *Review of thematic maps and brochures:* Information of brochures and maps was scanned, geo-referenced and digitized
2. *Information of supply chain and expert knowledge:* Coffee supply-chain actors of the coffee supply chain provided indications on coffee sites;
3. *Review of scientific literature and databases:* Scientific literature and databases were reviewed and coordinates of coffee production sites extracted;
4. *Identification through Google earth:* Coffee presence location indications without coordinates were geo-referenced in Google earth where possible; and
5. In municipalities where there were insufficient data to characterize the climate trends, we randomly generated new sites with the same range of altitude as the evidence sites.

6b. 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. The authors 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 Peru are from 573 stations with precipitation data, 137 stations with mean temperature, and 74 stations with minimum and maximum temperatures. For the Piura Department there were 45 stations with precipitation data and 7 stations with mean temperature data (Figure 2) and 3 stations with minimum and maximum temperature.

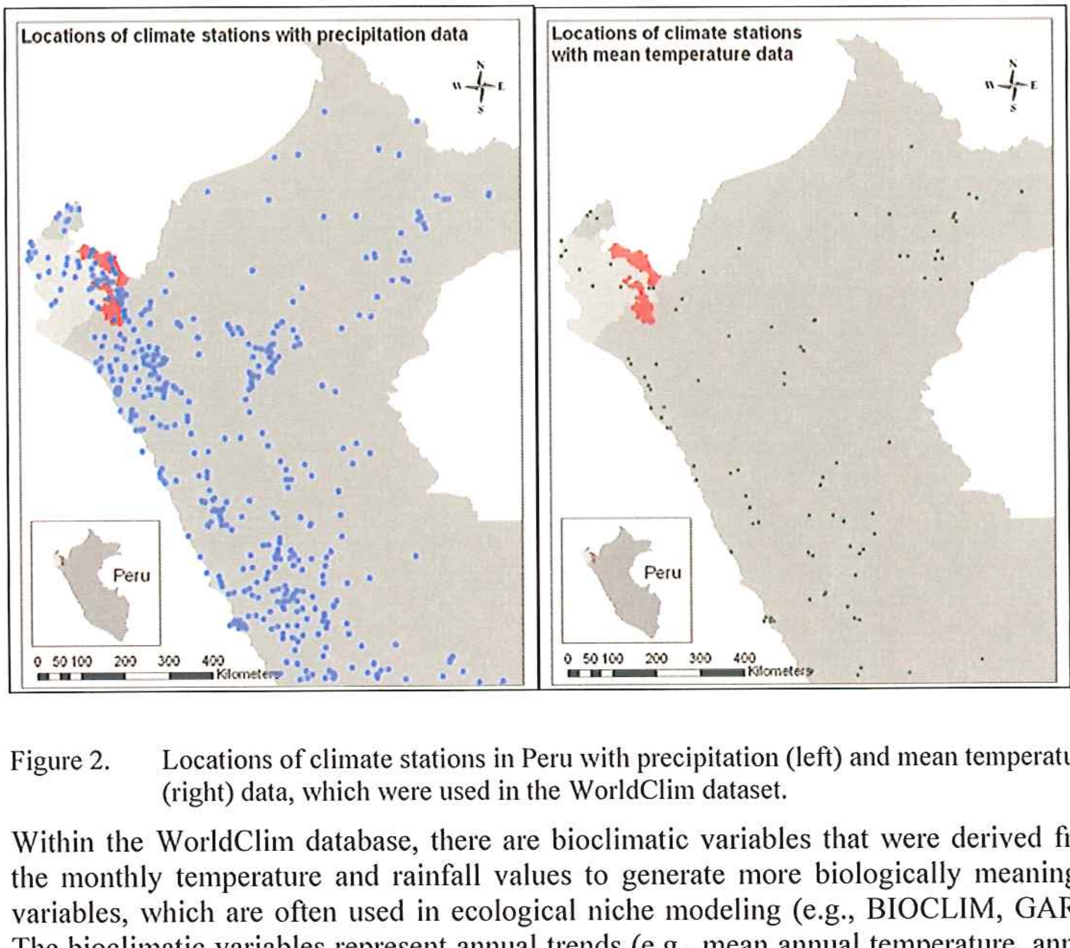


Figure 2. Locations of climate stations in Peru with precipitation (left) and mean temperature (right) data, which were used in the WorldClim dataset.

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

6c. Future Climate

6c (i). Global Circulation Models GCM's

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. GCM's 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-MK2.0	CSIRO_MK2	64x32	2020
	Australia	CSIRO-Mk3.0	CSIRO_MK3	192x96	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_0	144x90	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	Japan	MIROC3.2(hires)	MIROC3_2_HIRES	320x160	2050
National Institute for Environmental Studies	Japan	MIROC3.2(medres)	MIROC3_2_MEDRES	128x64	2050
Frontier Research Center for Global Change (JAMSTEC)					
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
Center for Climate System Research (CCSR) National Institute for Environmental Studies (NIES)	Japan	NIES-99	NIES-99	64x32	2020

6c (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 6c (i). A statistical downscaling method was applied to these data to produce 10km, 5km and 1km resolution surfaces for 2020 (4 GCMs) and 2050 (18 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.

6d. 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.

6d (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 nature and they can only be used to describe overall trends.

6d (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".

6d (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., 2005b)

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.

6d (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.

Before feeding the climatic data into MAXENT the coefficient of variance (CV) for the entire set of 22 models (4 models of 2020 and 18 models of 2050) and its 19 bioclimatic variables was calculated. The aim of this process was to use only variables for which there was general agreement between all the GCM models, so as to reduce uncertainty in the final predictions. Five bioclimatic variables exceeded the arbitrary threshold (CV > 20%), and were removed for the crop prediction analyses. The five variables that were removed were BIO 4 temperature seasonality, BIO14 precipitation of driest month, BIO 17 precipitation of driest quarter, BIO 18 precipitation of warmest quarter, and BIO19 precipitation of coldest quarter. The 14 remaining bioclimatic variables of the 4 models of 2020 and the 18 models of 2050 were averaged respectively. The average values, representing a mean climatic scenario were then used as input to MAXENT. In MAXENT the logistic function was applied, which gives estimates between 0 and 1 of the probability of presence.

6e. Driving Environmental Variable Analyses

In order to determine the environmental factors driving suitability principal component analyses (PCA) was conducted. PCA is a multivariate technique for examining relationships among several quantitative variables. Given a data set with p numeric variables, one can compute p principal components. Each principal component is a linear combination of the original variables, with coefficients equal to the eigenvectors of the correlation or covariance matrix.

The first principal component has the largest variance of any unit-length linear combination of the observed variables. The jth principal component has the largest variance of any unit-length linear combination orthogonal to the first j-1 principal components. The last principal component has the smallest variance of any linear combination of the original variables. The scores on the first j principal components have the highest possible generalized variance of any set of unit-length linear combinations of the original variables. The first two or three principal components typically capture the majority of the variance in the data set under consideration.

We calculated a PCA for the changes in climate for each variable, and then correlated each principal component with the change in suitability. We then interpreted the eigenvectors of the bioclimatic variable within the highest correlated principal component.

7. Results I: Overview of data confidence

The data available for each region of the AdpaCC project were not of equal quality. The difference in data quality is summarized in Table 2.

The point data of Veracruz was of highest quality since its origin is a Denomination of Origin project conducted by the University of Chapingo in Veracruz. The sites of Veracruz had been selected to cover all the environmental variability and the geographical location of each site was determined by a global positioning system (GPS). Each of the nineteen bioclimatic variables show low coefficents of variance (CV < 20%) for the Veracruz Department, and therefore the entire set was used for the analyses.

Table 2. Comparison of data confidence in AdapCC study regions. One star indicates low, two medium and three high confidence.

Region	Point data distribution	Point data precision	Climate variable variance
Veracruz, Mexico	***	***	***
Chiapas, Mexico	*	***	***
Nicaragua	**	***	**
Piura, Peru	**	*	**

The quality of the distribution of point data for Chiapas was low since it did not capture the entire region: most points were for only three municipalities. However location of the sites is very precise since they were taken with a GPS. The variability of each of the nineteen bioclimatic variables is low (CV < 20%) and therefore the entire set of variables was be used for the analyses.

The point data in Nicaragua was well distributed. However, since the data originated from different scientific studies, it is possible that some coffee-producing areas are under-represented. The coordinates of each site were taken by GPS and are therefore highly precise. Unfortunately, the predictions for five environmental variables (mainly related to precipitation) for the coffee area in Nicaragua was highly variable (CV > 20%) and could not be used for the analyses.

The distribution of point data for Piura is of medium quality since the sample points were selected by coffee experts using Google Earth. It is possible that the area might not be fully represented and also the Google Earth maps of Piura are very low quality so that the precision of the sites is low. Moreover the prediction of five environmental variables (mainly related to precipitation) for the Piura coffee area is highly variable (CV > 20%) and could not be used for the analyses.

The impact of low data quality is:

Low point data distribution: The variability of the whole natural environment is not captured so that the suitability predictions for the coffee areas may underestimate some areas that are under-represented.

Low point data precision: The environmental interactions that impact the mapping of coffee suitability and the identification of limiting factors are not well captured.

High climate variability between models: The entire set of bioclimatic variables cannot be used and nor can their impact on suitability be quantified.

8. Results II: Cross regional impacts

Of the four regions analyzed in the AdapCC project has Chiapas the highest precipitation followed by Veracruz, Nicaragua and Piura. The average precipitation in the studied areas in Chiapas, Veracruz and Nicaragua will decrease by both 2020 and by 2050, but will increase in Piura (Figure 3).

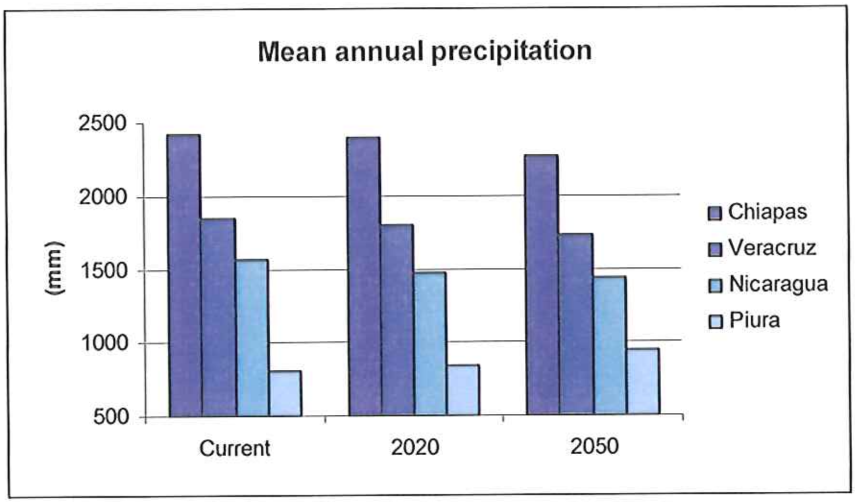


Figure 3. Comparison of predictions for 2020 and 2050 for mean annual precipitation for the four coffee growing-regions of the AdapCC project

The temperature increases in all four regions by 2020 and 2050 (Figure 4). The increase is less between today and 2020 than between 2020 and 2050. Chiapas has the highest mean temperature today and also in the future followed by Nicaragua, Veracruz, and Piura.

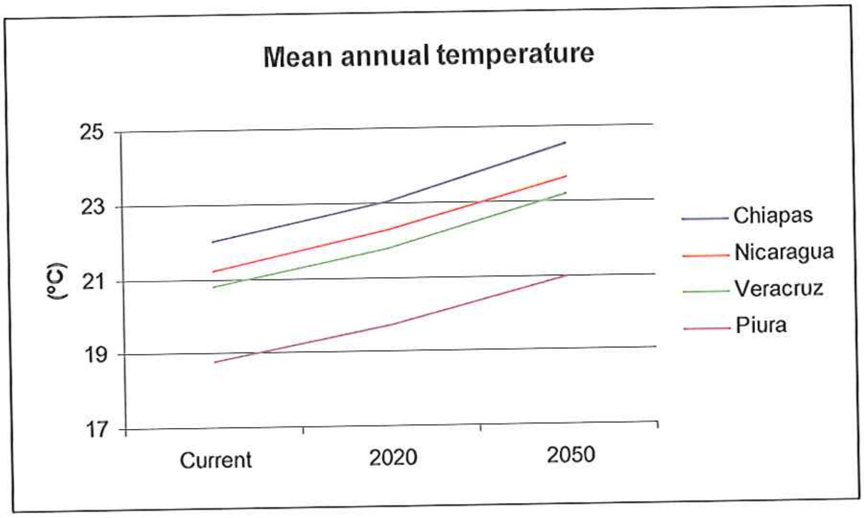


Figure 4. Comparison of predictions for 2020 and 2050 for mean annual temperature for the four coffee growing-regions of the AdapCC project

Figures 3 and 4 show a snapshot of the current situation, in 2020, and in 2050. However if we look at the changes as snapshots every 10 years, we see that the changes are not always linear (Figure. 5). The changes are very area specific. Both the Veracruz and Nicaragua areas have a fairly linear behavior, meaning that temperature increases over time and precipitation decreases, both more or less regularly. In contrast, the changes in both Chiapas and Piura are much more variable. In some consecutive years the temperature increases while in others it decreases and the same with precipitation.

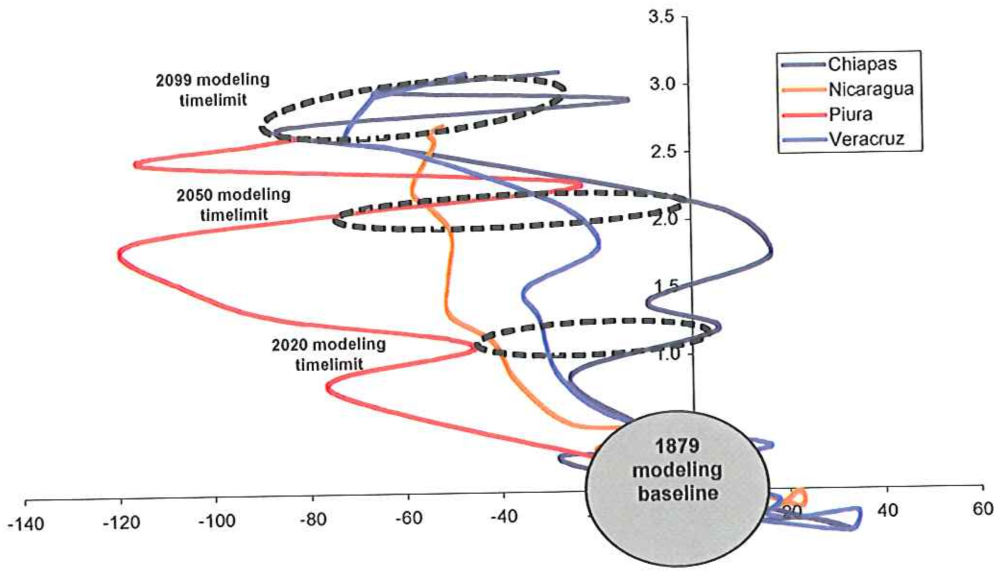


Figure 5. Prediction of changes in mean annual temperature and mean annual precipitation in the study areas in 10-year intervals between1879 and 2099.

9. Results III: Evidence data

For the coffee-growing areas in Peru, the coordinates of 102 coffee farms were identified. Internet review, through literature, and located in Google Earth, 32 sites were identified. Eva Ringhof (GTZ), together with local experts, located a further 70 sites in Google Earth (Table 3). The Department of Piura where the AdapCC project mainly focuses was well covered by sample points; the remaining departments however were only poorly represented. For this reason the analyses focused on the Piura Department and especially on the districts where the growers' organizations and AdapCC partners are located.

Table 3. Summary of sample sites in Peru showing the predominance of sites in the Department of Piura.

Department	Samples (#)
Amazonas	6
Ayacucho	2
Cajamarca	6
Cusco	2
Junín	2
Pasco	4
Piura	71
Puna	3
San Martin	8
Ucayali	2
TOTAL	**102**

Of the 102 sites identified, 72 belong to the department of Piura, however only 53 of these fell in the altitudinal range of 700 to 2000 masl, which is where coffee is traditionally produced. This is because the coordinates were not taken with a GPS on the ground, but identified by experts using Google Earth and the images for the Piura region are not of the highest quality. Hence for the crop prediction model, the 53 evidence points were used (Figure 6).

For the characterization of the trend in climate in each of the twelve districts in the Piura Department, the 53 evidence points were augmented by a further 30 sample points per district generated at random (Table 4). We took care that the generated points fell within the same altitudinal range overall as the evidence sites.

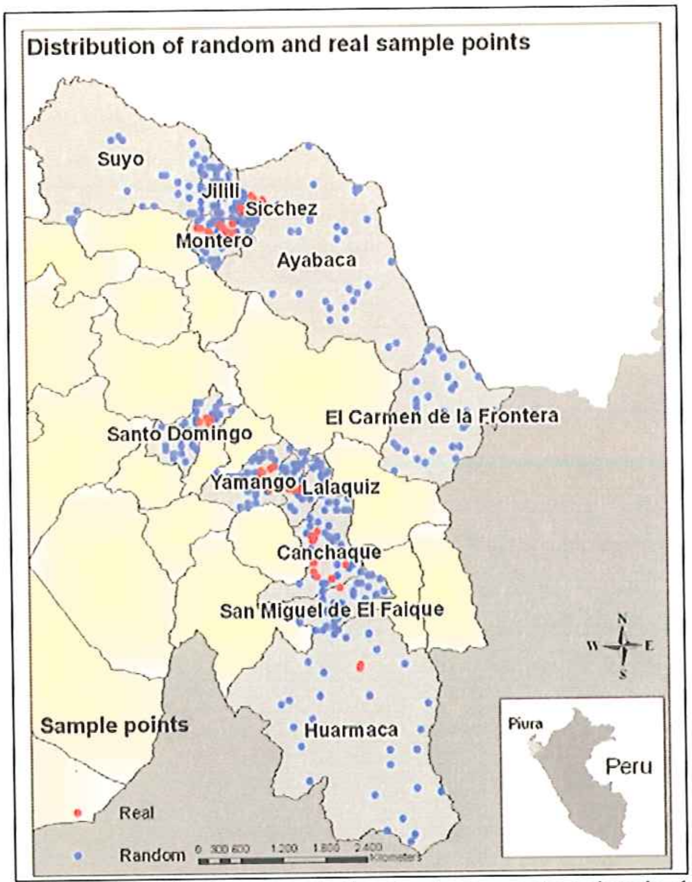


Figure 6. Distribution of randomly-generated and actual sample points in the coffee growing districts of Piura Department, Peru.

