Output 3.3: Enhancing tree seed and seedling supply to provide diverse and climate adapted species and varieties within the framework of TREPA 2022-2027

Climate trend analysis

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1. Project area

The project area consists of seven districts in the eastern province of Rwanda (figures 1.1 - 1.3).

Figure 1.1. Focal districts for the project have been labelled in this map. Administrative boundaries from the GADM database (www.gadm.org; version 3.6; downloaded 2-DEC-18). Boundary of Akagera National Park (green) obtained from World Database on Protected Areas (https://www.protectedplanet.net/862; version 1.4; downloaded 2-DEC-18) Map prepared in QGIS with OpenLayers plugin.

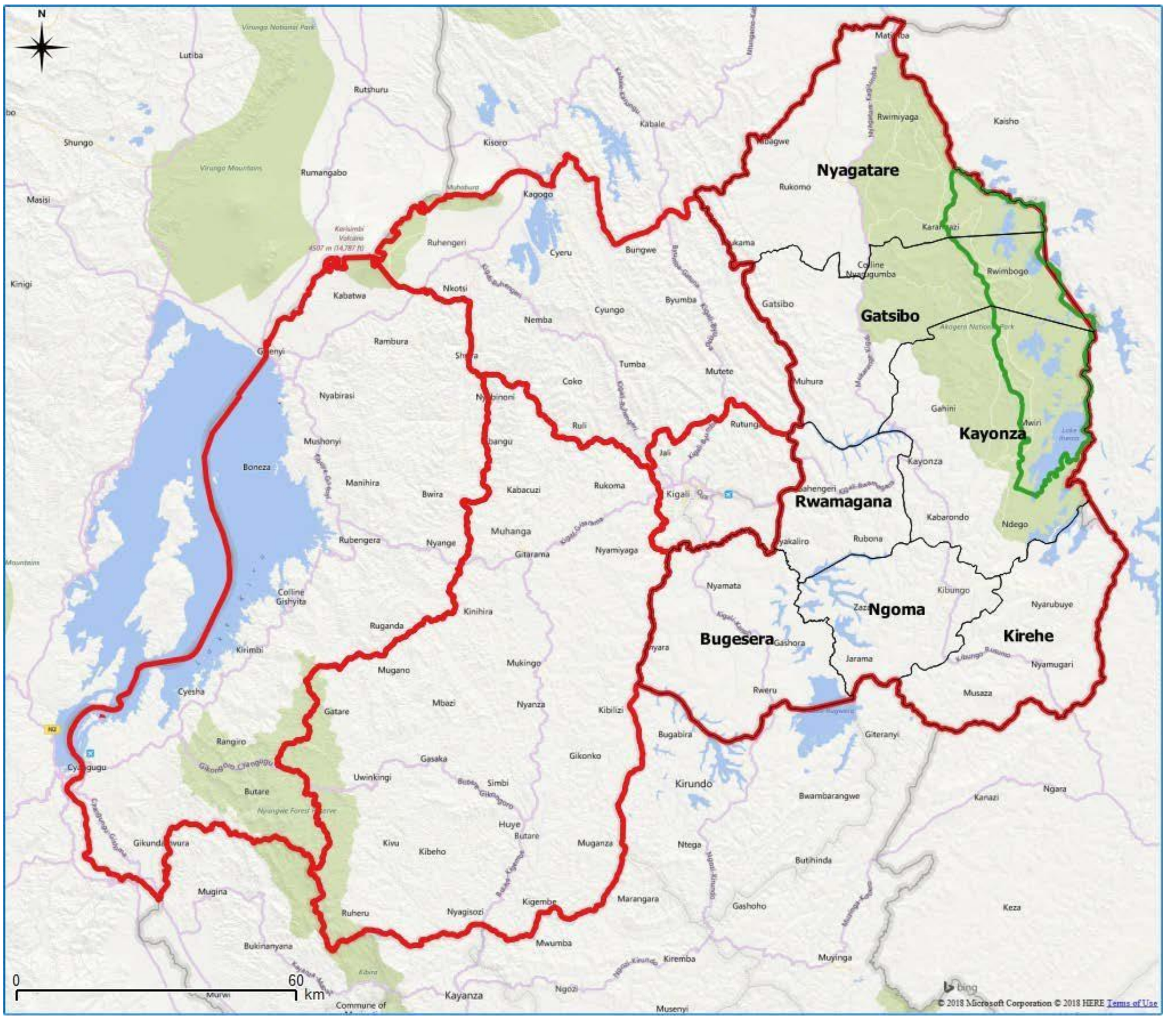


Figure 1.2. Focal districts for the project have been labelled in this map. Administrative boundaries from the GADM database (www.gadm.org; version 3.6; downloaded 2-DEC-18). Map prepared in QGIS with OpenLayers plugin, using the OSM map background instead of Bing as in Figure 1.1.

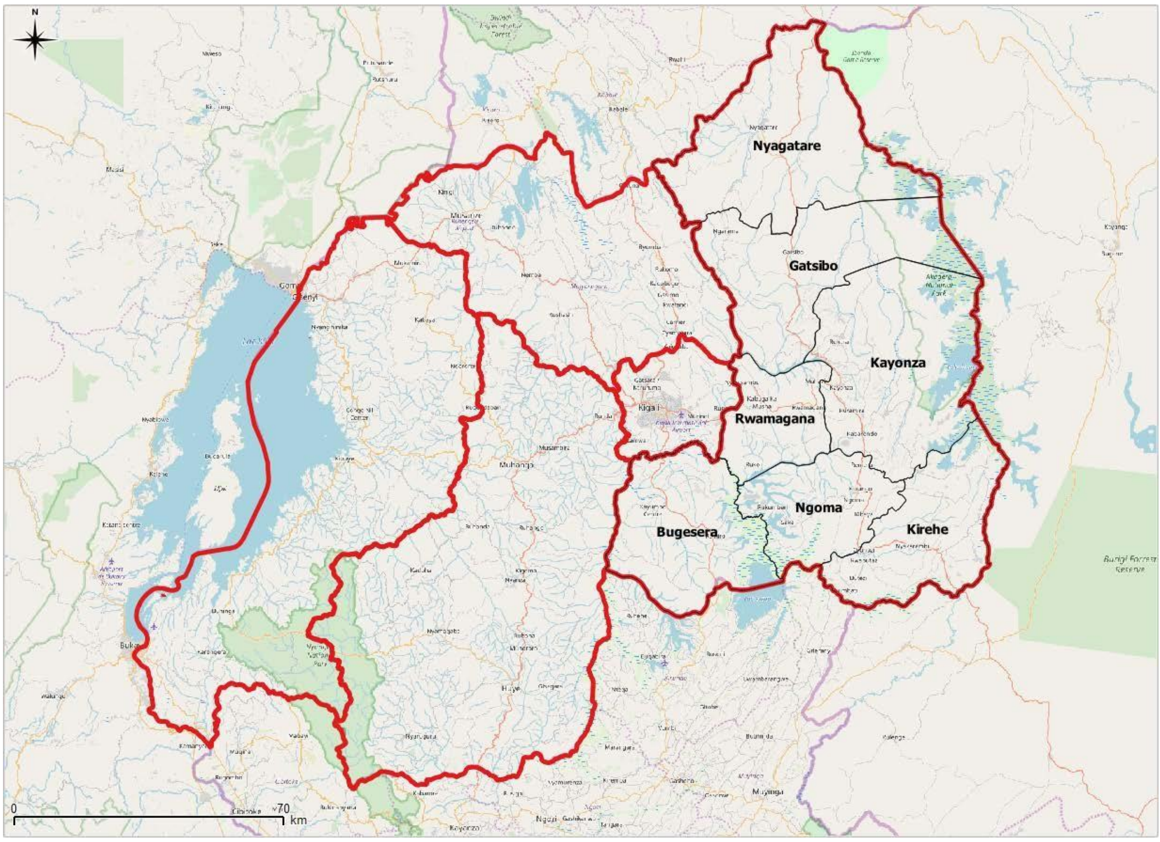
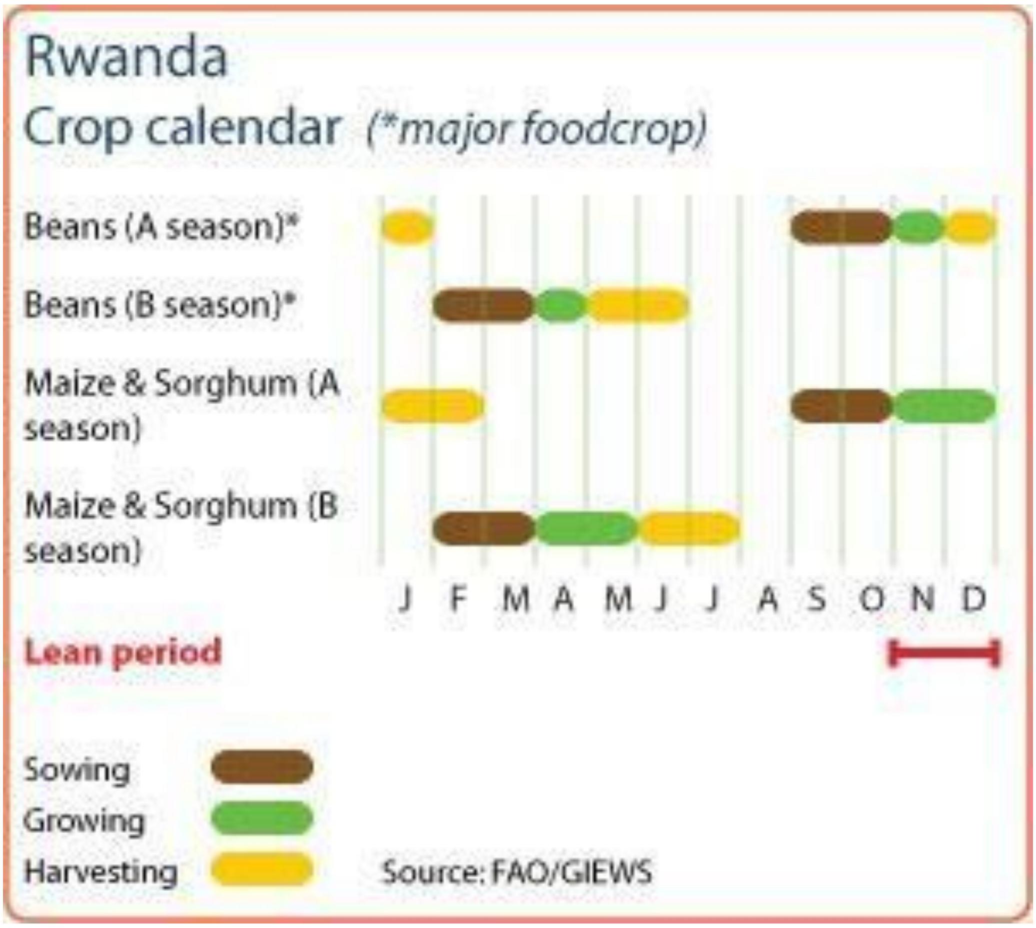


Figure 1.3. Focal districts for the project have been labelled in this map. Administrative boundaries from the GADM database (www.gadm.org; version 3.6; downloaded 2-DEC-18). Map prepared in QGIS with OpenLayers plugin, using the ESRI National Geographic map background instead of Bing as in Figure 1.1. Point locations are centroids used for subsequent analyses.

