Food and Agriculture Organization of the United Nations

Annex 2

Feasibility Study – Part A

Climate Impact Potential Assessment

For the GCF-FAO Project "Transforming Livelihoods through Climate Resilient, Low Carbon, Sustainable Agricultural Value Chains in the Lake Region Economic Bloc, Kenya"

Office of Climate Change, Biodiversity and Environment (OCB)
Food and Agriculture Organization of the United Nations (FAO)

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A1. Climate impact potential assessment

1. Introduction to the climate rationale

1. **The agricultural sector in Kenya's Lake Region Economic Bloc (LREB) is a major contributor to food security and income to the entire country** (through both staple and alternative, cash food commodities sold domestically and internationally) thanks to a highly suitable climate with lower maximum temperatures and higher total annual rainfall than the observed average in the country. Precipitations are evenly distributed year-round compared to the arid and semi-arid regions of Kenya.
2. **At the same time, the country is exposed and vulnerable to natural rainfall variability, influenced by El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD), and its impacts on positive and negative rainfall anomalies, which are likely to be exacerbated by human-induced climate change, thus enhancing the risk of extreme high temperatures, drought, heavy rainfall, and flooding events.** The increase of dry days and heavy rainfall events including hailstorms in the region, combined with increasing temperatures, is considered to have substantial impacts on the selected crops and livelihoods' income, such as extreme heat and drought stresses on livestock, and decreased soil fertility, increased soil erosion, evapotranspiration, and increased crop-water demand on crops.
3. The analysis conducted in this document is of the observational dataset W5E5 and using CORDEX-CORE climate projections for the Representative Concentration Pathways (RCP) 2.6 and RCP8.5. This shows observed and projected climate hazards including increasing minimum and maximum temperatures, as well as heat waves, dry spells, and heavy rainfall events in the LREB. Compounded climate hazards have negative impacts on crop and livestock production from changes in onset and length of the rainy and growing seasons, to increasing evapotranspiration rates and soil moisture stress, heat- and drought stress on livestock, flooding events and soil erosion, as well as increased food spoilage and damages to storage, processing, transportation, and market infrastructure at post-harvest stages of the food value chains.
4. **In the LREB, key cash crops such as coffee, tea, and bananas are produced, and poultry and dairy products as well as African Leafy Vegetables (ALVs) contribute to food security. The LREB is the most populous region in Kenya, but climate-resilient agricultural practices for small-holder farmers remain underdeveloped**. Low adaptive capacity is due to rainfed production, limited agricultural inputs and post-harvest practices, and limited market opportunities, as well as limited access to climate-proof technologies and climate information services along the value chains. In addition, overall transport, internet, and post-harvest infrastructure undermine optimal agricultural productivity and, consequently, constrain farmers income generation.
5. **The food value chains targeted by the project were identified by the county stakeholders as being vulnerable to climate change and carrying significant environmental, social, and economic importance to the counties' vulnerable smallholder population.** The selection of the agrifood commodities is the result of stakeholder consultations performed in each county and is aligned with the selection of commodities proposed by CGIAR-CIAT studies based on climate risks for each individual county and food value chain. The results of this work for each food value chain, integrated with a literature review and FAO's analysis of historical and projected simulated agroclimatic potential yields of tea, coffee, bananas, and cowpea, are further analyzed in this study.
6. **Different observed and projected climate hazards driven by natural decadal variability and teleconnections with ENSO and IOD phenomena, as well as human-induced climate change highlight the need for incremental and systemic adaptation measures** tailored to seasonal, inter-

annual, decadal, and long-term climate hazards, as well as differences between targeted counties in the identified hazards to set up ad hoc plans for each targeted value chain, in alignment with Kenya's priority adaptation measures for the agriculture sector. The main findings of the climate impact potential assessment are summarized in the Table 1 below.

1.1. Summary of observed and projected climate hazards, impacts on selected agricultural systems, and recommended climate adaptation actions

Table 1. Summary of observed and projected climate hazards along the Lake Region Economic Bloc, their impacts on selected value chains and climate actions with highest societal, economic, and environmental benefits.

<table>
<tr><th rowspan="2">Climate hazard (statistically significant changes)</th><th colspan="2">Climate impacts</th><th colspan="2">Adaptation interventions</th></tr>
<tr><th>Crop systems</th><th>Livestock systems</th><th>Crop systems</th><th>Livestock systems</th></tr>
<tr><td>Temperature:
- Observed and projected increasing average maximum and minimum temperatures.
- Observed extreme heat events in central counties.
- Projected increasing extreme heat events across the region.</td><td>- High evapotranspiration risks.
- Loss of arable land.
- Future risk of tea and coffee crop unsuitability.
- Projected decreased productivity of tea, coffee, and banana compared to historical simulations under rainfed and irrigated conditions, and farmers' revenues.
- Projected potential in increased productivity of cowpea under rainfed conditions.
- Projected decreased coffee growing areas.
- Observed coffee berry borer spread.
- High temperatures and relative humidity: moderate to severe impacts on mycotoxin contamination during coffee storage.</td><td>- Heat stress; decreased productivity (meat, milk, eggs quantity and quality).
- Weather-related hazards: pathogens.
- Feed intake leads to energy deficits, decreased fertility rates, animal fitness and longevity, animal mortality.</td><td>Activity 1.1.1 and 1.1.2:
- Pest and disease forecasts.
- Extreme heat and evapotranspiration. advisory; information on soil moisture.
- Advisory on climate-resilient varieties.
- Temperature advisory services for storage and processing.
- Information on water resource availability and water management advisory.
- Weather-informed advisory on harvesting techniques.

Activity 1.1.5, 3.1.1, and 3.1.2:
- Introduction of heat tolerant, high yielding, and early maturing crop varieties.
- Shaded nets and greenhouse production.
- Integrated soil, water, and pest management practices, balanced application of fertilizers, pesticides, herbicides, and fungicides.
- Establishment of cover crops (e.g., Leguminosae).
- Tea pruning, selective coffee picking techniques.
- Optimal temperatures, ventilation, and relative humidity for storage and processing through use of electronic machinery.
- Use of climate-controlled ripening chambers, solar refrigeration, cold chain practices.</td><td>Activity 1.1.1 and 1.1.2:
- Pest and disease forecasts.
- Information on water resource availability.
- Temperature advisory services for storage and processing.

Activity 1.1.5, 3.1.1, and 3.1.2:
- Introduction of heat tolerant pasture and breeds.
- Development of feed storage facilities, use of fresh, dried fodder, diversification of feed according to the season.
- Climate-proof poultry and input storage facilities and hatcheries, temperature and air circulation regulators.
- Training on optimal temperature and humidity conditions, pest and disease control systems for weather-related disease prevention.
- Milk antimicrobial treatments, hygiene and sanitation. Aluminum containers for transportation and cleaning, specialized milk trucks.
- Use of ventilated cages for transportation.</td></tr>
</table>

Climate hazard (statistically significant changes)	Climate impacts		Adaptation interventions	
	Crop systems	Livestock systems	Crop systems	Livestock systems
			Activity 2.1.1, 3.1.1, and 3.1.2: - Agroforestry practices, planting of indigenous trees. **Activity 4.1.1 and 4.1.3:** - E-marketing channels and networks.	- Climate-proofed milk collection and processing plants, cold chain facilities. - Climate-resilient value addition/processing practices. **Activity 2.1.1, 2.1.2, 3.1.1, and 3.1.2:** - Agroforestry practices. - Integrated water management. - Establishment of local collection points. **Activity 4.1.1 and 4.1.3:** - Marketplace information.
Precipitation – Drought: - Observed increasing dry days in southern counties and projected increasing dry days across the region. - High interannual rainfall variability, negative rainfall anomalies influenced by ENSO and IOD phenomena during the OND season.	- Drought and moisture stress: major impacts on Tea and Fruit trees through decreased crop revenues. - Reduced annual growth rate. - Reduced soil moisture, soil compaction. - Water scarcity and quality degradation through higher concentration of contaminants. - Loss of arable land. - Decreased crop productivity and farmers' revenues.	- Drought stress (major impact on dairy production). - Decreased productivity (meat, milk, eggs quality and quantity). - Weather-related hazards: pathogens. - animal mortality. - Indirect impacts on grassland, reduced quality and quantity of feed and water sources. - Reduction of calving rates from the normal rates.	**Activity 1.1.1 and 1.1.2:** - Drought forecasting, early-warning systems. - Advisory on climate-resilient varieties, water management and irrigation, fertilizer, pesticide, and herbicide management practices. - Information on the onset and offset of the rainy seasons. - Advisory on planting date, land management. **Activity 1.1.5, 2.1.1, 3.1.1, and 3.1.2:** - Integrated soil and pest management, organic matter as mulch; mechanized and early land preparation; local seed and manure production and commercialization. - Shaded nets and greenhouse production. - Introduction of drought, pest tolerant, high yielding and early maturing varieties. - Conservation agriculture (crop cover, mulching). - Optimized early timing for planting, optimized fertilizer application.	**Activity 1.1.1 and 1.1.2:** - Drought forecasting, early-warning systems. - Advisory on climate-resilient varieties, water management and irrigation. - Information on water resource availability. **Activity 1.1.5, 2.1.1, 3.1.1, and 3.1.2:** - Introduction of drought and disease tolerant pasture. - Development of feed storage facilities, use of fresh, dried fodder, diversification of feed. - Animal disease control and prevention (vaccines) for weather-related pathologies.

Climate hazard (statistically significant changes)	Climate impacts		Adaptation interventions	
	Crop systems	Livestock systems	Crop systems	Livestock systems
			- Training on solar drying, use of insulated containers and cold chain practices, and optimal timing for sun drying and storage; facilitate ventilation; technologies and techniques for value-adding practices. **Activity 2.1.2, 3.1.1, and 3.1.2:** - Integrated water management (water conservation, efficiency, and recycling, rainwater harvesting, storage, water reservoirs, canals, aquifers recharge, drip irrigation systems, ZAI pit systems). - Agroforestry practices, planting of indigenous trees.	**Activity 2.1.2, 3.1.1, and 3.1.2:** - Integrated water management, improved drainage systems. - Agroforestry practices. **Activity 4.2.1:** - Establishment of emergency funds/insurance, contract milk farming.
Precipitation – Heavy rainfall and flooding: - Observed and projected increasing heavy rainfall events. - High interannual rainfall variability, positive rainfall anomalies influenced by ENSO and IOD phenomena during the OND season.	- Heavy rainfall, hailstorms, and flooding: major impacts on Tea, Coffee, Fruit trees, and African Leafy Vegetables, decreased crop revenues. - Water runoff, soil erosion and water logging, nutrient leaching, pest and disease outbreaks. - Impacts along the value chain: food spoilage at storage, damaged transportation infrastructure, reduced food value at markets.	- Heavy rainfall and flooding: major impacts on poultry production. - Weather-related hazards: water-borne diseases. - Indirect impacts: reduced quality and quantity of feed and water sources. - Impacts along the value chain: food spoilage at storage, damaged transportation infrastructure, reduced value at markets.	**Activity 1.1.1 and 1.1.2:** - Flooding forecasting, early-warning systems, and weather-informed agricultural advisories. - Advisory on fertilizer, pesticide, and herbicide management practices. - Weather-informed recommendations on harvesting techniques and best timing. - Precipitation and relative humidity advisory services for storage and processing. - Weather-informed transportation advisory. **Activity 2.1.2, 3.1.1, and 3.1.2:** - Integrated water management, water harvesting, dams and canals, drainage, and anti-erosion systems. - Optimized early timing for planting; optimized fertilizer application; balanced application of herbicides and fungicides. **Activity 1.1.5, 2.1.1, 3.1.1, and 3.1.2:** - Shaded nets and greenhouse production. - Flooding forecasting, early-warning systems, and agricultural advisory. - Selective picking techniques.	**Activity 1.1.1 and 1.1.2:** - Flooding forecasting, early-warning systems and agricultural advisory. - Advisory on fertilizer, pesticide, and herbicide management practices. - Precipitation and relative humidity advisory services for storage, processing, and markets. - Weather-informed transportation advisory. **Activity 2.1.1, 2.1.2, 3.1.1, and 3.1.2:** - Agroforestry practices. **Activity 1.1.5, 2.1.1, 3.1.1, and 3.1.2:** - Input subsidies to farmers, facilitate access to inputs. - Animal disease control and prevention (vaccines) for weather-related pathologies.

Climate hazard (statistically significant changes)	Climate impacts		Adaptation interventions	
	Crop systems	Livestock systems	Crop systems	Livestock systems
			- Climate proof storage, processing, and market facilities; cold storage and common facilities; technologies and techniques for value-adding practices. - Moisture-measuring equipment; optimize time of storage; facilitate ventilation during storage. - Solar air drying and heating technologies, use of ripening chambers. **Activity 4.1.1 and 4.1.3:** - E-marketing channels and networks. **Activity 4.2.1:** - Climate risk crop insurance.	- Climate-proof poultry and input storage facilities and hatcheries. - Climate-proofed milk collection and processing plants, cold chain facilities. - Climate-resilient value addition/processing practices, milk antimicrobial treatments and standards. **Activity 4.1.1 and 4.1.3:** - Establish local collection points; increase access to poultry cages and boxes for markets. - Marketplace information. **Activity 4.2.1:** - Establishment of emergency funds/insurance, contract milk farming.

2. Methodology

2.1. Climate hazard assessment

7. For past climate analysis, the FAO Risks team used the W5E5 merged dataset for the 1981-2010 period that combines WFDE5 data over land with ERA5 over the ocean[1]. The W5E5 bias-corrected reanalysis dataset is considered an observational gridded product. W5E5 is currently used in many impact assessment studies, and it has been adopted by the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) as the official product for the bias-correction of atmospheric models. The bias-corrected W5E5 reanalysis dataset was validated with station-level data from three meteorological stations in Mombasa (Mombasa County), Jomo Kenyatta International (Nairobi County), and Kitale (Trans-Nzoia county), retrieved from NOAA database[2], using the correlation coefficient analysis, which scored a correlation >80% both for maximum temperatures and total precipitation at station level (Figure 1).

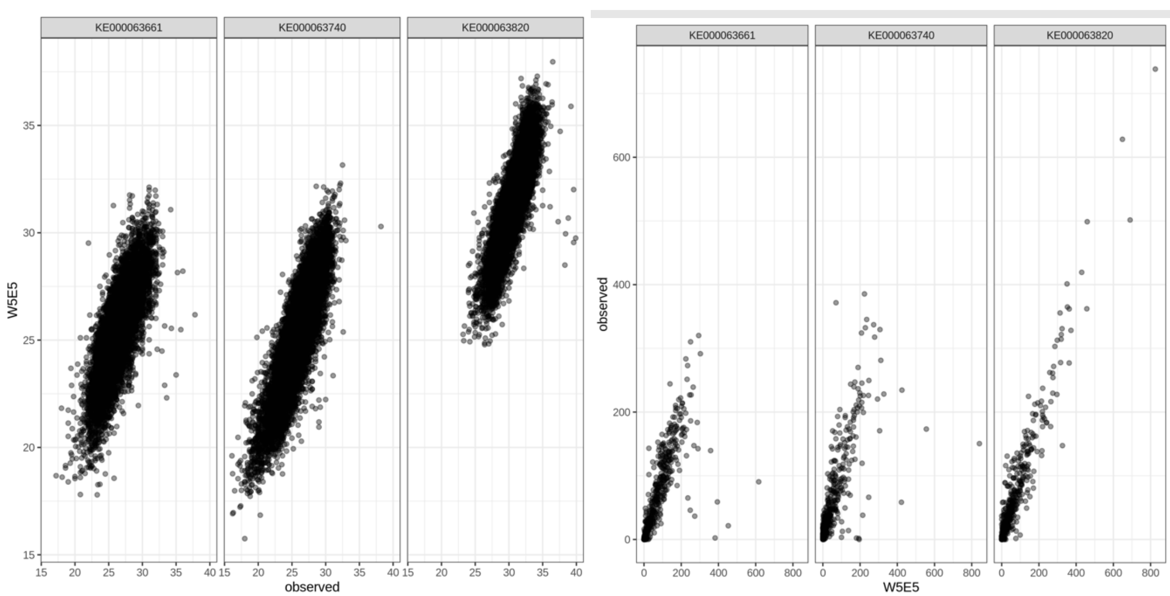

Figure 1. Statistical correlation coefficient of maximum temperature (left) and total precipitation (right) between the W5E5 dataset and observed station-level data in 3 meteorological stations in Kenya.

8. CAVA Analytics is an application based on cloud computing developed by the Risk team at OCB division at FAO in collaboration with the University of Cantabria (Meteorology group). CAVA Analytics access CORDEX-CORE data (MOHC-HadGEM2-ES, MPI-M-MPI-ESM-LR, NCC-NorESM1-M downscaled with two Regional Climate Models – RCMs - REMO2015 and RegCM4-4) and allows user to perform simple and advanced analyses on the fly. For example, CAVA Analytics allows the calculation of the model agreement in the sign of the climate change signal, which is defined as the difference between future projection (30-year time frame) and the models' baseline period (1976-2005). CORDEX-CORE provides climate models at 25 Km resolution and for two RCP scenarios, the RCP2.6 (low emissions and low

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[1] Cucchi, Marco, Graham P. Weedon, Alessandro Amici, Nicolas Bellouin, Stefan Lange, Hannes Müller Schmied, Hans Hersbach, and Carlo Buontempo. 2020. 'WFDE5: Bias-Adjusted ERA5 Reanalysis Data for Impact Studies'. Earth System Science Data 12 (3): 2097–2120. https://doi.org/10.5194/essd-12-2097-2020.

[2] NOAA. 2022. Daily Summaries Location Details. https://www.ncei.noaa.gov/cdo-web/datasets/GHCND/locations/FIPS:KE/detail#stationlist

radiative forcing level scenario) and RCP8.5 (high-emissions and high radiative forcing level scenario), covering the extremities of the whole IPCC range[34] .

9. Overall, model uncertainties arise from the challenges in detecting the emergence of historical and projected anthropogenic climate change signals, particularly in terms of long-term precipitation changes, from regional decadal climate variability, and particularly teleconnections with coupled ocean-atmospheric phenomena. At the same time, the emergence in climate change signal of global surface temperature changes is detected with high confidence[5]. The CAVA Analytics tool provides high flexibility in analyzing past and future climatic and agroclimatic trends and can reproduce the observed drying trend of the long rainy season in the LREB using CORDEX-RCMs which better capture rainfall variability[6] compared to GCMs which instead are less effective in reproducing regional forcing features fundamental in the region, frequently leading to the so called "Eastern African Climate Paradox" of misalignment between observed and projected climate trends[7]. Lastly, CAVA Analytics allows the user to apply any relevant thresholds, of particular interest when analyzing climate change and agroclimatic indices tailored to the agrifood commodities targeted by the project.

10. Unless specified in the figure caption, figures are produced with FAO CAVA Analytics. For figures showing trends, linear regression is applied to each pixel and, thus, a statistically significant change is represented with a black dot, conversely pixels with an absence of a black dot are not statistically significant. For figures on projected climate change signals, the black dot indicates whether at least 60% of the models agree in the sign of the climate change signal (positive or negative).

2.2. Climate impact assessment

11. The climate impact assessment in agriculture for tea, coffee, bananas, and cowpea for representative counties in the LREB, is based on findings on simulated agroclimatic potential yields (kg/ha) emerging from the Python Package for Agro-ecological zoning (PyAEZ) tool developed by FAO, which estimates biomass based on an eco-physiological model[8],[9]. A constraint free crop biomass is accumulated along the growing season mainly driven by incoming solar radiation, temperature, and crop specific characteristics (e.g., length growth, maximum rate of photosynthesis, Leaf Area Index-LAI at full development, harvest index and crop's sensitivity to heat provision). To maximize yields, the choice of the start of the growing season is determined automatically by the Agro-ecological zoning (AEZ)

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[3] WCRP Coordinated Regional Climate Downscaling Experiment. 2022. CORDEX CORE Simulations. https://cordex.org/experiment-guidelines/cordex-core/cordex-core-simulations/

[4] van Vuuren, D.P., Edmonds, J., Kainuma, M. et al. The representative concentration pathways: an overview. Climatic Change 109, 5 (2011). https://doi.org/10.1007/s10584-011-0148-z

[5] Arias, P.A. et al. 2021. Technical Summary. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 33−144. doi:10.1017/9781009157896.002.

[6] Onyutha, C., Rutkowska, A., Nyeko-Ogiramoi, P. et al. How well do climate models reproduce variability in observed rainfall? A case study of the Lake Victoria basin considering CMIP3, CMIP5 and CORDEX simulations. Stoch Environ Res Risk Assess 33, 687–707 (2019). https://doi.org/10.1007/s00477-018-1611-4

[7] Endris, H.S., Lennard, C., Hewitson, B. et al. Future changes in rainfall associated with ENSO, IOD and changes in the mean state over Eastern Africa. Clim Dyn 52, 2029–2053 (2019). https://doi.org/10.1007/s00382-018-4239-7

[8] Kassam, A. H. 1977. Net Biomass Production and Yield of Crops with Provisional Results for Tropical Africa. Soil Resources, Management and Conservation Service, Land and Water Development Division, FAO.

[9] Kassam, A. H., Van Velthuizen, H. T., Fischer, G. W., & Shah, M. M. 1991. Agroecological land resources assessment for agricultural development planning. A case study of Kenya. Resources data base and land productivity. Technical Annex, 1, 9 31.

tool. The simulation is conducted independently for rainfed conditions and irrigated conditions. Furthermore, the AEZ tool simulates optimal sowing and harvesting dates to obtain maximum potential yields in each analyzed grid-cell, separately for rainfed and irrigated conditions[10]. Yield projections are bias-corrected based on historical simulations using the differences between the simulated yield in the first projected year and the simulated yield in the last historical year (2010).

12. Furthermore, the framework applied to obtain the climate change impact maps is the following:
    1. pyAEZ was run for simulating the maximum potential yield for several crops using 3 bias-corrected CORDEX-CORE simulations. The bias correction was performed with the W5E5 bias-corrected reanalysis dataset. The simulation period started in 1976 until 2099.
    2. The results were averaged by county as pyAEZ produces results at the same spatial resolution as the used climate models.
    3. Results from different climate models were averaged (ensemble) and averaged based on the time frame (2031-2060 and 2061-2090).