Table 4. Summary of the actual and the randomly-generated sample sites in 12 coffee-growing districts of the Piura Department, Peru

District	Number of sites		
	Sample	Randomly generated	Total
Ayabaca	3	30	33
Canchaque	11	30	41
El Carmen de la Frontera	-	30	30
Huarmaca	2	30	32
Jilili	-	30	30
Lalaquiz	7	30	37
Montero	12	30	42
San Miguel de El Faique	1	30	31
Santo Domingo	4	30	34
Sicchez	3	30	33
Suyo	-	30	30
Yamango	10	30	40
TOTAL	**53**		**413**

10. Results IV: Regional changes

10a. Changes in mean annual precipitation

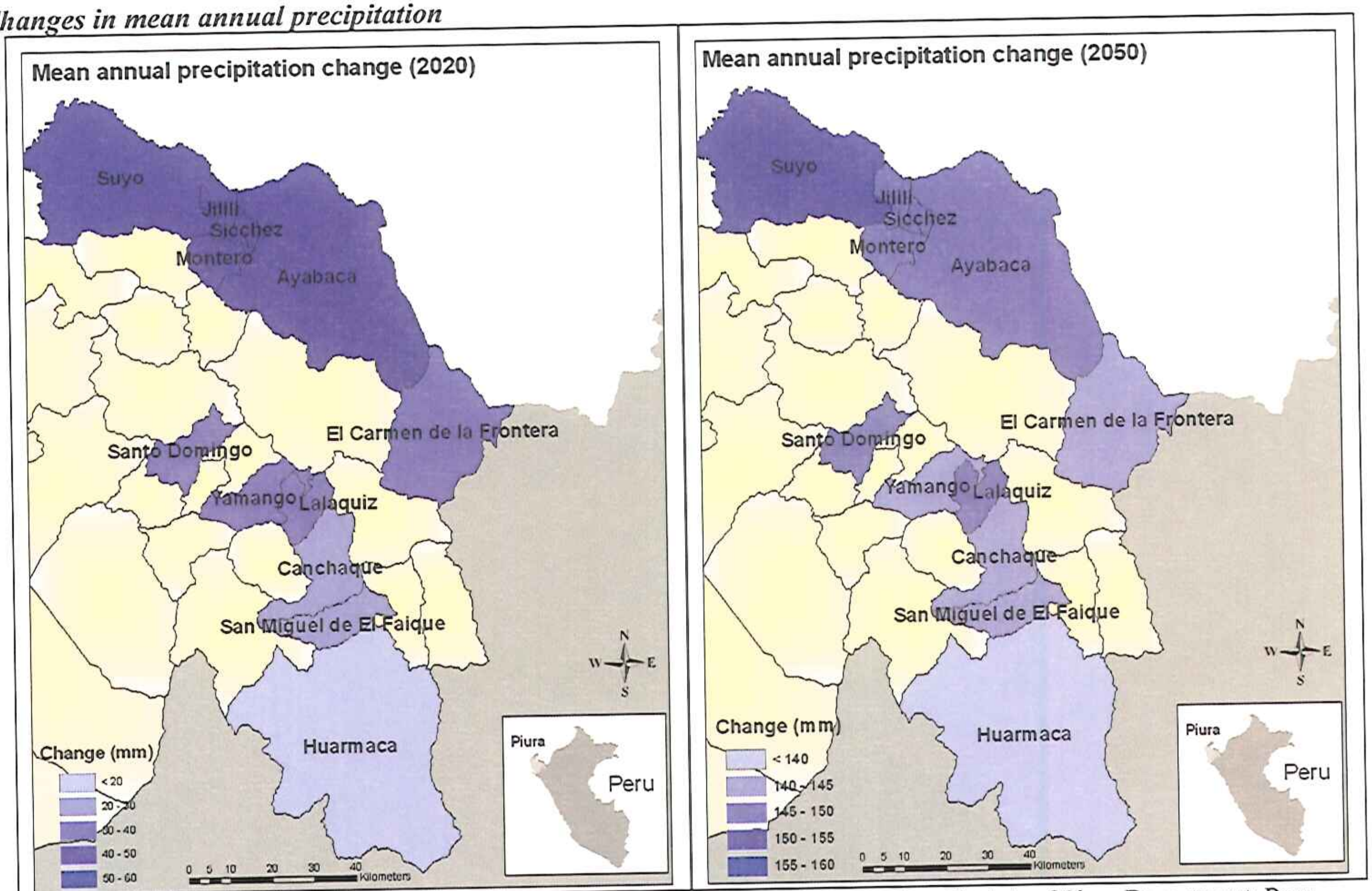


Figure 7. Changes in mean annual precipitation by 2020 and 2050 for the 12 coffee-growing districts of Piura Department, Peru.

The mean annual precipitation increases progressively by 2020 to between 20 and 50 mm more than at present and by 2050 between 140 and 160 mm more (Figure 7). The northern districts will have larger increases in precipitation than those in the south of the Department. Huarmaca district will have the smallest increase in precipitation and the Suyo district will have the largest increase. The variability in precipitation between the sites sampled within a district is largest in El Carmen de la Frontera and smallest in Jilili in both 2020 and 2050 (Figures. 8 and 9).

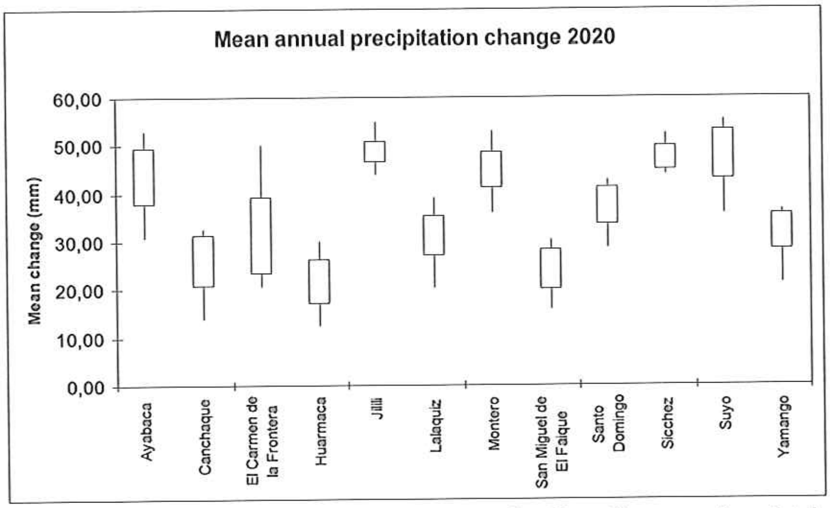


Figure 8. Mean annual precipitation change by 2020 for 12 coffee-growing districts of Piura Department, Peru. The edges of the boxes indicate the mean maximum and mean minimum values and the ends of the line the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation.

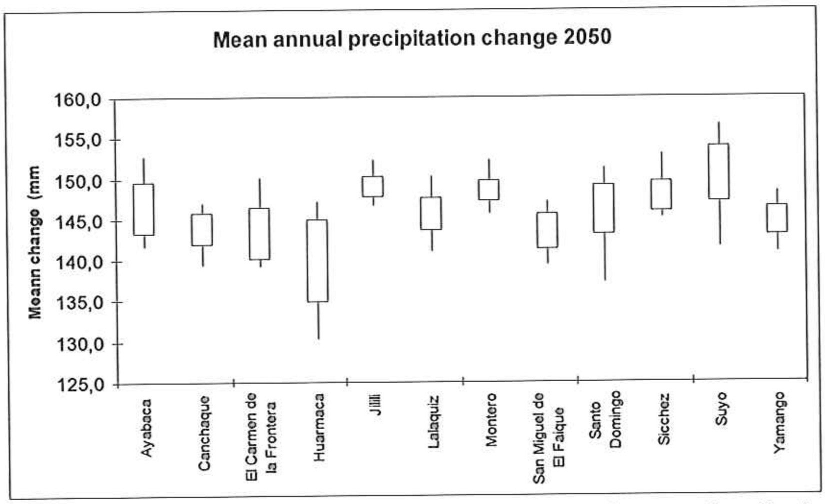


Figure 9. Mean annual precipitation change by2050 for 12 coffee-growing districts of Piura Department, Peru. The edges of the boxes indicate the mean maximum and mean minimum values and the ends of the line the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation.

10b. *Changes in mean annual temperature*

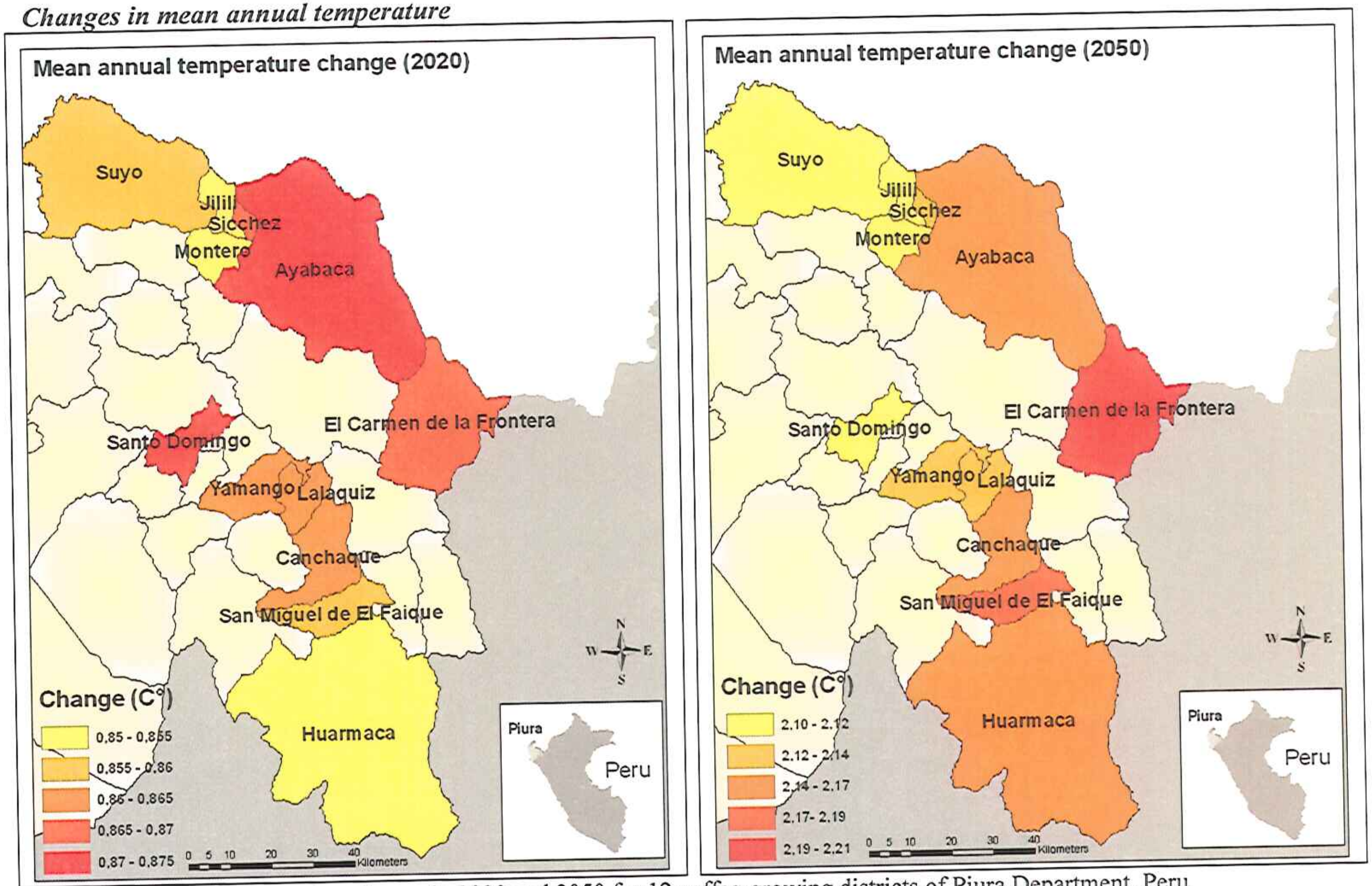


Figure 10. Mean annual temperature change in 2020 and 2050 for 12 coffee-growing districts of Piura Department, Peru.

The mean annual temperature will increase progressively. The increase by 2020 differs little between districts and will be almost 0.9°C and will be between 2.1°C and 2.2 °C by 2050 (Figure 10). Temperatures will increase somewhat more in the northern districts compared with the districts in the south of the Department. The variability in temperature between the sites sampled within each district is similar to the variability between districts (Figure 11).

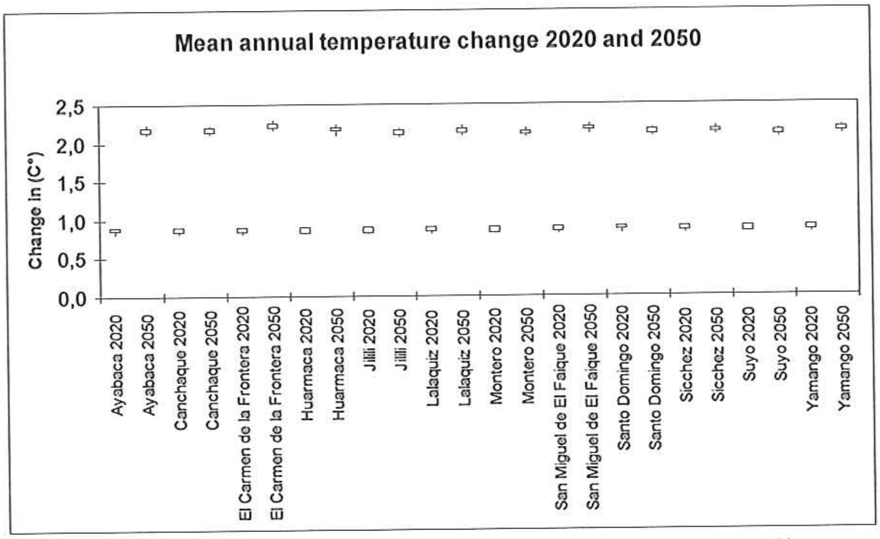


Figure 11. Mean annual temperature change by 2020 and by 2050 for 12 coffee-growing districts of Piura Department, Peru.

10c. Summary of coffee production sites inPiura Department

The summary climate characteristics for all the random and real sample points of the entire Piura Department are presented here.

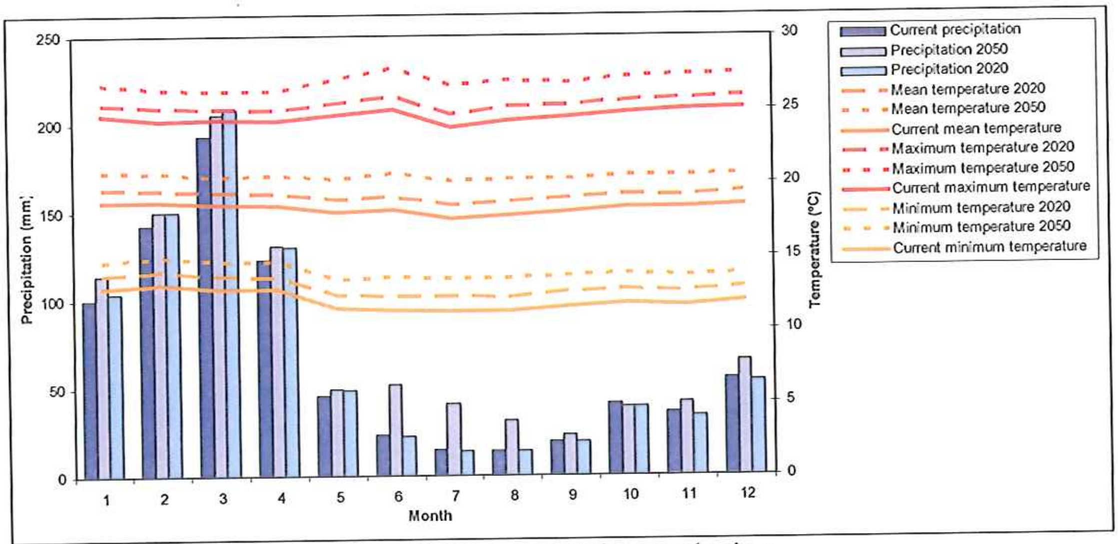


Figure 12: Climate trend summary 2020 and 2050 for sample sites.

General climatic characteristics

- The rainfall increases from 806 millimeters to 950 millimeters in 2050 passing through 840 in 2020
- Temperatures increase and the average increase is 2,2 °C passing through an increment of 0,9 °C in 2020
- The mean daily temperature range increases from 12,6 °C to 12,9 °C in 2050
- The maximum number of cumulative dry months decreases from 9 months to 8 months

Extreme conditions

- The maximum temperature of the year increases from 25,3 °C to 28,1 °C while the warmest quarter gets hotter by 2,2 °C in 2050
- The minimum temperature of the year increases from 11,1 °C to 13,1 °C while the coldest quarter gets hotter by 2,2 °C in 2050
- The driest month gets wetter with 15 millimeters instead of 10 millimeters while the driest quarter gets wetter by 20 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 4%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 11%
- Precipitation predictions were uniform between models and thus no outliers were detected

10d. Suitability of coffee production areas

Currently the main coffee-producing areas in Piura Department run northward along the Andes from Huarmaca in the south to Jilili and Suyo in the north (Figure 13). According to the MAXENT model, the most suitable areas within them are concentrated in the central districts of Yamango, Lalaquiz, and Canchaque. The remaining districts are in general rather less suitable although there are smaller areas within them that can have suitability indices as high as 70 and 80 %.

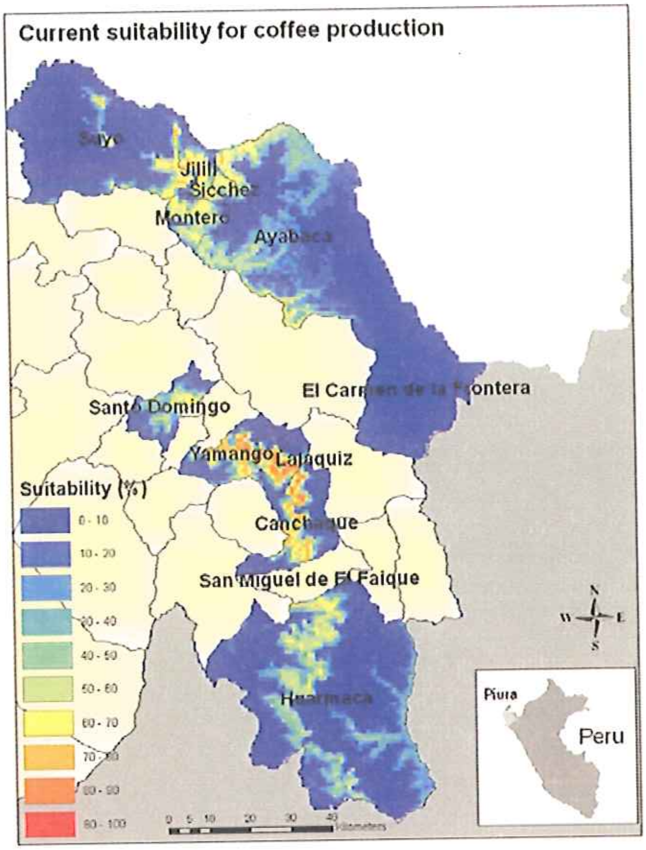


Figure 13. Current suitability for coffee production in 12 coffee-growing districts of Piura Department, Peru.

The suitability of the coffee areas by 2020 shows broadly similar patterns to the current suitability (Figure 14). By the year 2020 the areas between Santo Domingo and Huarmaca move further east, which means that they move up the altitudinal gradient. In general terms, it is apparent that the areas of land with suitable climates for coffee will increase. It has been reported for other crops that the GCMs do not predict great changes by 2020; only between 2020 and 2050 will the changes due to climate become more important. This is due to the significant lags that occur in the climate system. In the case of Piura it is apparent that an important part of the mayor growing zones may even become more suitable than they are at present by 2020.