Figure 1.4. Crop calendar for Rwanda.



Source: http://www.fao.org/giews/countrybrief/country.jsp?lang=en&code=RWA

Rwanda has two main cropping seasons (Figure 1.4). These seasons correspond to the long rains (MAM) and short rain (SOND) precipitation patterns of Rwanda and East Africa that are associated with the latitudinal migration of the Inter-Tropical Convergence Zone (Ngarukiyimana *et al.* 2018).

2. Climate changes throughout the year

Analysis with the moisture index confirms the sowing and growing periods identified from the cropping calendar (Figure 2.1).

Using the likelihood scale recommended by the IPCC with 33% and 66% thresholds confirms previous analyses with data from WorldClim 1.4, as shown in Figure 1 and Table 2 of the current version of the TREPA funding proposal:

- The moisture index is likely to decrease in the months of April and May, months with growing ‘B’ seasons for maize, sorghum and beans.
- The moisture index is likely to decrease in the month of October, a month for sowing maize, sorghum and beans in the ‘A’ season.
- The moisture index is likely to increase in the months of January and December, months respectively in the growing and harvesting seasons for maize, sorghum and beans.

The same summary applies to tables 2.1 and 2.3 that show ranges in projected values for the driest district (identified as the district with the lowest annual moisture index for its centroid location) and the wettest district.

There is complete consensus among climate models about future increases in temperatures, with ranges given in tables 2.2 and 2.4.

Figure 2.1. Monthly range in moisture index for Baseline (1970-2000) and future range in values (2041 – 2060 for [Shared Socio-economic Pathway](#) SSP3-7.0). The red polygon shows Eastern Province. The colour scheme for the baseline climate corresponds to moisture index values, with orange values indicating dry periods. The colour scheme for future climates show increases (blue), decreases (red) or no change (grey, showing a 5 percent range across zero).

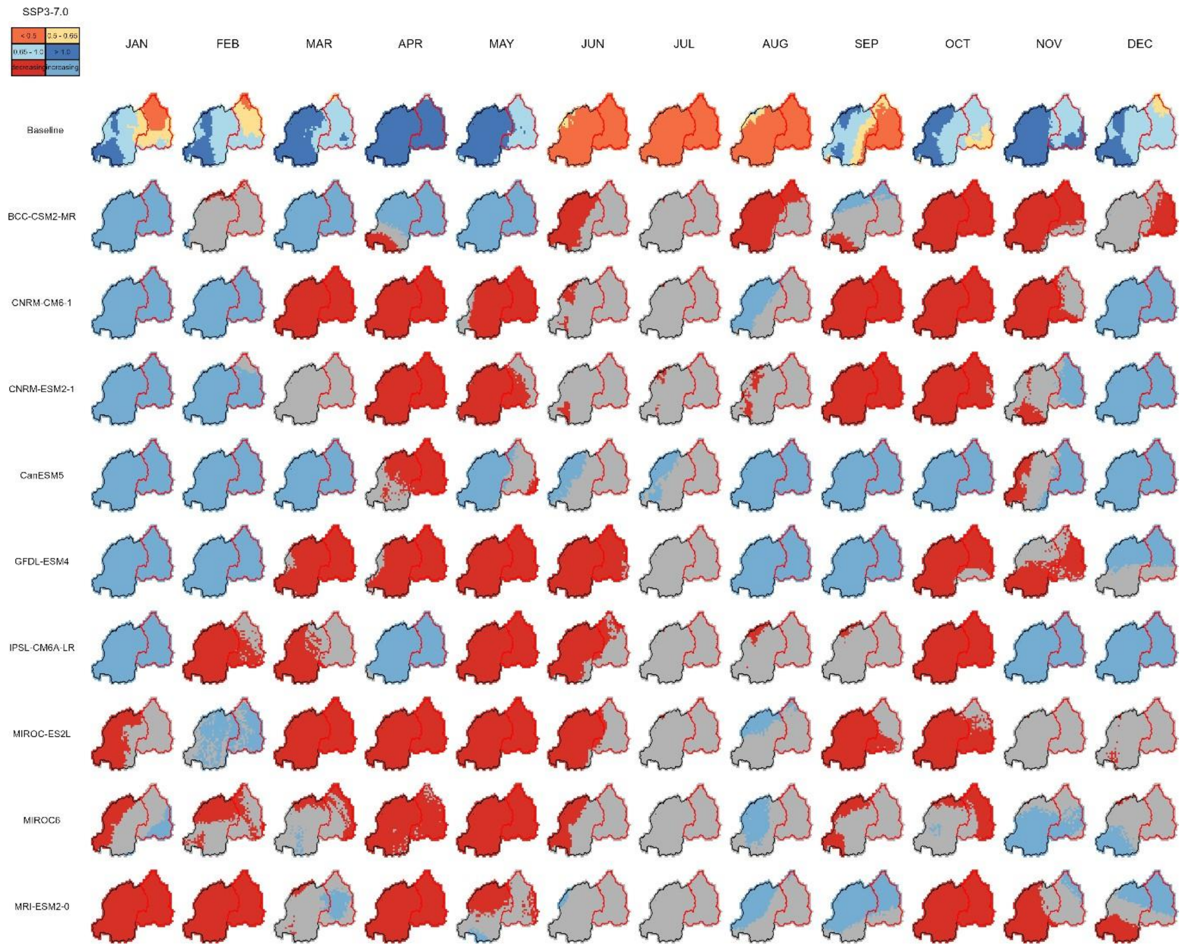


Table 2.1. Baseline (1970-2000) and future range in values (2021 – 2040 for Shared Socio-economic Pathway SSP3-7.0) for the moisture index (MI) for Nyagatare, the district with lowest annual MI. The colour scheme was inspired by the likelihood scale recommended for the fifth assessment report of the IPCC (Mastrandea *et al.* 2011).

Month	Baseline	Minimum	33%	Median	66%	Maximum
January	61.9	55.9	66.6	74.5	77.4	89.9
February	66.9	59.6	65.3	69.5	73.2	92.2
March	92.2	80.3	89.4	90.7	93.9	117.7
April	135.1	112.9	122.1	128	130.9	146.2
May	93.1	74.8	86.2	87.3	90.2	103.3
June	12.6	9.6	11.3	11.9	12.0	12.4
July	4.8	4.4	4.5	4.6	4.6	5.2
August	14.8	13.0	14.4	14.8	15.7	22.0
September	37.1	32.6	35.4	36.8	38.4	80.1
October	64.0	56.0	58.8	59.7	61.2	106.1
November	102.7	99.8	101.5	102.3	105.8	111.9
December	73.2	69.5	73.7	74.9	79.0	97.9

Table 2.2. Baseline (1970-2000) and future range in values (2021 – 2040 for Shared Socio-economic Pathway SSP3-7.0) for the maximum temperature for Nyagatare, the district with lowest annual MI. The colour scheme was inspired by the likelihood scale recommended for the fifth assessment report of the IPCC (Mastrandea *et al.* 2011).

Month	Baseline	Minimum	33%	Median	66%	Maximum
January	26.6	27.8	28.0	28.1	28.3	28.7
February	26.6	27.9	28.2	28.5	28.6	29.3
March	26.3	27.2	28.1	28.1	28.4	29.1
April	25.5	27.0	27.3	27.4	27.7	28.6
May	25.8	27.3	27.8	27.9	27.9	28.5
June	26.6	28.2	28.8	28.9	29.0	29.6
July	27.3	28.8	29.4	29.5	29.5	30.4
August	27.6	28.5	29.7	29.9	29.9	30.4
September	27.4	28.4	29.2	29.4	29.6	30.2
October	26.4	27.6	28.0	28.5	28.6	28.8
November	25.5	26.8	27.1	27.2	27.4	27.9
December	26.0	27.5	27.5	27.6	27.7	28.2

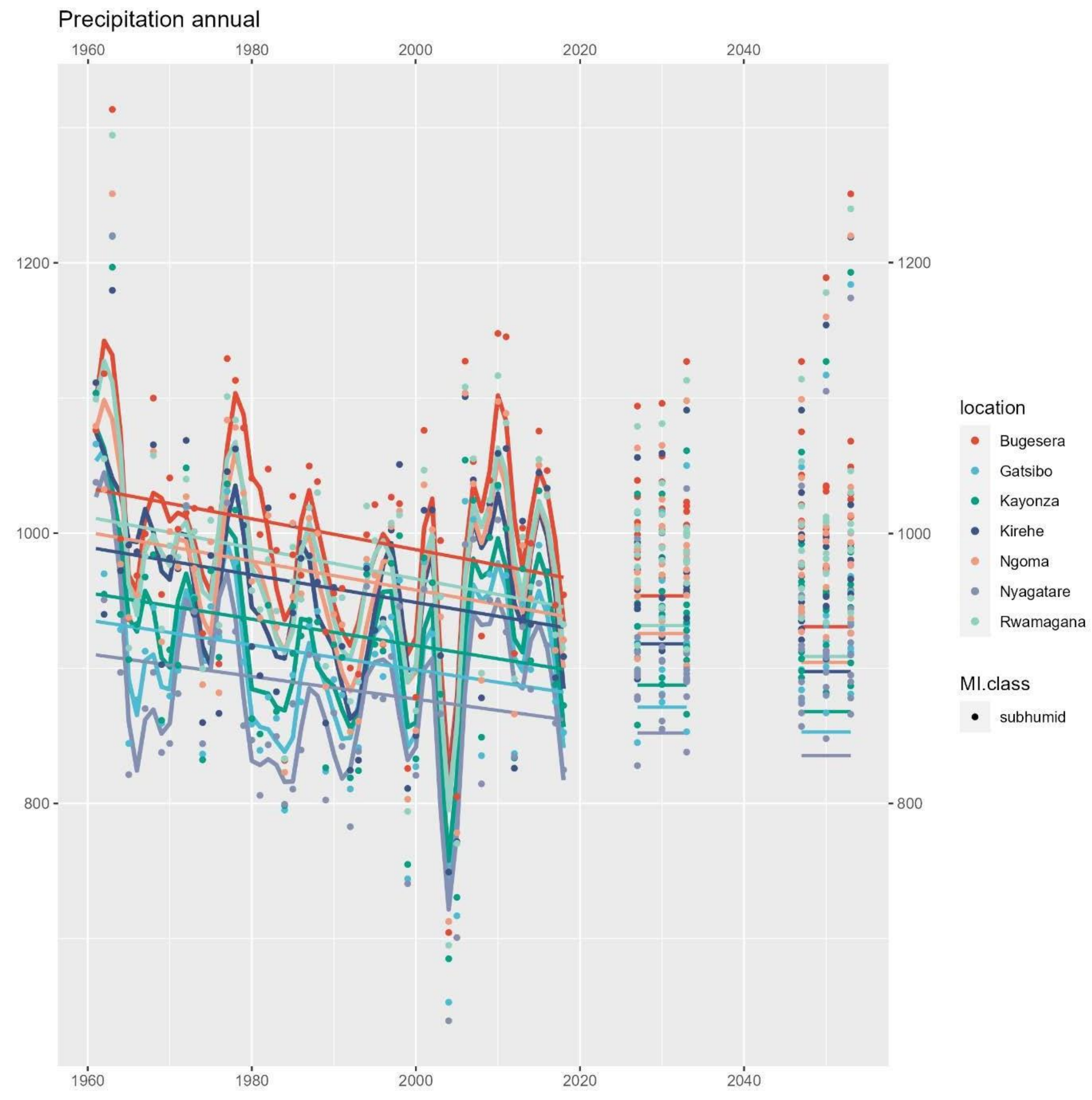
Table 2.3. Baseline (1970-2000) and future range in values (2021 – 2040 for Shared Socio-economic Pathway SSP3-7.0) for the moisture index (MI) for Rwamagana, the district with highest annual MI. The colour scheme was inspired by the likelihood scale recommended for the fifth assessment report of the IPCC (Mastrandea *et al.* 2011).