13. The resolution of the map is at county level since it reflects the resolution of CORDEX-CORE data at 25Km.

14. **<u>The crop yield potential maps</u>** are calculated by dividing into 3 clusters (k-means clustering) the results of the historical simulated yields based on the different levels of maximum potential yields. The counties with the highest yield potential are the counties with the highest yield.

15. **<u>The irrigation potential map</u>** describes which counties would mostly benefit from irrigation in terms of yield increases compared to simulated rainfed conditions under present climatic conditions (1981-2010). The historical potential of irrigation is calculated based on the difference between simulated yields with and without irrigation (represented as optimal and stable rainfall conditions) when the differences between yields are higher than 50%.

16. **<u>Climate change impact maps</u>** are based on the % of yield decline calculated as (projected_yield-historical_yield/historical_yield)*100. This number allows an understanding of the increase/decrease in rainfed or irrigated yield compared to the respective historical simulation run. **Counties colored in green indicate a projected yield increase.**

17. Overall, the analysis is useful to determine counties with different yield potential under both rainfed and irrigated conditions, to further guide the selection of crop investments for each county based on climate risk as well as climate-resilience potential.

18. The results from the AEZ tool are complemented with the most recent literature on climate risks in Kenya and the LREB to link each observed and projected climate hazard with impacts on the selected food value chains. County-level climate risk assessments and climate resilient recommendations tailored to selected agrifood commodities were performed by the Ministry of Agriculture, Livestock, and Fisheries of Kenya (MoALF) in collaboration with the International Center for Tropical Agriculture (CIAT) and the CGIAR Research Programme on Climate Change, Agriculture, and Food Security (CCAFS), and supported by the World Bank, as part of the Kenya Climate Smart Agriculture Project (KCSAP)[11]. CGIAR-CIAT's counties climate risk profiles highlight observed and projected climate hazards and impacts to each stage of selected agrifood value chains, as well as implemented climate-

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[10] Fischer, G., Nachtergaele, F.O., van Velthuizen, H.T., Chiozza, F., Franceschini, G., Henry, M., Muchoney, D. and Tramberend, S. 2021. Global Agro-Ecological Zones v4 – Model documentation. Rome, FAO. https://doi.org/10.4060/cb4744en

[11] CGIAR-CIAT. Ministry of Agriculture, Livestock, Fisheries and Cooperatives. 2022. Kenya County Climate Risk Profiles. https://ccafs.cgiar.org/resources/publications/kenya-county-climate-risk-profiles

smart agriculture practices by farmers and other value chain actors, and potential adaptation interventions.

19. The assessment of the exposure, vulnerability, and adaptation potential of the selected value chains using the existing climate impact information for each individual county and value chain targeted by the project was complemented by the delivery of an online climate-sensitive value chain survey, distributed among 112 respondents in the project area, involved in different steps of the 6 value chains targeted by the project, and 12 out of the 14 counties of the LREB (**Error! Reference source not found.**). The climate-sensitive food value chain survey analysis aimed at achieving the following objectives:

- **Mapping** of the agri-food value chain, with an analysis of the food commodity in question, the actors and activities involved.
- A **climate risk assessment** of climate and weather-related hazards and impacts on each step of the food value chains as perceived by the survey respondents.
- Analysis of **climate services** development, including the access and the use of climate and weather information products and services among targeted actors at each step of the value chain, as well as the availability of digital communication tools.
- Identification of **climate resilient practices** implemented and to implement further at each stage of the food value chain.

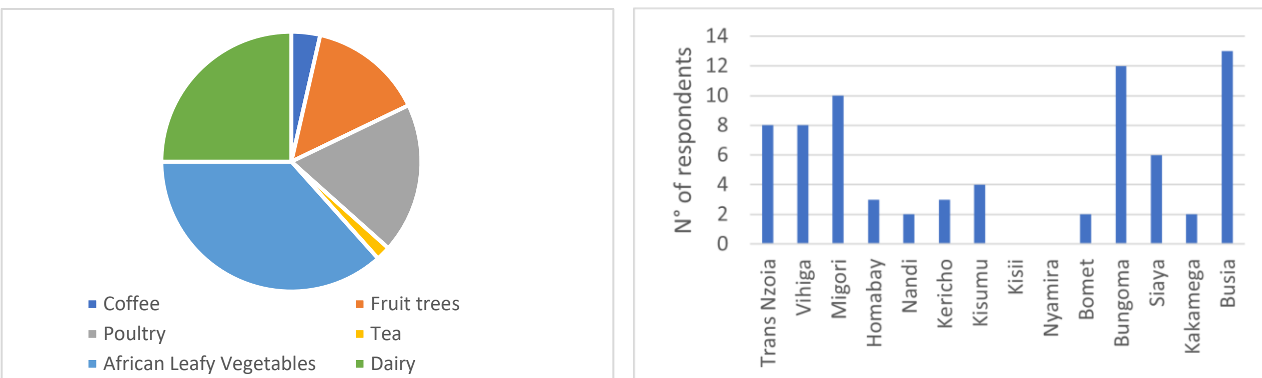

Figure 2. Food value chains and LREB counties involved in the online climate-sensitive value chain survey. Figure produced by FAO.

3. Climate and Agroecological Baseline

20. According to the Köppen-Geiger Climate Classification, areas within the Lake Region Economic Bloc in Kenya prevalently have an equatorial, humid (Af) and subtropical (Cfa) wet climate year-round from westernmost to easternmost areas and equatorial monsoonal (Am) influences in northernmost and easternmost areas[12]. Mean annual temperatures range between 20-28°C in the region, with highest temperatures in March (25.6°C) and lowest in July (22°C)[13]. As a result of its latitude, the LREB experiences little temperature variation throughout the year. Maximum temperatures in the LREB reach 30°C in the areas closest to Lake Victoria at lower altitudes, oscillating between 25°C in the northern counties and 27.5°C in the southern counties towards the easternmost areas where altitudes

[12] Kottek, M. et al. 2006. World Map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift, Vol. 15, No. 3, 259-263 (June 2006) c by Gebrüder Borntraeger 2006

[13] World Bank Group. WBG. 2021. Climate Risk Profile: Kenya (2021): The World Bank Group. https://climateknowledgeportal.worldbank.org/sites/default/files/2021-05/15724-WB_Kenya%20Country%20Profile-WEB.pdf

are higher (Figure 3). The same occurs for average minimum temperatures in the LREB which oscillate between 10°C in northern and eastern areas and 12.5-15°C towards Lake Victoria, reaching up to 17.5°C.

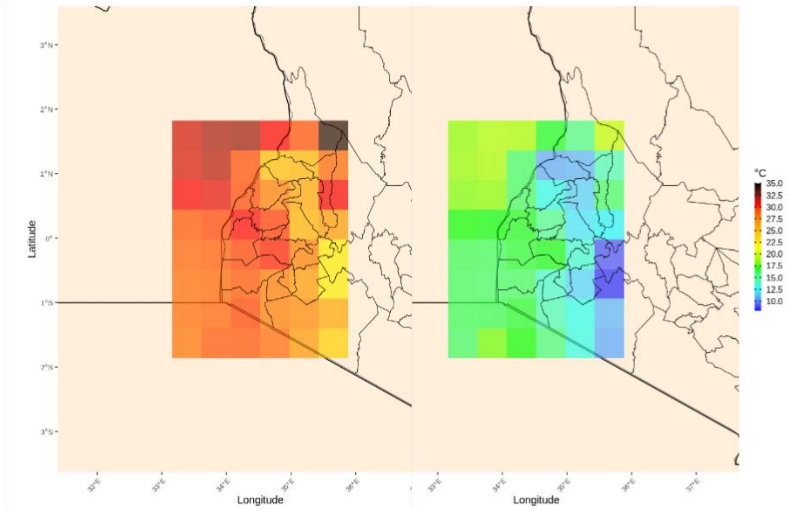

Figure 3. Average annual maximum (left) and minimum (right) temperature in the Lake Region Economic Bloc (1981-2010) using the bias-corrected W5E5 reanalysis dataset. Figures are produced with FAO CAVA Analytics.[14]

21. Total annual rainfall in the LREB is higher than the country's average[15] oscillating between 1200 to 1700 mm annually (Figure 4), with average monthly rainfall of 150mm/month during the rainy seasons, and spatial variations influenced by the topography characterized by undulating terrain and moisture inflow in proximity to the lake (e.g., Kisii and Nyamira in the southern areas, as well as Kakamega, Siaya, and Vihiga in the northern areas have higher annual precipitation).

22. The region encompasses four main seasons (January-February - JF: warm dry season; March-May - MAM: warm wet season; June-September - JJAS: cool dry season; October-December - OND: short wet season)[16]. However, while intra-annual (seasonal) precipitation trends vary throughout the country, variations are lower within the LREB due to a more even rainfall distribution year-round (Figure 5). In fact, while the months of January and February are characterized by almost no precipitation in the country, precipitation reaches up to 150-200mm/season in the region. The MAM season provides between 500-700mm/season and maintains higher values throughout the year compared to the rest of the country. During MAM, rainfall reaches 200mm/month particularly close to the Lake Victoria Basin (LVB). In April, the highest monthly rainfall is registered throughout the region[17]. The long rainy season from March to May contributes to 30-50% of the total annual rainfall. The short rainy season (from October to December, OND) contributes to 300-400 mm/season, equivalent to 20% of the total annual rainfall. In addition, while at the country level there is a

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[14] The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

[15] USAID. 2018. Climate Risk Profile. Kenya. Fact Sheet. https://www.climatelinks.org/sites/default/files/asset/document/2018_USAID-ATLAS-Project_Climate-Risk-Profile-Kenya.pdf

[16] K. Abebe Kiflie, Li Tao, "Opposite Effects of ENSO on the Rainfall over the Northern and Equatorial Great Horn of Africa and Possible Causes", Advances in Meteorology, vol. 2020, Article ID 9028523, 16 pages, 2020. https://doi.org/10.1155/2020/9028523

[17] World Bank Group. WBG. 2021. Climate Risk Profile: Kenya (2021): The World Bank Group. https://climateknowledgeportal.worldbank.org/sites/default/files/2021-05/15724-WB_Kenya%20Country%20Profile-WEB.pdf

substantial reduction in seasonal precipitation during JJAS, this trend is not followed in the LREB where precipitation contributes around 30% to total annual precipitation (400-500mm/season)[18]. Prevailing westerlies in fact contribute to high precipitation to the west of the Rift Valley Mountain range picking up moisture while flowing over the Lake Victoria[19],[20],[21].

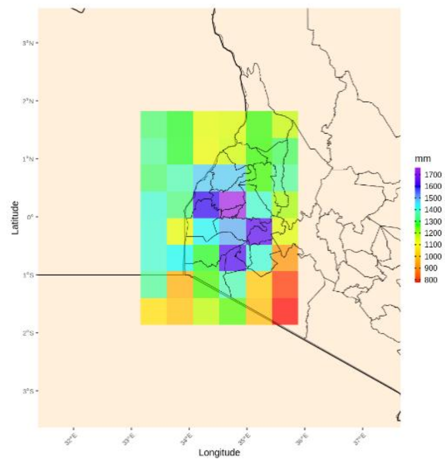

Figure 4. Total annual precipitation in the Lake Region Economic Bloc, Kenya (1981-2010) using the W5E5 reanalysis dataset.[22]

[18] Mwangi et al. 2020. Vulnerability of Kenya's Water Towers to Future Climate Change: An Assessment to Inform Decision Making in Watershed Management. American Journal of Climate Change. 9(3). DOI: 10.4236/ajcc.2020.93020

[19] Evans, W. Et al. 2020. The Spatial and Temporal Characteristics of Rainfall over the Lake Victoria Basin of Kenya in 1987-2016. Atmospheric and Climate Sciences. 10(2). DOI: 10.4236/acs.2020.102013

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[22] The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

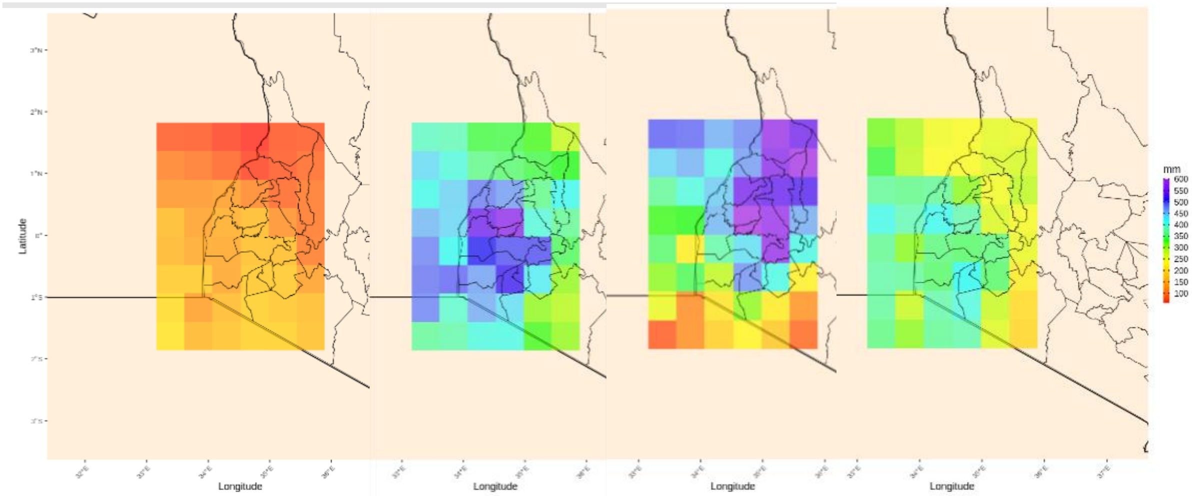

Figure 5. Total seasonal precipitation in the Lake Region Economic Bloc (from left to right: JF, MAM, JJAS, OND) (1981-2010) using the W5E5 reanalysis dataset.[23]

23. Kenya's rainfall seasons are heavily influenced by the transboundary coupled ocean-atmospheric phenomena of:

- The Inter Tropical Convergence Zone (ITCZ) from the southernmost areas of the country, which determines the four different seasons. In fact, the OND short rainy season and the MAM long rainy season occur during the period of the year in which the low atmospheric pressure belt caused by the Inter-Tropical Convergence Zone (ITCZ) migrates southwards and northwards respectively, and are thus alternated by drier periods[24],[25]
- Inter-annual rainfall variability during the OND short rainy season is due to large scale oceanic-atmospheric phenomena such as El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) phenomenon which frequently coincides with ENSO events through non-stationary teleconnections[26], resulting in above-normal rainfall due to the warming of the western Indian Ocean and positive El Niño events, as well as drier conditions during negative IOD and La Niña events[27],[28]
- High total annual precipitation in Kenya's LVB is also influenced by the warm and moist Congo airstream and westerlies which brings convective precipitation[29].

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[23] The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

[24] Ongoma, V., Chen, H. & Omony, G.W. Variability of extreme weather events over the equatorial East Africa, a case study of rainfall in Kenya and Uganda. *Theor Appl Climatol* **131**, 295–308 (2018). https://doi.org/10.1007/s00704-016-1973-9

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[26] King, J. A., & Washington, R. (2021). Future changes in the Indian Ocean Walker Circulation and links to Kenyan rainfall. *Journal of Geophysical Research: Atmospheres*, 126, e2021JD034585. https://doi.org/10.1029/2021JD034585

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[28] MacLeod, D, Graham, R, O'Reilly, C, Otieno, G, Todd, M. Causal pathways linking different flavours of ENSO with the Greater Horn of Africa short rains. *Atmos Sci Lett*. 2021; 22:e1015. https://doi.org/10.1002/asl.1015

[29] Evans, W. Et al. 2020. The Spatial and Temporal Characteristics of Rainfall over the Lake Victoria Basin of Kenya in 1987-2016. Atmospheric and Climate Sciences. 10(2). DOI: 10.4236/acs.2020.102013

- Monsoons bring drier conditions around Lake Victoria[30].

24. Inter-annual rainfall anomalies in East Africa and the Lake Victoria Basin are primarily associated with natural decadal variability influenced by the two coupled ocean-atmospheric phenomena of El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD)[31],[32],[33]. Furthermore, El Niño and La Niña phenomena[34] have increased in intensity (Figure 6 and Figure 7), thus exacerbating intra-annual and interannual rainfall variability in the region. Historical human-induced climate change is also a contributing factor of higher rainfall variability as a result of increasing zonal surface temperatures and consequent enhanced hydrological cycle, consequently increasing the drier and wetter conditions as influenced by ENSO and IOD phenomena in East Africa[35],[36],[37].

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[30] Evans, W. Et al. 2020. The Spatial and Temporal Characteristics of Rainfall over the Lake Victoria Basin of Kenya in 1987-2016. Atmospheric and Climate Sciences. 10(2). DOI: 10.4236/acs.2020.102013

[31] Lucia Mumo, Jinhua Yu, Brian Ayugi. 2019. Evaluation of spatiotemporal variability of rainfall over Kenya from 1979 to 2017. Journal of Atmospheric and Solar-Terrestrial Physics. Volume 194, 105097, ISSN 1364-6826. https://doi.org/10.1016/j.jastp.2019.105097.

[32] Lucia Mumo, Jinhua Yu. 2020. Gauging the performance of CMIP5 historical simulation in reproducing observed gauge rainfall over Kenya, Atmospheric Research, Volume 236, 104808, ISSN 0169-8095, https://doi.org/10.1016/j.atmosres.2019.104808.

[33] King, J. A., & Washington, R. (2021). Future changes in the Indian Ocean Walker Circulation and links to Kenyan rainfall. *Journal of Geophysical Research: Atmospheres*, 126, e2021JD034585. https://doi.org/10.1029/2021JD034585

[34] Rojas. 2020. Agricultural extreme drought assessment at global level using the FAO-Agricultural Stress Index System (ASIS). Weather and Climate Extremes. 27, 100184. https://www.sciencedirect.com/science/article/pii/S2212094718300999

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[36] Endris, H.S., Lennard, C., Hewitson, B. *et al.* Future changes in rainfall associated with ENSO, IOD and changes in the mean state over Eastern Africa. *Clim Dyn* **52**, 2029–2053 (2019). https://doi.org/10.1007/s00382-018-4239-7

[37] Arias, P.A. et al. 2021. Technical Summary. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 33−144. doi:10.1017/9781009157896.002.

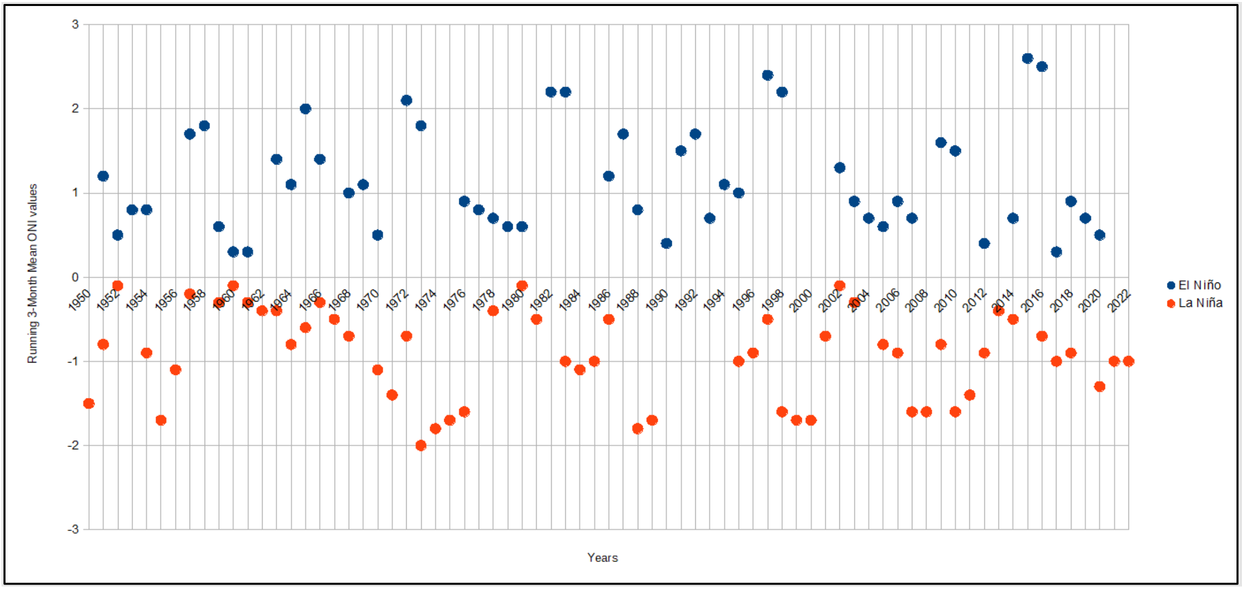

Figure 6. ENSO indices. Blue (orange) dots indicate El Niño (La Niña) events. Data was reanalyzed from NOAA (2022)[38].

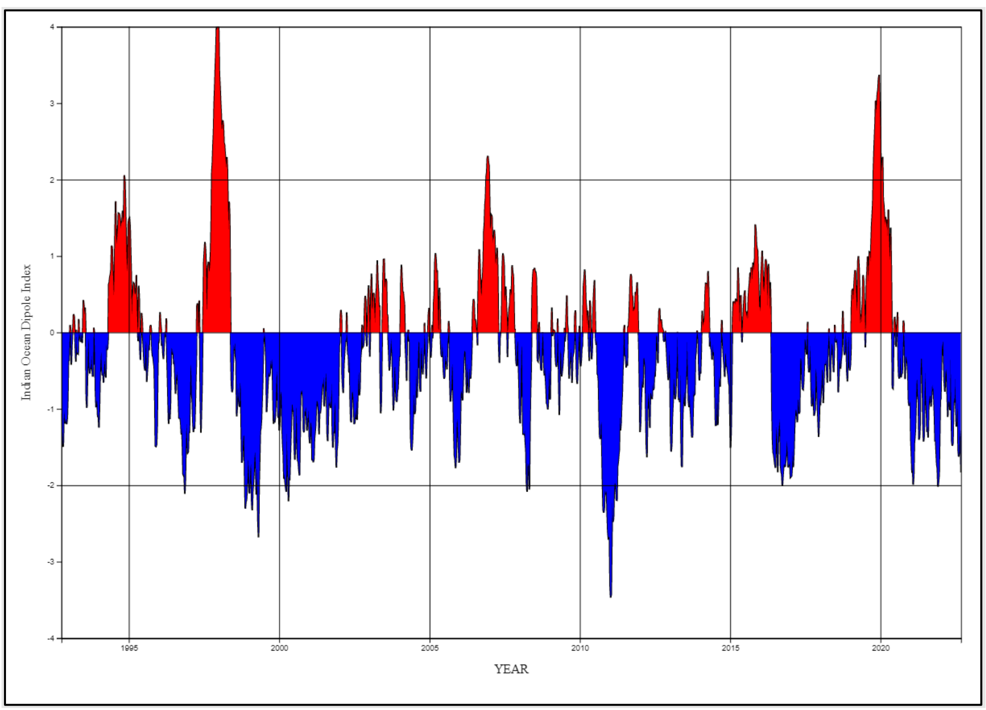

Figure 7. IOD INDEX: 1993-PRESENT. Data source: Satellite sea level observations. Credit: NASA MEaSUREs/PO.DAAC[39].