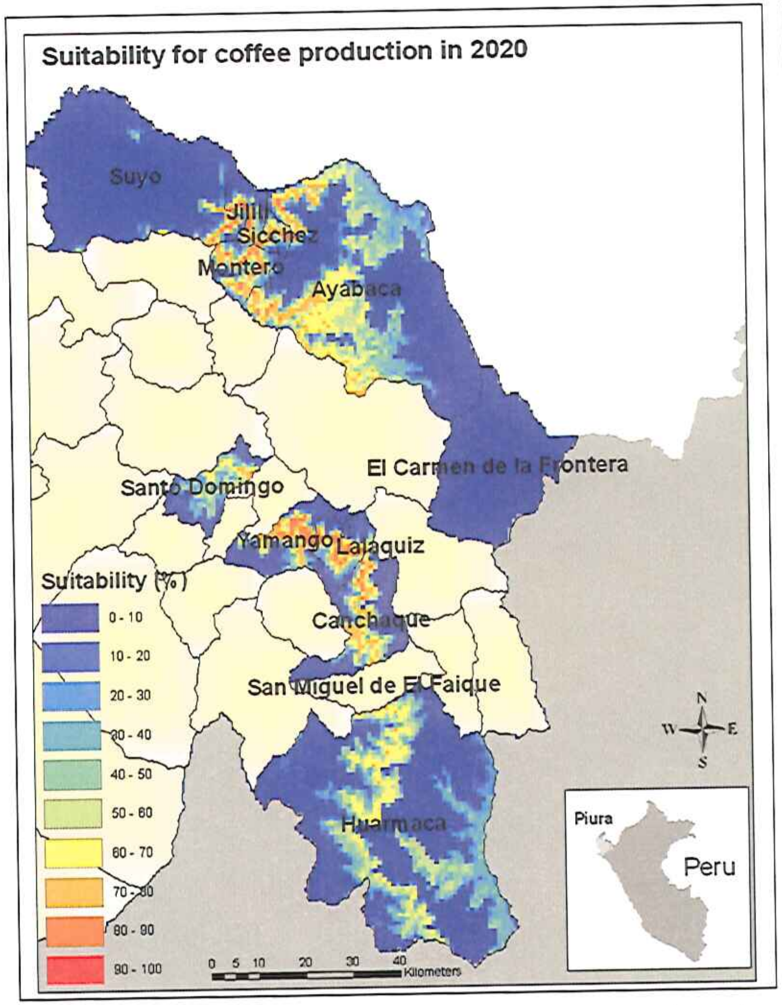
The coefficient of variance (CV) is a measure of the agreement between the bioclimatic variables produced by the GCMs. CVs less than 20% are considered low. The CVs for the 2020 predictions vary between 0 and 25 %. For the main areas of coffee production the CV < 20% (Figure14).

By 2050 the suitability of Piura Department for coffee production in general decreases quite seriously, with the trend more pronounced in the northern than in the southern districts (Figure 16). The areas that still show some suitability to produce coffee are all located on a north-south axis along the Andes. In addition to the north-south pattern, areas that face the sea are more suitable than areas that are enclosed in valleys. For example, Ayabaca's coffee areas are totally enclosed by the Andes and become entirely unsuitable by 2050.

The CV for 2050 ranges between 0 and 20 % and may therefore be accepted as reliable. The only areas that gain suitability by 2050 are in the Hurmaca district (Figure 17).

With progressive climate change, areas at higher altitudes become suitable for producing coffee (Figure 18). We did not use altitude 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 of 1320 masl, by 2020 in the altitude of the optimum increases to 1470 masl, and by 2050 increases further to 1720 masl. Increasing altitude compensates for the increase in temperature (Figure 18).

Between today and 2020 areas at altitudes around 1000 masl will suffer the highest decrease in suitability and the areas around 1500 masl the highest increase in suitability. By 2050 the corresponding altitudes are 1200 masl and 1750 masl (Figure 19).



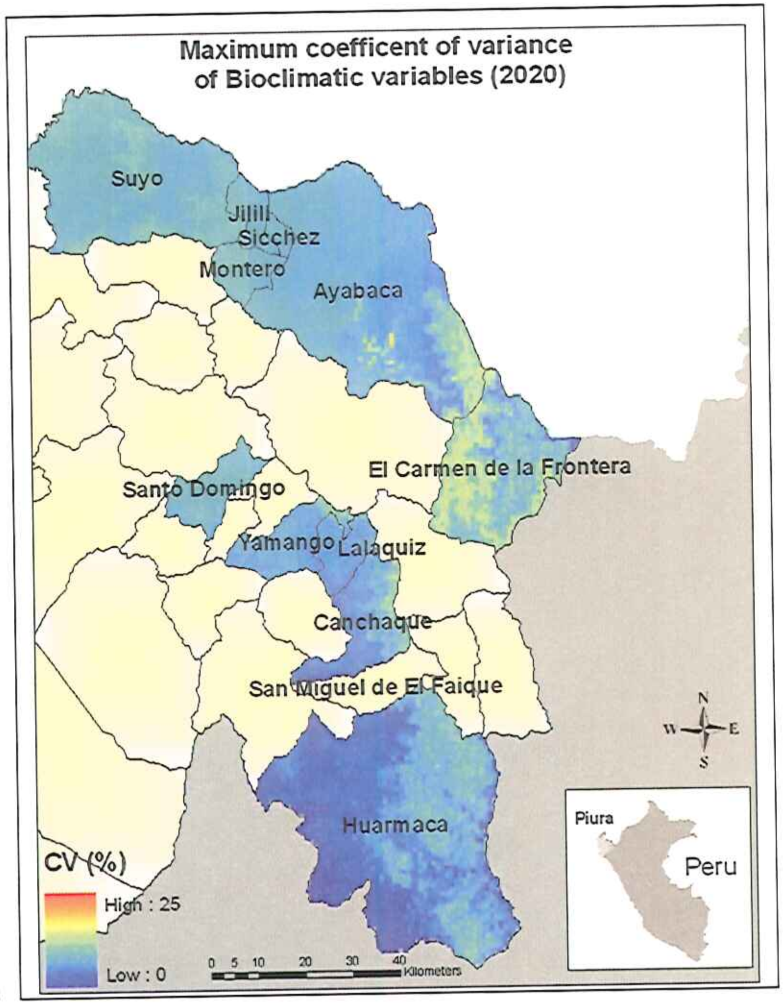


Figure 14. Suitability for coffee production in 2020 (left) and maximum coefficient of variance of bioclimatic variables in 2020 (right) in 12 coffee-growing districts of Piura Department, Peru.

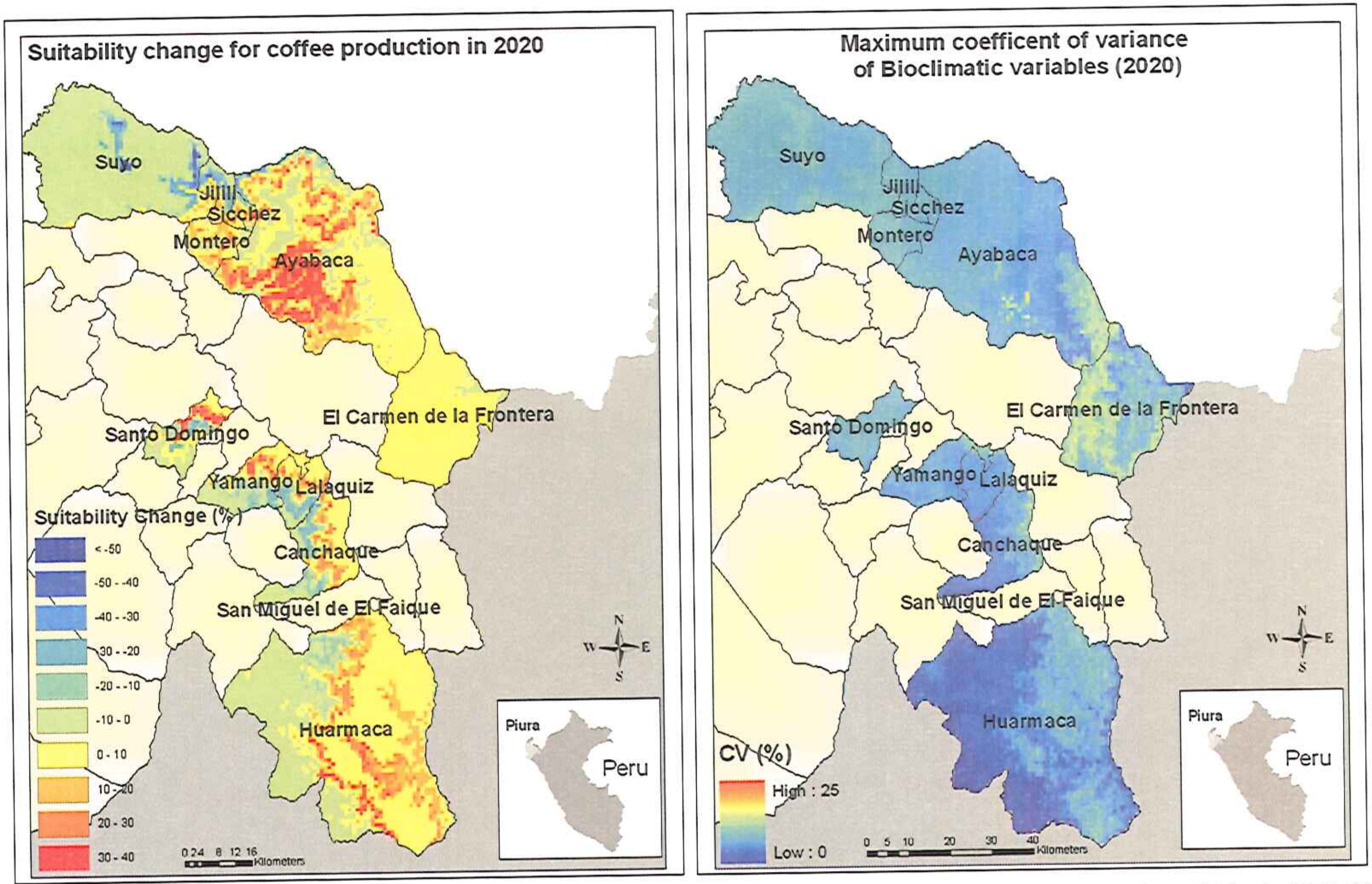


Figure 15. Suitability change for coffee production in 2020 (left) and maximum coefficient of variance of Bioclimatic variables in 2020 (right) in 12 coffee-growing districts of Piura Department, Peru.

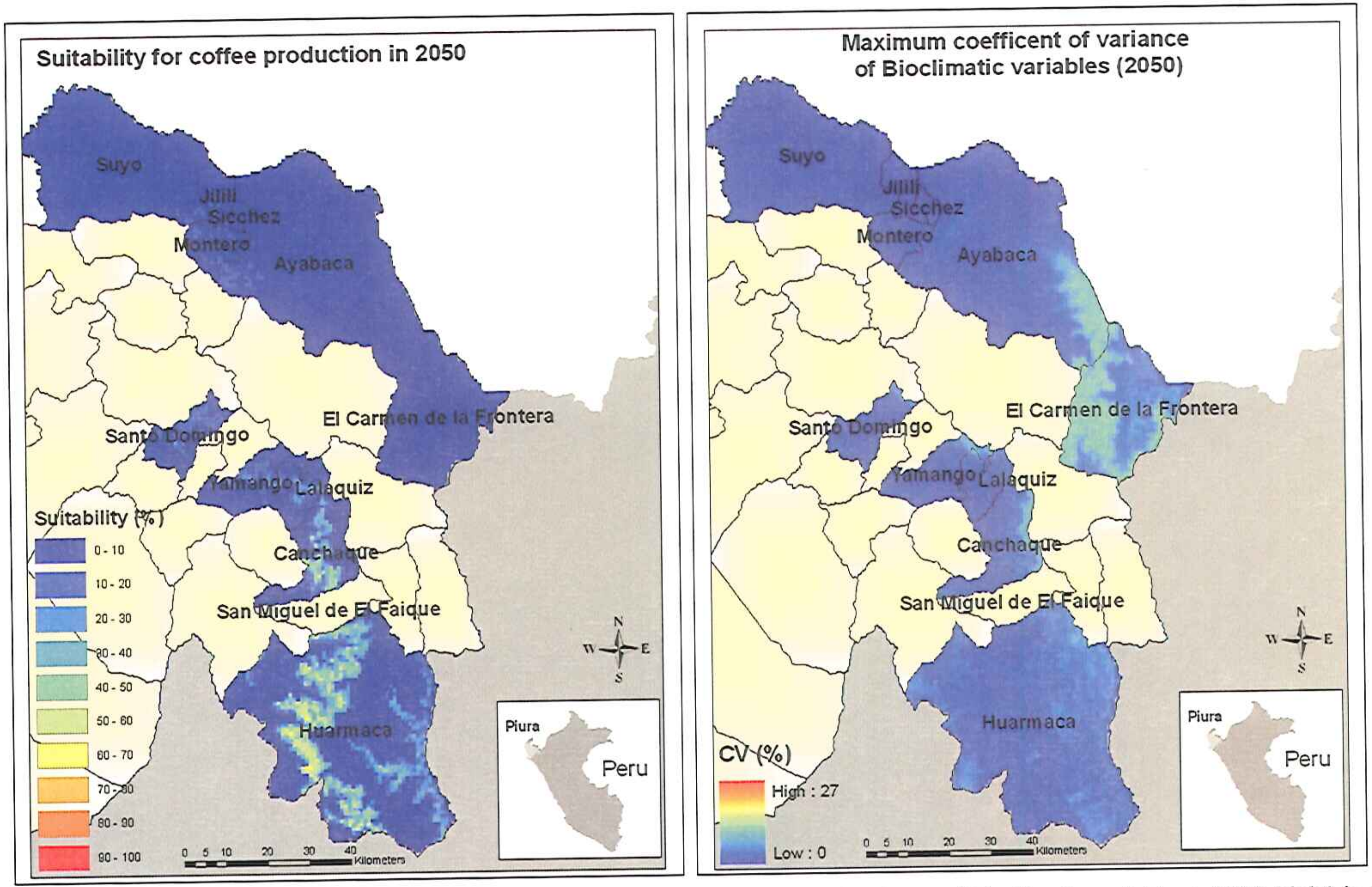


Figure 16. Suitability for coffee production in 2050 (left) and maximum coefficient of variance of Bioclimatic variables in 2050 (right) in 12 coffee-growing districts of Piura Department, Peru.

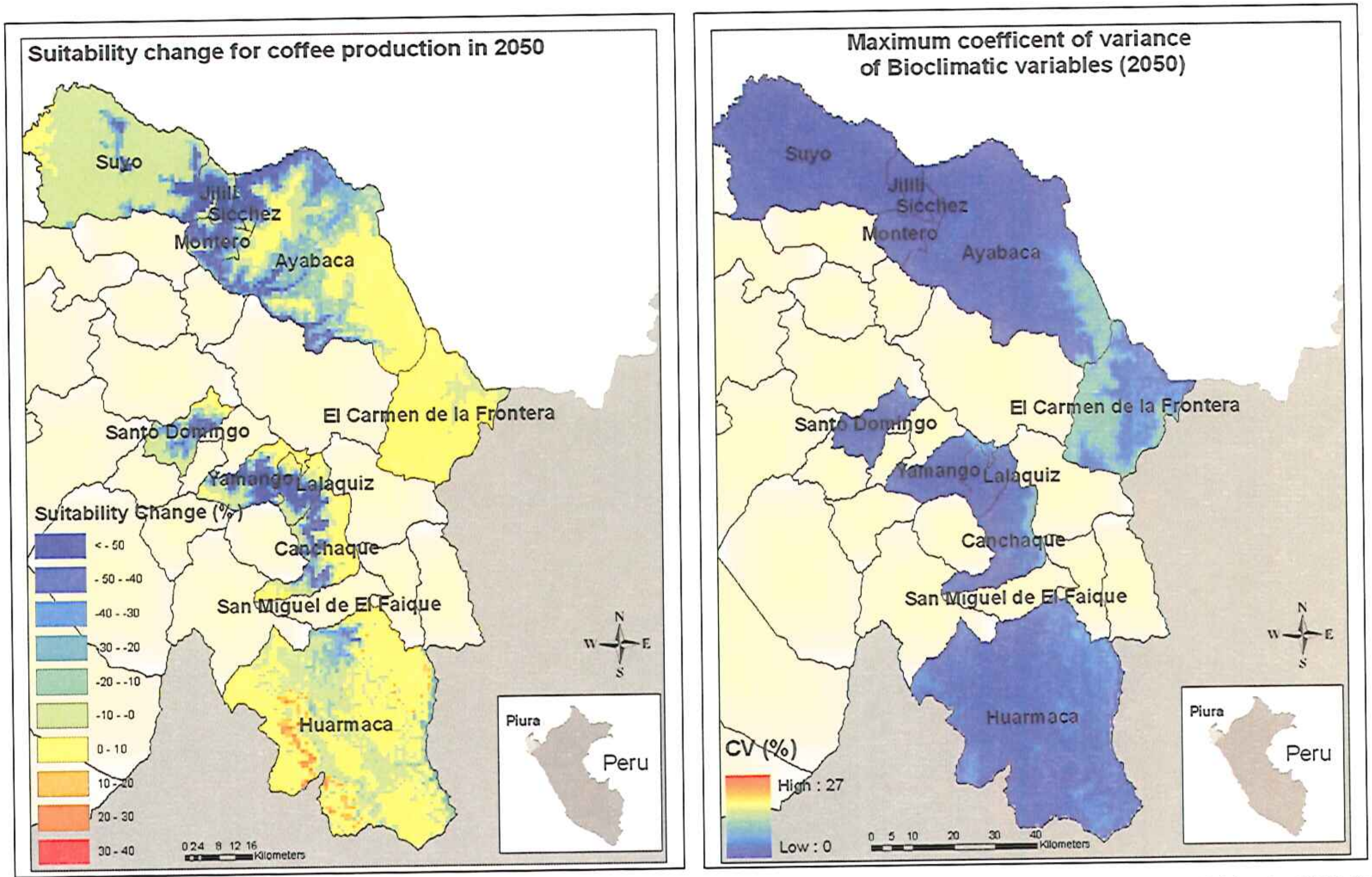


Figure 17. Suitability change for coffee production in 2050 (left) and maximum coefficient of variance of Bioclimatic variables in 2050 (right) in 12 coffee-growing districts of Piura Department, Peru.