Month	Baseline	Minimum	33%	Median	66%	Maximum
January	51.3	45.7	54.9	62.2	64.0	74.7
February	65.3	57.1	63.5	67.5	70.8	88.2
March	92.8	81.5	89.5	91.2	94.2	120.3
April	143.2	120.6	129.3	133.6	138.5	155.3
May	98.5	79.6	91.5	92.1	95.1	110.6
June	13.6	9.7	12.3	12.9	13.0	13.4
July	6.4	5.9	6.1	6.1	6.3	6.9
August	17.2	15.3	16.7	17.9	18.5	26.8
September	40.3	35.2	38.4	40.4	41.3	89.4
October	67.8	59.5	62.5	63.3	64.6	112.0
November	96.2	92.8	94.5	95.5	99.5	106.3
December	73.0	70.2	75.0	76.5	79.6	98.3

Table 2.4. Baseline (1970-2000) and future range in values (2021 – 2040 for Shared Socio-economic Pathway SSP3-7.0) for the maximum temperature for Rwamagana, the district with highest annual MI. The colour scheme was inspired by the likelihood scale recommended for the fifth assessment report of the IPCC (Mastrandea *et al.* 2011).

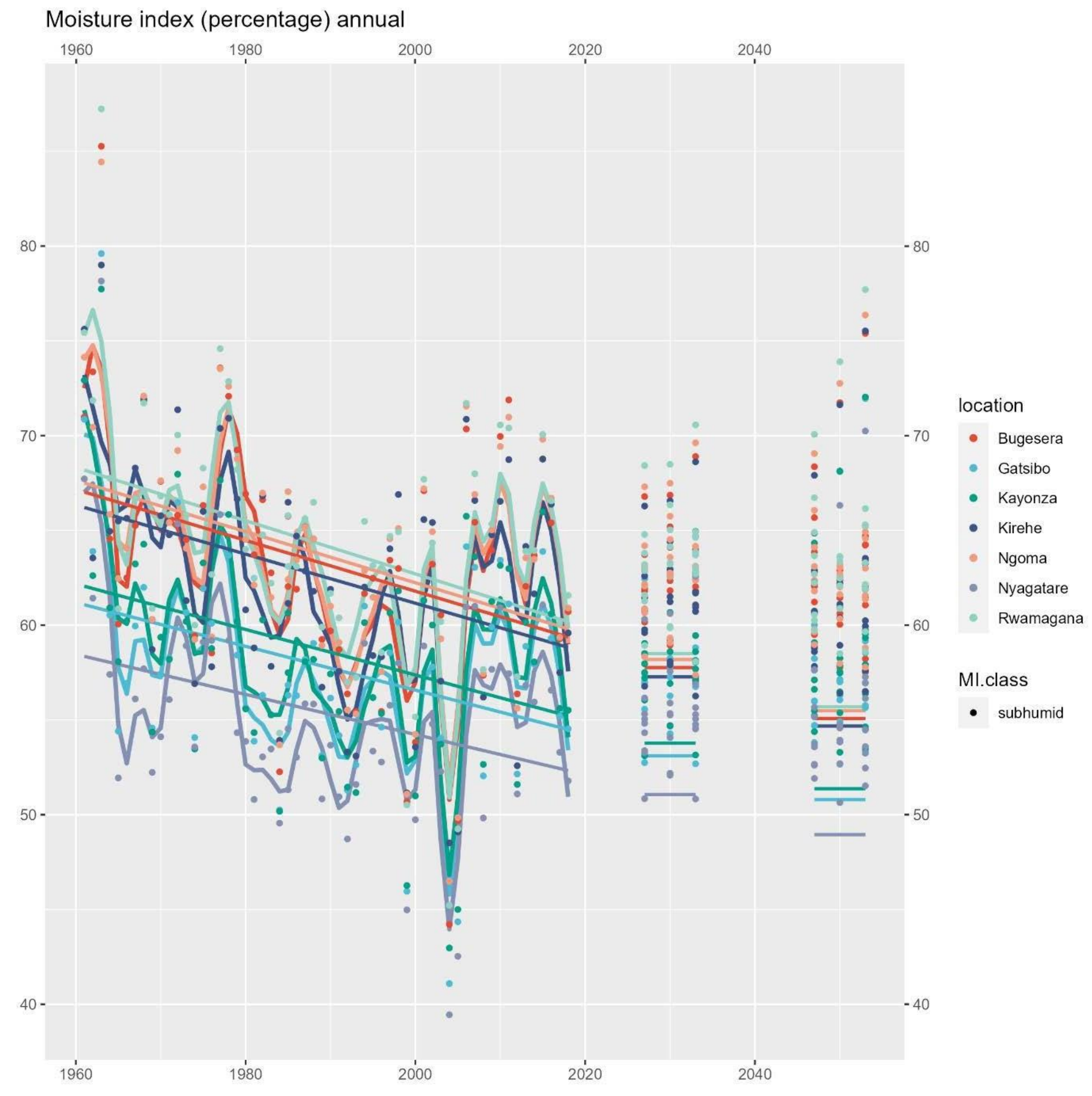
Month	Baseline	Minimum	33%	Median	66%	Maximum
January	25.6	26.7	27.0	27.1	27.3	27.8
February	25.6	26.9	27.1	27.4	27.5	28.2
March	25.3	26.2	27.0	27.1	27.4	28.1
April	24.7	26.0	26.4	26.5	26.8	27.7
May	24.8	26.3	26.9	26.9	27.0	27.6
June	25.4	26.9	27.5	27.7	27.8	28.5
July	26.2	27.8	28.3	28.4	28.5	29.4
August	27.0	28.0	29.0	29.3	29.3	29.8
September	26.7	27.7	28.7	28.8	29.1	29.5
October	25.8	27.0	27.4	27.9	28.1	28.3
November	24.6	25.9	26.2	26.4	26.6	26.9
December	24.9	26.4	26.5	26.6	26.6	27.1

Figure 2.2. Historical trends (1961-2018) and future projections (2030s and 2050s) for annual rainfall. Note that future projections are all centred on 2030 and 2050, but that projections for SSP1-1.9 are plotted to the left, for SSP2-4.5 in the middle and for SSP3-7.0 to the right. Full lines show linear regression trends fitted to the historical data for each location.



Historically, annual precipitation and moisture indices have been decreasing for each of the districts according to a linear model (figures 2.2 and 2.3). However, there also have been strong fluctuations throughout the years. The projections for the future depict a significant variation among the different GCMs.

Figure 2.3. Historical trends (1961-2018) and future projections (2030s and 2050s) for annual moisture index. Note that future projections are all centred on 2030 and 2050, but that projections for SSP1-1.9 are plotted to the left, for SSP2-4.5 in the middle and for SSP3-7.0 to the right. Full lines show linear regression trends fitted to the historical data for each location.



3. Climate change analysis with focus on the month April

This section focuses on the month of April, a growing month for maize, sorghum and beans in the 'B' season. Historically, the maximum temperature has been increasing and the moisture index has been decreasing in this month (figures 3.1, 3.2, 3.3 and 3.5).

Figure 3.1. Historical trends (1961-2018) and future projections (2030s and 2050s) for maximum temperature in April. Note that future projections are all centred on 2030 and 2050, but that projections for SSP1-1.9 are plotted to the left, for SSP2-4.5 in the middle and for SSP3-7.0 to the right. Full lines show linear regression trends fitted to the historical data for each location.