[38] NOAA. 2022. Cold & Warm Episodes by season. National Weather Service Climate Prediction Center. htntps://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php

[39] NOAA. 2022. IOD INDEX: 1993-PRESENT. https://sealevel.jpl.nasa.gov/overlay-iod/

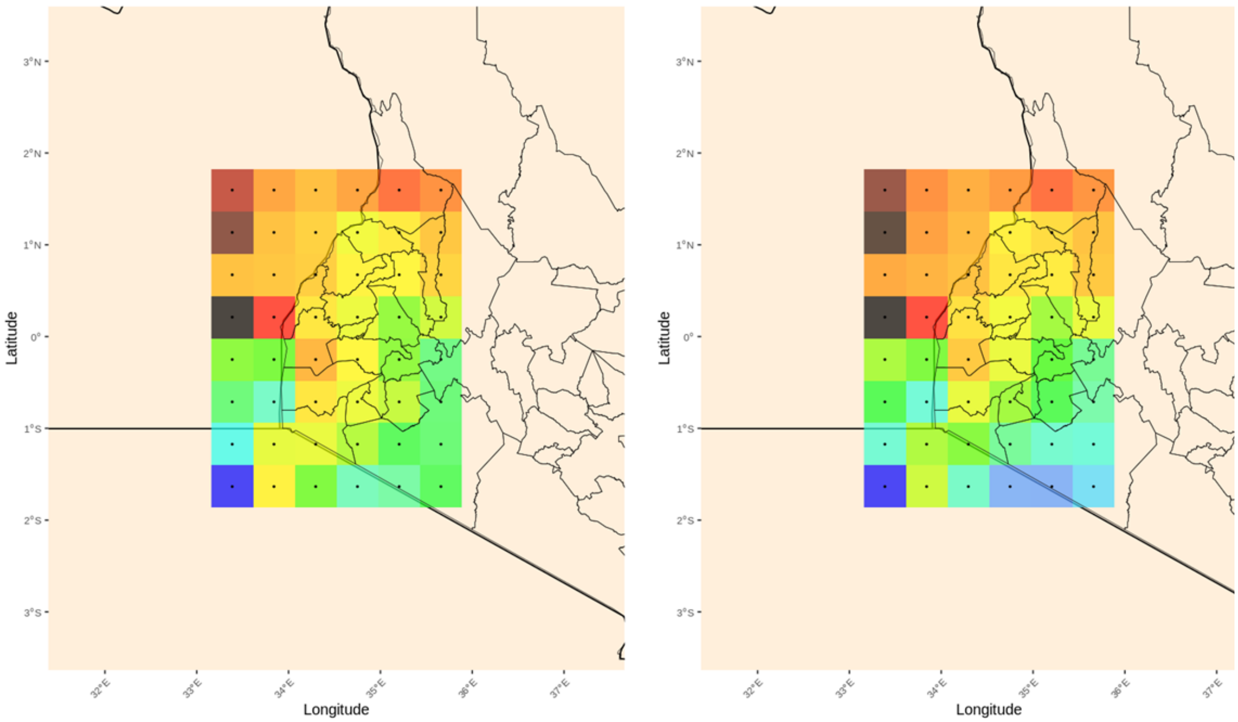

Figure 8:Changes in average of daily minimum (left) and maximum (right) temperatures (1981-2010) using the bias-corrected W5E5 reanalysis dataset. Linear regression is applied to each pixel and, thus, a statistically significant change is represented with a black dot, conversely pixels with an absence of a black dot are not statistically significantly different.[40]

4. Hazards: historical climate trends

4.1. Temperature

25. Annual average of daily maximum surface temperatures within the LREB increased by 0.7-1.0°C in the period from 1981 to 2010, equivalent to 0.3°C per decade (**Error! Reference source not found.**). Annual average of daily minimum temperatures increased by 0.8-1.1°C from 1981 to 2010, particularly in areas closer to Lake Victoria, including the counties of Bungoma, Busia, Siaya, and Kisumu, and the northern county of Trans-Nzoia (0,4ºC/decade). While the rate of change differs spatially for both minimum and maximum temperatures, it is statistically significant ($p<0.05$) throughout the region. At monthly levels, daily maximum temperatures have increased particularly during the dry warm season (January-February) as well as during the dry cold season (June-September). Overall, the LREB experienced higher increases in both daily maximum and minimum temperatures (by 0.7-1°C from 1981 to 2010) compared to the rest of the country (by 0.5-0.7°C from 1981 to 2010).

[40] The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

4.2. Precipitation

26. Total annual precipitation increased by up to 230mm (15%) in northern areas of the LREB from 1981 to 2010 and decreased by 60mm (-5%) in southern areas closer to Lake Victoria with respect to the average total annual precipitation of 1200-1400mm in the LREB (Figure 9). While annual rainfall trends show an overall increase since 1981 in northern counties of the LREB, the disaggregation of rainfall trends by season shows decreasing rainfall during the MAM seasons by up to 14% and increasing trends during the OND season by up to 25% from 1981 to 2010 (

27. Figure 10). Furthermore, according to Wainwright et al. (2019), the overall drying of the long rainy season in East Africa is also driven by a delay in the onset of the season and an earlier end of the season[41].

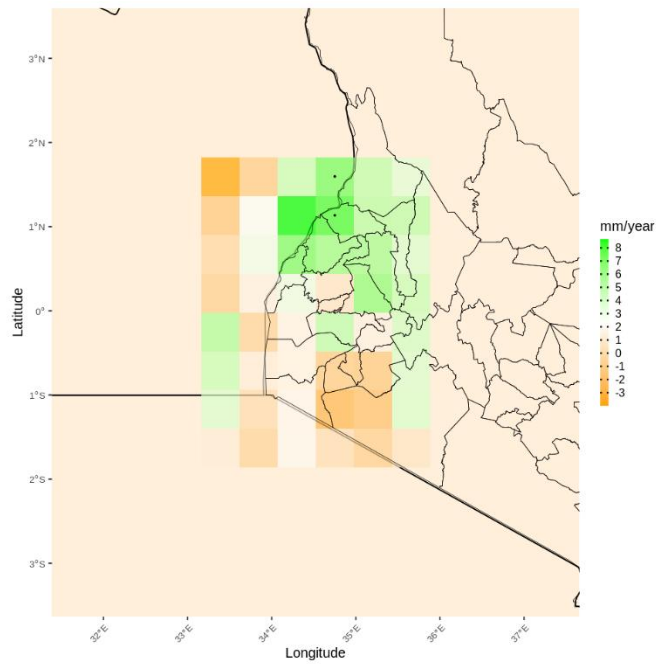

Figure 9. Historical changes in total annual precipitation per year (1981-2010) using the W5E5 reanalysis dataset.[42]

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[41] Wainwright, C.M., Marsham, J.H., Keane, R.J. *et al.* 'Eastern African Paradox' rainfall decline due to shorter not less intense Long Rains. *npj Clim Atmos Sci* **2**, 34 (2019). https://doi.org/10.1038/s41612-019-0091-7

[42] The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

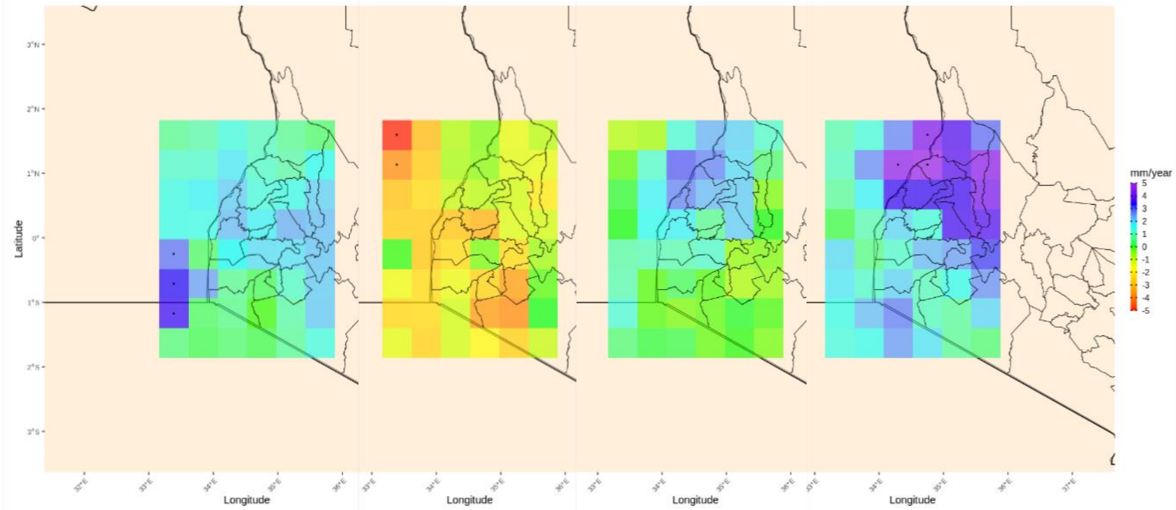

Figure 10. Total annual precipitation changes in the Lake Region Economic Bloc (from left to right: JF, MAM, JJAS, OND) (1981-2010) using the W5E5 reanalysis dataset.[43]

4.2.1. Interannual rainfall variability and associations with ENSO-IOD phenomena

28. The rainfall climatology of the LVB experienced high interannual variability with the occurrence of wetter conditions in 1997 with positive ENSO events, drier conditions in 2003-2005 coinciding with negative ENSO events, and overall wetter conditions in 2006-2016 compared to the average period between the 1980s and 2010s[44].

29. The following section examines the extent to which ENSO events can explain interannual rainfall anomalies during the two main rainy seasons (long rainy season in MAM and short rainy season in OND) in the LREB counties through the Pearson correlation coefficient using NINO3.4 index. The latter index is used to detect ENSO impacts in a specific region's climate. Annual rainfall anomalies are calculated from observed gridded data (interpolated satellite and station level data from 1990 to 2018) on daily precipitation for each county in the LREB provided by the Kenya Meteorological Department (2022). First, total precipitation during the MAM and OND seasons for each year is subtracted by the 1990-2018 climatological mean. The obtained anomaly value is therefore normalized by dividing the anomaly by the corresponding standard deviation[45].

30. Over the 1990-2018 period, Table 2 shows decadal patterns of decreased precipitation from 2000 to 2009 by 40mm per decade compared to the 1990-1999 period, and a subsequent increased precipitation from 2010 to 2018 by 50mm per decade compared to the 2000-2009 period, in most counties in the LREB. These include Bomet, Bungoma, Busia, Kakamega, Kericho, Kisii, Kisumu, Trans-Nzoia, Nandi, and Vihiga, showing an increase in the coefficient of variation from about 10% to 15% when comparing the 1990-1999 and 2010-2018 periods, thus showing increased rainfall variability particularly over the last decade.

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[43] The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

[44] Evans, W. Et al. 2020. The Spatial and Temporal Characteristics of Rainfall over the Lake Victoria Basin of Kenya in 1987-2016. Atmospheric and Climate Sciences. 10(2). DOI: 10.4236/acs.2020.102013

[45] Muthama, N. et al. 2014. The influence of El-niño Southern Oscillation on seasonal rainfall over the 47 counties of Kenya. 2(2). http://www.accessinterjournals.org/aijas

31. Furthermore, key negative rainfall anomalies were observed in 2000, 2004 and 2005, as well as 2012, 2014, and 2016 in most of the counties, primarily coinciding with negative ENSO events, whereas positive rainfall anomalies were observed in 2006, 2010, 2013, 2015, and 2017-2018, also coinciding with positive ENSO events. As shown in Figure 11, there is a moderate correlation (R=0,58) between the intensity of ENSO events during the OND season and rainfall anomalies during the same year and season in the LREB. Therefore, 58% of the OND rainfall anomalies can be explained by the ENSO phenomenon in the LREB, in accordance with Muthama et al. (2014)46. Since ENSO events occur over a prolonged period, they are expected to cause lag effects to the subsequent seasons by several months47. However, no correlation was found between ENSO indices during the OND season and rainfall anomalies during the MAM rainy season in the subsequent year (R=-0,02) (Figure 11). This result is in alignment with the literature48. In fact, it is widely acknowledged how El Niño (La Niña) phenomena and positive (negative) IOD impacts on rainfall anomalies are stronger during the OND season rather than in MAM and JJAS seasons in East Africa[49],[50].

Table 2. Moving averages and temporal rainfall variability over the 1990-2018 period along each county in the Lake Region Economic Bloc. Data was reanalyzed from the Kenya Meteorological Department (2022).

Average precipitation (mm)														
Years	Bomet	Bungoma	Busia	HomaBay	Kakamega	Kericho	Kisii	Kisumu	Migori	Nandi	Nyamira	Siaya	TransNzoia	Vihiga
1990-1999	1412,3	1446,6	1389,9	1085,3	1730,2	1481,7	1613,0	1276,4	1237,5	1539,4	1616,5	1192,2	1178,9	1800,1
2000-2009	1376,1	1460,2	1351,8	1176,4	1636,5	1430,8	1621,7	1263,7	1293,2	1452,7	1573,0	1231,5	1186,0	1796,4
2010-2018	1397,4	1643,3	1447,7	1211,7	1795,9	1543,0	1720,9	1320,9	1282,9	1583,2	1675,9	1229,2	1347,5	1827,6
1990-2018	1395,2	1512,3	1394,7	1155,9	1718,3	1483,1	1649,5	1285,8	1270,8	1523,1	1620,0	1217,3	1233,7	1807,3

Coefficient of variation (%)														
Years	Bomet	Bungoma	Busia	HomaBay	Kakamega	Kericho	Kisii	Kisumu	Migori	Nandi	Nyamira	Siaya	TransNzoia	Vihiga
1990-1999	8,0	6,7	9,0	9,7	7,7	5,7	9,1	10,0	10,7	7,1	11,3	9,2	7,7	14,5
2000-2009	13,1	12,5	11,3	17,5	11,0	13,0	10,0	14,5	17,2	10,8	10,3	15,7	13,6	12,6
2010-2018	15,6	12,3	11,7	10,4	13,1	15,1	11,6	10,5	13,4	12,6	12,6	12,6	12,8	9,1

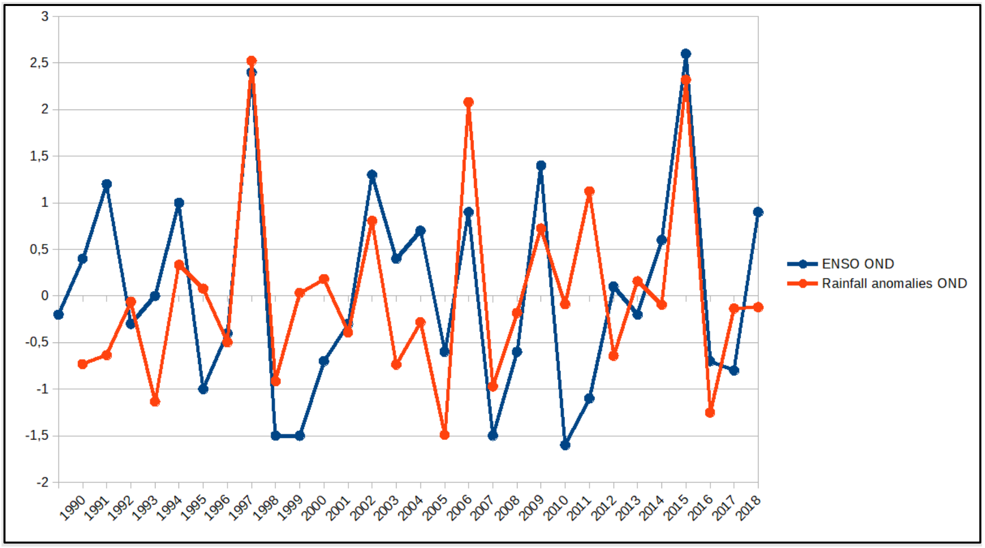
[46] Muthama, N. et al. 2014. The influence of El-niño Southern Oscillation on seasonal rainfall over the 47 counties of Kenya. 2(2). http://www.accessinterjournals.org/aijas

[47] Davey et al. 2014. The probability of the impact of ENSO on precipitation and near-surface temperature. Climate Risk Management. 1. https://www.sciencedirect.com/science/article/pii/S2212096313000053

[48] Endris, H.S., Lennard, C., Hewitson, B. *et al.* Future changes in rainfall associated with ENSO, IOD and changes in the mean state over Eastern Africa. *Clim Dyn* **52**, 2029–2053 (2019). https://doi.org/10.1007/s00382-018-4239-7

[49] Lucia Mumo, Jinhua Yu. 2020. Gauging the performance of CMIP5 historical simulation in reproducing observed gauge rainfall over Kenya, Atmospheric Research, Volume 236, 104808, ISSN 0169-8095, https://doi.org/10.1016/j.atmosres.2019.104808.

[50] Endris, H.S., Lennard, C., Hewitson, B. *et al.* Future changes in rainfall associated with ENSO, IOD and changes in the mean state over Eastern Africa. *Clim Dyn* **52**, 2029–2053 (2019). https://doi.org/10.1007/s00382-018-4239-7



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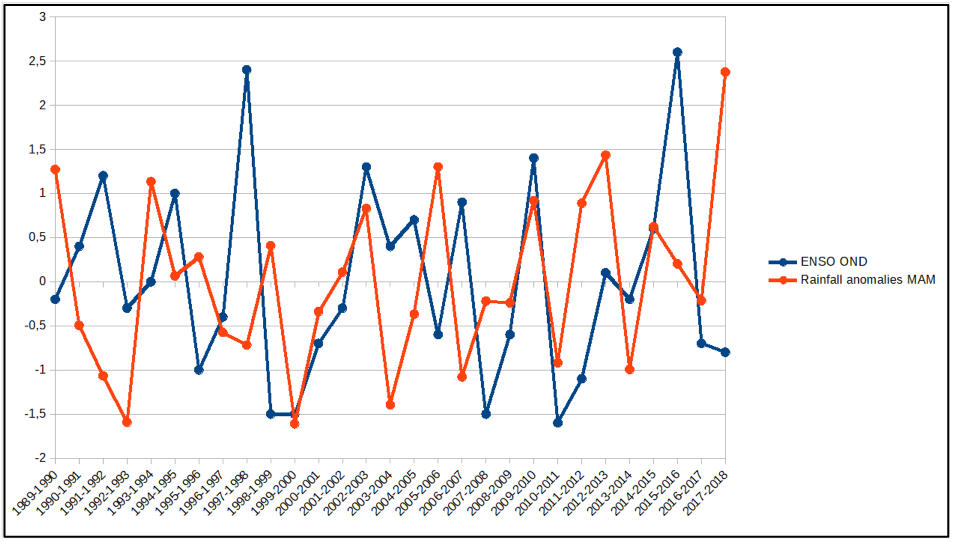

Figure 11. Correlation between three-months ENSO index and precipitation anomalies during the OND (upper figure) and MAM (bottom figure) seasons (1989-2018). For each pair of years in the figures, the first year refers to the ENSO phenomenon during the OND season, whereas the second year refers to rainfall anomalies for the MAM season, respectively. Data was reanalyzed from NOAA (2022)[51] and Kenya Meteorological Department (2022).

4.3. Extreme weather events

32. Whilst all countries have been experiencing an increase in heavy rainfall and dry spell events, intra-regional differences in the increased frequency of extreme weather events arise between the counties within the LREB due to different topographic and agroclimatic zones, with northern counties at higher latitudes experiencing increasing total precipitation, central counties at lower altitudes and closer to Lake Victoria experiencing higher minimum and maximum temperature increases, and southern counties experiencing increasing dry days[52].

4.3.1. Temperature

33. Between 1981 to 2010, an increase in the number of days (by 12 to 24 days) per year with maximum temperatures above 35°C (Tmax >35ºC) was reported in Kisumu, Busia, and Siaya counties, located in the northern side and characterized by lower altitudes than 1200masl (Figure 12). In these three countries, the rate of change over the 1981-2010 period is statistically significant ($p<0.05$). Furthermore, the year 2020 was the warmest year on record, where several stations in the LREB including Kericho, Kakamega, and Kisii registered both maximum and minimum temperature values exceeding their long-term means[53].

[51] NOAA. 2022. Cold & Warm Episodes by season. National Weather Service Climate Prediction Center. https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php

[52] CGIAR-CIAT. Ministry of Agriculture, Livestock, Fisheries and Cooperatives. 2022. Kenya County Climate Risk Profiles. https://ccafs.cgiar.org/resources/publications/kenya-county-climate-risk-profiles

[53] Kenya Meteorological Department, 2021. Extreme climate events in Kenya 2011 to 2020. https://meteo.go.ke/sites/default/files/downloads/STATE%20OF%20THE%20%20CLIMATE%202020_14042021.pdf

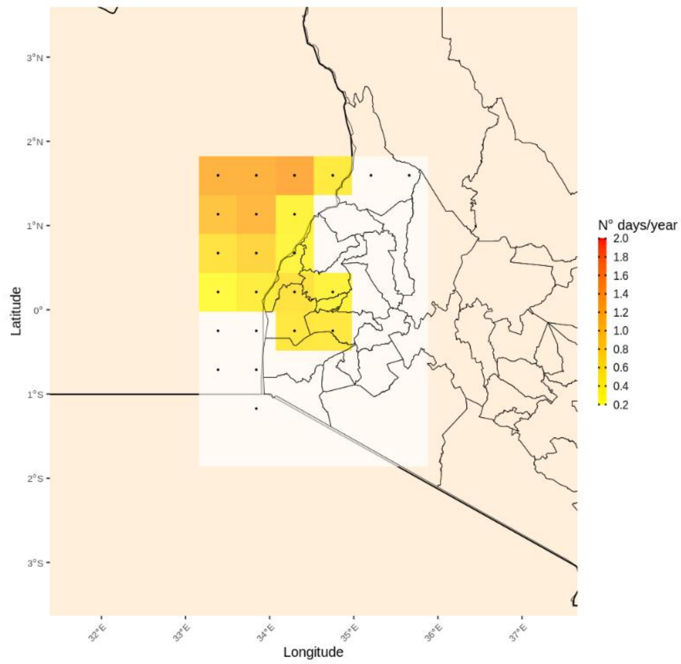

Figure 12. Changes in the number of extreme heat days (Tmax>35°C) in the Lake Region Economic Bloc (1981-2010) using the W5E5 reanalysis dataset.[54]

4.3.2. Precipitation

Dry spells

34. The LREB is becoming increasingly exposed to drier conditions during the long rainy season,[55] particularly in the southern counties - Kericho, Bomet, Nyamira and Kisii- where the dry spells become more frequent and prolonged[56]. From 1981 to 2010, the number of dry days per year increased by up to 24 days in the southern counties (e.g., Bomet and Nyamira) of the LREB and decreased by up to 17 days in northern counties (e.g., Bungoma and Trans-Nzoia) (Figure 13). While the rate and direction of change differs spatially (positive or negative), this change is statistically significant ($p<0.05$) in northern and southern counties. During the MAM rainy season, the number of dry days increased by 6 days (Figure 14) reaching up to 50 dry days in three months, with a maximum duration of 10 consecutive dry days.