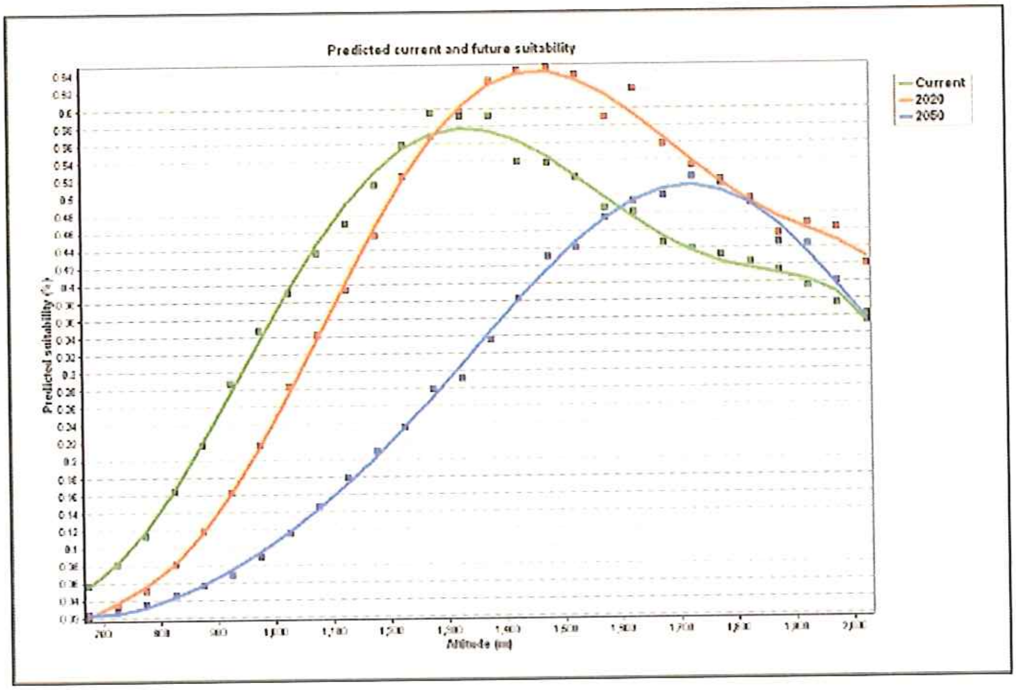


Figure 18. The relation between the suitability of areas for coffee production and altitude for current climates, and predicted for 2020 and 2050.

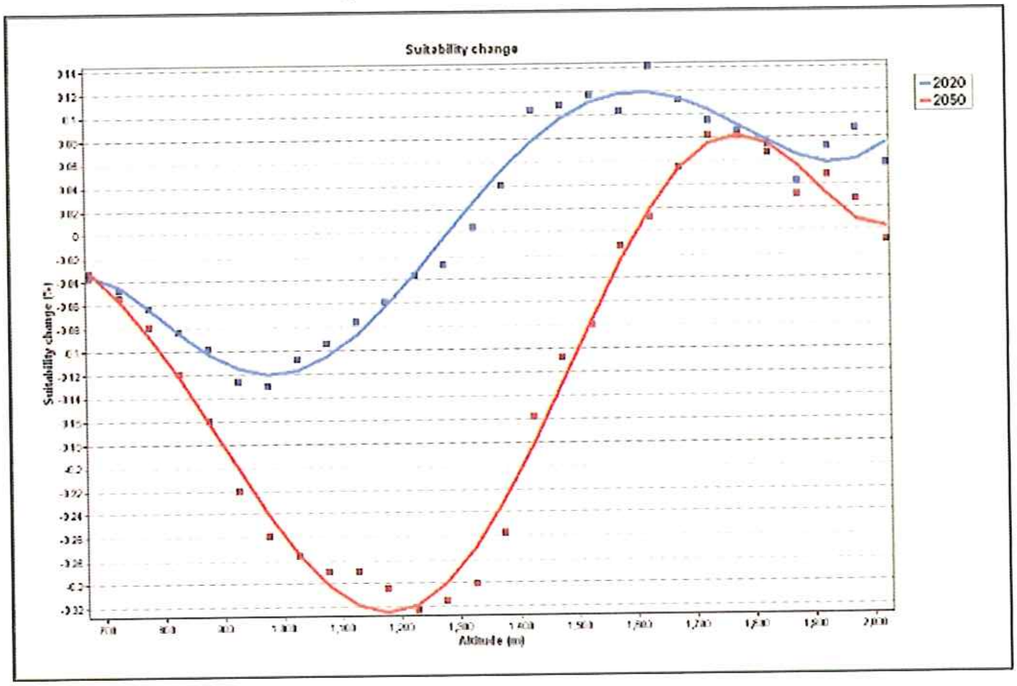


Figure 19. The relation between the change in suitability of areas for coffee production and altitude for 2020 and 2050 compared with current suitability.

10e. Driving environmental variables

To determine the variables that drive change in suitability by 2020 and by 2050 we carried out a principal component analysis (PCA) for each variable and then determined the correlation of each principal component with the change in suitability.

In 2020 the first principal component (Prin1) explains 30 % of the variance and the second principal component (Prin2) 18 % of the variance, with correlation coefficients of r =0.12 and r = -0.60 respectively (Tables 5 and 6 and Figure 43-45 in the Appendix). In 2050 the first principal component (Prin1) explains 45 % of the variance and the second principal component (Prin2) 13 % of the variance, with correlation coefficients of r = -0.28 and r = -0.37 respectively. The most significant principal component for 2020 is therefore Prin2 and for 2050 mainly Prin1 but Prin2 also contributes.

The variables that contribute most, and negatively, in 2020 are all temperature-related variables such as maximum temperature of the warmest month and minimum temperature of the coldest month. We conclude therefore that rising minimum and maximum temperature are the factors that have most negative impact by 2020. The change in isothermality and annual temperature range also has a negative impact. Laderach (2006b) showed that daily and annual temperature differences could have major impact on coffee quality.

In 2050 the same variables continue to be important, but precipitation-related variables also become more important. In Figure 3 we saw that Piura Department is the only of the four regions included in this analysis that will experience an increase in precipitation caused by climate change. It seems, however, that by 205,0 in contrast to 2020, the additional precipitation cannot compensate for the increased evapo-transpiration caused by the increased temperatures.

11. Results V: Site-specific changes

11a. Average climate change trends Ayabaca (Piura)

11a (i). Predictions Ayabaca (Piura) 2020

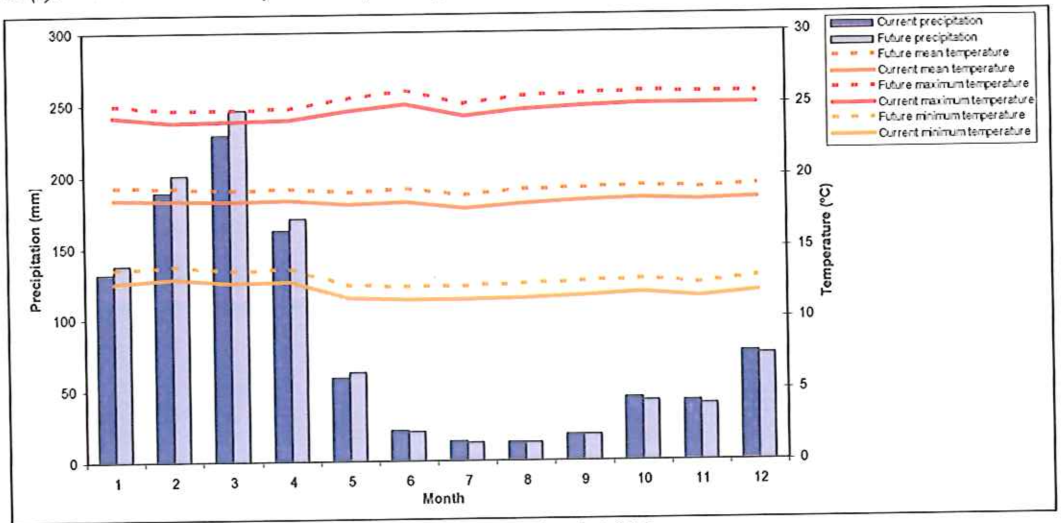


Figure 20. Climate trend summary Ayabaca (Piura) 2020.

General climatic characteristics

- The rainfall increases from 990 millimeters to 1040 millimeters
- Temperatures increase and the average increase is 0,9 °C
- The mean daily temperature range decreases from 12,6 °C to 12,5 °C
- The maximum number of cumulative dry months keeps constant in 8 months

Extreme conditions

- The maximum temperature of the year increases from 25,2 °C to 26,1 °C while the warmest quarter gets hotter by 0,9 °C
- The minimum temperature of the year increases from 11,2 °C to 12,1 °C while the coldest quarter gets hotter by 0,8 °C
- The wettest month gets wetter with 250 millimeters instead of 230 millimeters, while the wettest quarter gets wetter by 40 mm
- The driest month and the driest quarter stay nearly the same.

Climate seasonality

- Overall this climate becomes more 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 1%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 3%
- Precipitation predictions were uniform between models and thus no outliers were detected

11a (ii). Predictions Ayabaca (Piura) 2050

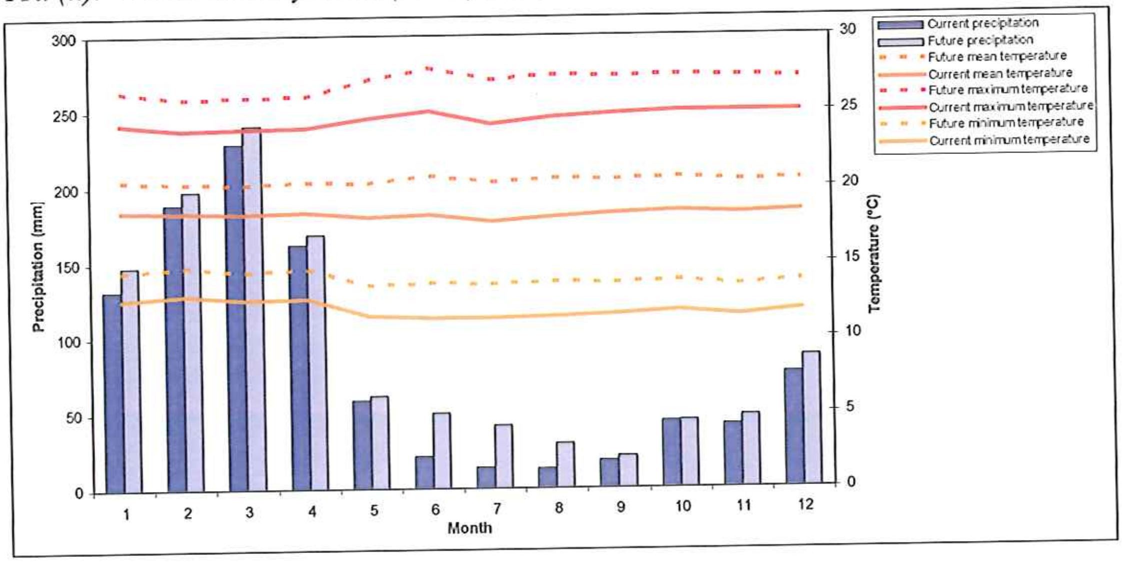


Figure 21. Climate trend summary Ayabaca (Piura) 2050.

General climatic characteristics

- The rainfall increases from 990 millimeters to 1140 millimeters
- Temperatures increase and the average increase is 2,2 °C
- The mean daily temperature range increases from 12,6 °C to 13 °C
- The maximum number of cumulative dry months decreases from 8 months to 7 months

Extreme conditions

- The maximum temperature of the year increases from 25,2 °C to 28,2 °C while the warmest quarter gets hotter by 2,4 °C
- The minimum temperature of the year increases from 11,2 °C to 13,2 °C while the coldest quarter gets hotter by 2 °C
- The wettest month gets wetter with 240, millimeters instead of 230 millimeters, while the wettest quarter gets wetter by 30 mm
- The driest month gets wetter with 15 millimeters instead of 10 millimeters while the driest quarter gets wetter by 25 mm

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 4%
- 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

11b. Average climate change trends Canchaque (Piura)

11b (i). Predictions Canchaque (Piura) 2020

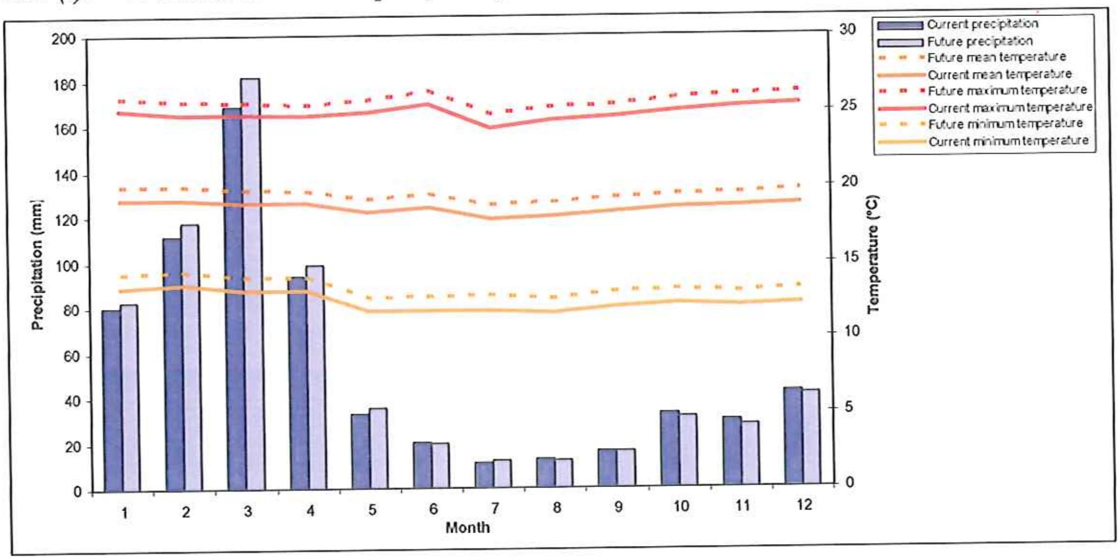


Figure 22. Climate trend summary Canchaque (Piura) 2020.

General climatic characteristics

- The rainfall increases from 650 millimeters to 670 millimeters
- Temperatures increase and the average increase is 0,9 °C
- The mean daily temperature range decreases from 12,5 °C to 12,3 °C
- The maximum number of cumulative dry months keeps constant in 10 months

Extreme conditions

- The maximum temperature of the year increases from 25,8 °C to 26,6 °C while the warmest quarter gets hotter by 0,9 °C
- The minimum temperature of the year increases from 11,5 °C to 12,3 °C while the coldest quarter gets hotter by 0,92 °C
- The wettest month gets wetter with 180 millimeters instead of 170 millimeters, while the wettest quarter gets wetter by 20 mm
- The driest month and the driest quarter stay nearly the same.

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 1%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 2%
- Precipitation predictions were uniform between models and thus no outliers were detected

11b (ii). Predictions Canchaque (Piura) 2050

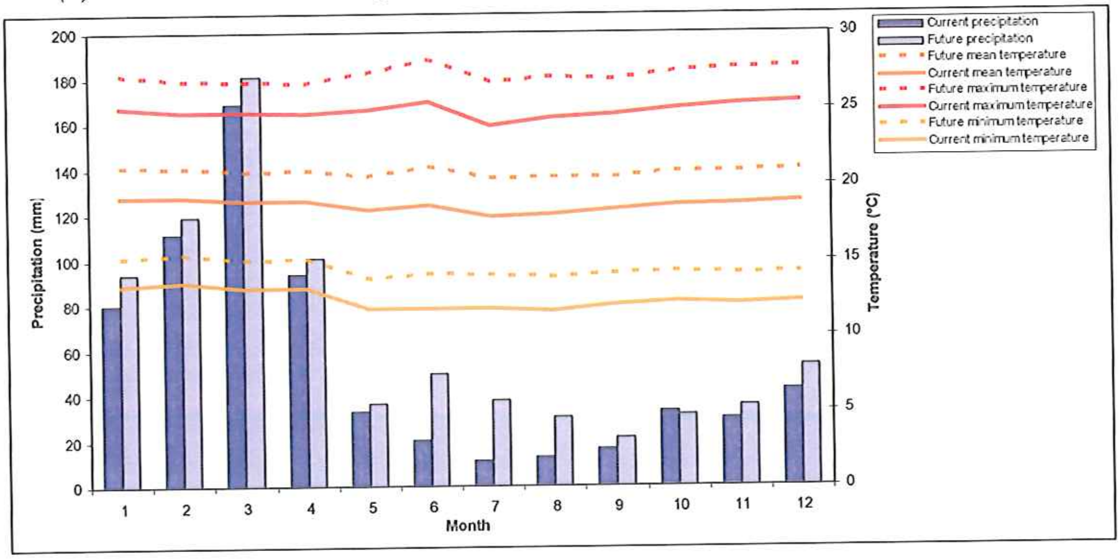


Figure 23. Climate trend summary Canchaque (Piura) 2050.

General climatic characteristics

- The rainfall increases from 650 millimeters to 790 millimeters
- Temperatures increase and the average increase is 2,2 °C
- The mean daily temperature range increases from 12,5 °C to 12,8 °C
- The maximum number of cumulative dry months decreases from 10 months to 9 months

Extreme conditions

- The maximum temperature of the year increases from 25,8 °C to 28,5 °C while the warmest quarter gets hotter by 2,2 °C
- The minimum temperature of the year increases from 11,5 °C to 13,5 °C while the coldest quarter gets hotter by 2,2 °C
- The wettest month gets wetter with 180 millimeters instead of 170 millimeters, while the wettest quarter gets wetter by 30 mm
- The driest month stay nearly the same while the driest quarter gets wetter by 20 mm

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 3%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 12%
- Precipitation predictions were uniform between models and thus no outliers were detected

11c. Average climate change trends El Carmen de la Frontera (Piura)

11c (i). Predictions El Carmen de la Frontera (Piura) 2020

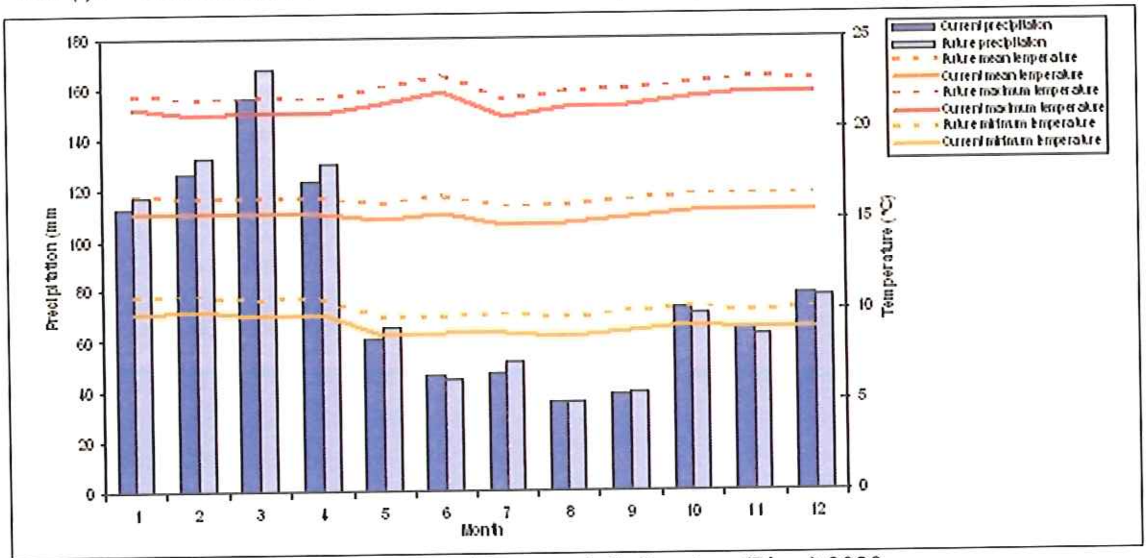


Figure 24. Climate trend summary El Carmen de la Frontera (Piura) 2020.