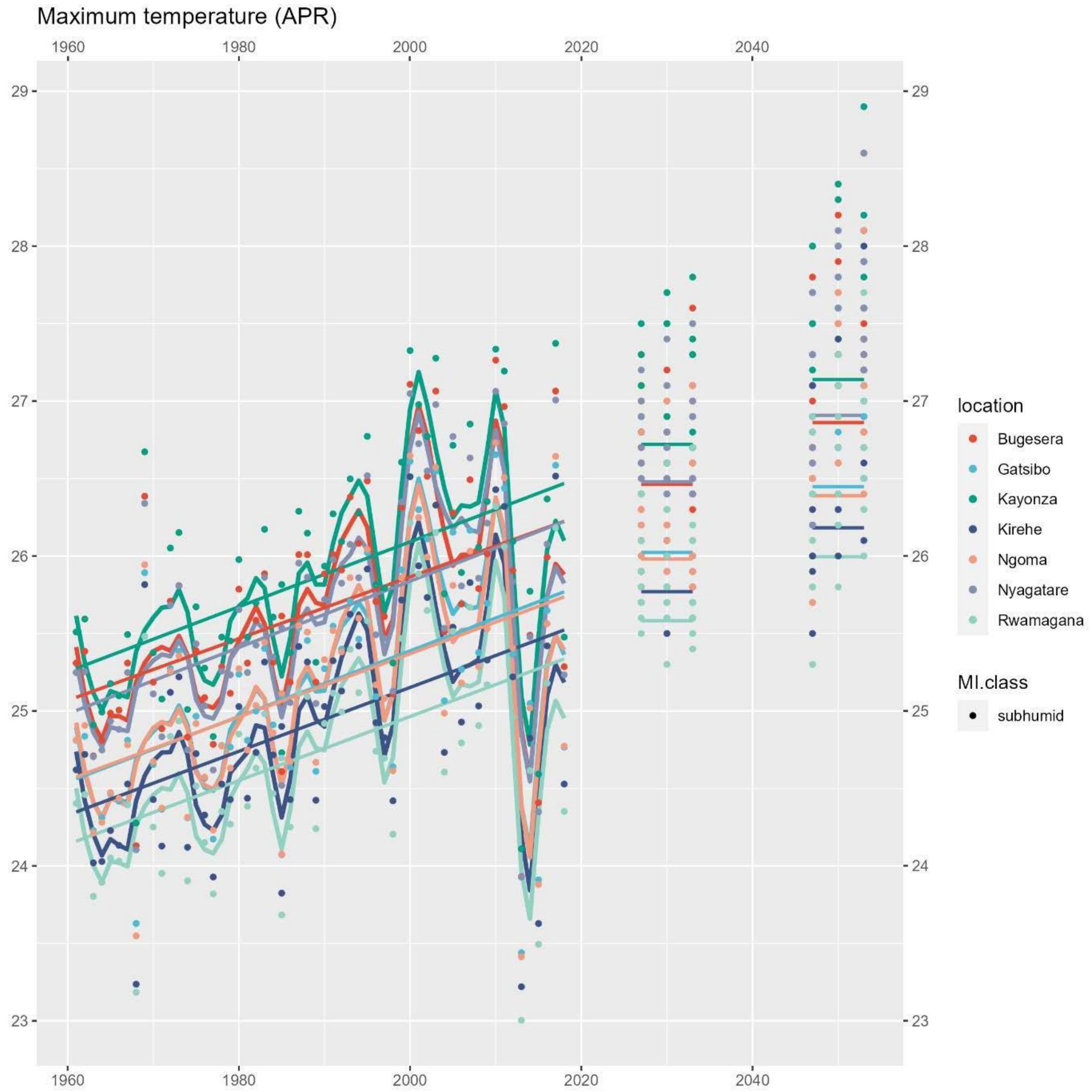


Figure 3.2. Historical trends (1961-2018) and future projections (2030s and 2050s) for the moisture index in April. Note that future projections are all centred on 2030 and 2050, but that projections for SSP1-1.9 are plotted to the left, for SSP2-4.5 in the middle and for SSP3-7.0 to the right. Full lines show linear regression trends fitted to the historical data for each location.

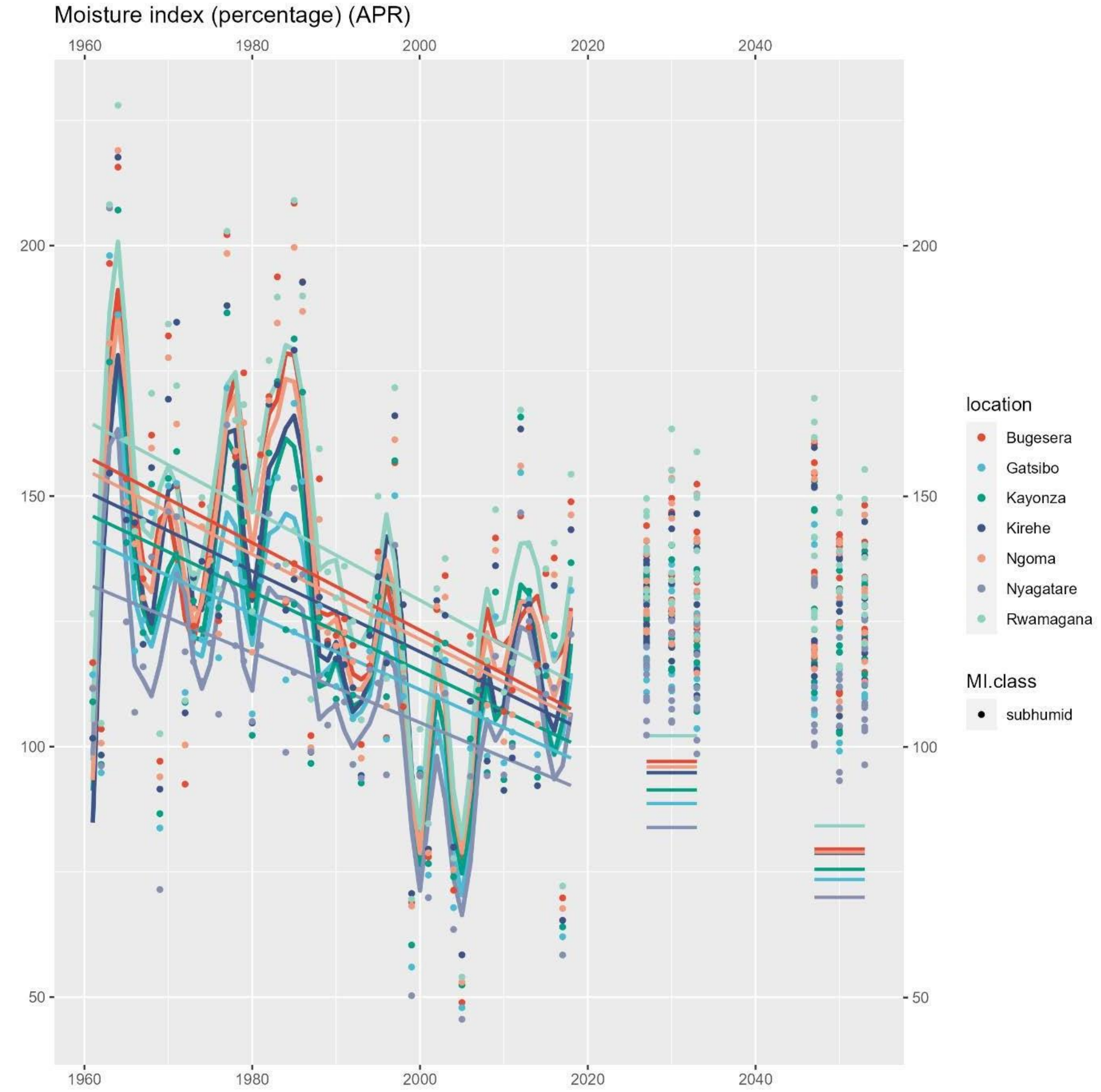


Figure 3.3. Historical trends (1961-2018) for the moisture index in April for the driest district in the baseline climate. Green, red and blue lines show fits and confidence intervals of local regression models with respectively 0.5, 0.3 and 0.15 spans. Black lines show fits and confidence intervals of a linear regression model. Years with observations outside the local regression model with the 0.5 span are labelled.

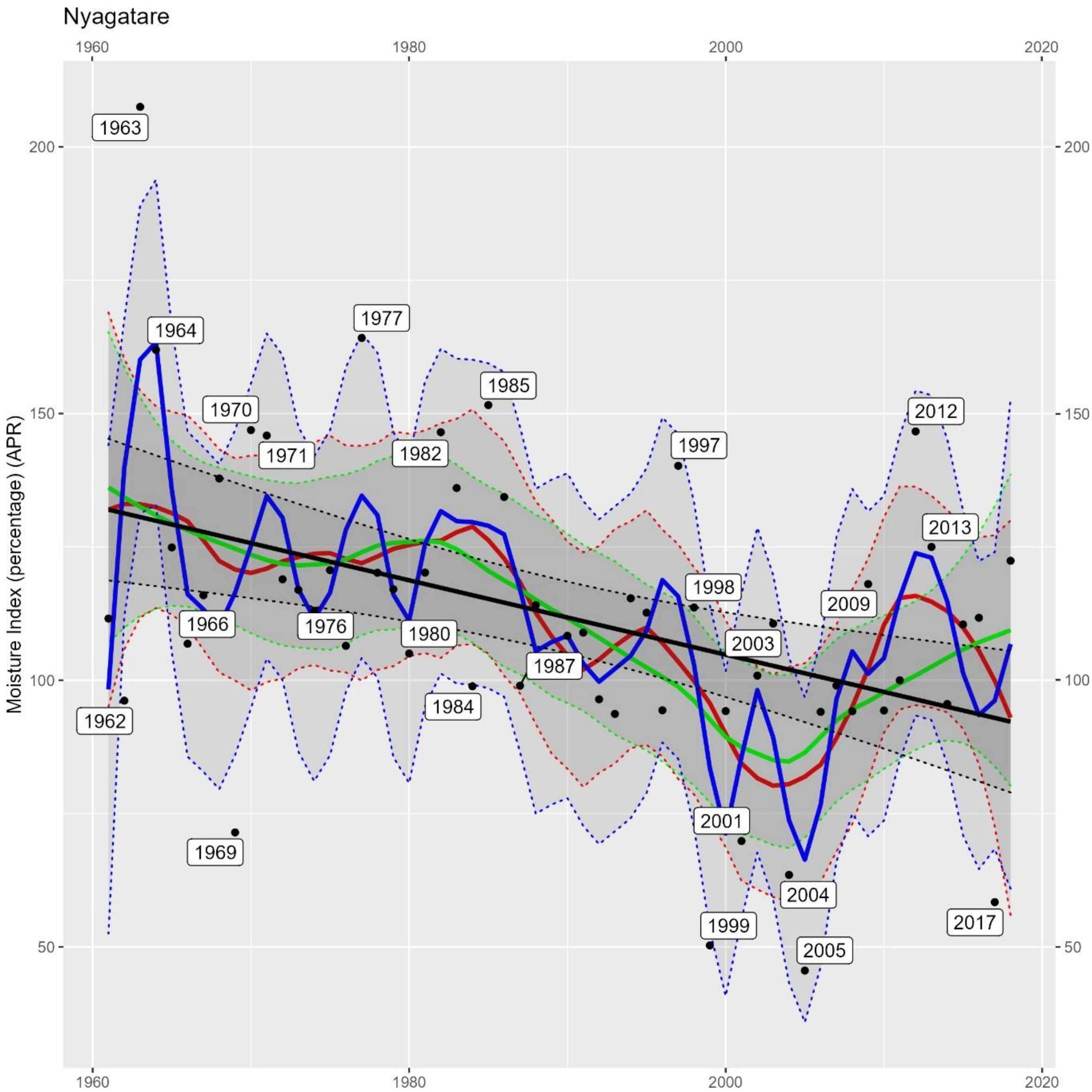
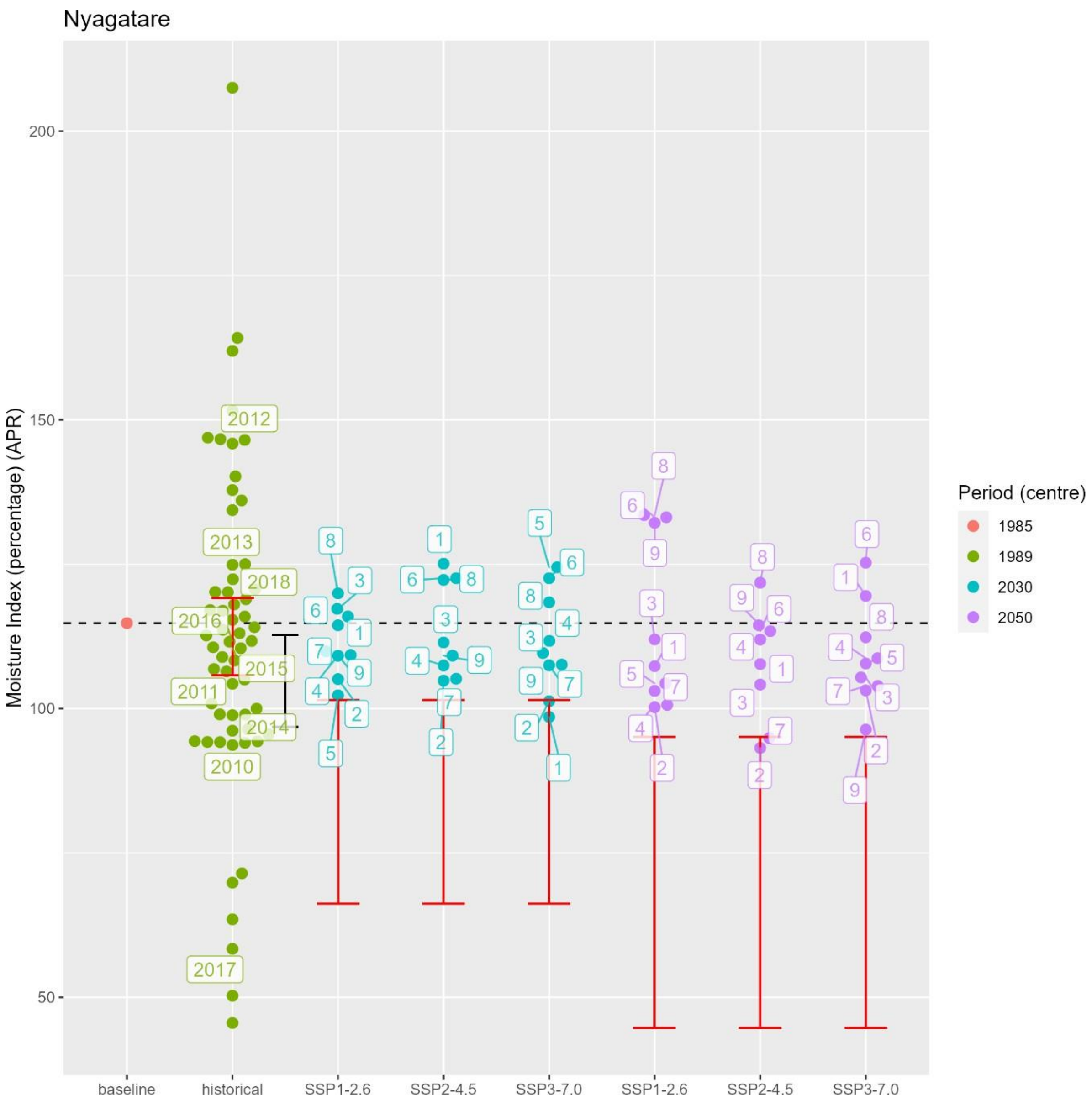