[54] The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.
[55] Evans, W. Et al. 2020. The Spatial and Temporal Characteristics of Rainfall over the Lake Victoria Basin of Kenya in 1987-2016. Atmospheric and Climate Sciences. 10(2). DOI: 10.4236/acs.2020.102013
[56] CGIAR-CIAT. Ministry of Agriculture, Livestock, Fisheries and Cooperatives. 2022. Kenya County Climate Risk Profiles. https://ccafs.cgiar.org/resources/publications/kenya-county-climate-risk-profiles

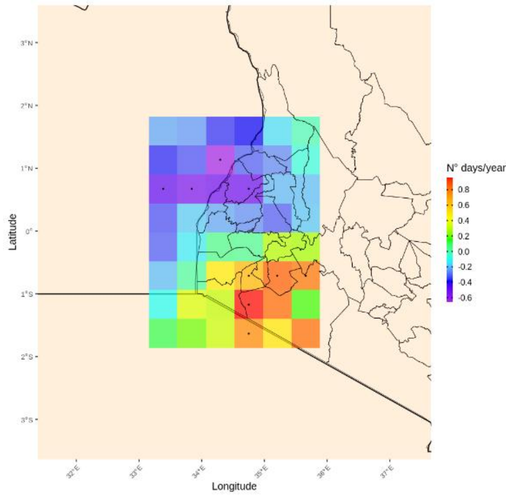

Figure 13. Changes in annual number of dry days per year (1981-2010) using the W5E5 reanalysis dataset.[57]

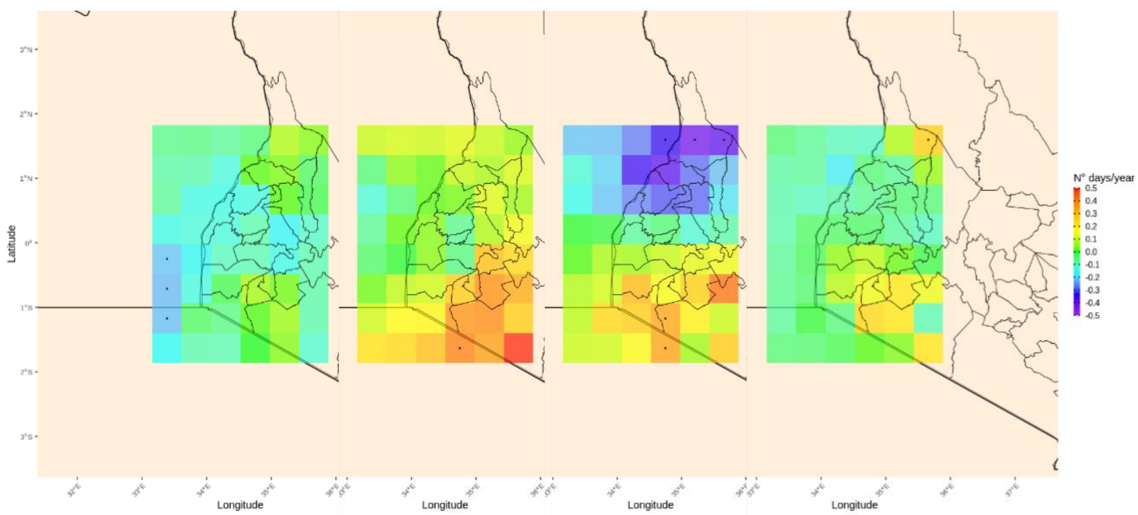

Figure 14. Changes in number of dry days in the Lake Region Economic Bloc (from top-left to bottom-right: JF, MAM, JJAS, OND) (1981-2010) using the W5E5 reanalysis dataset.[58]

Heavy rainfall events

35. The number of heavy rainfall events, corresponding to days with precipitation exceeding 20mm, increased by 5-6 days from 1981 to 2010. The rate of change is statistically significant ($p<0.05$) throughout the region (Figure 15). Furthermore, the LREB experienced higher frequency and intensity

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[57] The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

[58] The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

of heavy rainfall events during positive El Niño Southern Oscillation (ENSO) phenomena resulting in flooding events in 2014, 2015, 2018, and 2019[59], as well as hailstorms.

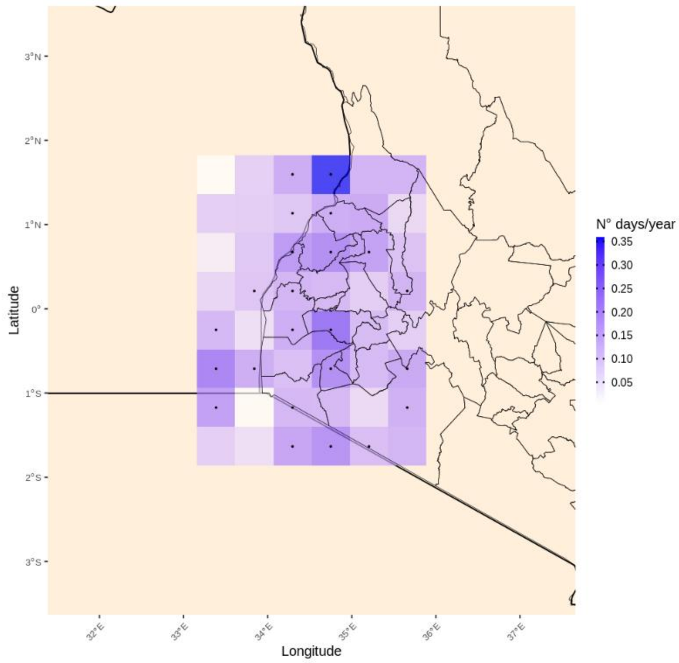

Figure 15. Changes in number of days with precipitation>20mm per year in the Lake Region Economic Bloc (1981-2010) using the W5E5 reanalysis dataset.[60]

5. Hazards: climate projections

5.1 Temperature

36. There is a positive model agreement (at least 60% of the models agree in the sign of the climate change signal) in maximum and minimum surface temperature change. In the near-term (from 2010 to 2039), maximum and minimum temperatures are projected to increase by 1°C under both RCPs 2.6 and 8.5 compared to the 1976-2005 baseline period. In the mid-term (from 2040 to 2069), maximum and minimum temperatures are projected to increase by 1.5°C under RCP2.6 and by 2.5°C under RCP8.5 compared to the baseline period. By end-century (from 2070 to 2099), under RCP2.6 both maximum and minimum temperatures are predicted to maintain an increase of 1°C, whereas under RCP8.5, the increase will reach 4°C for maximum temperatures and up to 4.5°C for minimum temperatures, particularly in north-eastern counties (Figure 16). Temperatures are projected to

[59] MENR. 2016. Kenya National Adaptation Plan 2015-2030. https://academia-ke.org/library/download/menr-kenya-national-adaptation-plan-2015-2030-2016/

[60] The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

increase at higher rates during the long rainy season (March to May) and over the cool dry season (June to September) than other seasons,[61],[62].

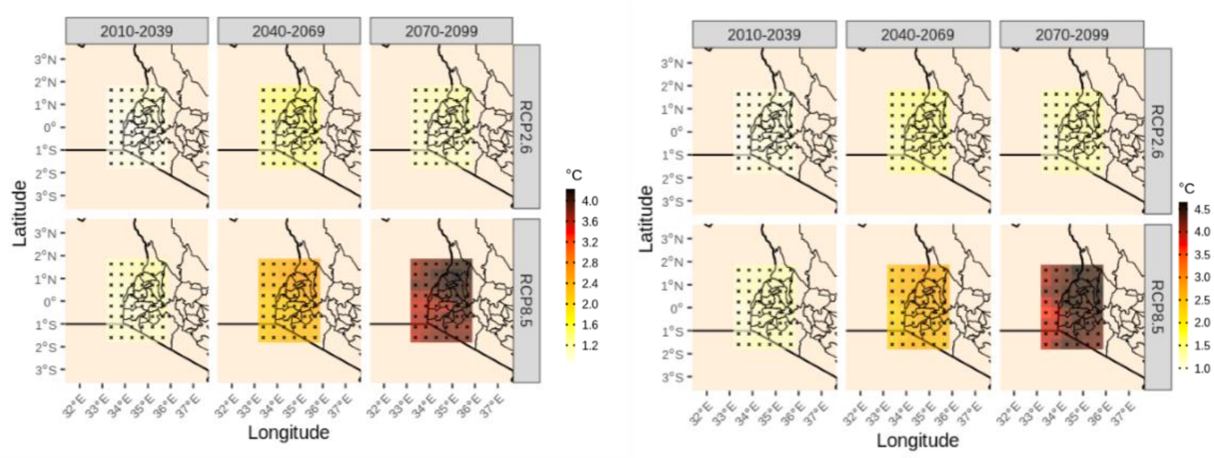

Figure 16. Climate change signal in annual average of daily maximum (left) and minimum (right) temperatures in the Lake Region Economic Bloc (average of 6 CORDEX-CORE simulations) from the historical period (1976-2005). Black dots indicate whether at least 60% of the models agree in the sign of the climate change signal (positive or negative).[63]

5.2. Precipitation

37. Annual rainfall is projected to decrease by up to 50mm (-3%) in the mid-term (2040-2069) and increase by 50mm (+3%) in the long-term (2070-2099) under RCP2.6 and increase by 100mm (+7%) in the long-term under RCP8.5 compared to the 1976-2005 baseline period (Figure 17). Overall, there is a high model agreement in the climate change signal of total annual precipitation.

38. At seasonal level, future projections indicate a decrease in total precipitation during the MAM season by 5% as well as during the JJAS season by 10% by mid-century (2040-2069), both under RCP2.6 and RCP8.5 compared to the 1976-2005 baseline period. In the long-term, precipitation during the MAM season is projected to stabilize under RCP2.6 and continue to slightly decrease under RCP8.5, whereas a continuous decreasing trend is shown during the JJAS season by end-century under both RCPs 2.6 and 8.5. The OND season is projected to experience an increase of 7% in the mid- to long-term under RCP2.6 and by up to 15% under RCP8.5 (Figure 18) compared to the 1976-2005 baseline period. In most cases, there is model agreement in the climate change signal of total seasonal precipitation. FAO's results agree with those reported in literature. For example, Olaka et al. (2019)[64] project an increase in total annual rainfall of 5-25% under both RCPs 2.6 and 8.5 by 2050s-2070s, a decrease in precipitation during the MAM (5%) and JJAS (10%) seasons, and an increase in precipitation during the OND (25%) season in the LVB.

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[61] L.A. Olaka et al. 2019. Projected Climatic and Hydrologic Changes to Lake Victoria Basin Rivers under Three RCP Emission Scenarios for 2015–2100 and Impacts on the Water Sector. *Water*, 1449 (11): 1 -27

[62] Sagero, P.O., Shisanya, C.A. and Makokha, G. 2021. Projected Changes in Rainfall and Temperature Extremes Over Kenya. Research Square.

[63] The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

[64] L.A. Olaka et al. 2019. Projected Climatic and Hydrologic Changes to Lake Victoria Basin Rivers under Three RCP Emission Scenarios for 2015–2100 and Impacts on the Water Sector. *Water*, 1449 (11): 1 -27

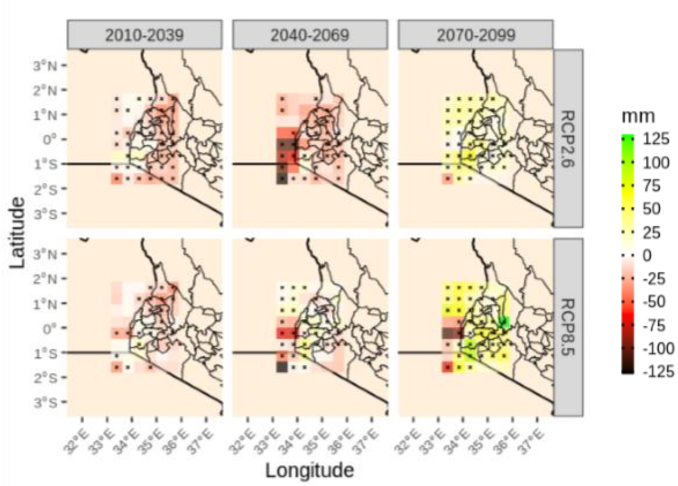


Figure 17. Climate change signal in total annual precipitation in the Lake Region Economic Bloc (average of 6 CORDEX-CORE simulations) with respect to the historical period (1976-2005). The black dot indicates whether at least 60% of the models agree in the sign of the climate change signal (positive or negative).[65]

[65] The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

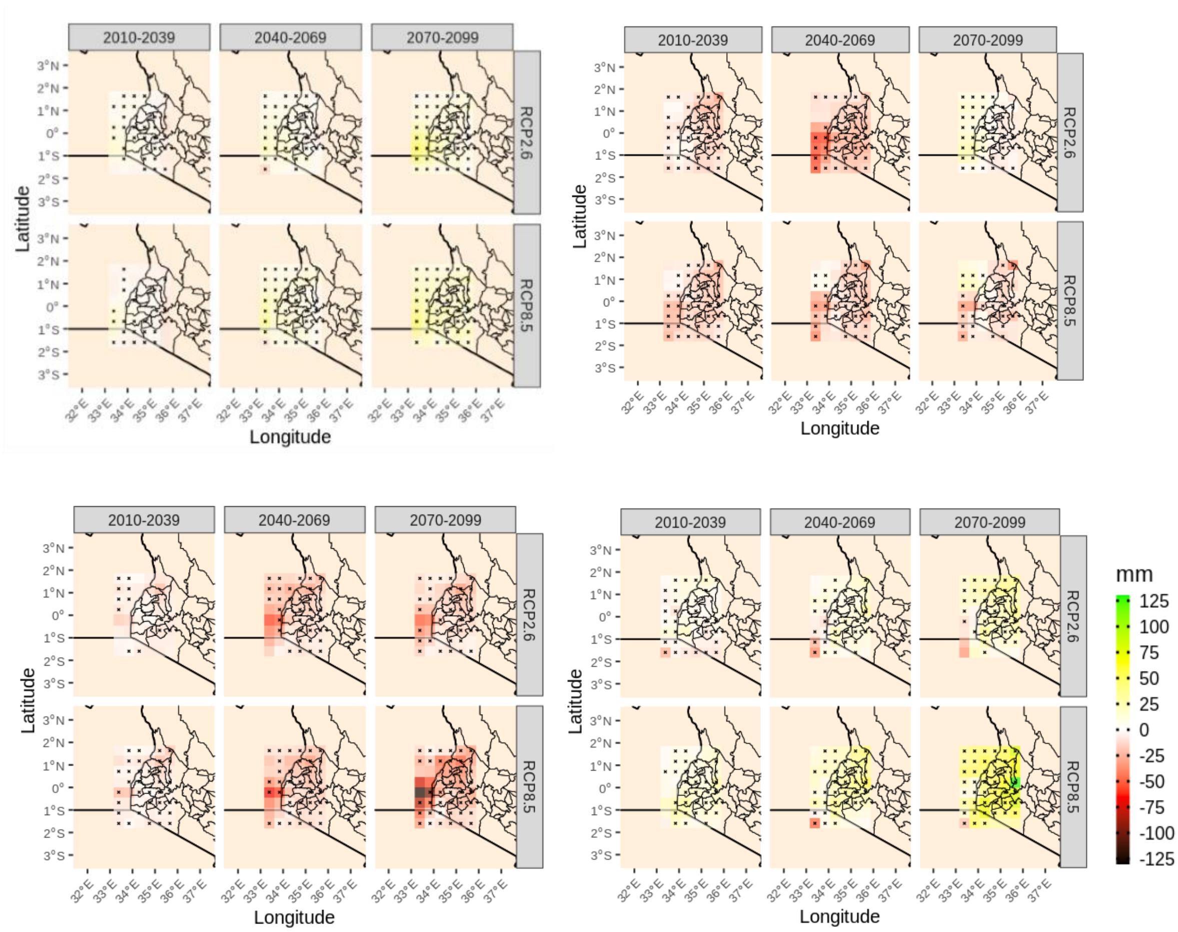


Figure 18. Climate change signal in seasonal precipitation in the Lake Region Economic Bloc (Upper-left: JF; upper-right: MAM; bottom-left: JJAS; bottom-right: OND) (Average of 6 CORDEX-CORE simulations) with respect to the baseline period (1976-2005).[66]

39. To further validate the findings of this document, the time of emergence of the climate change signal[67] is calculated to define the time in which precipitation changes can be attributed to climate change. The climate change signal (delta from the historical period, 1976-2005) emerges from the noise (inter-model variation), when the mean climate change signal stays consistently (for at least 5 consecutive years) above or below the inter-model variation (mean/SD > or < 1). Therefore, the time of emergence predicts when climate change will become stronger than the differences between climate models. According to this, the time of emergence of the climate change signal in a decrease in total precipitation during the MAM season is projected by 2060s under RCP2.6 and by 2040s under RCP8.5 in eastern-most counties (Figure 19).

[66] The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

[67] Rojas, Maisa, Fabrice Lambert, Julian Ramirez-Villegas, and Andrew J. Challinor. 2019. 'Emergence of Robust Precipitation Changes across Crop Production Areas in the 21st Century'. *Proceedings of the National Academy of Sciences* 116 (14): 6673–78. https://doi.org/10.1073/pnas.1811463116.

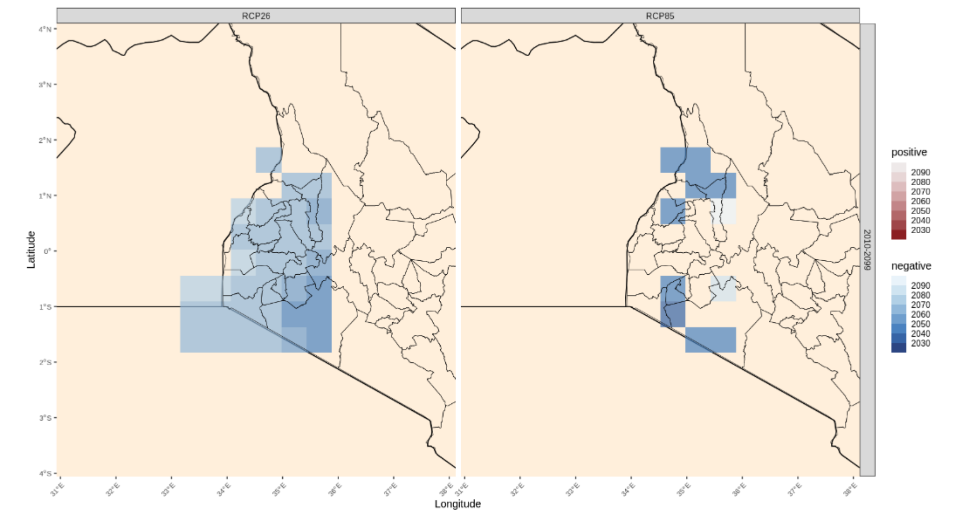


Figure 19. Time of emergence of the climate change signal in total precipitation during the MAM season. Pixels coloured in red indicate in which year total annual precipitation is expected to consistently emerge from the noise (inter-model differences) for positive values, hence an increase in precipitation. Blue pixels indicate the opposite, thus when and whether it is expected to witness a decrease in precipitation.[68]

5.3. Extreme weather events

5.3.1. Temperature

40. There is a high model agreement in the number of extreme heat days (Tmax>35°C) remaining stable compared to the baseline period (1981-2010) (around 20 days/yr) under RCP2.6 from the near- to long-term (Figure 20), with the maximum duration of heat spells lasting up to 10 days. The number of extreme heat days (Tmax>35°C) is projected to increase under RCP8.5, reaching 20 days in the mid-term (with a maximum duration of heat spells ranging between 10 and 20 days) and up to 50 days by end-century (with a maximum duration of heat spells ranging between 20 and 40 days), except for the high-altitude counties of Bomet, Nandi, Kericho, and Trans-Nzoia.