General climatic characteristics

- The rainfall increases from 960 millimeters to 990 millimeters
- Temperatures increase and the average increase is 0,9 °C
- The mean daily temperature range decreases from 12,1 °C to 12 °C
- The maximum number of cumulative dry months keeps constant in 9 months

Extreme conditions

- The maximum temperature of the year increases from 22 °C to 23 °C while the warmest quarter gets hotter by 0,9 °C
- The minimum temperature of the year increases from 8,4 °C to 9,3 °C while the coldest quarter gets hotter by 0,9 °C
- The wettest month gets wetter with 170 millimeters instead of 160 millimeters, while the wettest quarter gets wetter by 20 mm
- The driest month and the driest quarter stay the same.

Climate seasonality

- Overall this climate becomes more 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 1%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 1%
- Precipitation predictions were uniform between models and thus no outliers were detected

11c (ii). Predictions El Carmen de la Frontera (Piura) 2050

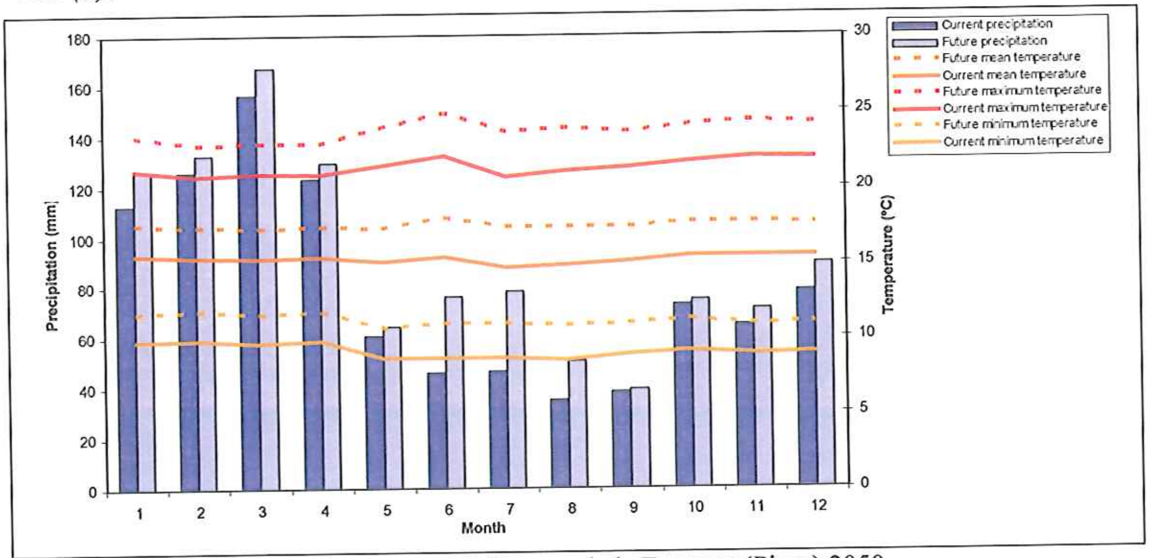


Figure 25. Climate trend summary El Carmen de la Frontera (Piura) 2050.

General climatic characteristics

- The rainfall increases from 960 millimeters to 1100 millimeters
- Temperatures increase and the average increase is 2,2 °C
- The mean daily temperature range increases from 12,1 °C to 12,5 °C
- The maximum number of cumulative dry months decreases from 9 months to 7 months

Extreme conditions

- The maximum temperature of the year increases from 22,1 °C to 25,1 °C while the warmest quarter gets hotter by 2,4 °C
- The minimum temperature of the year increases from 8,4 °C to 10,4 °C while the coldest quarter gets hotter by 2,2 °C
- The wettest month gets wetter with 170 millimeters instead of 160 millimeters, while the wettest quarter gets wetter by 30 mm
- The driest month stay nearly the same while the driest quarter gets wetter by 17,8 mm

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%
- 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

11d. Average climate change trends Huarmaca (Piura)

11d (i). Predictions Huarmaca (Piura) 2020

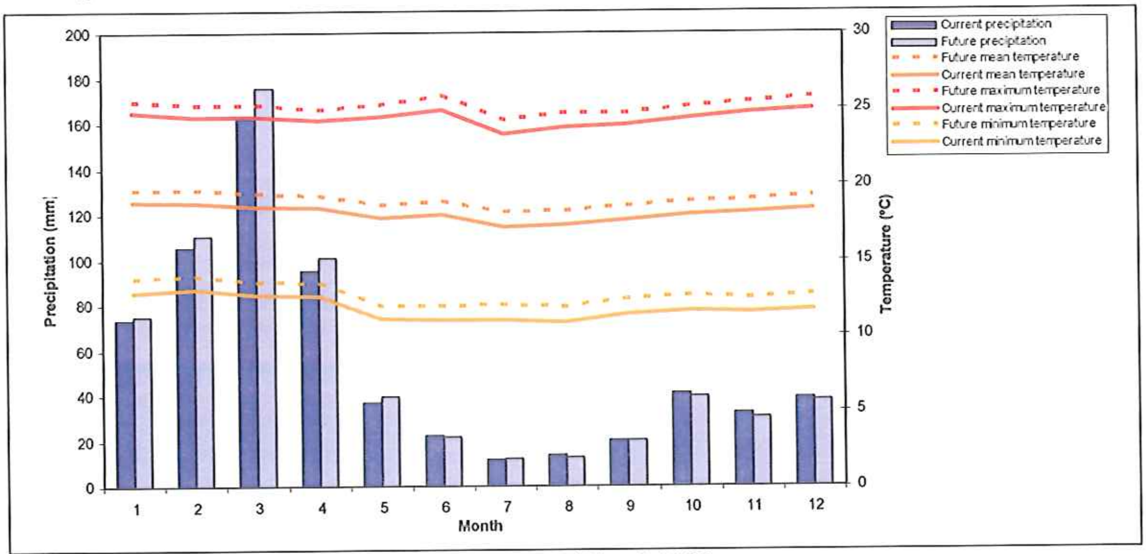


Figure 26. Climate trend summary Huarmaca (Piura) 2020.

General climatic characteristics

- The rainfall increases from 650 millimeters to 670 millimeters
- Temperatures increase and the average increase is 0,8 °C
- The mean daily temperature range decreases from 12,6 °C to 12,4 °C
- The maximum number of cumulative dry months keeps constant in 10 months

Extreme conditions

- The maximum temperature of the year increases from 25,2 °C to 26,1 °C while the warmest quarter gets hotter by 0,8 °C
- The minimum temperature of the year increases from 10,8 °C to 11,7 °C while the coldest quarter gets hotter by 0,9 °C
- The wettest month gets wetter with 180 millimeters instead of 160 millimeters, while the wettest quarter gets wetter by 20 mm
- The driest month and the driest quarter stay nearly the same.

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 1%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 2%
- Precipitation predictions were uniform between models and thus no outliers were detected

11d (ii). Predictions Huarmaca (Piura) 2050

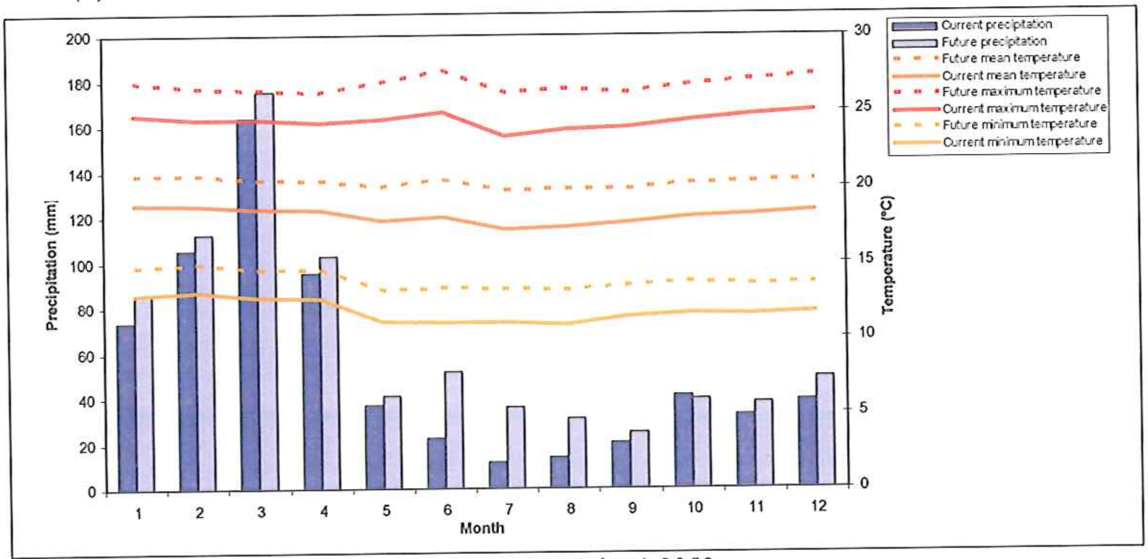


Figure 27. Climate trend summary Huarmaca (Piura) 2050.

General climatic characteristics

- The rainfall increases from 650 millimeters to 790 millimeters
- Temperatures increase and the average increase is 2,2 °C
- The mean daily temperature range increases from 12,6 °C to 12,9 °C
- The maximum number of cumulative dry months decreases from 10 months to 9 months

Extreme conditions

- The maximum temperature of the year increases from 25,2 °C to 27,9 °C while the warmest quarter gets hotter by 2,1 °C
- The minimum temperature of the year increases from 10,8 °C to 12,8 °C while the coldest quarter gets hotter by 2,3 °C
- The wettest month gets wetter with 180 millimeters instead of 160 millimeters, while the wettest quarter gets wetter by 30 mm
- The driest month gets wetter with 15 millimeters instead of 10 millimeters while the driest quarter gets wetter by 22 mm

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 4%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 12%
- Precipitation predictions were uniform between models and thus no outliers were detected

11e. Average climate change trends Jilili (Piura)

11e (i). Predictions Jilili (Piura) 2020

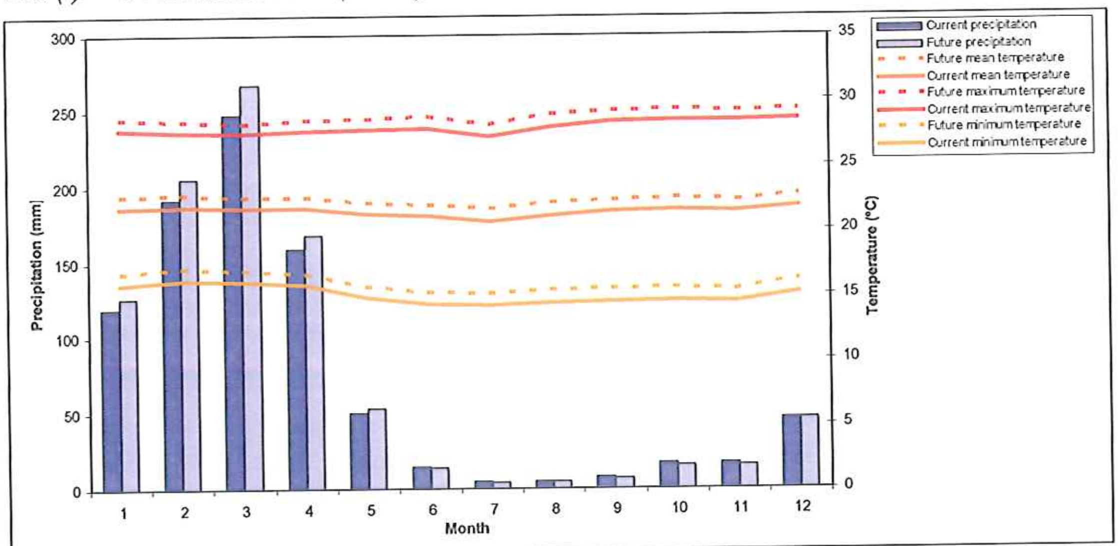


Figure 28, Climate trend summary Jilili (Piura) 2020.

General climatic characteristics

- The rainfall increases from 870 millimeters to 920 millimeters
- Temperatures increase and the average increase is 0,90 °C
- The mean daily temperature range decreases from 12,9 °C to 12,8 °C
- The maximum number of cumulative dry months keeps constant in 8 months

Extreme conditions

- The maximum temperature of the year increases from 28,6 °C to 29,5 °C while the warmest quarter gets hotter by 0,9 °C
- The minimum temperature of the year increases from 14,1 °C to 15 °C while the coldest quarter gets hotter by 0,9 °C
- The wettest month gets wetter with 270 millimeters instead of 250 millimeters, while the wettest quarter gets wetter by 40 mm
- The driest month and the driest quarter stay nearly the same.

Climate seasonality

- Overall this climate becomes more 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 1%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 5%
- Precipitation predictions were uniform between models and thus no outliers were detected

11e (ii). Predictions Jilili (Piura) 2050

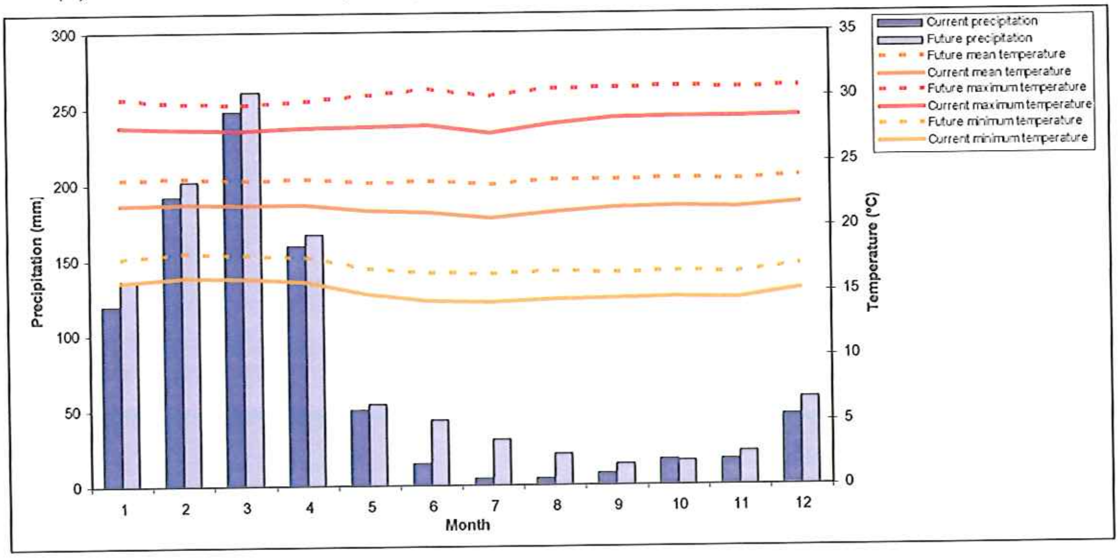


Figure 29. Climate trend summary Jilili (Piura) 2050.

General climatic characteristics

- The rainfall increases from 880 millimeters to 1030 millimeters
- Temperatures increase and the average increase is 2,1 °C
- The mean daily temperature range increases from 12,9 °C to 13,3 °C
- The maximum number of cumulative dry months keeps constant in 8 months

Extreme conditions

- The maximum temperature of the year increases from 28,6 °C to 31,4 °C while the warmest quarter gets hotter by 2,2 °C
- The minimum temperature of the year increases from 14,1 °C to 16,1 °C while the coldest quarter gets hotter by 2,1 °C
- The wettest month gets wetter with 260 millimeters instead of 250 millimeters, while the wettest quarter gets wetter by 30,6 mm
- The driest month gets wetter with 40 millimeters instead of 10 millimeters while the driest quarter gets wetter by 60 mm

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 3%
- 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

11f. Average climate change trends Lalaquiz (Piura)

11f (i). Predictions Lalaquiz (Piura) 2020

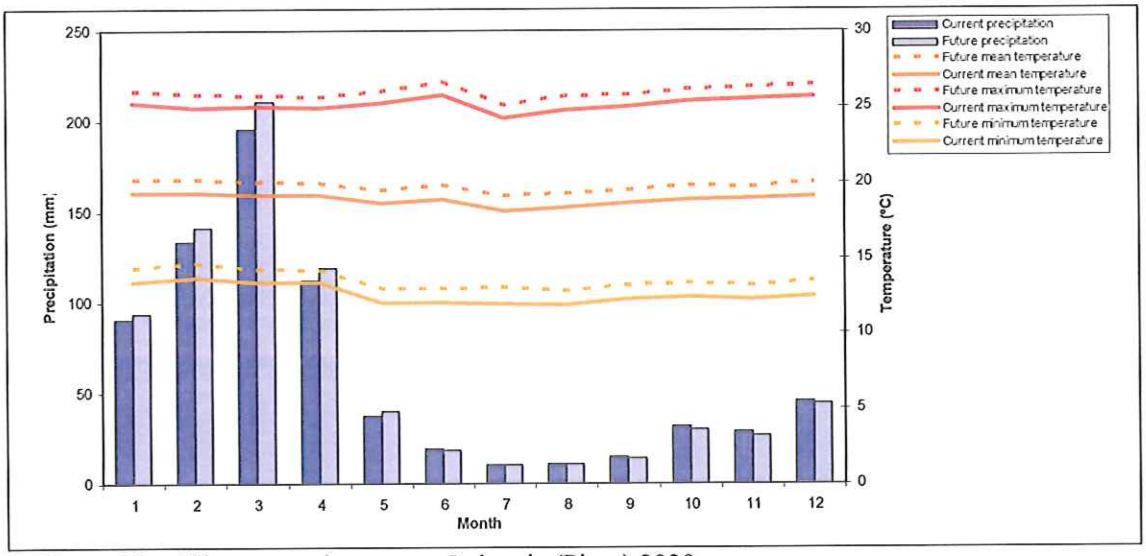


Figure 30. Climate trend summary Lalaquiz (Piura) 2020.

General climatic characteristics

- The rainfall increases from 730 millimeters to 760 millimeters
- Temperatures increase and the average increase is 0,9 °C
- The mean daily temperature range decreases from 12,5 °C to 12,4 °C
- The maximum number of cumulative dry months keeps constant in 9 months

Extreme conditions

- The maximum temperature of the year increases from 26 °C to 27 °C while the warmest quarter gets hotter by 0,9 °C
- The minimum temperature of the year increases from 11,8 °C to 12,6 °C while the coldest quarter gets hotter by 0,9 °C
- The wettest month gets wetter with 210 millimeters instead of 190 millimeters, while the wettest quarter gets wetter by 30 mm
- The driest month and the driest quarter stay nearly the same.