Figure 3.4. Historical range (1961-2018) and future projections (2030s and 2050s) for the moisture index in April for the driest district in the baseline climate. The red error bar shows the 95% confidence interval for a linear regression model fitted to the historical data. Labels of future projections corresponds to the alphabetical sorting of GCMs (1 = BCC-CSM2-MR ; 2 = CNRM-CM6-1 ; 3 = CNRM-ESM2-1 ; 4 = CanESM5 ; 5 = GFDL-ESM4 ; 6 = IPSL-CM6A-LR ; 7 = MIROC-ES2L ; 8 = MIROC6 ; 9 = MRI-ESM2-0). Years in the most recent historical decennium (2010-2018) are also labelled.



It is likely that the moisture index will decrease for the driest district, with all scenarios for the 2050s having six or more models showing a decrease in the moisture index (Figure 3.4).

Figure 3.5. Historical trends (1961-2018) for the moisture index in April for the wettest district in the baseline climate. Green, red and blue lines show fits and confidence intervals of local regression models with respectively 0.5, 0.3 and 0.15 spans. Black lines show fits and confidence intervals of a linear regression model. Years with observations outside the local regression model with the 0.5 span are labelled.

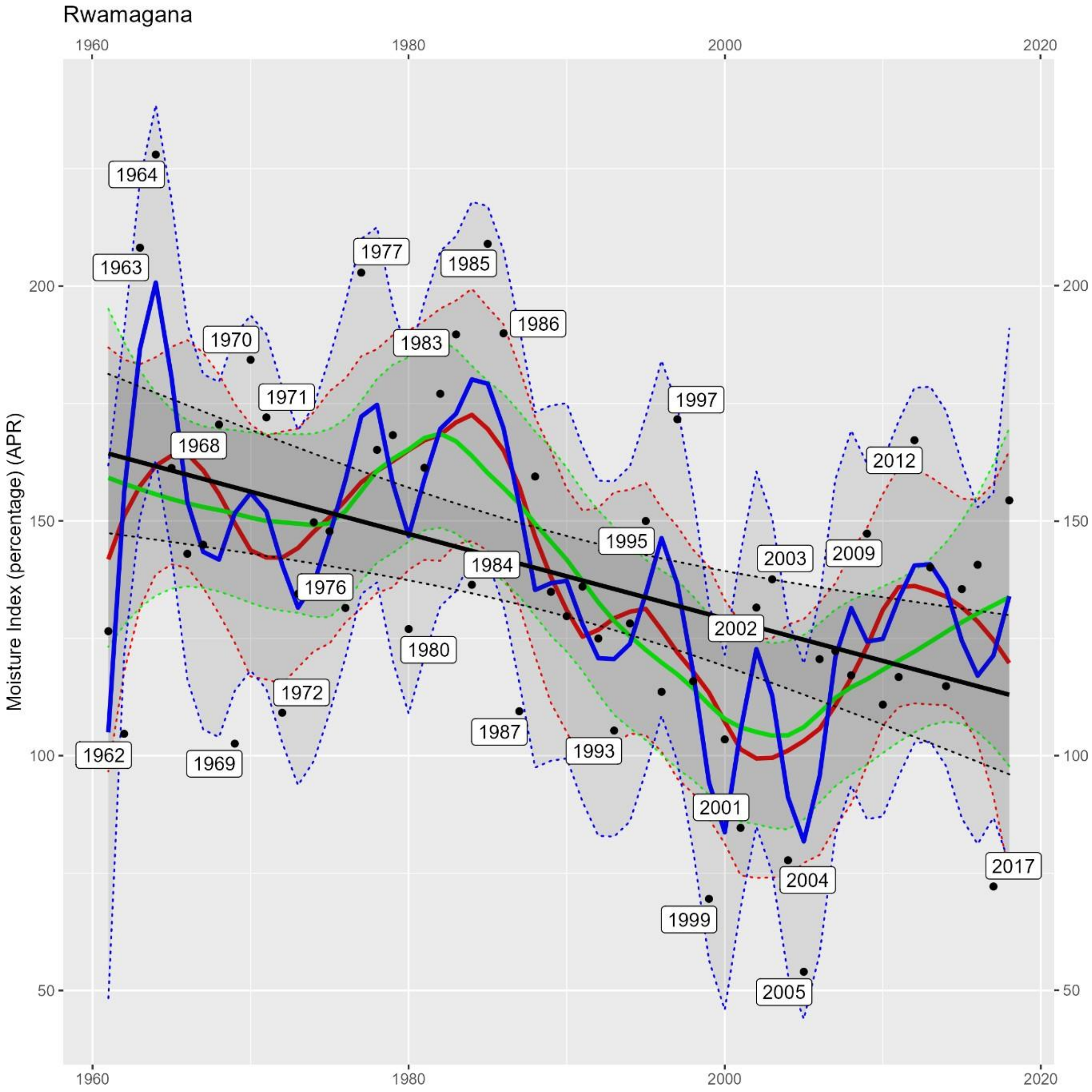
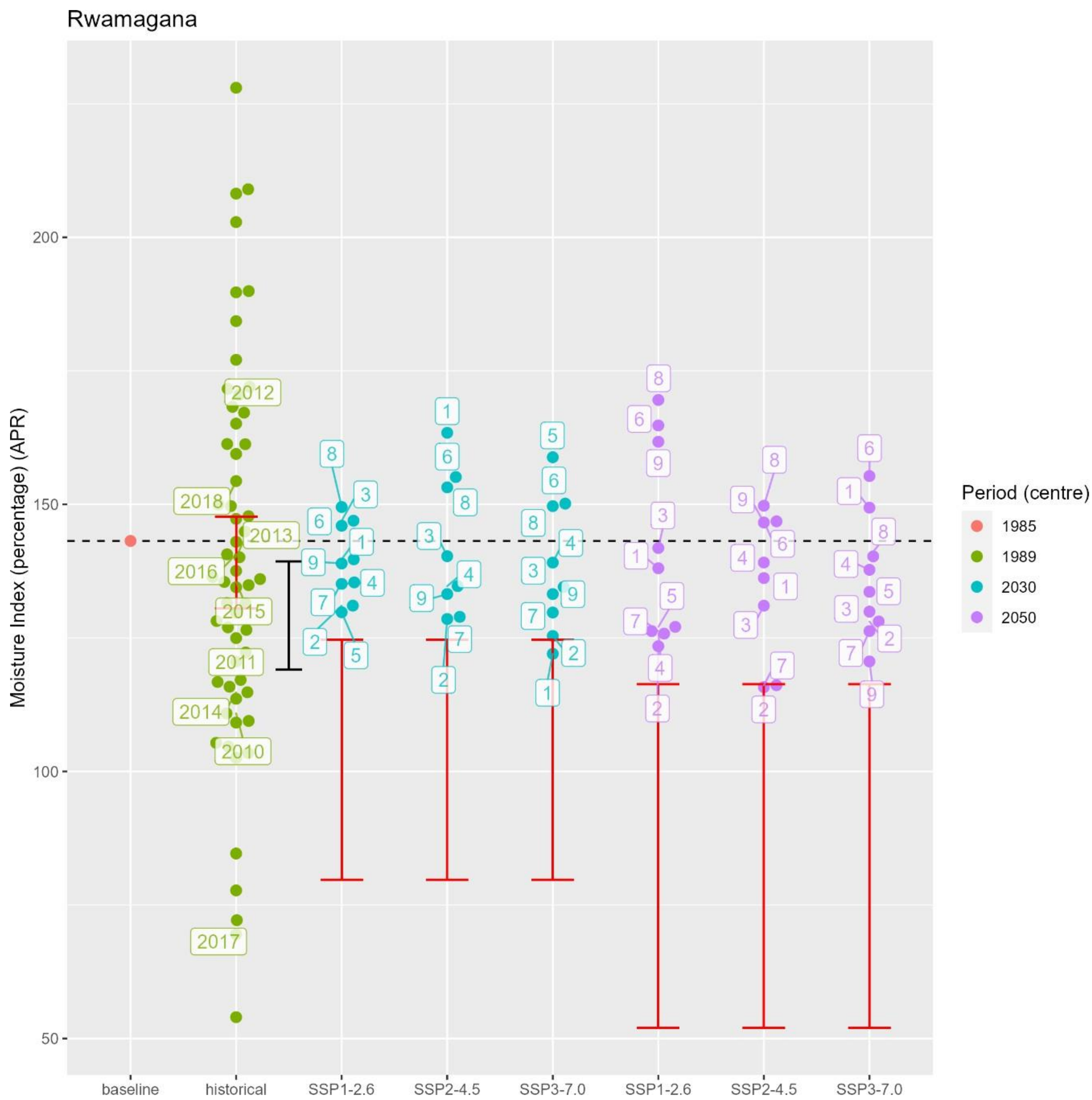