[68] The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

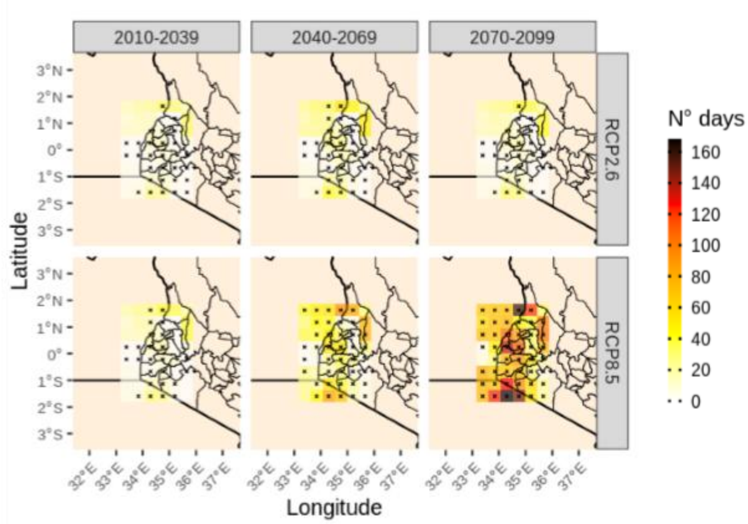


Figure 20. Climate change signal in extreme temperatures (Tmax>35°C) in the Lake Region Economic Bloc. The plot indicates the overall difference in days with extreme temperatures (average of 6 CORDEX-CORE simulations) from the historical period (1976-2005).[69]

5.3.2. Precipitation

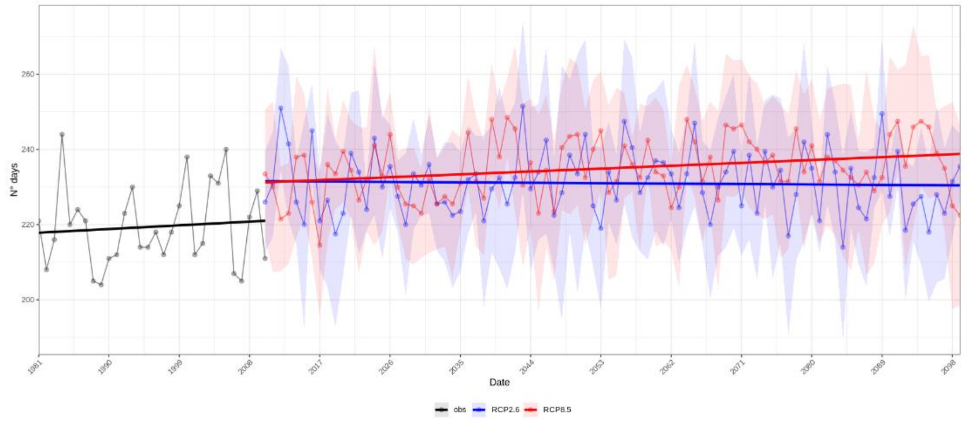
Dry spells

41. In alignment with Sagero et al. (2021)[70]'s study, FAO estimations show an increase in the annual number of dry days in the LREB by 10 days by mid-century under RCP2.6, and by 10 to 20 days from mid- to end-century under RCP8.5 with respect to the average annual number of 150 to 200 dry days in the baseline period (1981-2010) (Figure 21). In addition, the annual maximum length of consecutive dry days is projected to increase by up to 10 days by the mid- to end-century under RCP8.5 with respect to the maximum length of 20 consecutive dry days in the baseline period. Furthermore, the climate change signal in the increased number of dry days per year is projected to emerge by 2030-2040 under RCP2.6 in southern and northern areas of the LREB, and under RCP8.5 throughout the region (Figure 22).

42. The number of dry days during the MAM season is projected to increase by 5 days under RCP2.6 and RCP8.5, reaching 18-20 dry days in the northern counties, and 12-16 days in southern and central counties. The climate change signal in the increased number of dry days during the MAM season, is projected to emerge by 2040s under RCP2.6 in southern and northern areas of the LREB, and under RCP8.5 throughout the region (Figure 22). During the JJAS season, the number of dry days is expected to reach 15 days in northern and central counties, and 30 days in southernmost counties under RCP8.5.

[69] The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

[70] Sagero, P.O., Shisanya, C.A. and Makokha, G. 2021. Projected Changes in Rainfall and Temperature Extremes Over Kenya. Research Square.

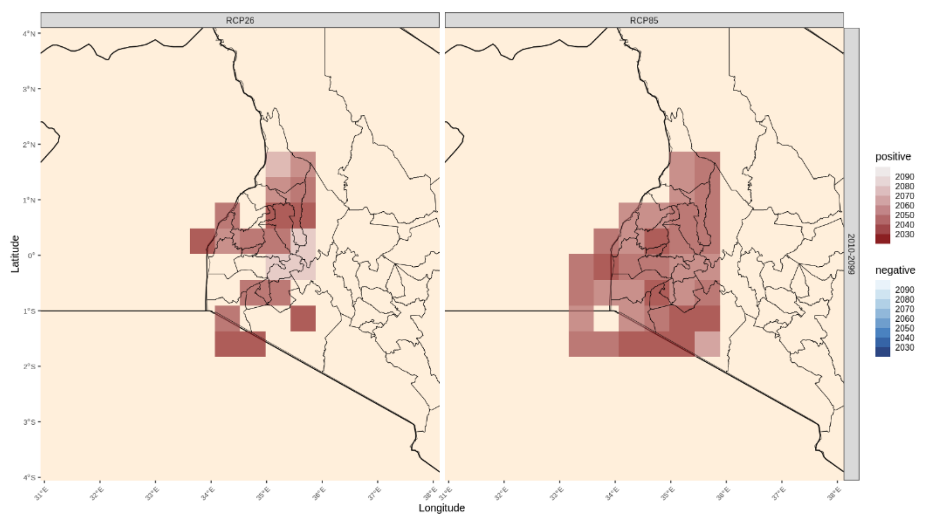


	slope	p.value
obs	0.11	0.64

	slope	p.value
RCP2.6	-0.01	0.72

	slope	p.value
RCP8.5	0.08	0.01

Figure 21. Historical and bias-corrected projected trends in the number of dry days per year over the 21st century from historical period (1981-2010). A multi model ensemble mean of 6 CORDEX-CORE simulations is used for future simulations. The figure shows the average trends for the two RCPs originating from the GCMs and RCMs ensemble, as well as the maximum and minimum extremities of the projected number of heavy rainfall events as detected by individual GCMs with a standard deviation of 80%.



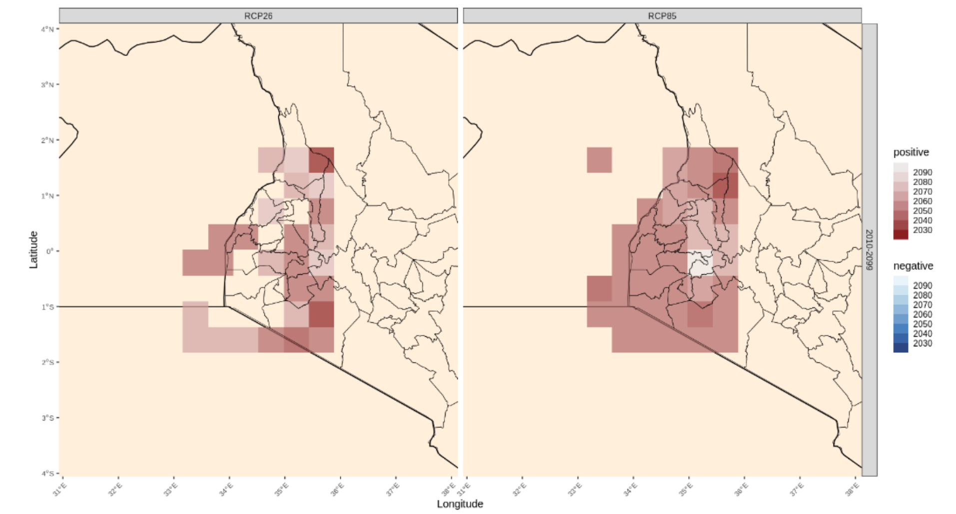


Figure 22. Time of emergence of the climate change signal in the number of dry days per year (top) and per MAM season (bottom). Pixels colored in red indicate in which year the number of dry days is expected to consistently emerge from the noise (inter-model differences) for positive values. Blue pixels indicate the opposite, thus when and whether is expected to witness a decrease in the number of dry days.[71]

Heavy rainfall events

43. FAO results project an increase in the annual number of heavy rainfall events (pr>20mm/day) reaching an average of 10 days (varying between 5 and 15 days per year), with an average length of 2-3 consecutive heavy rainfall events by mid-century, and up to 20 days by end-century, compared to the average annual number of 3-7 heavy rainfall events during the baseline period (1981-2010), under both RCP2.6 and RCP8.5 (Figure 23).

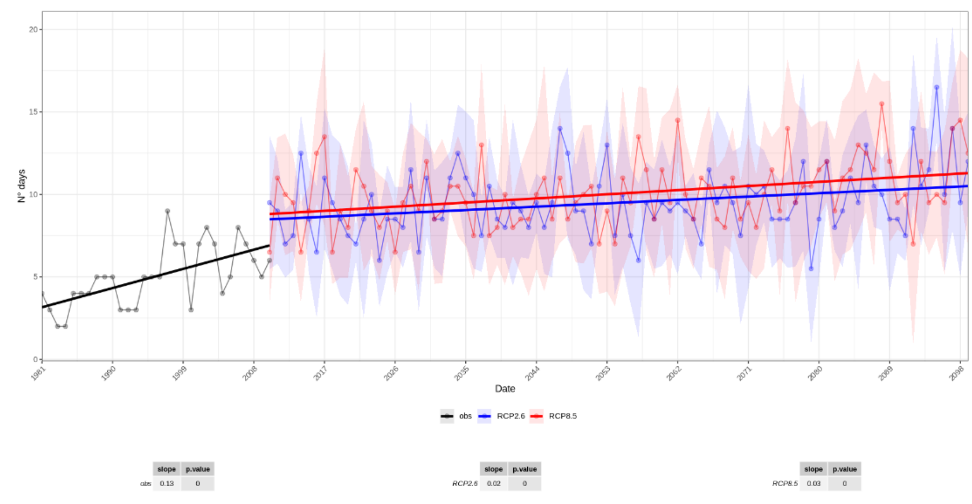


Figure 23. Historical and bias-corrected projected trends in the number of heavy rainfall events per year over the 21st century from historical period (1981-2010). A multimodel ensemble mean of 6 CORDEX-CORE simulations is used for future simulations. The figure shows the average trends for the two RCPs originating from the GCMs ensemble, as well as the interannual heavy

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rainfall variability through maximum and minimum extremities of the projected number of heavy rainfall events as detected by individual GCMs with a standard deviation of 80%.

6. Climate exposure and vulnerability

6.1. Livelihoods' exposure to observed high-impact events

44. The LVB is highly exposed to increasing temperatures and interannual rainfall anomalies resulting in dry spells and drought events as well as unpredictable and extreme rainfall and flooding events, which cause compounded socio-economic impacts across the country worth around 8% of the GDP every five years[72]. The International Disasters database (EMDAT) (2022)[73] reports the series of natural disasters occurring in Kenya, with a focus on the LREB, from 1960s to 2022 (Figure 24 and Table 3).

Livelihoods' exposure to drought

45. Drought conditions in East Africa have been particularly driven by a significant decrease in rainfall during the long rainy MAM season from -14 to -65mm per decade since 1980s[74]. Recent observed climate trends in the LREB are supported by the literature, according to which the LREB experienced drought periods in 1983-84, 2008, and 2011, coinciding with La Niña events as identified by the NOAA[75]. The severe and prolonged drought in Kenya in 2008–2011 affected 3.7 million people, causing damages and losses worth $12.1 billion, and recovery and reconstruction needs over $1.7 billion[76]. Counties in the LREB not historically drought-prone compared to the arid and semi-arid regions of the country such as Bomet, Kisumu, Busia, Kakamega, and Homa-Bay were also affected by the drought occurring in 2016 until 2018[77].

Livelihoods' exposure to flooding

46. Extreme flooding events in Kenya are linked to the ESNO phenomenon and occur every 3-4 years on average. At the same time, the LREB is particularly exposed to seasonal flooding during the long and short rainy seasons, causing high levels of mortality[78]. Riverine floods are the most common in Kenya (Figure 24), and responsible for GDP losses of up to 5.5%, and of 60% of weather-related casualties such as waterborne diseases[79] and landslides. The country, however, is ill-equipped with climate-proofed roads, bridges, dams, and water pipelines infrastructure to limit flooding impacts. Flooding

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[72] World Bank Group. WBG. 2021. Climate Risk Profile: Kenya (2021): The World Bank Group. https://climateknowledgeportal.worldbank.org/sites/default/files/2021-05/15724-WB_Kenya%20Country%20Profile-WEB.pdf

[73] EM-DAT. 2022. The International Disaster Database. https://www.emdat.be/

[74] Maidment, R. I., Allan, R. P., and Black, E. (2015), Recent observed and simulated changes in precipitation over Africa, *Geophys. Res. Lett.*, 42, 8155– 8164, doi:10.1002/2015GL065765.

[75] NOAA. 2022. Multivariate ENSO Index Version 2 (MEI.v2). https://psl.noaa.gov/enso/mei/

[76] World Bank Group. WBG. 2021. Climate Risk Profile: Kenya (2021): The World Bank Group. https://climateknowledgeportal.worldbank.org/sites/default/files/2021-05/15724-WB_Kenya%20Country%20Profile-WEB.pdf

[77] Kenya Meteorological Department, 2021. Extreme climate events in Kenya 2011 to 2020. https://meteo.go.ke/sites/default/files/downloads/STATE%20OF%20THE%20%20CLIMATE%202020_14042021.pdf https://meteo.go.ke/sites/default/files/downloads/Extreme%20Climate%20Events_Kenya%202011_to_2020.pdf

[78] Parry et al. 2012. Climate Risks, Vulnerability and Governance in Kenya: A review. UNDP.

[79] Kenya National Adaptation Plan: 2015-2030, Government of Kenya, July 2016. https://www4.unfccc.int/sites/NAPC/Documents%20NAP/Kenya_NAP_Final.pdf

events are responsible for the highest livelihood losses in the country, with key counties in the LREB[80]. According to the EMDAT database, heavy rains during the long rainy season were the primary cause for the occurrence of riverine and flash floods, and associated storms, landslides, as well as water-borne disease outbreaks in LREB (Table 3).

47. According to the Kenya Red Cross Society, a flooding event in 2013 resulted in the displacement of 4000 households, the spread of poverty, the destruction of building and road infrastructure, the deaths of 10 people in April, and the deaths of 50 people by the end of the OND season[81]. The coastal, central, and western regions were hardest hit. Due to severe rains, riverbanks (Tana, Nyando, Nzoia, and Ewaso Nyiro) overflowed, resulting in more displacements in the flood plains. A flooding incident was reported in Siaya County in April 2015, as well as throughout the brief rainy season, mainly in Migori County. This flooding was brought on by severe rains brought on by a strong positive El Nio event, which resulted in dams collapsing and the loss of livelihoods downstream. During the MAM season in 2018, flooding events due to heavy rainfall caused deaths in Kisumu County and displacements countrywide[82]. Tropical cyclones such as Idai and Kenneth in 2019 contributed to sudden-late onsets of the MAM rainy season, an increase in consecutive heavy rainfall events and thunderstorms, and flooding events. Their impacts were exacerbated by El Niño and Madden Julian Oscillations as well as anthropogenic drivers of urbanization (causing reductions in water infiltration and increases in downstream flow of rainwater).

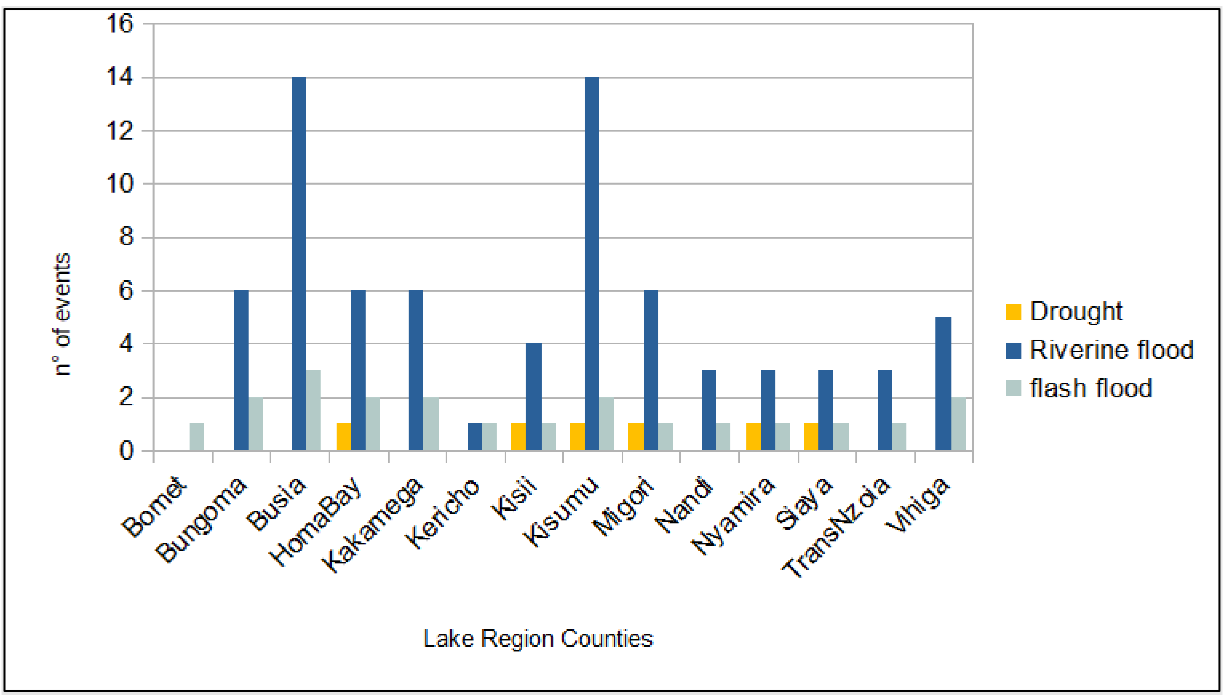

Figure 24. Climatological (drought) and hydrological (riverine flood and flash flood) events in the Lake Region Economic Bloc observed between 2000 and 2022. Source: EMDAT database (2022).

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[80] World Bank Group. WBG. 2021. Climate Risk Profile: Kenya (2021): The World Bank Group. https://climateknowledgeportal.worldbank.org/sites/default/files/2021-05/15724-WB_Kenya%20Country%20Profile-WEB.pdf

[81] Kenya Meteorological Department, 2021. Extreme climate events in Kenya 2011 to 2020. https://meteo.go.ke/sites/default/files/downloads/STATE%20OF%20THE%20%20CLIMATE%202020_14042021.pdf

[82] Kenya Meteorological Department, 2021. Extreme climate events in Kenya 2011 to 2020. https://meteo.go.ke/sites/default/files/downloads/STATE%20OF%20THE%20%20CLIMATE%202020_14042021.pdf

Table 3. Climatological, hydrological, and biological disasters in the Lake Region Economic Bloc. Source: EMDAT (2022)[83].

Disaster Type	Start-End	Counties/districts affected in the Lake Region Economic Bloc	Total Deaths	Total Affected
Flood	5/1964	Nyanza, Western Regions		15,000
Flood	5/1968	Nyanza, West provinces		
Drought	1/1971	Countrywide		150,000 (Countrywide)
Flash flood	10/1982	Near Lake Victoria	75	3,000
Parasitic disease	1/1994	Kisii, Nyamira, Narok, Kuria districts	1,000	6,500,000
Heavy rain - Riverine flood	4/1996	Nyanza province		1,000
poor sanitation, lack of safe water and socio-cultural factors – Bacterial disease	6/1997-10/1997	Nyatike Division (Migori District), Rachuonyo, Suba, Homa Bay and Kisumu District (Nyanza province) and Molo (Nakuru)	140	2,360
Bacterial disease	1/1997-12/1998	Migori, Rachuonyo, Suba, Homa Bay, Nyando, Kisumu districts	555	17,200
Flood	5/1998	Lake Victoria	40	200
Parasitic disease	6/1999	Kisii, Mt. Elgon, southwestern highlands	563	306,352
Heavy rain – Riverine flood - Slide (land, mud, snow, rock)	4/2002-5/2002	Migori, Kisumu, Nyando, Rachuonyo districts (Nyanza province), Busia districts (Western province)	53 (Countrywide)	150,008 (countrywide)

[83] EM-DAT. 2022. The International Disaster Database. https://www.emdat.be/

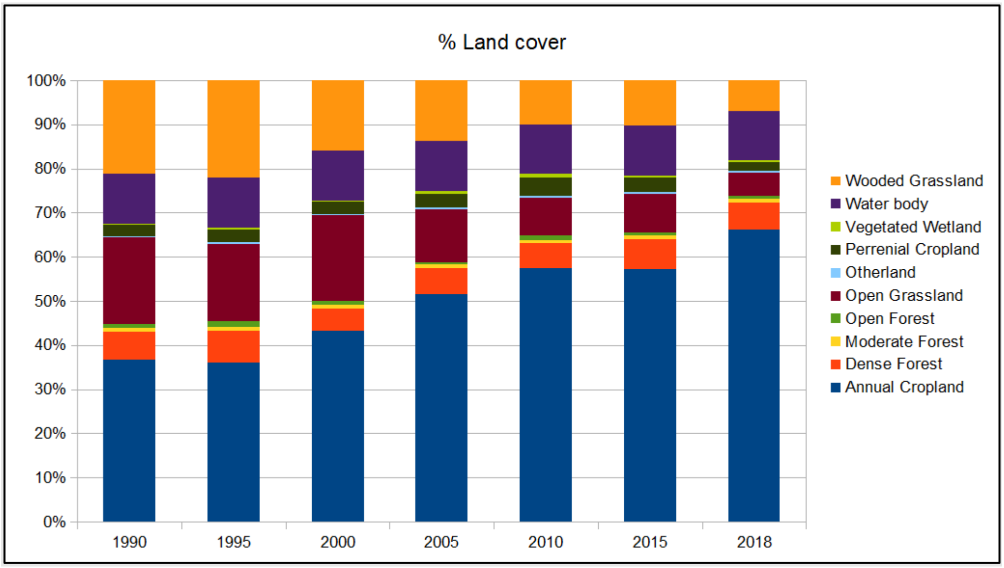
Disaster Type	Start-End	Counties/districts affected in the Lake Region Economic Bloc	Total Deaths	Total Affected
Heavy rain – Riverine flood - Slide (land, mud, snow, rock) Broken Dam/Burst bank	4/2003-5/2003	Nyando, Kisumu, Rachuonyo, Migori districts (Nyanza province), Busia district (Western province)	40	60,000
Heavy rain – Riverine flood	1/2003	Kisumu district (Nyanza province)		300
Heavy rain – Riverine flood - Slide (land, mud, snow, rock)	4/2004-5/2004	Nyamira, Nyando, Rachuonyo, Kisumu, Migori, Homa Bay districts (Nyanza province)	50 (Countrywide)	10,000 (Countrywide)
Heavy rain – Flash flood	4/2004	Nyando district (Nyanza province), Busia district (Western province)	4	2,000
Bacterial disease from Water source	5/2004-7/2004	Bungoma	8	141
Heavy rain – Flash flood	4/2005	Western, Nyanza provinces	1 (Countrywide)	25,000 (Countrywide)
Heavy rain – Flash flood	5/2005	Western provinces	5 (Countrywide)	10,000 (Countrywide)
Heavy rain – Riverine flood	6/2005	Bukhay, Walwasi areas (Busia district, Western province)	20	1,200
Heavy rain – Riverine flood	4/2006-5/2006	Nyanza, Western provinces	8 (Countrywide)	13,000 (Countrywide)
Torrential rain – Riverine flood	10/2006-12/2006	Busia district (Western province), Kisumu district (Nyanza province)	114 (Countrywide)	723,000 (Countrywide)
Heavy rain – Riverine flood - Broken Dam/Burst bank	8/2007-10/2007	Busia district (Western province)	13	40,000
Heavy rain – Landslide/Mudslide	8/2007	Kuvasali village (Kakamega district, Western province)	20	6