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 1%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 2%
- Precipitation predictions were uniform between models and thus no outliers were detected

11f (ii). Predictions Lalaquiz (Piura) 2050

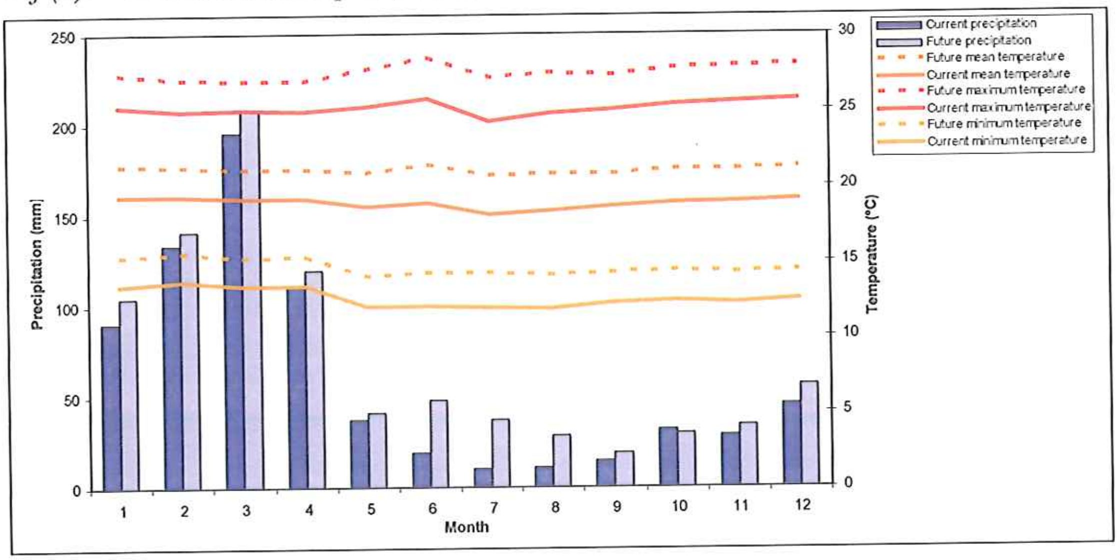


Figure 31. Climate trend summary Lalaquiz (Piura) 2050.

General climatic characteristics

- The rainfall increases from 730 millimeters to 870 millimeters
- Temperatures increase and the average increase is 2,1 °C
- The mean daily temperature range increases from 12,5 °C to 12,9 °C
- The maximum number of cumulative dry months decreases from 9 months to 8 months

Extreme conditions

- The maximum temperature of the year increases from 26 °C to 28,8 °C while the warmest quarter gets hotter by 2,2 °C
- The minimum temperature of the year increases from 11,8 °C to 13,7 °C while the coldest quarter gets hotter by 2,2 °C
- The wettest month gets wetter with 210 millimeters instead of 190 millimeters, while the wettest quarter gets wetter by 30 mm
- The driest month gets wetter with 30 millimeters instead of 10 millimeters while the driest quarter gets wetter by 50 mm

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 4%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 12%
- Precipitation predictions were uniform between models and thus no outliers were detected

11g. Average climate change trends Montero (Piura)

11g (i). Predictions Montero (Piura) 2020

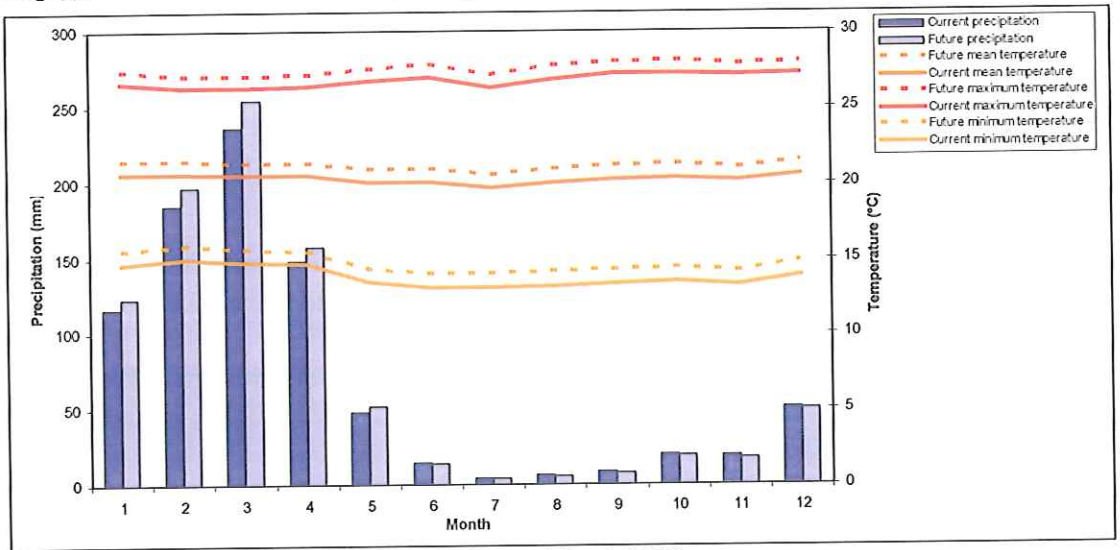


Figure 32. Climate trend summary Montero (Piura) 2020.

General climatic characteristics

- The rainfall increases from 850 millimeters to 900 millimeters
- Temperatures increase and the average increase is 0,8 °C
- The mean daily temperature range decreases from 12,9 °C to 12,8 °C
- The maximum number of cumulative dry months keeps constant in 8 months

Extreme conditions

- The maximum temperature of the year increases from 27,3 °C to 28,2 °C while the warmest quarter gets hotter by 0,9 °C
- The minimum temperature of the year increases from 13 °C to 13,8 °C while the coldest quarter gets hotter by 0,84 °C
- The wettest month gets wetter with 250 millimeters instead of 230 millimeters, while the wettest quarter gets wetter by 40 mm
- The driest month and the driest quarter stay nearly the same.

Climate seasonality

- Overall this climate becomes more 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 1%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 4%
- Precipitation predictions were uniform between models and thus no outliers were detected

11g (ii). Predictions Montero (Piura) 2050

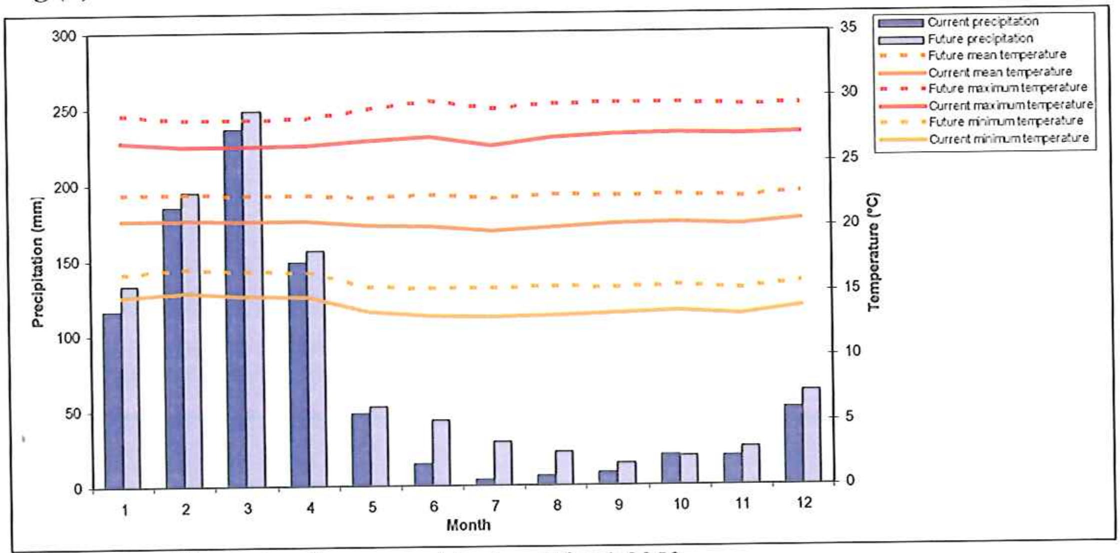


Figure 33. Climate trend summary Montero (Piura) 2050.

General climatic characteristics

- The rainfall increases from 850 millimeters to 1000 millimeters
- Temperatures increase and the average increase is 2,1 °C
- The mean daily temperature range increases from 12,9 °C to 13,3 °C
- The maximum number of cumulative dry months keeps constant in 8 months

Extreme conditions

- The maximum temperature of the year increases from 27,3 °C to 30,2 °C while the warmest quarter gets hotter by 2,2 °C
- The minimum temperature of the year increases from 13 °C to 14,9 °C while the coldest quarter gets hotter by 2,1 °C
- The wettest month gets wetter with 250 millimeters instead of 230 millimeters, while the wettest quarter gets wetter by 30 mm
- The driest month gets wetter with 20 millimeters instead of 0 millimeters while the driest quarter gets wetter by 40 mm

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 4%
- 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

11h. Average climate change trends San Miguel Faique (Piura)

11h (i). Predictions San Miguel Faique (Piura) 2020

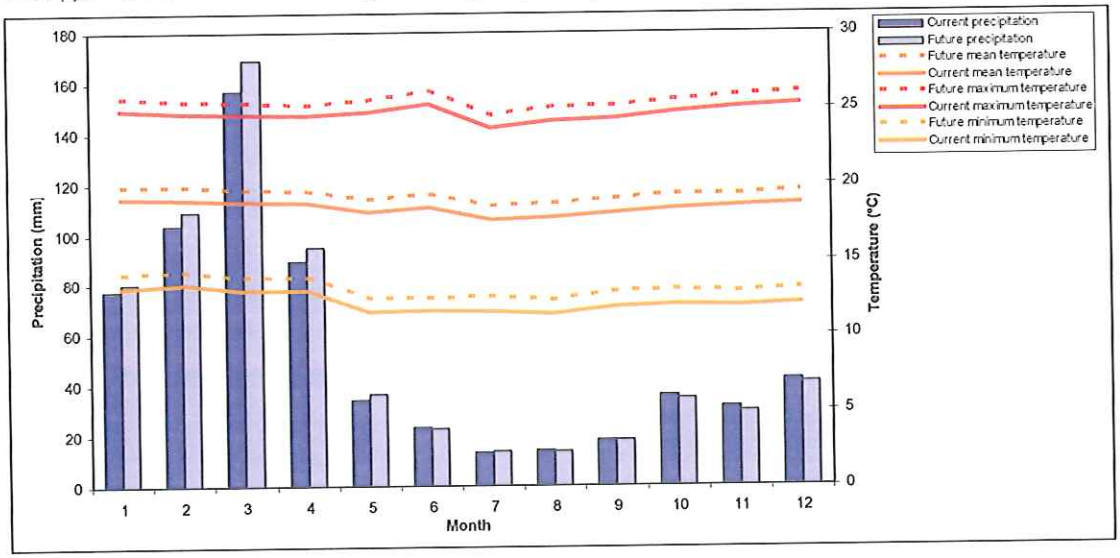


Figure 34. Climate trend summary San Miguel Faique (Piura) 2020.

General climatic characteristics

- The rainfall increases from 640 millimeters to 660 millimeters
- Temperatures increase and the average increase is 0,9 °C
- The mean daily temperature range decreases from 12,5 °C to 12,4 °C
- The maximum number of cumulative dry months keeps constant in 10 months

Extreme conditions

- The maximum temperature of the year increases from 25,6 °C to 26,5 °C while the warmest quarter gets hotter by 0,8 °C
- The minimum temperature of the year increases from 11,3 °C to 12,1 °C while the coldest quarter gets hotter by 0,9 °C
- The wettest month gets wetter with 170 millimeters instead of 160 millimeters, while the wettest quarter gets wetter by 20 mm
- The driest month and the driest quarter stay nearly the same.

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 1%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 1%
- Precipitation predictions were uniform between models and thus no outliers were detected

11h (ii). Predictions San Miguel Faique (Piura) 2050

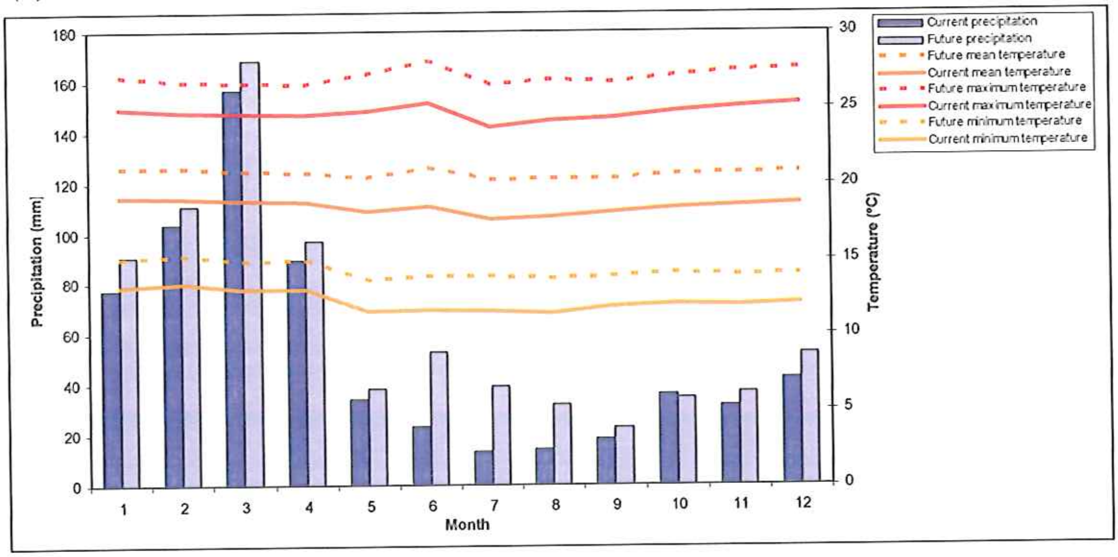


Figure 35, Climate trend summary San Miguel Faique (Piura) 2050.

General climatic characteristics

- The rainfall increases from 640 millimeters to 780 millimeters
- Temperatures increase and the average increase is 2,2 °C
- The mean daily temperature range increases from 12,5 °C to 12,8 °C
- The maximum number of cumulative dry months decreases from 10 months to 9 months

Extreme conditions

- The maximum temperature of the year increases from 25,6 °C to 28,4 °C while the warmest quarter gets hotter by 2,2 °C
- The minimum temperature of the year increases from 11,3 °C to 13,3 °C while the coldest quarter gets hotter by 2,2 °C
- The wettest month gets wetter with 170 millimeters instead of 160 millimeters, while the wettest quarter gets wetter by 30 mm
- The driest month gets wetter with 10 millimeters instead of 40 millimeters while the driest quarter gets wetter by 50 mm

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 4%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 13%
- Precipitation predictions were uniform between models and thus no outliers were detected

11i. *Average climate change trends Santo Domingo (Piura)*

11i (i). *Predictions Santo Domingo (Piura) 2020*

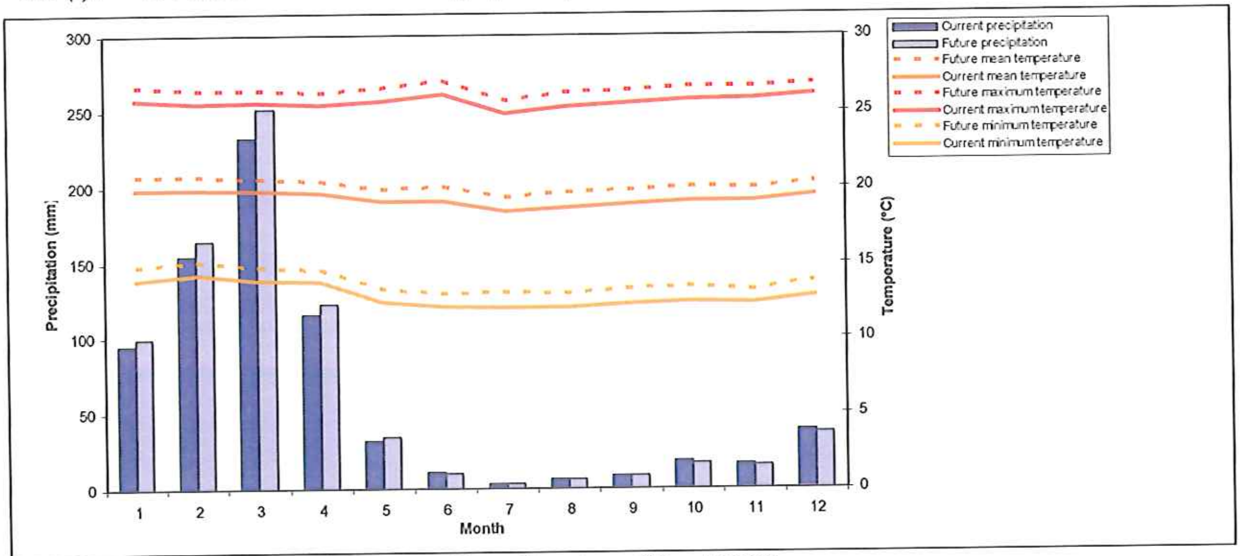


Figure 36. Climate trend summary Santo Domingo (Piura) 2020.

General climatic characteristics

- The rainfall increases from 730 millimeters to 770 millimeters
- Temperatures increase and the average increase is 0,9 °C
- The mean daily temperature range decreases from 12,8 °C to 12,7 °C
- The maximum number of cumulative dry months keeps constant in 9 months

Extreme conditions

- The maximum temperature of the year increases from 26,4 °C to 27,3 °C while the warmest quarter gets hotter by 0,8 °C
- The minimum temperature of the year increases from 11,9 °C to 12,8 °C while the coldest quarter gets hotter by 0,9 °C
- The wettest month gets wetter with 250 millimeters instead of 230 millimeters, while the wettest quarter gets wetter by 40 mm
- The driest month and the driest quarter stay nearly the same.

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 1%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 4%
- Precipitation predictions were uniform between models and thus no outliers were detected

11i (ii). Predictions Santo Domingo (Piura) 2050

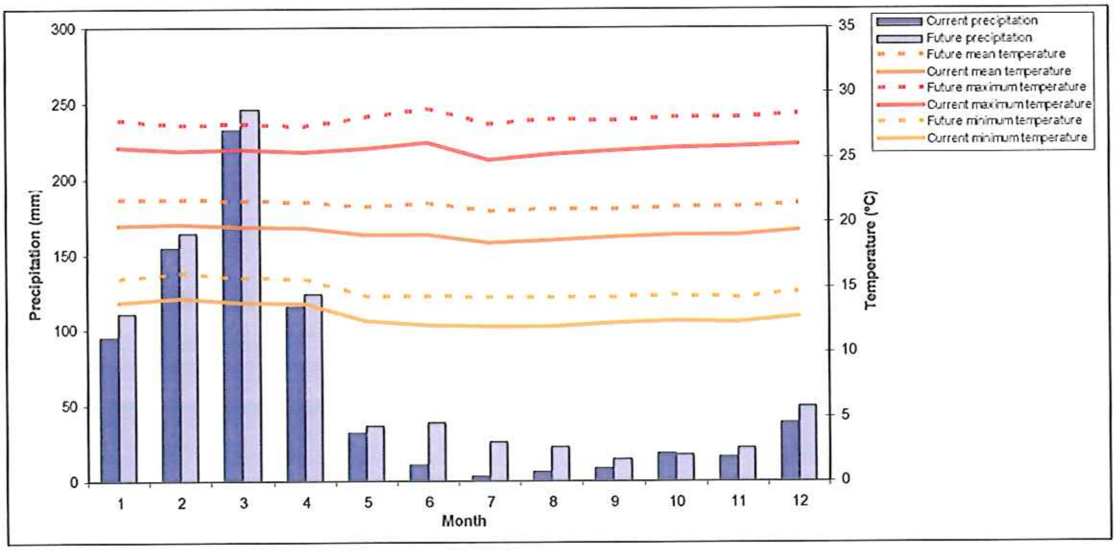


Figure 37, Climate trend summary Santo Domingo (Piura) 2050.