Figure 3.6. Historical range (1961-2018) and future projections (2030s and 2050s) for the moisture index in April for the wettest district in the baseline climate. The red error bar shows the 95% confidence interval for a linear regression model fitted to the historical data. Labels of future projections corresponds to the alphabetical sorting of GCMs (1 = BCC-CSM2-MR ; 2 = CNRM-CM6-1 ; 3 = CNRM-ESM2-1 ; 4 = CanESM5 ; 5 = GFDL-ESM4 ; 6 = IPSL-CM6A-LR ; 7 = MIROC-ES2L ; 8 = MIROC6 ; 9 = MRI-ESM2-0). Years in the most recent historical decennium (2010-2018) are also labelled.



Also for the wettest location, it is likely that the moisture index will decrease for the driest district for April, with the SSP1-2.6 and SSP3-7.0 scenarios for the 2050s having six or more models showing a decrease in the moisture index (Figure 3.6; scenario SSP2-4.5 with eight models had five models of decreased moisture index).

4. Climate change analysis with a focus on the month of May

This section focuses on the month of May, a growing month for maize and sorghum in the ‘B’ season. Historically, the maximum temperature has been increasing and the moisture index has been decreasing in this month (figures 4.1, 4.2, 4.3 and 4.5).

Figure 4.1. Historical trends (1961-2018) and future projections (2030s and 2050s) for maximum temperature in May. Note that future projections are all centred on 2030 and 2050, but that projections for SSP1-1.9 are plotted to the left, for SSP2-4.5 in the middle and for SSP3-7.0 to the right. Full lines show linear regression trends fitted to the historical data for each location.

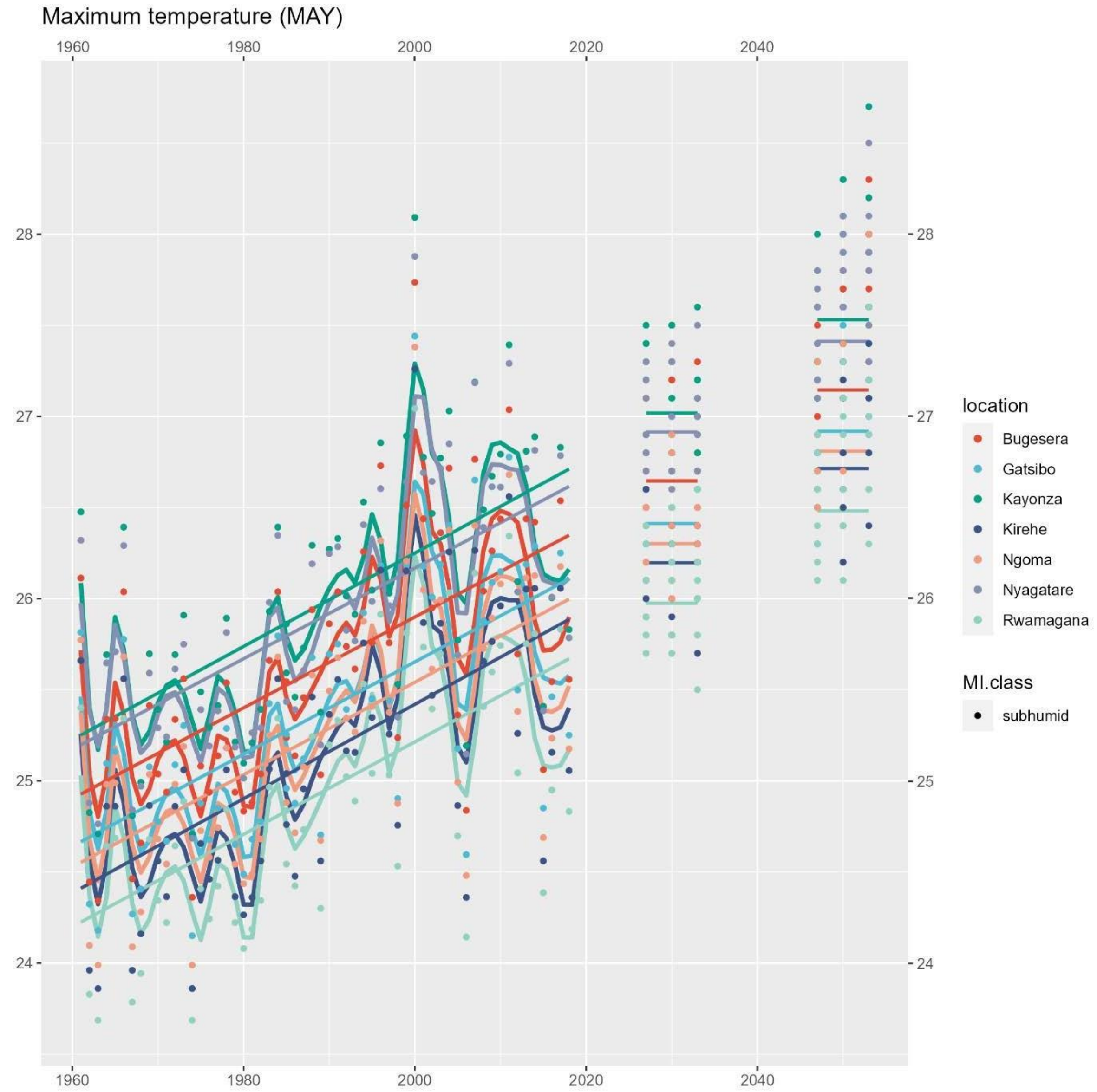


Figure 4.2. Historical trends (1961-2018) and future projections (2030s and 2050s) for the moisture index in May. Note that future projections are all centred on 2030 and 2050, but that projections for SSP1-1.9 are plotted to the left, for SSP2-4.5 in the middle and for SSP3-7.0 to the right. Full lines show linear regression trends fitted to the historical data for each location.

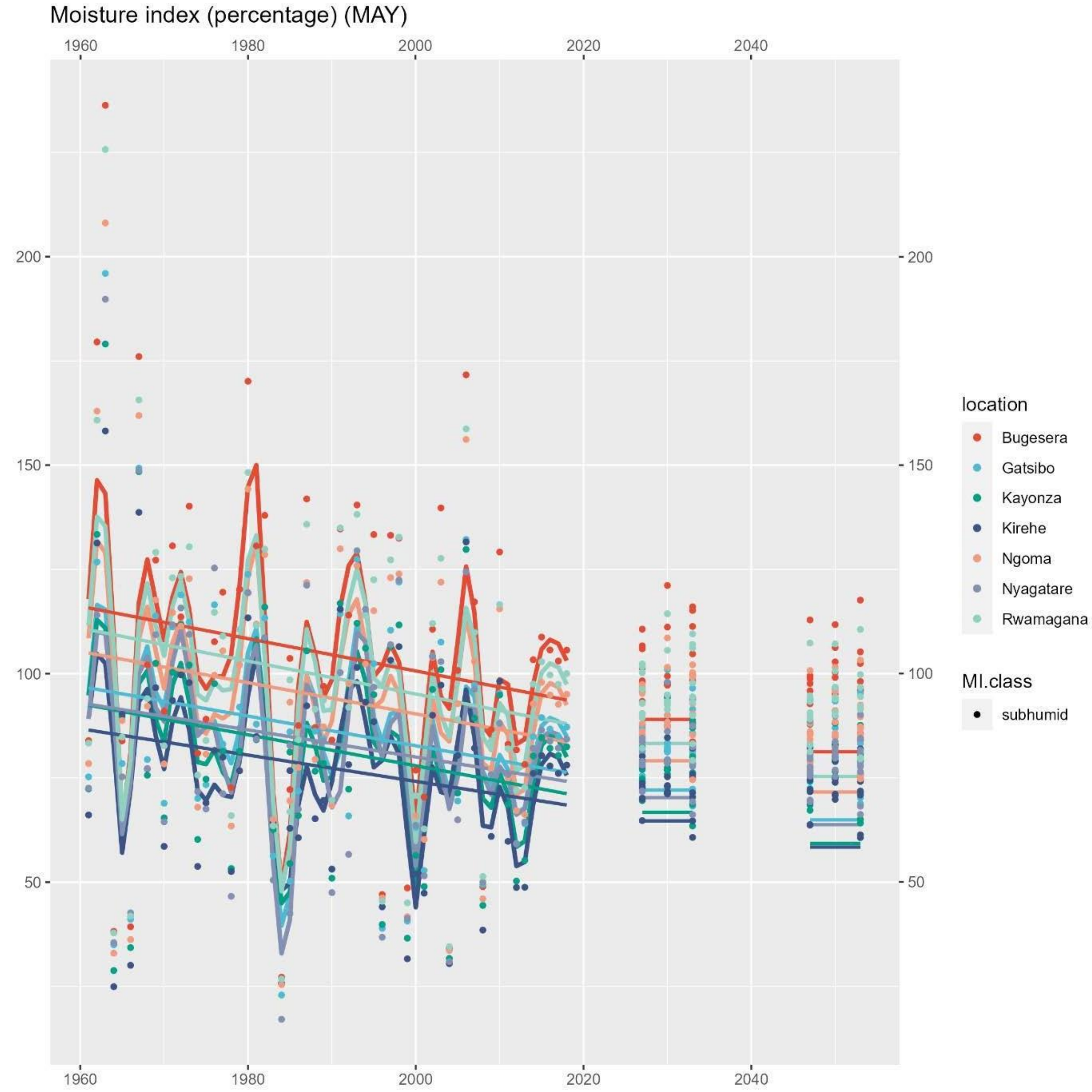


Figure 4.3. Historical trends (1961-2018) for the moisture index in May for the driest district in the baseline climate. Green, red and blue lines show fits and confidence intervals of local regression models with respectively 0.5, 0.3 and 0.15 spans. Black lines show fits and confidence intervals of a linear regression model. Years with observations outside the local regression model with the 0.5 span are labelled.