Disaster Type	Start-End	Counties/districts affected in the Lake Region Economic Bloc	Total Deaths	Total Affected
Heavy rain – Riverine flood - Slide (land, mud, snow, rock)	11/2008	Busia district (Western province), Migori, Nyando districts (Nyanza province)	17 (Countrywide)	30,770 (Countrywide)
Poor sanitation and hygiene – Bacterial disease	1/2009-5/2009	Busia, Bungoma, Siaya, Kisumu West districts	201 (Countrywide)	10,048 (Countrywide)
El Niño, exceptional heavy rains – Riverine flood - Slide (land, mud, snow, rock)	10/2009-11/2009	Nyanza, Western provinces	16 (Countrywide)	44,850 (Countrywide)
Heavy rain – Riverine flood - Slide (land, mud, snow, rock)	12/2009-1/2010	Nyando district (Nyanza province), Homa Bay district (Nyanza province)	40 (Countrywide)	91,350 (Countrywide)
Riverine flood	5/2010	Western provinces	100 (Countrywide)	70,000 (Countrywide)
Heavy rain – Riverine flood	8/2011-9/2011	Kisumu town (Kisimu district, Nyanza province)	8 (Countrywide)	4,000 (Countrywide)
Heavy rain and storms – Riverine flood	11/2011-12/2012	Busia, Kakamega districts (Western province), Siaya, Kisumu, Rachuonyo, Central Kisii districts (Nyanza province)	25 (Countrywide)	91,692 (Countrywide)
Torrential rain – Riverine flood	4/2012-5/2012	Homa Bay, Kisumu, Suba, Nyando, Rachuonyo, Migori districts (Nyanza province), Busia district (Western province)	73 (Countrywide)	280,670 (Countrywide)
Heavy rain – Riverine flood - Slide (land, mud, snow, rock)	3/2013-4/2013	Kisumu district (Nyanza province), Western provinces	96 (Countrywide)	100,020 (Countrywide)
Heavy rain – Riverine flood	1/2013	Nandi North, Nandi South, Trans Nzoia, Nyando, Kisumu districts (Nyanza province)	18 (Countrywide)	10780 (Countrywide)

Disaster Type	Start-End	Counties/districts affected in the Lake Region Economic Bloc	Total Deaths	Total Affected
Bacterial disease	12/2014-5/2016	Homa Bay, Migori, Bomet, Kisii districts	72 (Countrywide)	3,459 (Countrywide)
Torrential rain – Flash flood	4/2015	Homa Bay district (Nyanza province)	13	1,500
Heavy rain – Riverine flood	4/2015-5/2015	Kisumu, Central Kisii, Homa Bay districts (Nyanza province)	13 (Countrywide)	3,000 (Countrywide)
Heavy rain – Riverine flood	12/2015-1/2016	Mt Elgon, Busia, Bungoma districts (Western province), Kisumu district (Nyanza province), Nandi North, Nandi South, Trans Nzoia districts (Rift Valley province)	112 (Countrywide)	240,799 (Countrywide)
Heavy rain – Riverine flood	5/2017	Western regions	26 (Countrywide)	25,000 countrywide)
Heavy rains – Flood	3/2018-5/2018	Kisumu	72 (Countrywide)	211,188 (Countrywide)
Flash flood - Slide (land, mud, snow, rock)	10/2019-12/2019	Trans-Nzoia, Nandi, Kakamega, Bungoma, Siaya, Kisumu, Homa Bay counties	90 (Countrywide)	233,339 (Countrywide)
Heavy rains – Flood - Slide (land, mud, snow, rock)	4/2020-6/2020	Kisumu, Homabay, Siaya, Kakamega, Bomet counties	285 (Countrywide)	810,655 (Countrywide)
Long Rains season – Flood	4/2021-5/2021	Busia, Kisumu, Homa Bay, Migori, Siaya Counties	9 (Countrywide)	300,000 (Countrywide)

6.2. Anthropogenic drivers of exposure and vulnerability

48. The impacts of inter-related climate hazards are exacerbated by anthropogenic pressure on key socio-economic activities in the region, such as deforestation, land use changes, urbanization, and weak water management systems and pollution[84] leading to losses in biodiversity and ecosystems diversification, Flooding impacts e are exacerbated by land quarrying, sand harvesting, and wetland drainage to support the development of agriculture, which frequently increase[85],[86],[87],[88]. Figure 25 and Figure 26 also showcases changes in land cover from 2000 to 2020 in the LREB. Hotspots of deforestation are detected in the southern areas of the LREB where tree cover shrunk to provide space to cropland.



[84] World Bank Group. WBG. 2021. Climate Risk Profile: Kenya (2021): The World Bank Group. https://climateknowledgeportal.worldbank.org/sites/default/files/2021-05/15724-WB_Kenya%20Country%20Profile-WEB.pdf

[85] Agol D, Reid H, Crick F,Wendo H. 2021 Ecosystem-based adaptation inLake Victoria Basin; synergies and trade-offs.R. Soc. Open Sci.8: 201847.https://doi.org/10.1098/rsos.201847

[86] Nyberg, Y., Wetterlind, J., Jonsson, M. and Öborn, I. (2021) Factors affecting smallholder adoption of adaptation and coping measures to deal with rainfall variability. International Journal of Agricultural Sustainability 19:2, pages 175-198.

[87] Parry et al. 2012. Climate Risks, Vulnerability and Governance in Kenya: A review. UNDP.

[88] Gabrielsson et al. 2013. Living without buffers-illustrating climate vulnerability in the Lake Victoria basin. Sustain Sci, 8:143-157. DOI 10.1007/s11625-012-0191-3

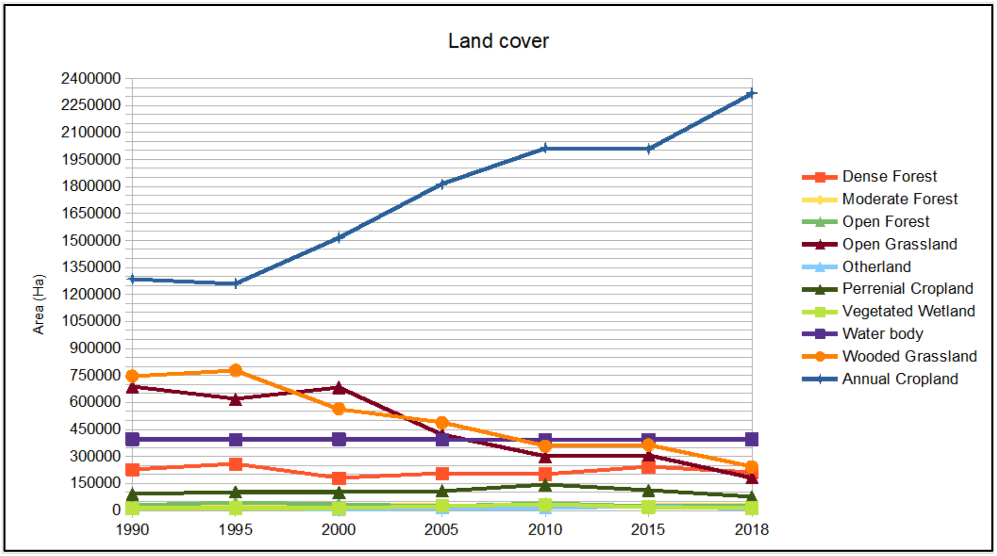


Figure 25. Land cover changes in hectares (upper figure) and as % (bottom figure) in the Lake Region Economic Bloc. Source: Kenya's Directorate of Resource Survey and Remote sensing.

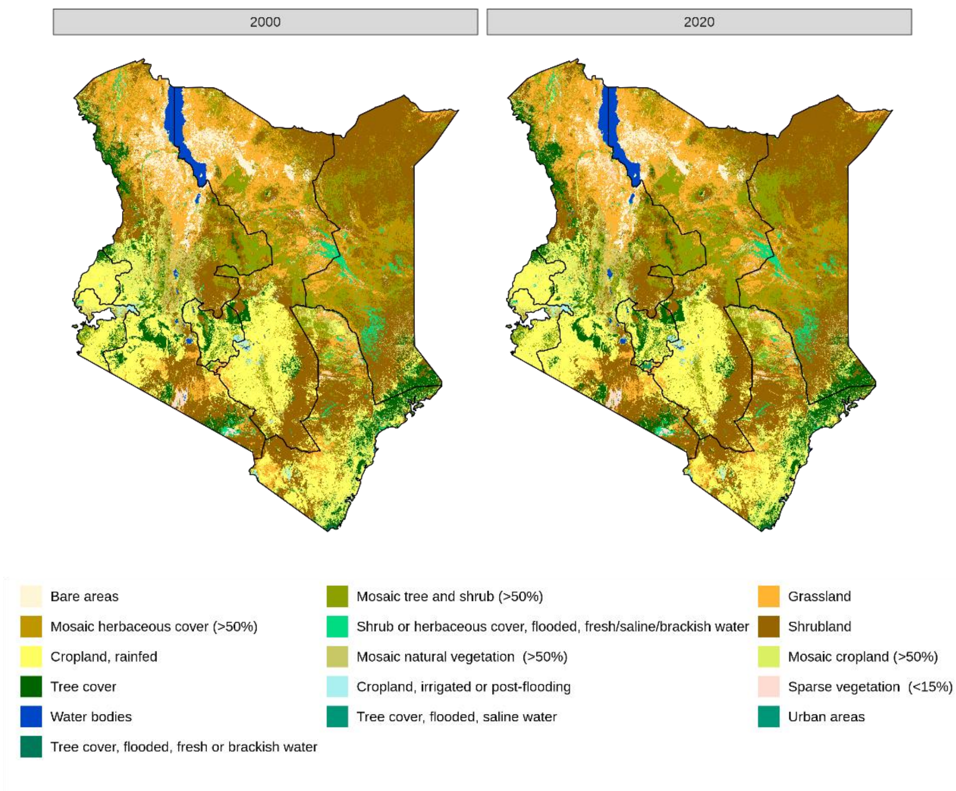


Figure 26. Copernicus land cover classification gridded maps in 2000 and 2020 derived from satellite observations at 300 m resolution[89]. Figure produced by FAO.[90]

6.3. Farmers' vulnerability

49. Overall, the agriculture sector is primarily rainfed, thus extremely vulnerable to changing inter-annual precipitation conditions which cause crop failures and production declines, undermining the objectives to develop sustainable agricultural practices[91]. Farmers' vulnerability to climate change is primarily driven by poorly diversified incomes, limited access to appropriate technologies and climate information, limited purchasing power for agricultural input and erratic access to water, exacerbating yield losses due to extreme weather events. The local adaptive capacity is low, as most smallholder farmers are producing on small areas of land with limited means, and without the risk reducing mechanisms to make more appropriate climate-informed production choices. According to a survey conducted in Kakamega and Vihiga counties in the LREB, smallholder farmers strongly rely on rainfed and seasonal as well as informal agricultural activities, thus do not have access to stable financial resources and credits from public or private supporting institutions[92]. The small sizes of the owned lands are also key factors undermining the access to agricultural credits. Therefore, they are

[89] Copernicus Climate Change Service, Climate Data Store, (2019): Land cover classification gridded maps from 1992 to present derived from satellite observation. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). (Accessed on DD-MMM-YYYY), 10.24381/cds.006f2c9a

[90] The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

[91] World Bank Group. WBG. 2021. Climate Risk Profile: Kenya (2021): The World Bank Group. https://climateknowledgeportal.worldbank.org/sites/default/files/2021-05/15724-WB_Kenya%20Country%20Profile-WEB.pdf

[92] Karugia et al. 2005. The Role of Rural Factor Markets in Reducing Poverty, Risks and Vulnerability in Rural Kenya: The Case of Kakamega and Vihiga Districts. Strategies and Analysis for Growth and Access.

particularly vulnerable to interannual rainfall variability and oscillating crop yield and livestock production trends, resulting in unstable and unreliable incomes. Overall, increasing rainfall variability has led 10% of the population in the Lake Victoria Basin to suffer chronic food insecurity, requiring short-term emergency food relief and long-term development programs[93]. Since the LREB is the main agricultural region in Kenya and the largest source of freshwater in a semi-arid region, transforming the agriculture sector in the LREB towards sustainable and climate resilient pathways is fundamental and beneficial for the entire country's economy.

6.4. Vulnerabilities across selected food value chains

Farmers' socio-economic vulnerability exacerbating climate impacts to each food value chain in the LREB are further summarized in Table 4 below.

[93] USAID. 2018. Lake Victoria Basin: Climate Change Adaptation Strategy and Action Plan, 2018 - 2023. Retrieved from: https://www.climatelinks.org/sites/default/files/asset/document/2018_USAID-PREPARED_Lake-Victoria-Basin-Adaptation-Strategy-Action-Plan.pdf

Table 4. Farmers' vulnerabilities along each selected food value chain in the LREB. Sources: [94], [95], [96], [97], [98], [99], [100], [101], [102], [103], [104], [105], [106], [107], [108].

Value chain	Socio-economic Vulnerabilities
All value chains	• Limited land ownership and access to technologies, and capacity to adopt climate resilient practices along the value chains, particularly among women and youth; • Population growth, pressure on land and land fragmentation, reliance on erratic rainfall, weak farming methods leading to unsustainable land use (e.g., soil erosion through cultivation in riverbanks, deforestation, use of chemical inputs); • Weak post-harvest and value adding facilities/activities (roads, electricity, cold chain technologies, use of stable water resources), including limited access to climate, agricultural, and market information, advisory, and networks; • Low incomes combined with expensive farming technologies (e.g., irrigation); • Limited financial resources to access climate resilient technologies; • Limited impact of climate policies and regulations at the farm level; • Limited support from funds, and extension services to enhance the resilience of agricultural development, for example through engagement in post-harvest activities and training.

[94] CGIAR-CIAT. Ministry of Agriculture, Livestock, Fisheries and Cooperatives. 2022. Kenya County Climate Risk Profiles. https://ccafs.cgiar.org/resources/publications/kenya-county-climate-risk-profiles

[95] International Livestock Research Institute (ILRI). 2020. Food safety landscape analysis: The dairy value chain in Kenya. https://cgspace.cgiar.org/bitstream/handle/10568/108989/Food%20safety%20Kenya%20dairy%20value%20chain.pdf?sequence=1

[96] Feliciano, R.J.; Boué, G.; Membré, J.-M. Overview of the Potential Impacts of Climate Change on the Microbial Safety of the Dairy Industry. Foods 2020, 9, 1794. https://doi.org/10.3390/foods9121794

[97] Guzmán- Luna et al., 2021. Analysing the interaction between the dairy sector and climate change from a life cycle perspective: A review. Trends in Food Science & Technology. 126.

[98] Ngigi, M.W., Mueller, U. & Birner, R. Livestock Diversification for Improved Resilience and Welfare Outcomes Under Climate Risks in Kenya. Eur J Dev Res 33, 1625–1648 (2021). https://doi.org/10.1057/s41287-020-00308-6

[99] Kennedy et al. 2022. Review Article: Heat stress and poultry: Adaptation to climate change, challenges and opportunities for genetic breeding in Kenya. Journal of Agriculture, Science and Technology. DOI: 10.4314/jagst.v21i1.6

[100] Okigbo, Raphael & Chiamaka Frances, Ejimofor. (2021). UNDERUTILIZED PLANTS OF AFRICA. 2395-5384.

[101] Shayanowako, A.I.T.; Morrissey, O.; Tanzi, A.; Muchuweti, M.; Mendiondo, G.M.; Mayes, S.; Modi, A.T.; Mabhaudhi, T. African Leafy Vegetables for Improved Human Nutrition and Food System Resilience in Southern Africa: A Scoping Review. Sustainability 2021, 13, 2896. https://doi.org/10.3390/su13052896

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[103] Jayasinghe, S.L.; Kumar, L. Potential Impact of the Current and Future Climate on the Yield, Quality, and Climate Suitability for Tea [Camellia sinensis (L.) O. Kuntze]: A Systematic Review. *Agronomy* 2021, *11*, 619. https://doi.org/10.3390/agronomy11040619

[104] United Nations Industrial Development Organization. 2017. Adaptation and mitigation in the Kenyan tea industry. https://open.unido.org/api/documents/5239228/download/2.Value%20chain%20vulnerability-Kenya%20country%20report.pdf

[105] International Coffee Organization. 2019. Country Coffee Profile: Kenya. https://www.ico.org/documents/cy2018-19/icc-124-7e-profile-kenya.pdf

[106] Aragie, E. (2018). Identifying opportunities for value chain development in the Kenyan coffee sector: A modelling approach. *Outlook on Agriculture*, *47*(2), 150–159. https://doi.org/10.1177/0030727018766956

[107] Nyagwansa, Rose & Ochola, Washington & Odhiambo, Judith & Bunyatta, David & Omweno, Job. (2021). East African Scholars Journal of Agriculture and Life Sciences Abbreviated Key Title: East African Scholars J Agri Life Sci Effectiveness of Selected Advisory Channels on Safe Use of Pesticides among the Small Holder Kale Farmers, A case of Kisii County, Kenya. 4. 151-156. 10.36349/easjals.2021.v04i06.003.

[108] Nabiswa, P. Koyi and Wakhungu, J.W. 2018. MARKETING FRAMEWORK IN THE DAIRY VALUE CHAIN FOR FOOD SECURITY AND SUSTAINABLE DEVELOPMENT IN BUNGOMA COUNTY, KENYA. Global Journal of Agricultural Research Vol.6, No.3, pp.40-61.

Value chain	Socio-economic Vulnerabilities
Tea	• Inconsistent use of fertilizers between and within regions per hectare, affecting the yields, income, as well as fertility of soils; • Weak post-harvest infrastructure for tea transportation and processing and regulations on tea pricing; • Low access to weather-informed agricultural advisory; • Limited diversification practices; • Incapacity to fully meet labor requirements due to labor-intensive activities required for tea growing and harvesting and limited time allocated to tea production; • Lack of access to technologies and suitable management practices among smallholders compared to large-scale plantations; • Farmers' challenges to adopt new tea varieties, such as limited land availability, lack of access to extension services, training, credit, and limited market networks; • Disincentives in shifting to high-yielding clones due to long gestation periods, particularly without access to income safety nets; • Increasing future need to use pesticides due to a risk of pests and disease outbreaks as a result of climate change; • Overall lower yield performance among women and youth farmers is also due to lower access to climate information and agricultural knowledge exchange compared to male farmers; • Reduced global tea products' prices. Barriers for farmers to set appropriate prices based on quantity and quality of yields, which instead are set by tea processing factories.
Coffee	• Disincentives in effective application of fertilizers and control coffee diseases among farmers due to low, uncertain, and slow (up to six months after the coffee is sold) payments by traders combined with high costs for inputs and limited support from extension services, leading farmers to invest in other crops or dairy production to reduce risk of income losses. In some cases, coffee plants get uprooted; • Limited availability of more affordable organic fertilizers such as manure, as well as seedlings, and pesticides; • Use of inadequate picking techniques such as strip picking technique, reducing the overall quality of coffee cherries compared to selective picking methods; • Approximative drying and processing methods applied by farmers after harvest reducing coffee quality.
Fruit trees (Avocado, Banana)	• Limited superior varieties or planting materials, pests and diseases (beetles and thrips for bananas) with a large proportion of harvest losses (e.g., in the case of avocado); • Limited access to early warning systems; • Weak infrastructure for post-harvest and off-farm activities leading to food losses and reduced prices (transportation, storage, packaging); • Low access among women, youth, and poor farmers to financial resources and credit to invest in climate-proofed technologies (e.g., greenhouses and irrigation, post-harvest facilities, cold chain technologies).
African Leafy Vegetables	• Lack of information on tailored climate-resilient agricultural practices and technologies; • Lack of information on market opportunities; • Lack of public and private investments and credits; • Limited access to agronomic packages; • Low communication between agricultural extension services and farmers/value chain actors; • Expensive agricultural inputs for production, increased prices at markets; • Limited access to extension services; • Fragmented and untracked value chain, lacking a proper product classification and evaluation; • Informal markets due to several challenges to enter formal markets because of the poor value-addition capacities of vegetable products, the lack of research and forecasts on demand and supply trends; • The informal value chain reduces farmers' opportunities in setting fair prices and engagement in markets.
Dairy	• Weak fodder and water management practices for livestock nutrition, favoring free-range production systems, combined with limited natural resources dedicated to grassland and pastureland;

Value chain	Socio-economic Vulnerabilities
	• Lack of climate-based insurance schemes and financial support such as subsidies; • Limited infrastructure for feed storage and transportation as well as for milk cooling, processing, packaging and storage; lack of milk cooling centers and stable energy supply that are close to production sites and between urban and rural areas, poor links of producers to processors as well as markets; most farmers are not involved in milk processing activities; • Lack of regulations on fair market prices; low market prices discouraging farmers from selling milk; • Farmers do not optimize their revenue since they sell milk to collection centers at lower prices compared to the returns from the final product sale; along informal value chains, prices are low, while payments are provided on the spot thus with limited regulations, and with direct drawbacks on the monitoring of sustainability and safety of the products; • Low tendency in acquiring membership in cooperatives which leaves farmers alone in finding profitable markets and increases the chances for farmers to join informal value chains and markets; • Limited access to and delays in veterinary and breeding services.
Poultry	• Limited access to adequate feed and water resources, high costs of production and prices of inputs (e.g., drugs, vaccines); • Limited extension services or veterinary services for smallholder farmers to build capacities on climate resilient practices and technology adoption; • Limited access to market information and financial support (e.g., subsidies); • Weak post-harvest infrastructure; • Primary interest for commercial poultry breeds rather than for the indigenous poultry; • Disinvestments in poultry compared to other livestock breeds among farmers due to price volatility in food and inputs and the tendency of using poultry for liquid-to-smooth consumption purposes rather than marketing; • Limited opportunities for value addition due to an overall preference for selling chicken meat rather than by-products; • Farmers' exploitation by middlemen resulting in limited market opportunities for farmers; • Limited farmers' engagement in markets contributing to post-harvest losses and low prices; • Limited support by farmers' cooperatives for marketing and bargaining, and low farmers' participation in cooperatives; • Limited access to affordable and profitable financial schemes such as credits and agricultural insurance to counteract climate-driven changes in yields and prices; • Extension services lacking knowledge of key risks to agriculture, such as climate change, exacerbating the lack of support to farmers in accessing climate risk-based financial schemes; • Limited large scale post-harvest processing facilities and technologies; • Scarce quality certification schemes, and value-addition practices.