General climatic characteristics

- The rainfall increases from 730 millimeters to 880 millimeters
- Temperatures increase and the average increase is 2,1 °C
- The mean daily temperature range increases from 12,8 °C to 13,1 °C
- The maximum number of cumulative dry months decreases from 9 months to 8 months

Extreme conditions

- The maximum temperature of the year increases from 26,4 °C to 29,1 °C while the warmest quarter gets hotter by 2,1 °C
- The minimum temperature of the year increases from 11,9 °C to 13,8 °C while the coldest quarter gets hotter by 2,1 °C
- The wettest month gets wetter with 250 millimeters instead of 230 millimeters, while the wettest quarter gets wetter by 30 mm
- The driest month gets wetter with 20 millimeters instead of 5 millimeters while the driest quarter gets wetter by 50 mm

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 3,8%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 11,3%
- Precipitation predictions were uniform between models and thus no outliers were detected

11j. *Average climate change trends Sicchez (Piura)*

11j (i). *Predictions Sicchez (Piura) 2020*

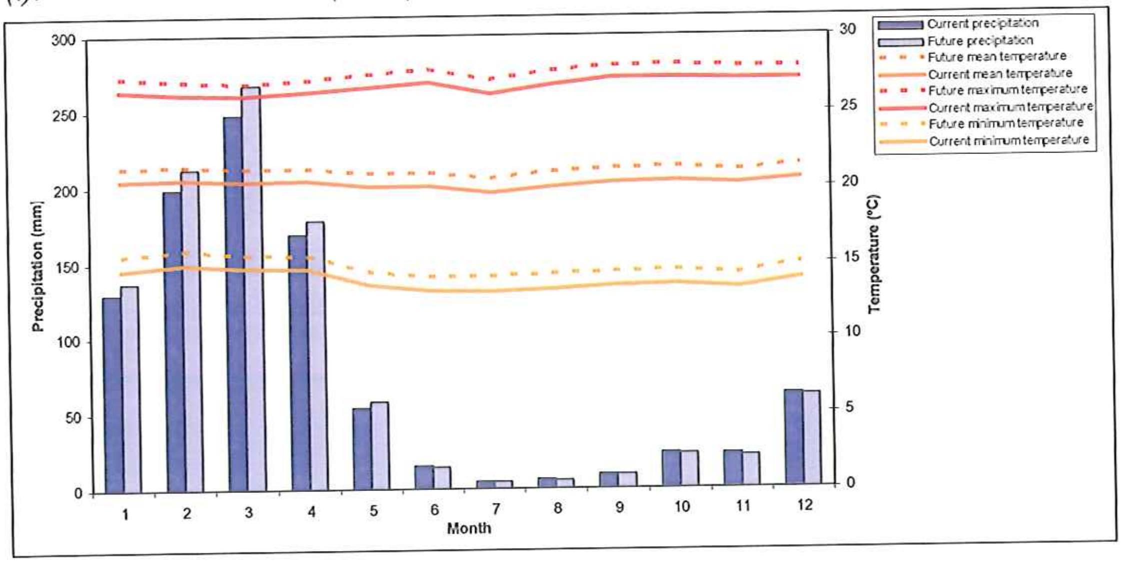


Figure 38. Climate trend summary Sicchez (Piura) 2020.

General climatic characteristics

- The rainfall increases from 940 millimeters to 990 millimeters
- Temperatures increase and the average increase is 0,9 °C
- The mean daily temperature range decreases from 12,8 °C to 12,7 °C
- The maximum number of cumulative dry months keeps constant in 8 months

Extreme conditions

- The maximum temperature of the year increases from 27,3 °C to 28,2 °C while the warmest quarter gets hotter by 0,9 °C
- The minimum temperature of the year increases from 13,1 °C to 13,9 °C while the coldest quarter gets hotter by 0,9 °C
- The wettest month gets wetter with 260 millimeters instead of 250 millimeters, while the wettest quarter gets wetter by 40 mm
- The driest month and the driest quarter stay nearly the same.

Climate seasonality

- Overall this climate becomes more 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 1%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 4%
- Precipitation predictions were uniform between models and thus no outliers were detected

11j (ii). Predictions Sicchez (Piura) 2050

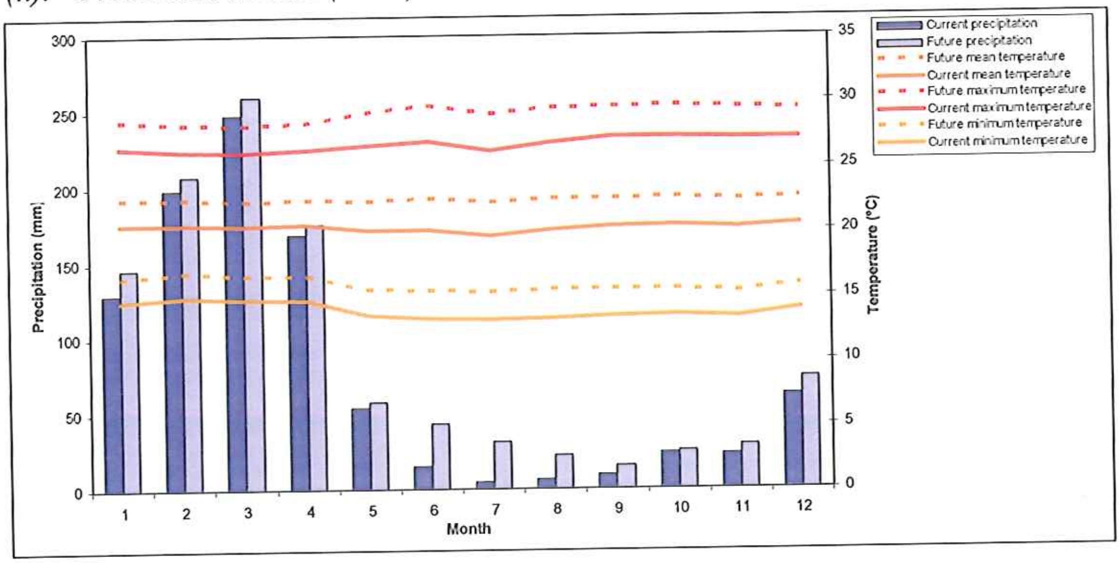


Figure 39. Climate trend summary Sicchez (Piura) 2050.

General climatic characteristics

- The rainfall increases from 940 millimeters to 1090 millimeters
- Temperatures increase and the average increase is 2,1 °C
- The mean daily temperature range increases from 12,8 °C to 13,2 °C
- The maximum number of cumulative dry months keeps constant in 8 months

Extreme conditions

- The maximum temperature of the year increases from 27,3 °C to 30,2 °C while the warmest quarter gets hotter by 2,3 °C
- The minimum temperature of the year increases from 13,1 °C to 15 °C while the coldest quarter gets hotter by 2,08 °C
- The wettest month gets wetter with 260 millimeters instead of 250 millimeters, while the wettest quarter gets wetter by 30 mm
- The driest month gets wetter with 15 millimeters instead of 10 millimeters while the driest quarter gets wetter by 50 mm

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 4%
- 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

11k. Average climate change trends Suyo (Piura)

11k (i). Predictions Suyo (Piura) 2020

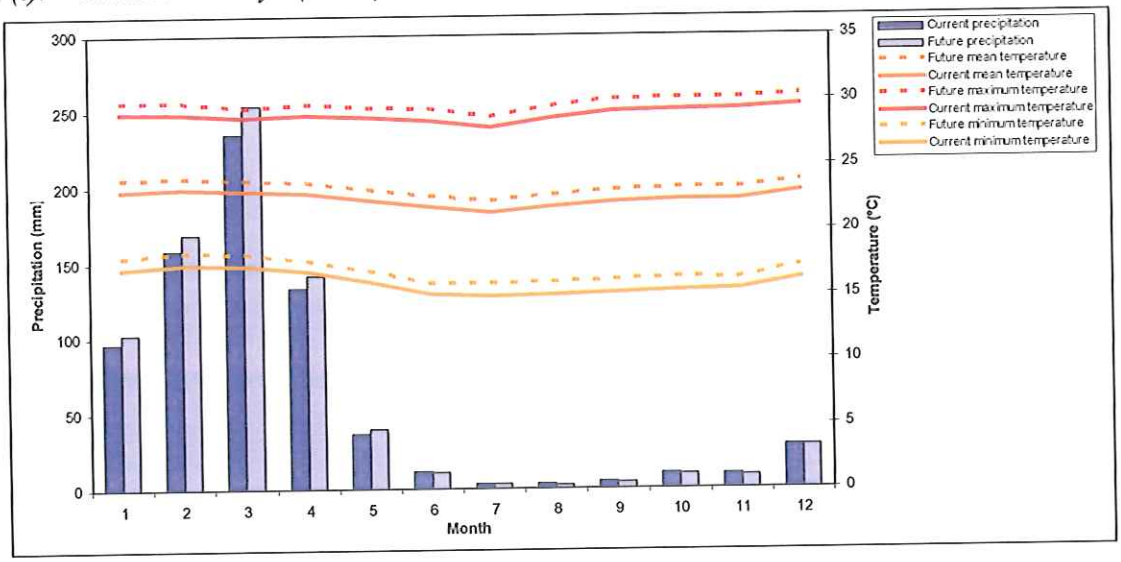


Figure 40. Climate trend summary Suyo (Piura) 2020.

General climatic characteristics

- The rainfall increases from 730 millimeters to 770 millimeters
- Temperatures increase and the average increase is 0,9 °C
- The mean daily temperature range decreases from 12,9 °C to 12,8 °C
- The maximum number of cumulative dry months keeps constant in 9 months

Extreme conditions

- The maximum temperature of the year increases from 29,6 °C to 30,5 °C while the warmest quarter gets hotter by 0,9 °C
- The minimum temperature of the year increases from 14,9 °C to 15,7 °C while the coldest quarter gets hotter by 0,9 °C
- The wettest month gets wetter with 250 millimeters instead of 230 millimeters, while the wettest quarter gets wetter by 40 mm
- The driest month and the driest quarter stay nearly the same.

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 1%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 5%
- Precipitation predictions were uniform between models and thus no outliers were detected

11k (ii). Predictions Suyo (Piura) 2050

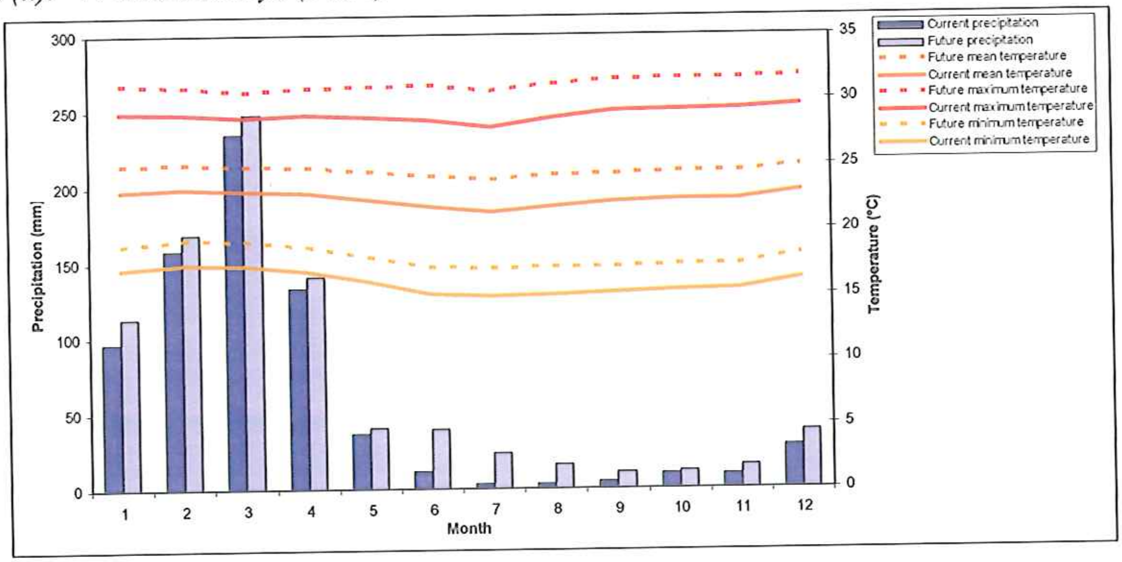


Figure 41. Climate trend summary Suyo (Piura) 2050.

General climatic characteristics

- The rainfall increases from 730 millimeters to 870 millimeters
- Temperatures increase and the average increase is 2,1 °C
- The mean daily temperature range increases from 12,9 °C to 13,3 °C
- The maximum number of cumulative dry months decreases from 9 months to 8 months

Extreme conditions

- The maximum temperature of the year increases from 29,6 °C to 32,3 °C while the warmest quarter gets hotter by 2,1 °C
- The minimum temperature of the year increases from 14,9 °C to 16,8 °C while the coldest quarter gets hotter by 2,2 °C
- The wettest month gets wetter with 250 millimeters instead of 230 millimeters, while the wettest quarter gets wetter by 30 mm
- The driest month gets wetter with 5 millimeters instead of 0 millimeters while the driest quarter gets wetter by 15 mm

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 3%
- Temperature predictions were uniform between models and thus no outliers were detected

- The coefficient of variation of precipitation predictions between models is 11%
- Precipitation predictions were uniform between models and thus no outliers were detected

11l. *Average climate change trends Yamango (Piura)*

11l (i). Predictions Yamango (Piura) 2020

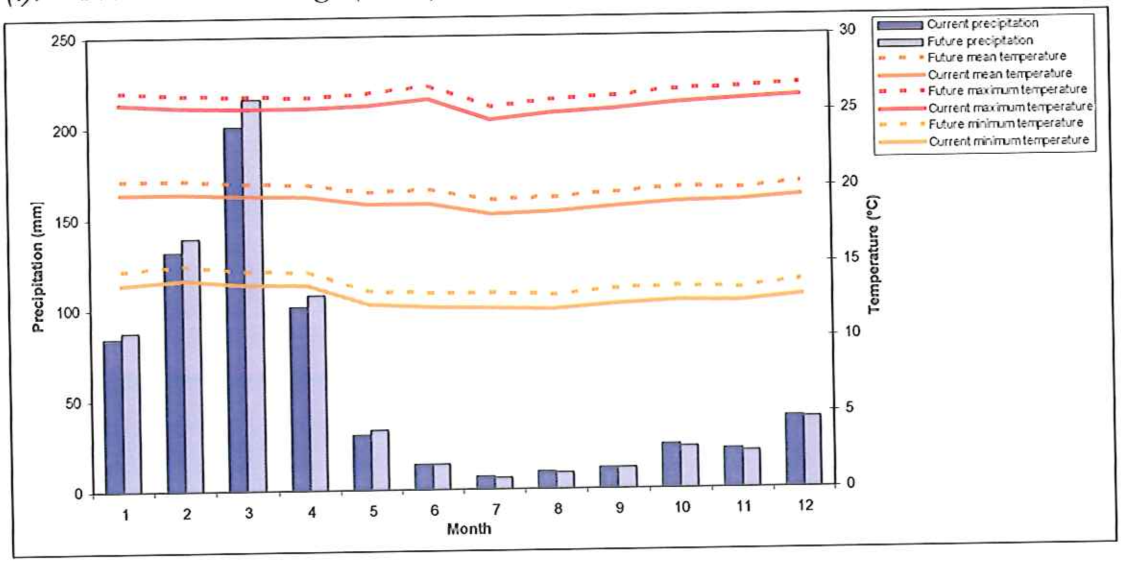


Figure 42. Climate trend summary Yamango (Piura) 2020.

General climatic characteristics

- The rainfall increases from 670 millimeters to 700 millimeters
- Temperatures increase and the average increase is 0,9 °C
- The mean daily temperature range decreases from 12,6 °C to 12,5 °C
- The maximum number of cumulative dry months decreases from 10 months to 9 months

Extreme conditions

- The maximum temperature of the year increases from 26,3 °C to 27,1 °C while the warmest quarter gets hotter by 0,9 °C
- The minimum temperature of the year increases from 11,8 °C to 12,7 °C while the coldest quarter gets hotter by 0,9 °C
- The wettest month gets wetter with 220 millimeters instead of 200 millimeters, while the wettest quarter gets wetter by 30 mm
- The driest month and the driest quarter stay the same.

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 1%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 3% Precipitation predictions were uniform between models and thus no outliers were detected
- Precipitation predictions were uniform between models and thus no outliers were detected

111 (ii). Predictions Yamango (Piura) 2050

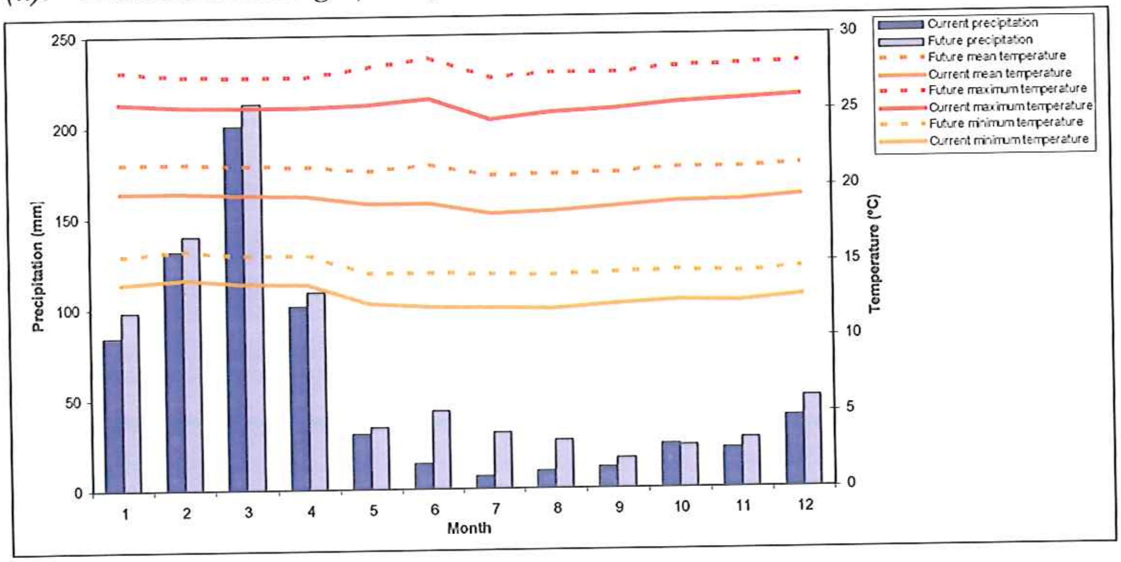


Figure 43. Climate trend summary Yamango (Piura) 2050.

General climatic characteristics

- The rainfall increases from 670 millimeters to 820 millimeters
- Temperatures increase and the average increase is 2,1 °C
- The mean daily temperature range increases from 12,6 °C to 13 °C
- The maximum number of cumulative dry months decreases from 10 months to 9 months

Extreme conditions

- The maximum temperature of the year increases from 26,3 °C to 29 °C while the warmest quarter gets hotter by 2,1 °C
- The minimum temperature of the year increases from 11,8 °C to 13,8 °C while the coldest quarter gets hotter by 2,2 °C
- The wettest month gets wetter with 210 millimeters instead of 200 millimeters, while the wettest quarter gets wetter by 30 mm
- The driest month stay nearly the same while the driest quarter gets wetter by 20 mm.