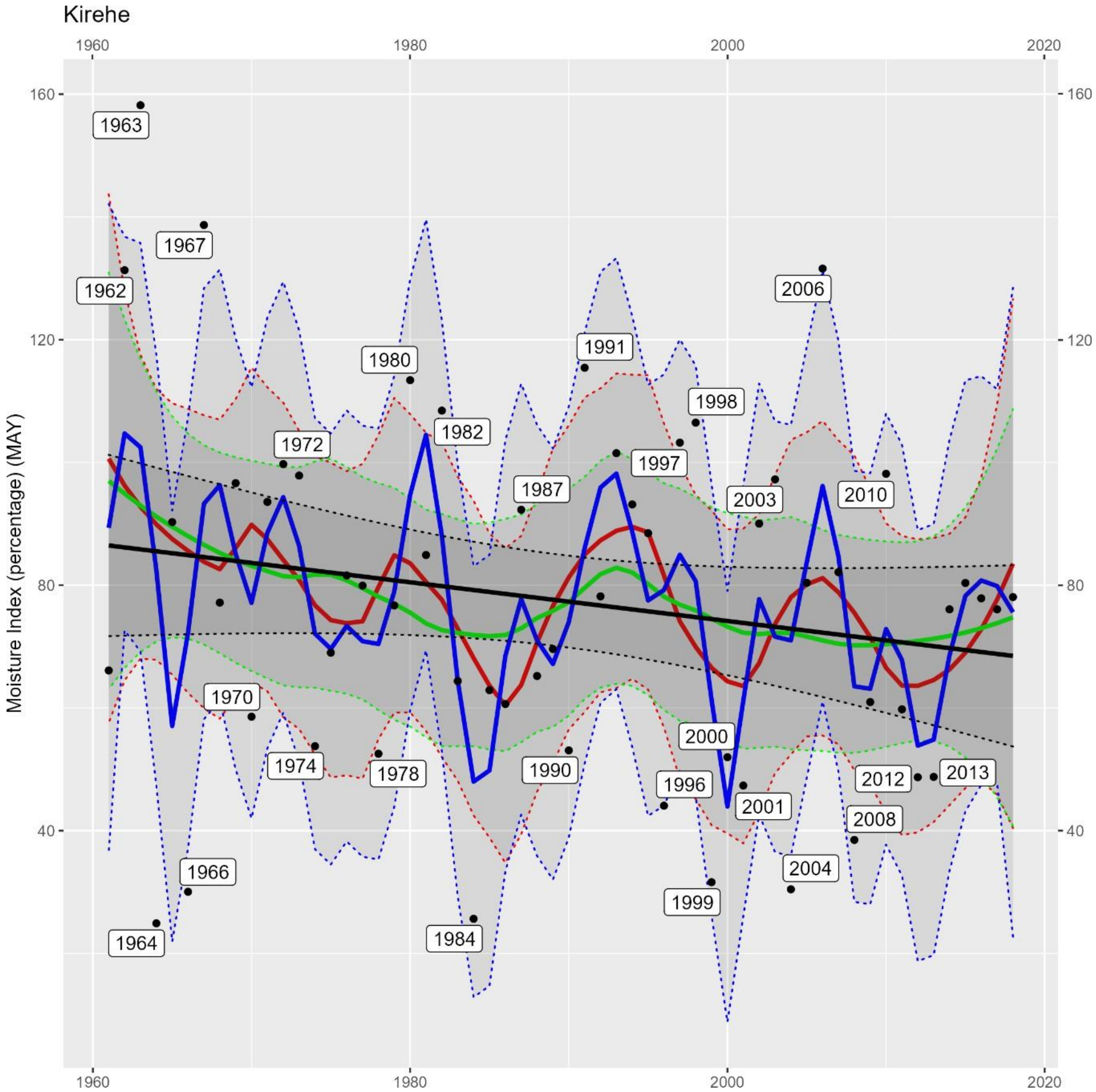
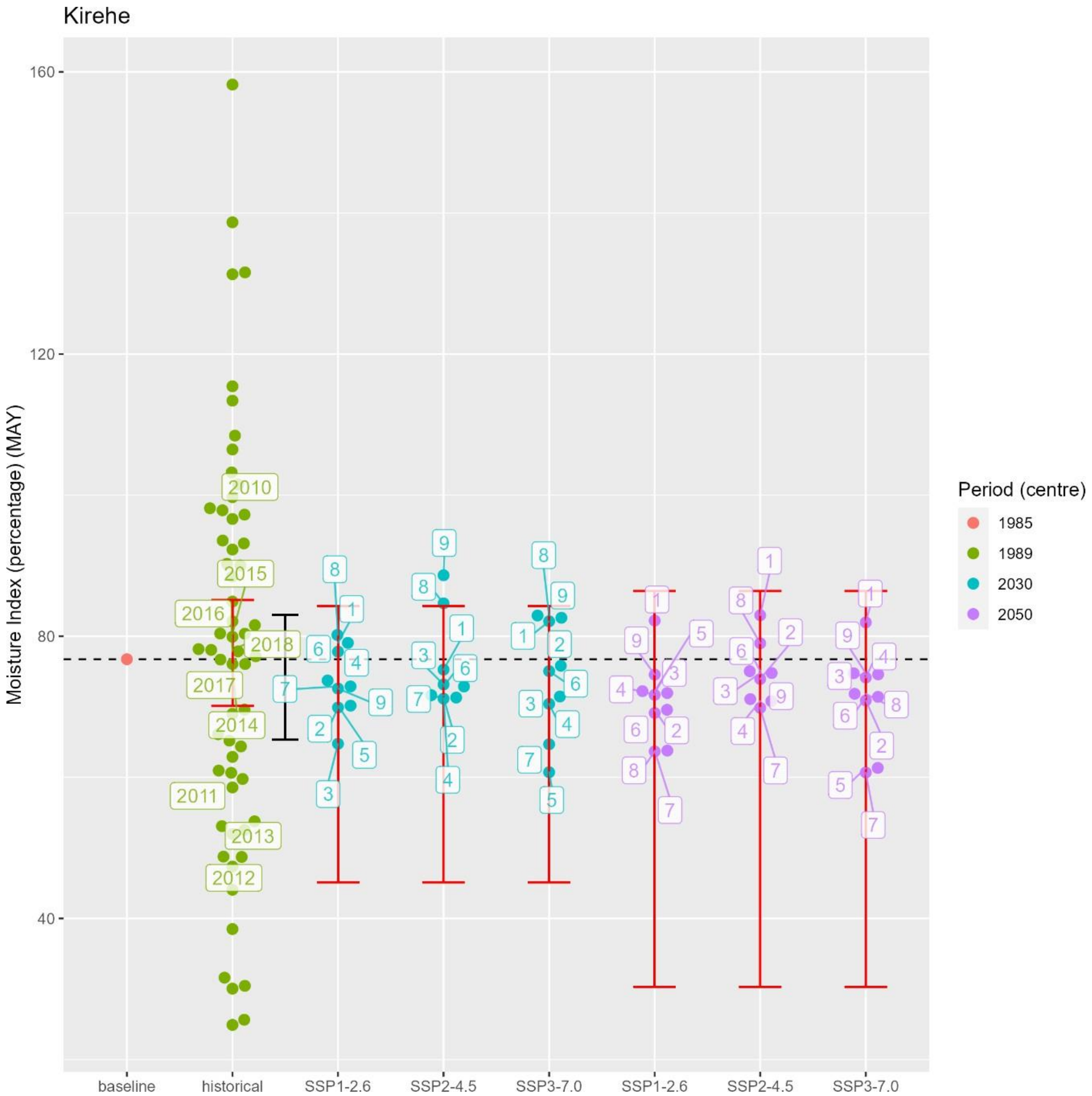


Figure 4.4. Historical range (1961-2018) and future projections (2030s and 2050s) for the moisture index in May for the driest district in the baseline climate. The red error bar shows the 95% confidence interval for a linear regression model fitted to the historical data. Labels of future projections corresponds to the alphabetical sorting of GCMs (1 = BCC-CSM2-MR ; 2 = CNRM-CM6-1 ; 3 = CNRM-ESM2-1 ; 4 = CanESM5 ; 5 = GFDL-ESM4 ; 6 = IPSL-CM6A-LR ; 7 = MIROC-ES2L ; 8 = MIROC6 ; 9 = MRI-ESM2-0). Years in the most recent historical decennium (2010-2018) are also labelled.



It is likely that the moisture index will decrease for the driest district, with all scenarios for the 2030s and 2050s having six or more models showing a decrease in the moisture index (Figure 4.4).

Figure 4.5. Historical trends (1961-2018) for the moisture index in May for the wettest district in the baseline climate. Green, red and blue lines show fits and confidence intervals of local regression models with respectively 0.5, 0.3 and 0.15 spans. Black lines show fits and confidence intervals of a linear regression model. Years with observations outside the local regression model with the 0.5 span are labelled.