7. Observed and projected climate impacts on selected agricultural systems

7.1. Climate impacts on crops

50. Kenya's LREB is facing impacts from increased temperatures and evapotranspiration rates, more frequent and consecutive dry days per year, as well as higher mean annual rainfall and increased flooding and runoff. Increasing temperatures cause high evaporation rates while dry spells reduce soil moisture and harden the surface layer as a result, during heavy rainfall events only a small fraction of water infiltrates the soil, consequently increasing water surface runoff and soil erosion, including macronutrient loss[109],[110]. With increasing intensity of seasonal and annual rainfall and combined with poor land management, the risk of flooding and landslide events is expected to increase over time. Extreme rainfall events will have detrimental impacts on soil erosion and water logging impacting agricultural productivity and the well-being of rural livelihoods. In addition, the length and intensity of the long rainy season (MAM), the primary growing season directly responsible for 26% of the GDP, as well as expected increases in maximum and lowest temperatures will have a substantial influence on Kenya's rainfed agricultural and economic systems[111],[112].

Observed and projected extreme temperature impacts on crops

51. Increased temperatures impact growth cycles of various crops, increase evapotranspiration rates, and crop water demand, while the increase in extreme heat events can also severely reduce productivity and cause partial crop loss. J. Oeching's et al.'s (2016)[113] model showed that under a scenario of a 1.0°C increase in surface temperatures in the 2020s, a 2.0°C in the 2030s, and 2.5°C in the 2040s, crop revenues in Kenya would be down by 14.2%, 14.8%, and by 15.2%, respectively. Declines in productivity are also expected to lead to significant losses in revenue for smallholder agri-businesses. A study on the economic impacts of climate change on crops in Kenya found that decreased productivity from increasing temperatures could range between 32$/ha and 178$/ha[114].

Observed interannual rainfall variability impacts on crops

52. Interannual rainfall variability and consequent wetter or drier conditions positively or negatively affect rainfed crop production performances through changes in soil moisture and impacts on soil erosion[115]. In this region, interannual rainfall variability is particularly influenced by ENSO and IOD phenomena. Overall, El Niño and a positive IOD bring wetter conditions as well as increased crop yields due to increased soil moisture and vegetation growth during the short rainy season (OND),

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[109]Wainwright, Caroline & Black, Emily & Allan, Richard. (2018). Later Wet Seasons with More Intense Rainfall over Africa under Future Climate Change. Journal of Climate. 31. 10.1175/JCLI-D-18-0102.1.

[110] Mwangi et al. 2020. Vulnerability of Kenya's Water Towers to Future Climate Change: An Assessment to Inform Decision Making in Watershed Management. American Journal of Climate Change. 9(3). DOI: 10.4236/ajcc.2020.93020

[111] Ayugi, Brian Odhiambo, Wang Wen and Daisy Chepkemoi. "Analysis of Spatial and Temporal Patterns of Rainfall Variations over Kenya." *Journal of environment and earth science* 6 (2016): 69-83.

[112] Kenya Meteorological Department, 2021. Extreme climate events in Kenya 2011 to 2020. https://meteo.go.ke/sites/default/files/downloads/STATE%20OF%20THE%20%20CLIMATE%202020_14042021.pdf

[113] Ochieng, J., Kirimi, L. and Makau, J. (2017), Adapting to climate variability and change in rural Kenya: farmer perceptions, strategies and climate trends. Nat Resour Forum, 41: 195-208. https://doi.org/10.1111/1477-8947.12111

[114] Kabubo-Mariara and Karanja. 2007. The Economic Impact of Climate Change on Kenyan Crop Agriculture: A Ricardian Approach. https://openknowledge.worldbank.org/bitstream/handle/10986/7276/wps4334.pdf?sequence=1&isAllowed=y

[115] Evans, W. Et al. 2020. The Spatial and Temporal Characteristics of Rainfall over the Lake Victoria Basin of Kenya in 1987-2016. Atmospheric and Climate Sciences. 10(2). DOI: 10.4236/acs.2020.102013

whereas La Niña and negative IOD cause dry conditions and yield decreases in the region[116]. La Niña events in 2003-2005 and 2017 increased NDVI anomalies in the LVB compared to above-average rainfall values in 2003. During the same years (2003-2005), drops in tea, coffee, and banana productivity were also reported by national statistics[117]. The El Niño event in 2015-2016 instead reduced NDVI anomalies although resulting in riverine and flash floods[118],[119]. In general, high interannual rainfall variability has significant effects on crop production, such as variations in yields based on years with reduced or enhanced precipitation, which increases uncertainties in the amount of rain received during each rainy season and complicates the decision on which agricultural management practices are best. Also, whereas crop productivity benefits overall from years with higher total annual precipitation, this gain is easily negated by the increasing temperatures that result in rising evapotranspiration rates[120].

Observed drought impacts on crops

53. From 1980 to 2022, drought periods were less frequent in the region, although their impacts were high based on the number of people affected, as well as on crop production levels. The severe drought between 1998 and 2000, caused damages to the agricultural sector and crop yields worth $2.8 billion[121]. The drought in 2004 affected 2,300,000 livelihoods countrywide causing crop failures and food shortages in Nyanza[122]. In 2008-2011, dry conditions in Kenya, combined with increased costs of agricultural inputs, led the agriculture sector to miss its annual growth rate by 7% (compared to the national GDP growth rate 1968-2012)[123]. From November 2016 to early 2017, Kenya was affected by a drought which resulted from La Nina phenomenon causing two relatively dry MAM and OND seasons in 2016, negatively affecting pasture and water resources. The drought period from 2020 to 2022 combined with the desert locust outbreak in 2020 increased acute food insecurity levels in many parts of the country by causing reduced livestock production and crop failures leading to increasing food prices[124],[125].

Observed heavy rainfall and flooding impacts on crops

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[116] Sazib Nazmus, Mladenova lliana E., Bolten John D. 2020. Assessing the Impact of ENSO on Agriculture Over Africa Using Earth Observation Data. Frontiers in Sustainable Food Systems. 4 https://www.frontiersin.org/articles/10.3389/fsufs.2020.509914

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[118] B. Morgan, J.L. Awange, A. Saleem, H. Kexiang. 2020. Understanding vegetation variability and their ‘‘hotspots’’ within Lake Victoria Basin (LVB: 2003–2018), Applied Geography, Volume 122, 102238, ISSN 0143-6228,

[119] Evans, W. Et al. 2020. The Spatial and Temporal Characteristics of Rainfall over the Lake Victoria Basin of Kenya in 1987-2016. Atmospheric and Climate Sciences. 10(2). DOI: 10.4236/acs.2020.102013

[120] Herreo, M. et al. 2010. Climate variability and climate change and their impacts on Kenya’s agricultural sector. International Livestock Research Institute. https://cgspace.cgiar.org/bitstream/handle/10568/3840/climateVariability.pdf

[121] World Bank Group. WBG. 2021. Climate Risk Profile: Kenya (2021): The World Bank Group. https://climateknowledgeportal.worldbank.org/sites/default/files/2021-05/15724-WB_Kenya%20Country%20Profile-WEB.pdf

[122] ReliefWeb. 2004. Kenya: Drought Emergency Appeal No. 18/2004 Operations Update No. 1. https://reliefweb.int/report/kenya/kenya-drought-emergency-appeal-no-182004-operations-update-no-1

[123] MALFI, 2018. National Climate Change Action Plan (NCCAP) 2018-2022. http://www.environment.go.ke/wp-content/uploads/2020/03/NCCAP-2018-2022-v2.pdf

[124] ReliefWeb. 2022. Kenya: Drought – 2014-2022. https://reliefweb.int/disaster/dr-2014-000131-ken

[125] ReliefWeb. 2020. WFP East Africa: Update on the Desert Locust Outbreak (12 June 2020). https://reliefweb.int/report/ethiopia/wfp-east-africa-update-desert-locust-outbreak-12-june-2020

54. The LREB is already affected by soil erosion due to high-intensity rainfall and flooding on continuously cultivated land that strips away nutrient-rich topsoil and runs off into the Lake, for example, in the Kano Plains and Budalangi in Busia. Fertilizers and pesticides, which are widely used by farmers, also leak into the lake, harming the environment, promoting the growth of invasive algae and hyacinth, and eutrophication in the Lake.[126]. Eroded soils lead to reduced crop yields and weed and pest proliferation. While an increase in rainfall would boost crop production, increasing intensity and duration of rainfall combined with more extreme temperatures is expected to result in negative impacts on crops[127],[128]. More intense rainfall over shorter periods will result in flooding and runoff, soil erosion, and decreasing soil fertility. In the event of longer dry periods between each rainfall event, the soil loses moisture. Consequently, when heavy rains occur, the soil is unable to properly absorb the rainfall causing runoff. Increased mean annual rainfall and flooding can also stress plant growth by causing water logging at inappropriate times in the growth cycle, causing crop loss, or by pest and diseases incidences.

7.2. Tea

7.2.1. Observed and projected climate hazards and impacts on tea production

55. As reported in the Feasibility Study (part B, chapter 1.5), the tea value chain was prioritized by the following counties: Bomet, Bungoma, Kericho, Nyamira, and Trans-Nzoia.

56. The following figures show maximum potential yields for tea under rainfed and net irrigated conditions using AEZ at county level. Figure 27 (a) shows which counties have the potential to sustain higher yields under present climatic conditions (1981-2010). Overall, counties in the central- and south-eastern areas of the LREB with an overall high elevation, including Kericho, Nyamira, and Bomet, have the highest historical yield potential. Trans-Nzoia instead shows the lowest potential yield. Figure 27 (b) also indicates in which provinces the strongest effect of climate change, without adaptation measures, is projected. Under rainfed conditions, declining trends are detected in all counties by end-century both under RCP2.6 and RCP8.5. Under RCP2.6, yields are projected to decrease in the LREB by up to 10% compared to the historical period, both in the mid-term (2031-2060) and long-term (2061-2090) future. Under RCP8.5, results demonstrate how counties with low-medium historical yield potential in the southern and westernmost areas of the LREB, with an overall low elevation, are the ones that will experience highest climate impacts on potential yield reductions by up to 20% in the mid-term, and up to 30% in the long-term.

57. Figure 27 (c) describes which counties would mostly benefit from irrigation in terms of yield increases compared to simulated rainfed conditions under present climatic conditions (1981-2010). In particular, counties in the northern and western areas of the LREB with low-medium yield potential under rainfed conditions (including Trans-Nzoia and Bungoma), as well as Bomet in the southern-easternmost areas, would experience at least 50% yield increase under irrigated conditions compared to simulated rainfed conditions. Figure 27 (d) also shows the extent to which irrigation can mitigate the effect of climate change into the future. Under RCP2.6, potential yields are projected to decrease by less than 10% by end-century in all counties of the LREB. Under RCP8.5, a decreasing trend is detected since 2061 by 10%. This results from the major role played by the temperature factor, which

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[126] L.A. Olaka et al. 2019. Projected Climatic and Hydrologic Changes to Lake Victoria Basin Rivers under Three RCP Emission Scenarios for 2015–2100 and Impacts on the Water Sector. *Water*, 1449 (11): 1 -27

[127]Wainwright, Caroline & Black, Emily & Allan, Richard. (2018). Later Wet Seasons with More Intense Rainfall over Africa under Future Climate Change. Journal of Climate. 31. 10.1175/JCLI-D-18-0102.1.

[128] Mwangi et al. 2020. Vulnerability of Kenya's Water Towers to Future Climate Change: An Assessment to Inform Decision Making in Watershed Management. American Journal of Climate Change. 9(3). DOI: 10.4236/ajcc.2020.93020

is projected to increase considerably under a high-emission scenario. At the same time, it is expected that the maximum yield potential under irrigated conditions will remain higher compared to the projected values under rainfed conditions, both under RCP2.6 and RCP8.5 (Figure 28). Overall, irrigation, by keeping soil-moisture levels constant and above the critical thresholds for stomata closure and canopy expansion, is essential for obtaining higher yields. Therefore, in the long-term irrigation has the potential to substantially reduce climate change impacts on decreased yields compared to rainfed conditions in all counties of the LREB.

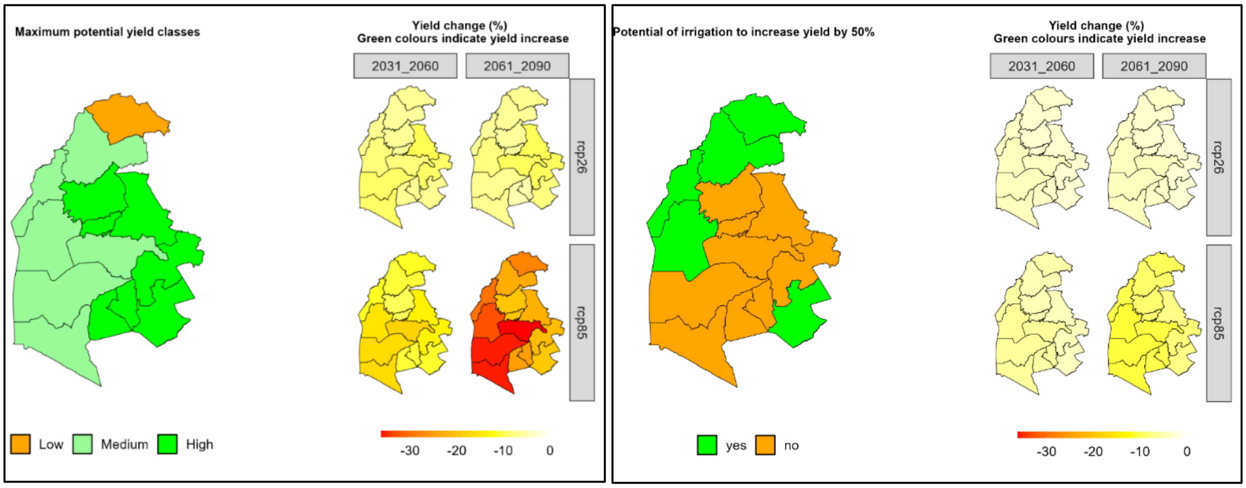

Figure 27. From left to right: a) maximum potential yield classes (baseline); b) projected yield changes (future) under rainfed conditions; c) potential of irrigation to increase tea yields (baseline); d) yield changes (future) under irrigated conditions.[129]

58. Direct linkages between observed and projected climate hazards and impacts on unstable tea yields as well as at post-harvest stages of the value chain in the LREB are further highlighted below.

[129] The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

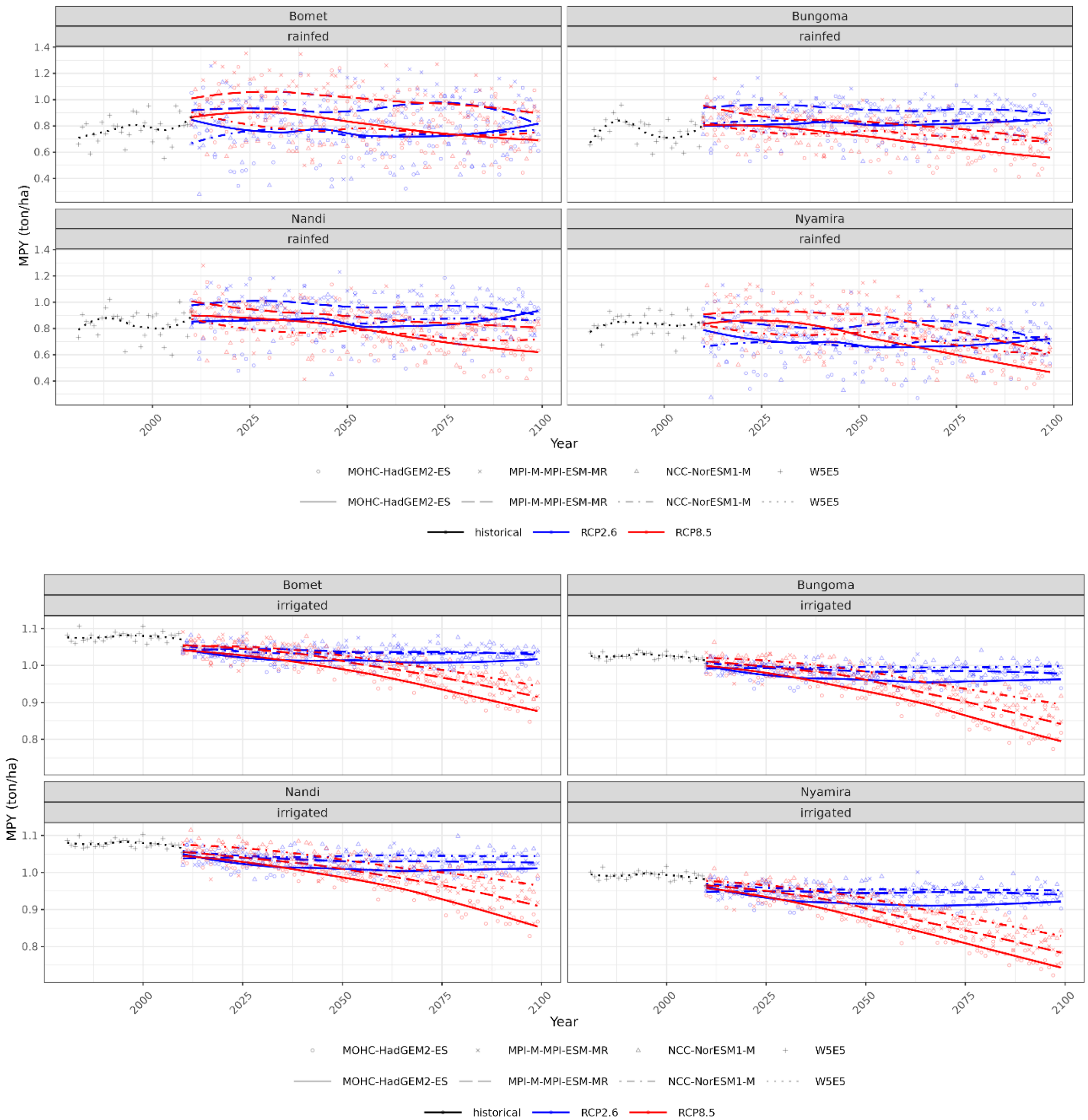

Figure 28. Maximum Potential Yield (MPY) for tea under net irrigated and rainfed conditions over the 2010-2099 period in representative counties of the LREB. Future yield simulations are based on 3 GCMs, while historical yield simulations on W5E5 database

Extreme temperatures

59. Mild temperatures around 21°C combined with high and constant precipitation are favorable conditions for tea production. Warmer temperatures normally have positive impacts on tea yields, but when associated with dry conditions, reduced soil moisture and high evapotranspiration, they reduce water content in tea plants, increase the spread of pests resistant to dry weather, and cause

weed growth, poor bud break, bud scorch, stem and collar canker, wood root, leaf, and bark desiccation[130],[131]. Maximum temperatures above 30°C cause a reduction in tea growth and directly damage leaves, thus reducing their quality for processing[132].

60. The increasing maximum temperatures and extreme heat events, pose a risk of future heat stress to tea plants[133] and crop unsuitability below 2000masl. According to the FAO (2015)[134], as a result of mean temperatures exceeding the optimal growing threshold (23.5ºC) compounded with changes in rainfall distribution by 2050 by mid-century, tea production may become unsuitable in Nandi, Kericho, and Gucha (Kisii County), whereas it is expected to remain stable in Bomet, Nyamira, and in high altitude areas in Kisii. Some areas outside the LREB such as Meru, Embu, Kirinyaga, Nyeri, Murangà, Kiambu, and Mount Kenya will however become more suitable. A regression model from J. Oeching et al. (2016)[135] simulating a 2.0°C temperature increase by 2030 and 2.5°C temperature increase by 2040 scenario, shows that changes in rainfall patterns combined with rising temperatures in each scenario would decrease tea revenues by 5.5% in the first scenario, and 8.8% in the second scenario. By 2030, using J. Oeching's et al. 's model, revenues would decrease to $1.07 billion and further decrease to $1.03 billion by the 2040s compared to $1.13 billion in 2019. According to findings from simulation models, suitable areas for tea production in Kenya, and particularly in the LREB, might decrease by up to 22,5% by 2075 under a scenario depicting an increase in mean temperatures by 11%[136].

Rainfall variability and drought

61. While total annual precipitation has increased in Kenya, tea growing areas have been exposed to a progressively uneven distribution of precipitation, including a higher number of consecutive dry days. Unstable onsets of the rainy season have induced low soil moisture content which consequently reduces plants' photosynthesis and growth, and directly affect the roots of tea shrubs. Changes in rainfall patterns and dry spells cause osmotic stress to tea plants, crop damage and failure, through large soil water deficit and moisture stress which are correlated with decreasing tea yields[137]. Furthermore, between December and March, regular three-month drought periods in Kenya have caused 14-20% tea yield losses which could reach 30% under severe drought conditions[138].