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 3,9%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 12,24%
- Precipitation predictions were uniform between models and thus no outliers were detected

12. Conclusions

12a. Overall conclusions

- The changes in suitability of a particular area to grow coffee is 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 new but also a lot of new potential.
- The winners will be those who are prepared for change and know how to adapt.

12b. Specific conclusions

12b (i). How will the climate in the project area change by the year 2020 and by 2050?

- The yearly and monthly rainfall will increase progressively by 2020 and by 2050.
- The yearly and monthly minimum and maximum temperatures will increase progressively by 2020 and by 2050.
- The overall climate will become more seasonal in terms of variability through the year in temperature and less seasonal in precipitation.
- The maximum number of cumulative dry months will decrease from 9 to 8.
- Precipitation for specific districts will increase 20 to 50 mm by 2020 and 100 to 150 mm by 2050.
- Temperature will increase in specific districts by about 0.9°C by 2020 is and by about 2.2°C by 2050.

12b (ii). What impact will climate change have for suitability of coffee and how will coffee areas change?

- The suitability of the current coffee-growing areas for production in 2020 will mostly remain unchanged and will even increase in some areas.
- By 2050, however, the suitability for coffee production of most of the areas will decrease. Only Huarmaca district will become more suitable by 2050.
- With progressive climate change, higher altitudes will become suitable to produce coffee. The optimum coffee-producing zone is currently at an altitude of 1320 masl. By 2020 the

optimum altitude will increase to 1470 masl, and by 2050 to 1720 masl. Increasing altitude compensates for the increases in temperature (Figure 18).

- Between today and 2020 areas at around 1000 masl will suffer the greatest decrease in suitability, while areas around 1500 masl will have the greatest increase in suitability. By 2050 areas up to 1200 masl will suffer and areas up to 1750 masl will benefit.

12b (iii). What are the climatic factors that determine the suitability for coffee?

- In the first instance, the environmental variables that drive the change in suitability for coffee production by 2020 are mainly related to temperature. The variables are very highly correlated and explain 18 % of the variance.
- The limiting effect of higher mean and extreme temperatures is also reflected in an increase in altitude of areas suitable for growing coffee.
- By 2050 the temperature-related variables maintain their importance but precipitation-related variables also become important, showing higher correlation coefficients than for 2020.
- The data suggest that increases in both annual and monthly precipitation are unlikely to compensate for the increases in evaporative demand due to higher temperature by 2050. By 2020 and more particularly by 2050 the mean temperature of both the driest and the wettest quarters become important determinants of suitability.

13. 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.

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15. Appendix

Table 5. Summary chart of Principal Component and Correlation Analyses for 2020

Principal Compnent and Correlation Analyses 2020

	Eigenvalue	Difference	Proportion	Cumulative
1	4.18432963	1.59487764	0.2989	0.2989
2	2.58945200	1.38111925	0.1850	0.4838
3	1.20833275	0.11291516	0.0863	0.5702
4	1.09541759	0.12661455	0.0782	0.6484
5	0.96880304	0.00740838	0.0692	0.7176
6	0.96139466	0.21671640	0.0687	0.7863
7	0.74467826	0.09843871	0.0532	0.8395
8	0.64623955	0.06447839	0.0462	0.8856
9	0.58176116	0.03496188	0.0416	0.9272
10	0.54679928	0.24180632	0.0391	0.9662
11	0.30499296	0.19464536	0.0218	0.9880
12	0.11034760	0.05739645	0.0079	0.9959
13	0.05295115	0.04845077	0.0038	0.9997
14	0.00450038		0.0003	1.0000

Eigenvectors

	Prin1	Prin2	Prin3	Prin4	Prin5	Prin6	Prin7
dif_b01_20	0.016351	0.005726	0.327341	0.246230	0.791983	-.447473	-.005828
dif_b02_20	0.110456	0.167901	-.056973	-.409625	0.482249	0.633930	0.035932
dif_b03_20	-.139849	0.511012	-.031959	-.069744	0.094636	0.111598	-.010015
dif_b05_20	0.274318	-.378539	0.040073	0.067316	-.022289	0.078785	0.206863
dif_b06_20	-.131212	0.417795	-.005482	0.222087	-.154384	-.103345	0.398826
dif_b07_20	0.279584	-.466309	0.045333	-.064911	0.027120	0.078559	-.063687
dif_b08_20	0.010272	0.041442	0.069025	0.756032	0.007619	0.486370	-.414595
dif_b09_20	0.017650	0.037218	0.781217	-.123415	-.217266	0.119897	0.156178
dif_b10_20	0.274994	0.027776	0.072733	0.298528	0.001223	0.196954	0.649444
dif_b11_20	-.260419	-.024968	0.493957	-.157617	-.056030	0.139820	-.182426
dif_b12_20	0.446720	0.198797	0.044658	-.040469	-.035291	-.059982	-.076210
dif_b13_20	0.423094	0.226891	-.003434	-.064012	0.000406	-.056988	-.123367
dif_b15_20	-.271128	-.209861	-.133726	0.012011	0.232971	0.209804	0.335640
dif_b16_20	0.448783	0.189250	0.025555	-.044611	-.015866	-.047475	-.087437

Pearson Correlation Coefficients, N = 3017

	Prin1	Prin2	Prin3	Prin4	Prin5
dif_sui_20	0.12032	-0.60172	-0.02545	-0.01306	0.08203

Table 6. Summary chart of Principal Component and Correlation Analyses for 2050

Principal Compnent and Correlation Analyses 2050

	Eigenvalue	Difference	Proportion	Cumulative
1	6.30320816	4.37893533	0.4502	0.4502
2	1.92427283	0.64201828	0.1374	0.5877
3	1.28225455	0.31396972	0.0916	0.6793
4	0.96828483	0.16212152	0.0692	0.7484
5	0.80616331	0.15563555	0.0576	0.8060
6	0.65052776	0.08175864	0.0465	0.8525
7	0.56876912	0.07307628	0.0406	0.8931
8	0.49569284	0.08874744	0.0354	0.9285
9	0.40694540	0.18708947	0.0291	0.9576
10	0.21985594	0.04992208	0.0157	0.9733
11	0.16993385	0.06694615	0.0121	0.9854
12	0.10298771	0.02692486	0.0074	0.9928
13	0.07606285	0.05102197	0.0054	0.9982
14	0.02504088		0.0018	1.0000

Eigenvectors

	Prin1	Prin2	Prin3	Prin4	Prin5	Prin6	Prin7
dif_b01_50	0.042700	-.451170	0.336055	-.135272	0.494608	0.296173	0.511671
dif_b02_50	0.183879	0.070518	0.181660	0.733698	-.025130	-.352062	0.432119
dif_b03_50	-.357520	0.075032	0.115034	0.184800	-.050161	-.128730	0.105128
dif_b05_50	0.372435	-.131359	0.029806	-.008474	0.081796	-.013586	-.182799
dif_b06_50	-.299383	-.112675	0.309986	0.145058	0.074533	-.232546	-.318052
dif_b07_50	0.384299	-.060111	-.064507	-.056503	0.042745	0.046702	-.052560
dif_b08_50	0.079916	-.235417	0.463726	-.221860	-.795947	0.023423	0.137560
dif_b09_50	-.225283	-.059959	0.354959	0.378912	0.066138	0.537296	-.438312
dif_b10_50	0.338927	-.174128	0.139241	0.138027	0.027043	-.103263	-.295686
dif_b11_50	-.325731	-.101311	0.057268	-.124447	-.015551	0.075249	0.212332
dif_b12_50	0.234832	0.373057	0.063904	0.127017	-.113194	0.443619	0.136723
dif_b13_50	-.013416	0.400169	0.515444	-.370740	0.276504	-.377191	-.063213
dif_b15_50	0.339296	-.126786	0.242733	-.021435	0.097033	-.100023	-.162514
dif_b16_50	0.109368	0.580772	0.217490	-.059624	0.024109	0.246339	0.102098

Pearson Correlation Coefficients, N = 3017

	Prin1	Prin2	Prin3	Prin4	Prin5
dif_sui_50	-0.28585	-0.37207	0.08749	-0.32232	0.12549

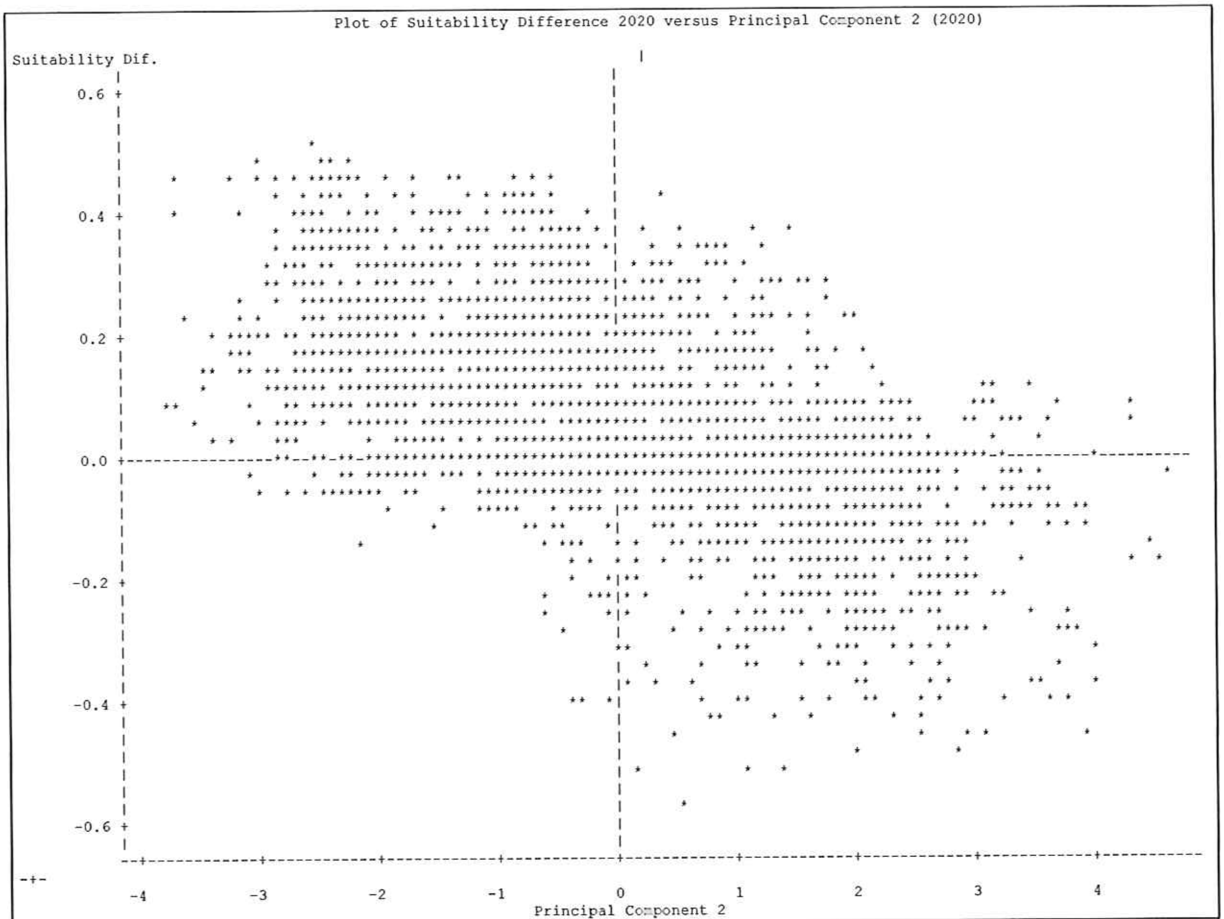

Figure 44: Graph of Principal Component and Correlation Analyses for Principal Component 2 versus Suitability Change by 2020.

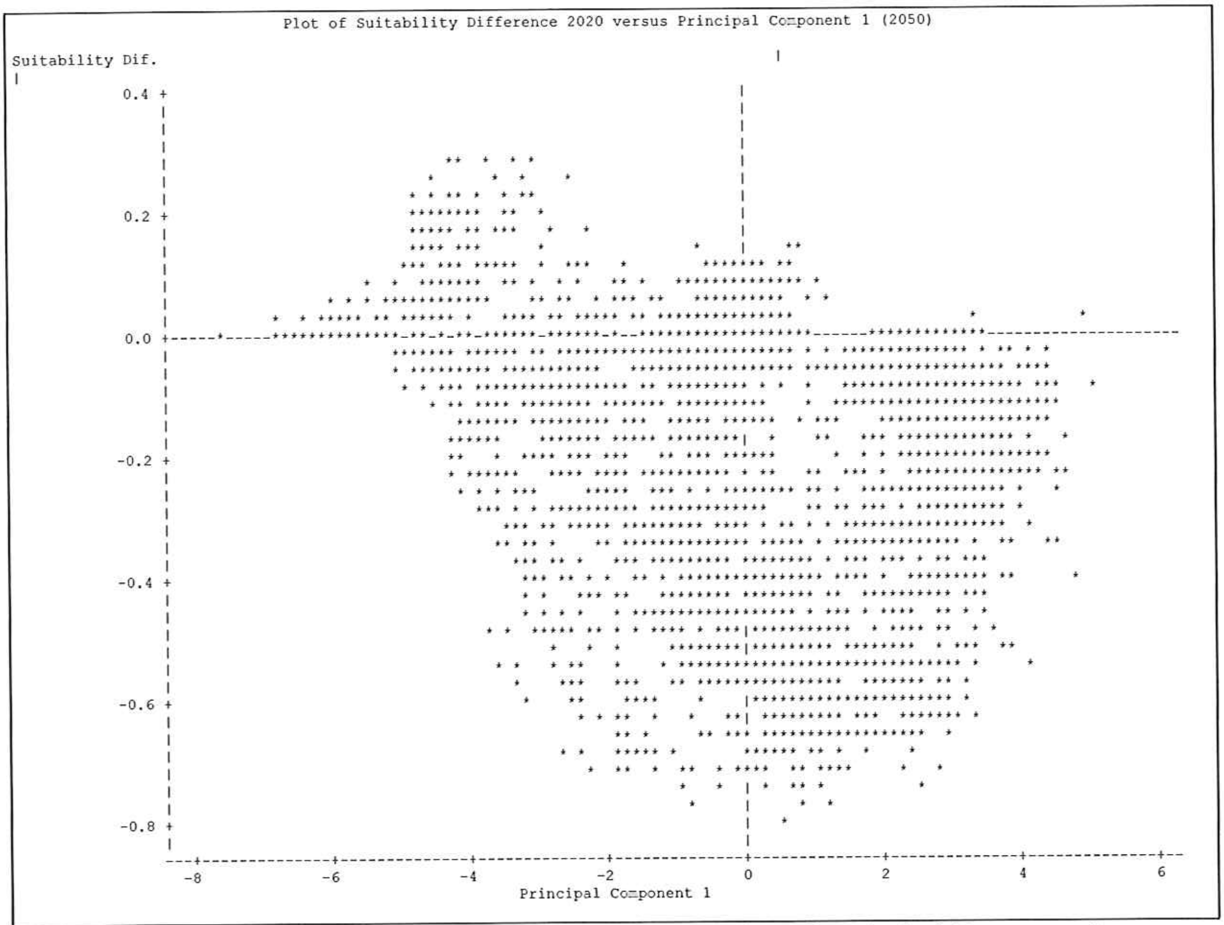

Figure 45: Graph of Principal Component and Correlation Analyses for Principal Component 1 versus Suitability Change by 2050.

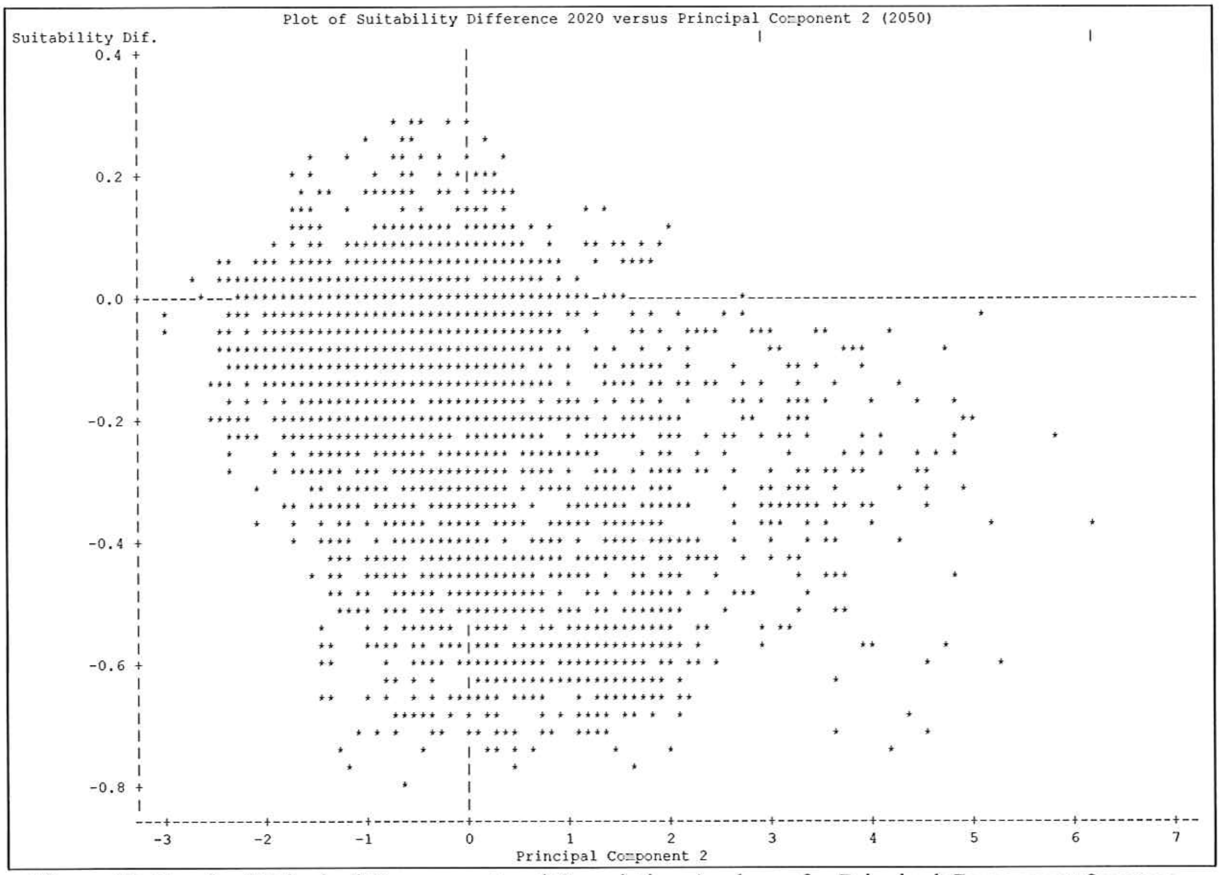

Figure 46: Graph of Principal Component and Correlation Analyses for Principal Component 2 versus Suitability Change by 2050.