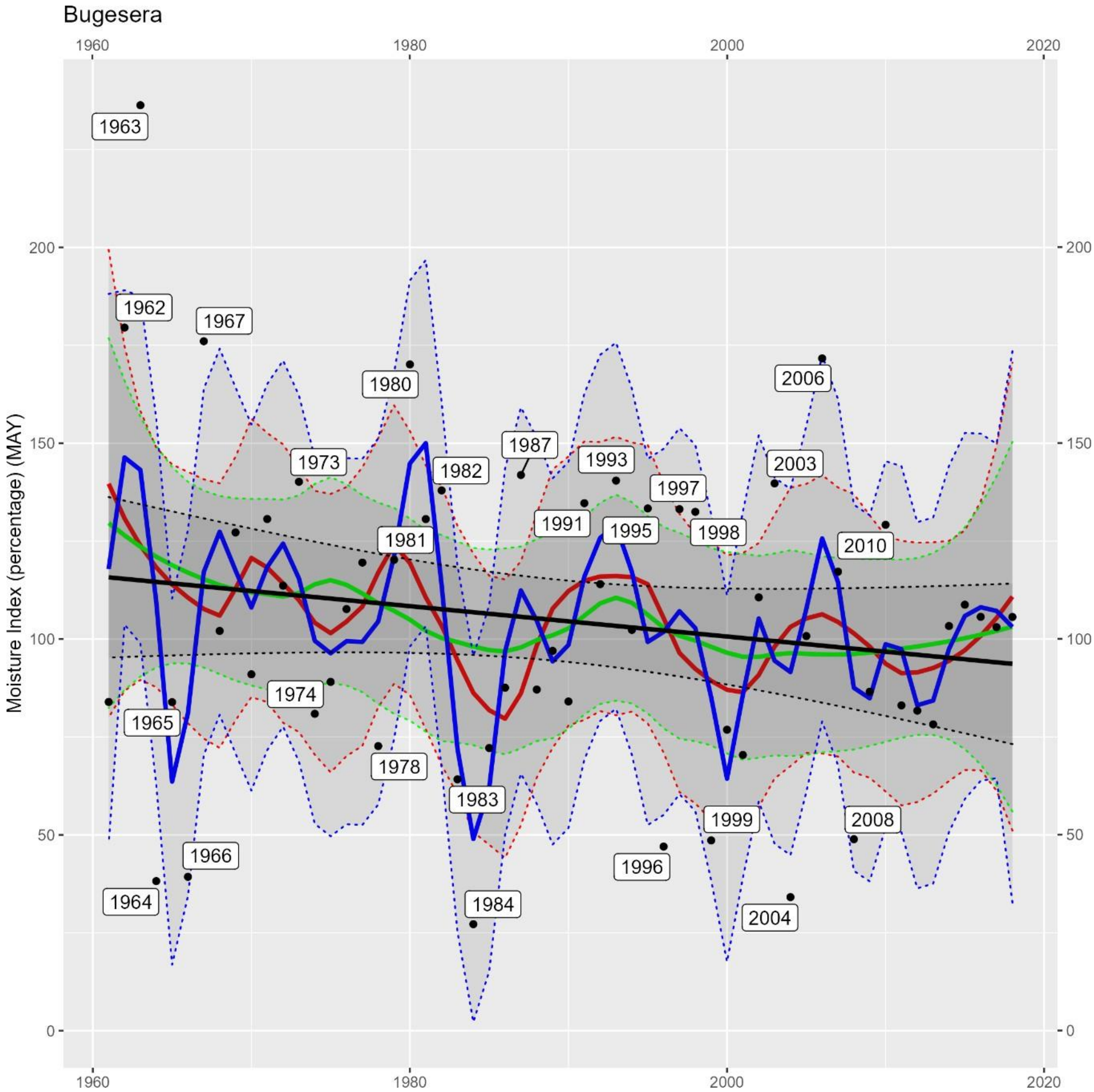
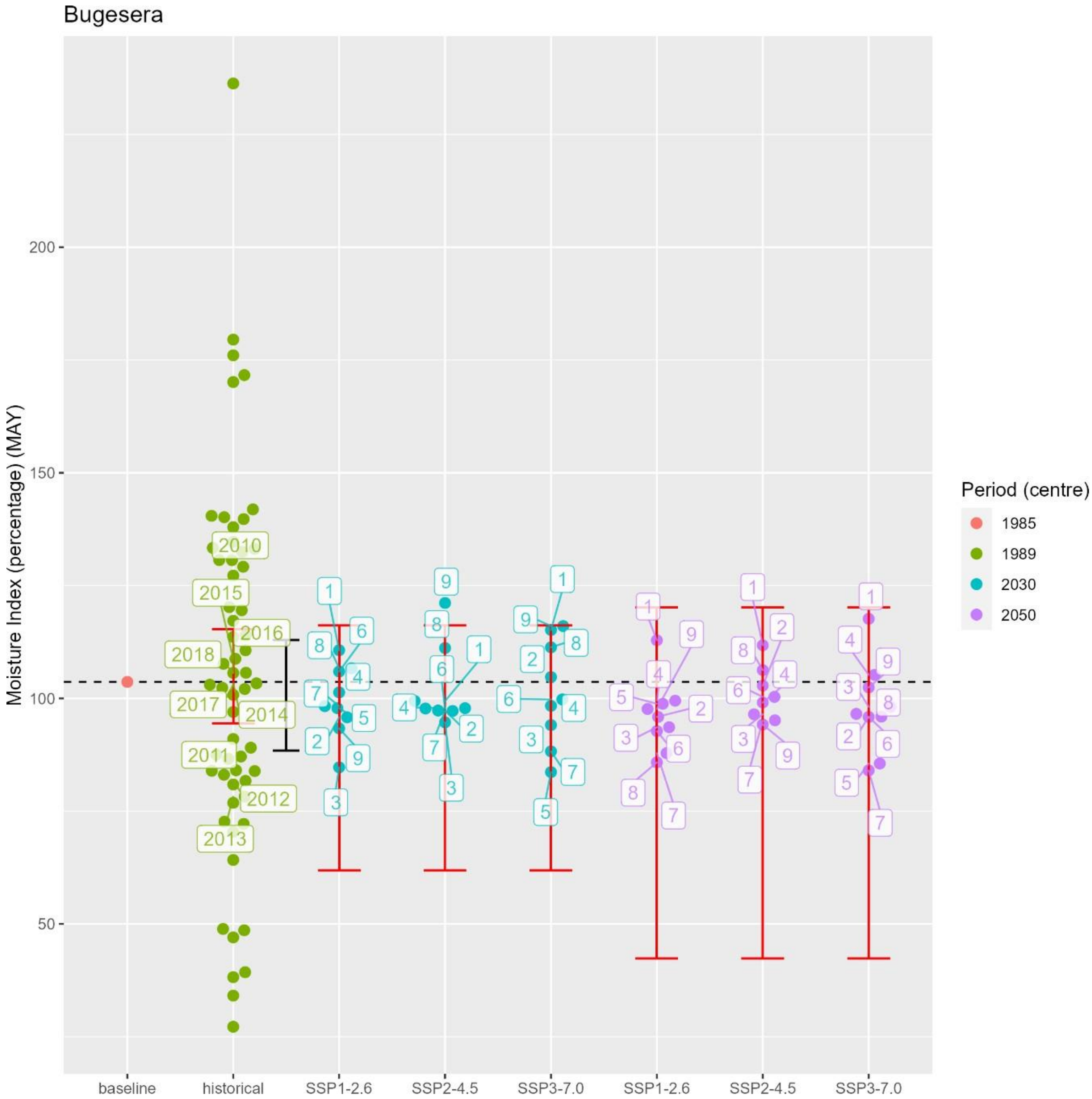


Figure 4.6. Historical range (1961-2018) and future projections (2030s and 2050s) for the moisture index in May for the wettest district in the baseline climate.. The red error bar shows the 95% confidence interval for a linear regression model fitted to the historical data. Labels of future projections corresponds to the alphabetical sorting of GCMs (1 = BCC-CSM2-MR ; 2 = CNRM-CM6-1 ; 3 = CNRM-ESM2-1 ; 4 = CanESM5 ; 5 = GFDL-ESM4 ; 6 = IPSL-CM6A-LR ; 7 = MIROC-ES2L ; 8 = MIROC6 ; 9 = MRI-ESM2-0). Years in the most recent historical decennium (2010-2018) are also labelled.

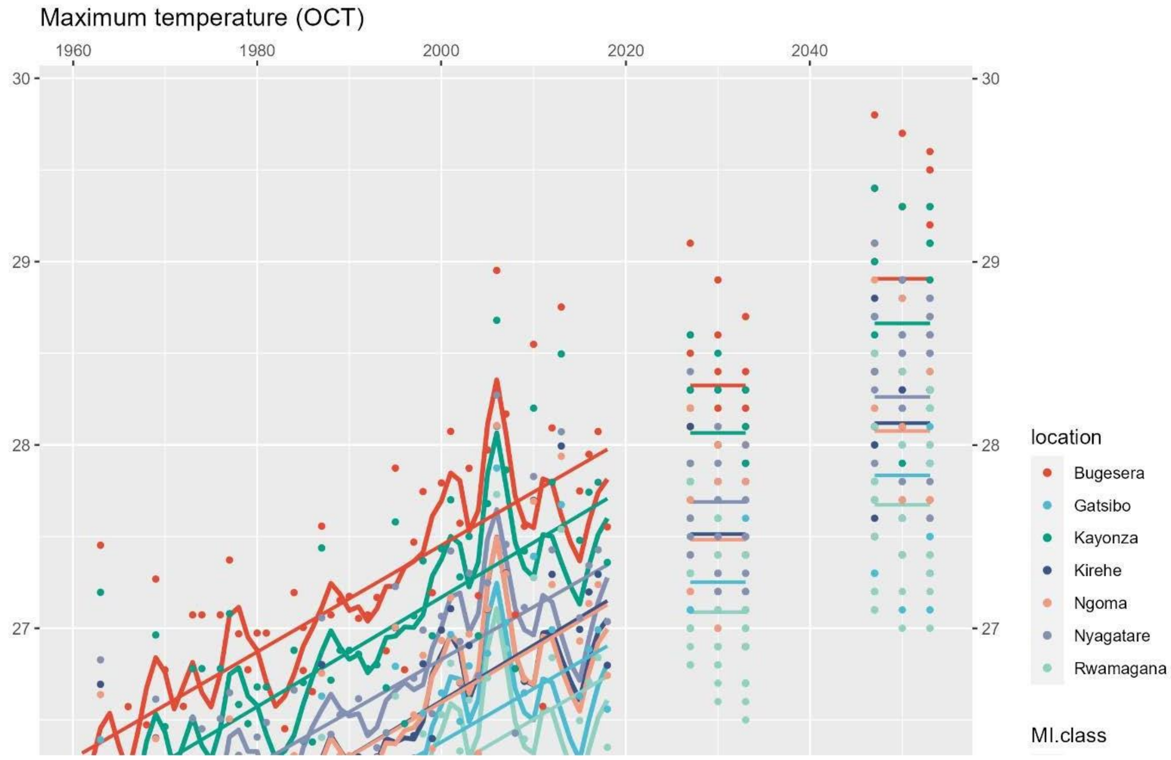


Also for the wettest district, it is likely that the moisture index will decrease, with all scenarios for the 2050s having six or more models showing a decrease in the moisture index (Figure 4.6).

5. Climate change analysis with focus on the month of October

This section focuses on the month of October, a sowing month for maize, sorghum and beans in the ‘A’ season. Historically, the maximum temperature has been increasing in this month (Figure 5.1). There was no strong linear increase for the moisture index (figures 5.2, 5.3 and 5.5).

Figure 5.1. Historical trends (1961-2018) and future projections (2030s and 2050s) for maximum temperature in October. Note that future projections are all centred on 2030 and 2050, but that projections for SSP1-1.9 are plotted to the left, for SSP2-4.5 in the middle and for SSP3-7.0 to the right. Full lines show linear regression trends fitted to the historical data for each location.



CLIMATE CHANGE ANALYSIS WITH WORLDCLIM 2.1. VOLUME 1

Additional analysis focused on the moisture index for critical months

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This report provides figures that show historical and future trends focused on the Eastern Province of Rwanda. The report was prepared with latest available data from WorldClim 2.1, corresponding to global circulation models and scenarios (Shared Socioeconomic Pathways) prepared for the IPCC AR6. All data and software used are open access.

Nairobi, April 2021