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[130] Cheserek et al., 2015. Analysis of Links between Climate Variables and Tea Production in the Recent Past in Kenya. Donnish Journal of Research in Environmental Studies Vol 2(2) pp. 005-017 March, 2015. http://www.donnishjournals.org/djres

[131] Rigden et al., 2020. Kenyan tea is made with heat and water: how will climate change influence its yield?. Environ. Res. Lett. 15 (2020) 044003 https://doi.org/10.1088/1748-9326/ab70be

[132] United Nations Industrial Development Organization. 2017. Adaptation and mitigation in the Kenyan tea industry. https://open.unido.org/api/documents/5239228/download/2.Value%20chain%20vulnerability-Kenya%20country%20report.pdf

[133] Ochieng, J., Kirimi, L. and Makau, J. (2017), Adapting to climate variability and change in rural Kenya: farmer perceptions, strategies and climate trends. Nat Resour Forum, 41: 195-208. https://doi.org/10.1111/1477-8947.12111

[134] FAO. 2015. Kenya's tea sector under climate change: An impact assessment and formulation of a climate smart strategy, by Elbehri, A., B. Cheserek, A. Azapagic, D. Raes, M. Mwale, J. Nyengena, P. Kiprono, and C. Ambasa. Rome, Italy.

[135] Ochieng et al., 2016. Effects of climate variability and change on agricultural production: The case of small scale farmers in Kenya. NJAS - Wageningen Journal of Life Sciences. 77 (2016) 71–78

[136] Muoki et al. 2020. Combating Climate Change in the Kenyan Tea Industry. Front. Plant Sci. 11:339. doi: 10.3389/fpls.2020.00339

[137] Cheserek, B. et al. 2015. Analysis of Links between Climate Variables and Tea Production in the Recent Past in Kenya. Donnish Journal of Research in Environmental Studies Vol 2(2) pp. 005-017 March, 2015. http://www.donnishjournals.org/djres

[138] Muoki et al. 2020. Combating Climate Change in the Kenyan Tea Industry. Front. Plant Sci. 11:339. doi: 10.3389/fpls.2020.00339

Heavy rainfall and hailstorms

62. According to the results from the climate-focused value chain survey conducted by the Kenya Meteorological Department representatives in Bomet and Kericho counties at the production stage (involving input supply and harvesting activities), extreme cold and frost together with heavy rainfall events, drought, hailstorms, were identified as climate hazards with the highest negative impacts on tea production and this is likely to worsen in the future. The major perceived impacts include soil erosion, soil moisture stress, yield losses and harvest delays. More than 500,000 smallholder tea farmers in Kenya are already facing the risks of decreasing tea productivity to their livelihoods[139].

63. Heavy rainfall and hailstorms cause crop damage and failure over three consecutive months after their occurrence. For example, annual net loss of green leaves due to hail amounts 27,000 tonnes in Kericho and Nandi Hills[140]. Hailstorms, exacerbated by increasing temperatures and rainfall intensity, can have adverse impacts on tea production by damaging thousands of kilograms in one single day, as occurred in Kericho county in 2013 when 12,980 kilograms of tea were lost in one day after a hailstorm[141]. Negative impacts on tea yields were also recently detected by the Kenya Meteorological Department in Kericho due to hailstones during the OND season in 2020[142]. Hailstorms destroy tea leaves and can impede harvesting for up to 60 days, while also damaging mother bushes' capacity to generate new planting materials for nurseries. Fertilizers application becomes ineffective due to combined hailstorms and heavy rains, with the associated costs for farmers to purchase new agricultural inputs. Such impacts are increasing in their frequency and intensity in the LREB, as also confirmed by initial consultations with tea farmers, particularly at lower-altitudes and depressions where cold air more easily accumulates[143]. Overall, the quality of tea will be impacted although the direction and magnitude of this change is complex as it is influenced not only by the environment but also by the variety, cultivar, and crop management[144]. Increased rainfall would mean that more water is inside the tea plant and when the daylight heat cools down during the night, water inside the tea plant's leaves expands, rupturing the leaves' cell walls. With more water inside the tea plant's leaves, and greater fluctuations between hotter days and cooler nights, there is a higher chance of ruptured leaves and lost tea plants. Not only does the lost tea production represent lost income for the individual farmer, but the cost of acquiring equipment or new varieties of tea plants that are better adapted for the warmer temperatures would be passed onto the farmer.

7.2.2. Climate hazards and impacts on post-harvest stages of the tea value chain

64. Extreme weather impacts are felt throughout the value chain through disruption to tea leaves' prices and sourcing, resulting in financial and income losses particularly for farmers. For instance, in 1997,

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139 Rwigema, P.C. 2021. Combating climate change impacts in tea and coffee farming in East Africa: theoretical perspective. The Strategic Journal of Business and Change Management. 8(2), pp.521-553.

140 FAO. 2015. Kenya's tea sector under climate change: An impact assessment and formulation of a climate smart strategy, by Elbehri, A., B. Cheserek, A. Azapagic, D. Raes, M. Mwale, J. Nyengena, P. Kiprono, and C. Ambasa. Rome, Italy.

141 CGIAR-CIAT. Ministry of Agriculture, Livestock, Fisheries and Cooperatives. 2022. Kenya County Climate Risk Profiles. https://ccafs.cgiar.org/resources/publications/kenya-county-climate-risk-profiles

142 Kenya Meteorological Department. 2021. State of the Climate in Kenya 2020. https://meteo.go.ke/sites/default/files/downloads/STATE%20OF%20THE%20%20CLIMATE%202020_14042021.pdf

143 United Nations Industrial Development Organization. 2017. Adaptation and mitigation in the Kenyan tea industry. https://open.unido.org/api/documents/5239228/download/2.Value%20chain%20vulnerability-Kenya%20country%20report.pdf

144 Ahme, S. et al. 2019. Environmental Factors Variably Impact Tea Secondary Metabolites in the Context of Climate Change. Frontiers in Plant Science, 2019, Vol 10. https://www.frontiersin.org/articles/10.3389/fpls.2019.00939 . DOI=10.3389/fpls.2019.00939

2000 and 2006, extreme weather conditions in Kenya resulted in reduced labor resources for tea processing activities, consequently leading to reduced tea leaves supply and income, and the closure of tea factories [145]. According to the results of the climate-sensitive value chain survey (Figure 29), respondents highlighted key observed climate hazards having a negative impact on tea distribution stage, including transportation and markets, which were however defined as having a low impact, primarily due to the overall direct linkages between climate impacts on tea production and the consequent indirect repercussions along the value chain. In fact, these included heavy rainfall events and flooding and fog, primarily affecting the tea value chain through physical damage to road and infrastructure, unfavorable conditions for tea transportation, thus causing reduced food sales and overall changes in tea prices.

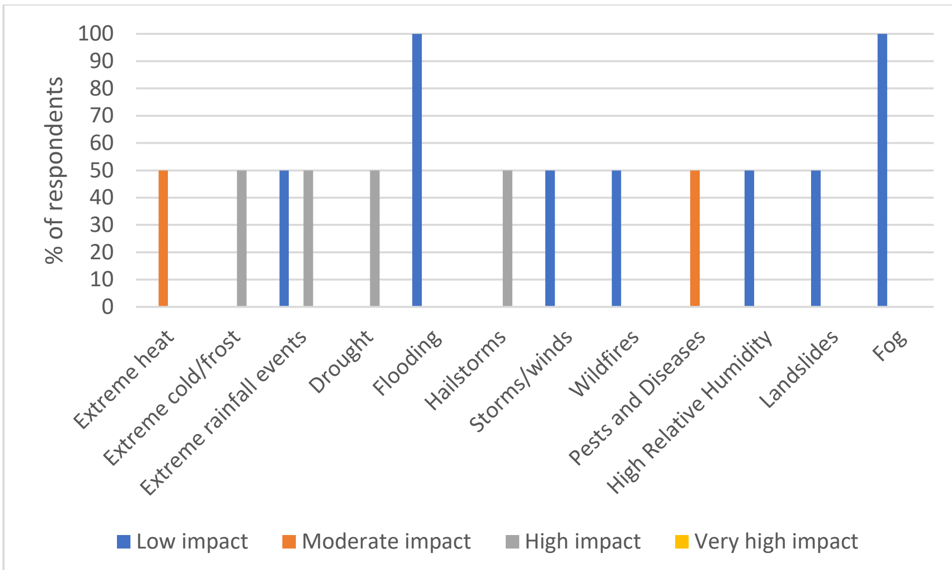


Figure 29. Perceived climate and weather-related hazards affecting the tea value chain.

[145] FAO. 2015. Kenya's tea sector under climate change: An impact assessment and formulation of a climate smart strategy, by Elbehri, A., B. Cheserek, A. Azapagic, D. Raes, M. Mwale, J. Nyengena, P. Kiprono, and C. Ambasa. Rome, Italy.

7.3. Coffee

7.3.1. Observed and projected climate hazards and impacts on coffee production

65. As reported in the Feasibility Study (part B, chapter 1.5), the coffee value chain was prioritized by the following counties: Bomet, Bungoma, Kericho, Kisii, Migori, Nandi, Nyamira, and Trans-Nzoia.

66. The following figures show historical simulations and future projections of AEZ simulations for maximum coffee yields under rainfed and net irrigated conditions at county level. Figure 30 (a) shows the counties with highest yield potential under rainfed conditions and present climatic conditions (1981-2010), such as Vihiga and Kakamega. Bungoma in the northern areas and Kisii, Nyamira, and Kericho in the southern and easternmost areas instead show a medium yield potential. Overall, counties with a low elevation along the Lake Victoria show a low yield potential. The maps on projected climate change impacts on coffee without adaptation measures (Figure 30, b) show a progressive decline in potential yields from the mid-term (2031-2060) to the long-term (2061-2090) future, under both RCP2.6 and RCP8.5, for all counties with the exception of Bomet and Nandi. Under RCP2.6, results for the rest of the counties show a higher decline from 5% to 10% in the central counties of Kericho and Trans-Nzoia, where the historical simulations already indicated a low-medium yield potential. While Nandi and Bomet show a historical low yield potential, both under RCP2.6 and RCP8.5, yields are instead projected to decrease by less than 5% and at lower rates compared to the rest of the counties for Nandi, and to increase for Bomet. Overall, climate change is projected to have a higher negative impact on the counties that prioritized coffee. Bomet and Nandi instead, which show a low historical yield potential, show benefits of increased-stable yields.

67. Under historical (1981-2010) simulated irrigated conditions, Figure 30 (c) shows a potential yield improvement by 50% for three counties only, located in the eastern areas of the LREB, such as Trans-Nzoia in the north, Nandi in the center, and Bomet in the south, compared to the results for historical rainfed simulations which showed low yield potential for the same three counties. Therefore, these would particularly benefit from irrigation. Future projections (Figure 30, d) indicate a slight yield decline compared to historical irrigated simulations for all counties under RCP2.6 in the mid- (2031-2060) to long-term (2061-2090) future by less than 5%. Under RCP8.5, projected yield declines are also low in the mid-term future (by up to 5%), whereas in the long-term they reach a 10% reduction particularly in western counties where irrigation has a lower potential to increase yields compared to rainfed conditions. Overall, the maximum coffee yield potential under irrigated conditions will remain above the projected values under rainfed conditions particularly under RCP2.6, suggesting a comparative advantage, of irrigating coffee. However, decreasing yield trends as a result of compounded increasing temperatures under RCP8.5 and irrigated conditions suggest how these negatively influence coffee yields (Figure 31).

68. Among the counties that prioritized the coffee value chain, climate change is projected to pose high negative impacts on coffee production in most of the counties, such as Bungoma, Kericho, Kisii, Migori, Nyamira, and Trans-Nzoia, therefore highlighting the need for the adoption of tailored climate-resilient practices. At the same time, coffee production in Bomet and Nandi has the potential to remain stable under rainfed conditions, whereas irrigation has the potential to reduce such negative impacts particularly in Bomet, Nandi, and Trans-Nzoia.

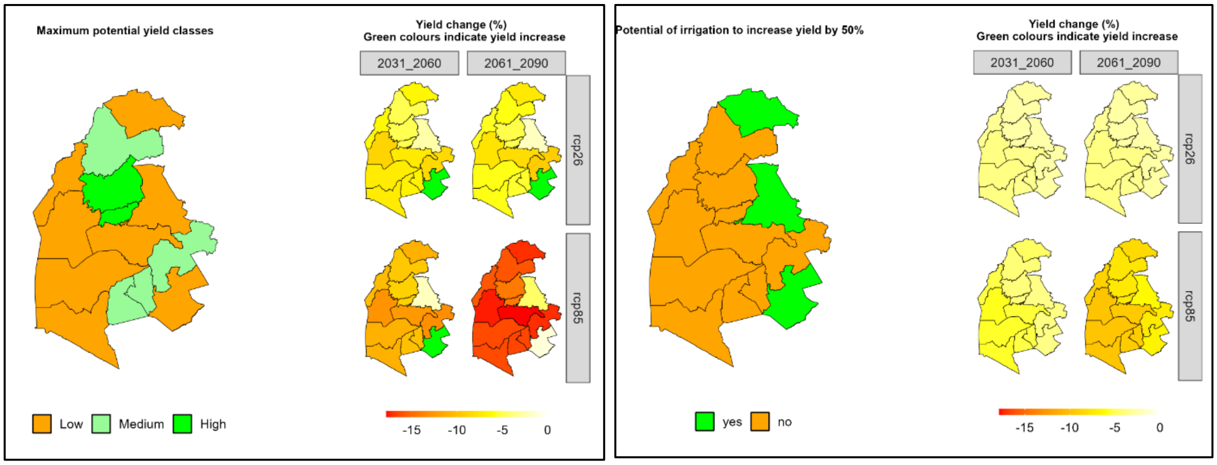
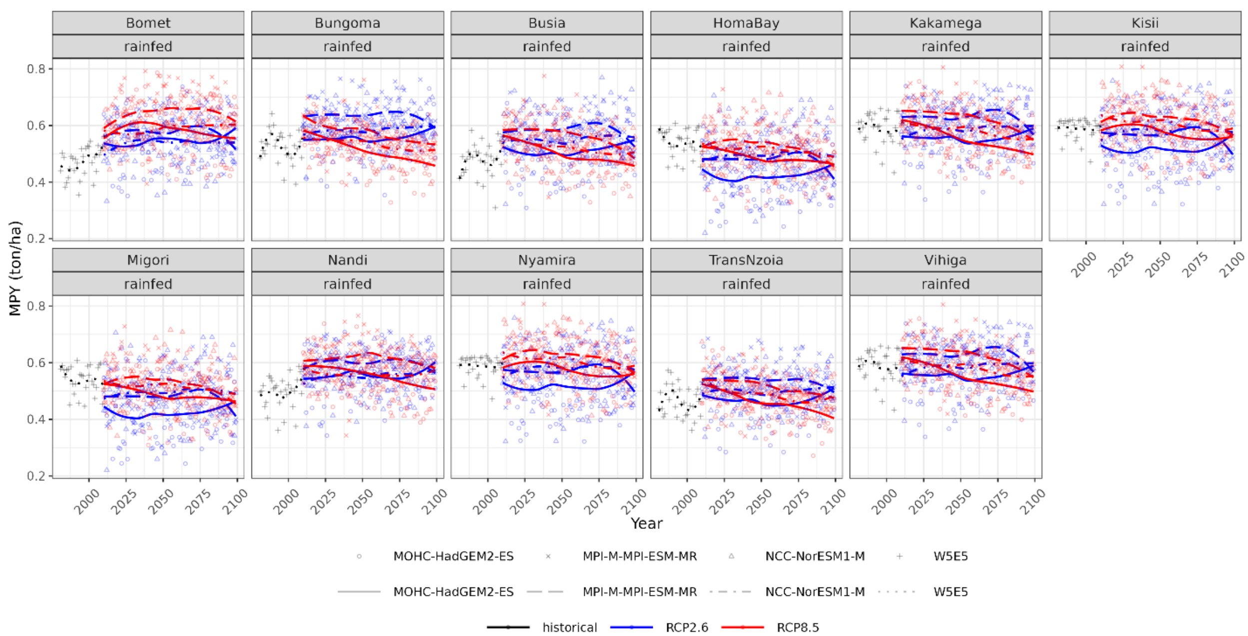


Figure 30. From left to right: a) maximum potential yield classes (baseline); b) projected yield changes (future) under rainfed conditions; c) potential of irrigation to increase coffee yields (baseline); d) yield changes (future) under irrigated conditions. [146]



[146] The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

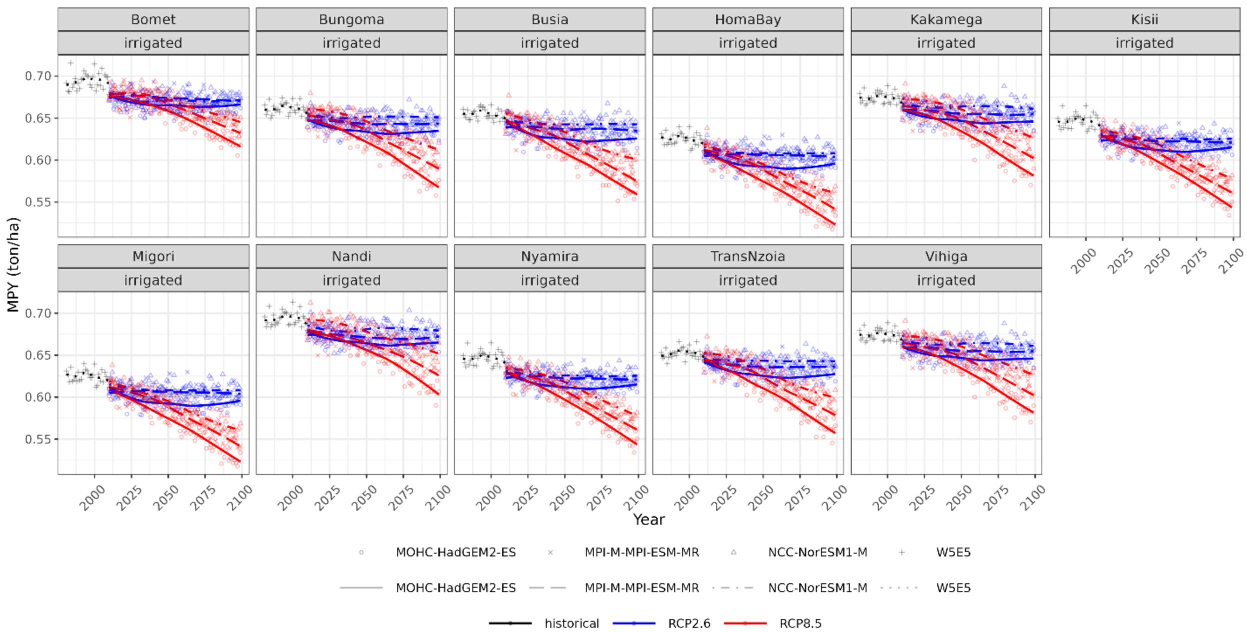


Figure 31. Maximum Potential Yield (MPY) for coffee under net irrigated and rainfed conditions over the 2010-2099 period in representative LREB counties. Future yield simulations are based on 3 GCMs, while historical yield simulations on W5E5 dataset.

69. The main climatic factors behind coffee yield declines included observed increasing maximum temperatures and interannual rainfall variability and anomalies, also favoring an observed increase in coffee berry borer pests[147],[148]. In addition, other anthropogenic factors such as market and price instabilities limit the expansion of coffee production[149].

70. According to the results from the climate-focused value chain survey conducted by County Government representatives in Busia, Nandi (Ministry of Agriculture and Cooperative Development), and Trans-Nzoia (Department of Agriculture) (Figure 32 and Figure 33), at the production stage, coffee production is mostly affected by drought, extreme cold/frost, and pests and diseases. The major impacts reported include soil erosion and soil moisture stress, lower access to rainfed, freshwater, and groundwater resources, increased mycotoxin spread and yield losses, as well as shorter crop growing seasons. Extreme heat, heavy rainfall events, flooding, storms, winds, wildfires, and landslides were also reported having moderate impacts on damaged flowers and newly formed fruit, nutrient leaching, and decreased land available for crop production.

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[147] Pham et al., 2019. The impact of climate change and variability on coffee production: a systematic review. Climatic Change. https://doi.org/10.1007/s10584-019-02538-y

[148] Getachew WeldeMichael, Demelash Teferi, “The Impact of Climate Change on Coffee (Coffea Arabica L.) Production and Genetic Resources” International Journal of Research Studies in Agricultural Sciences (IJRSAS), 2019; 5(11), pp. 26-34, http://dx.doi.org/10.20431/2454-6224.0511004

[149] Herreo, M. et al. 2010. Climate variability and climate change and their impacts on Kenya’s agricultural sector. International Livestock Research Institute. https://cgspace.cgiar.org/bitstream/handle/10568/3840/climateVariability.pdf

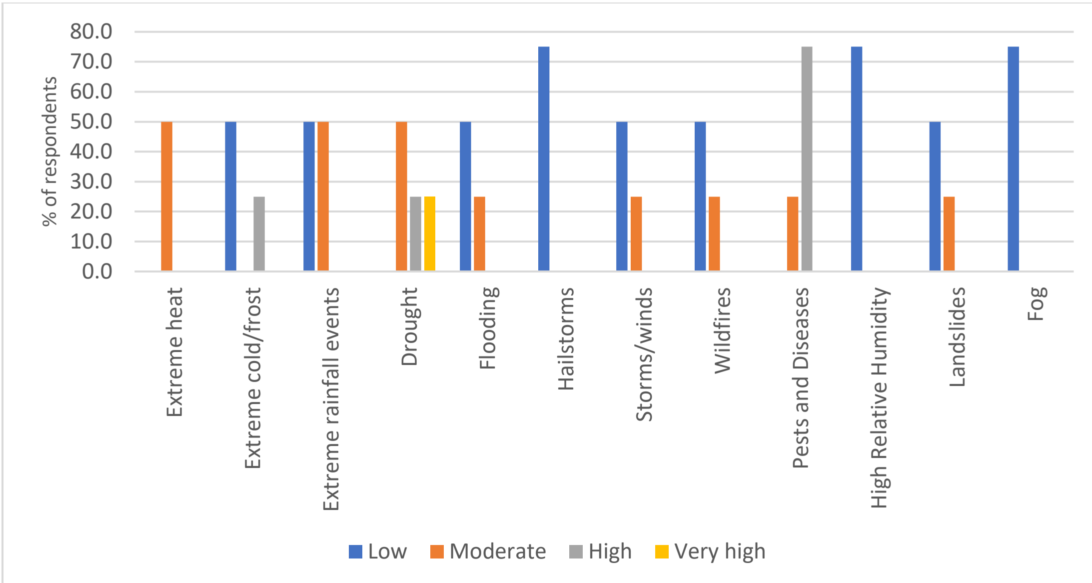

Figure 32. Perceived climate and weather-related hazards affecting coffee production.

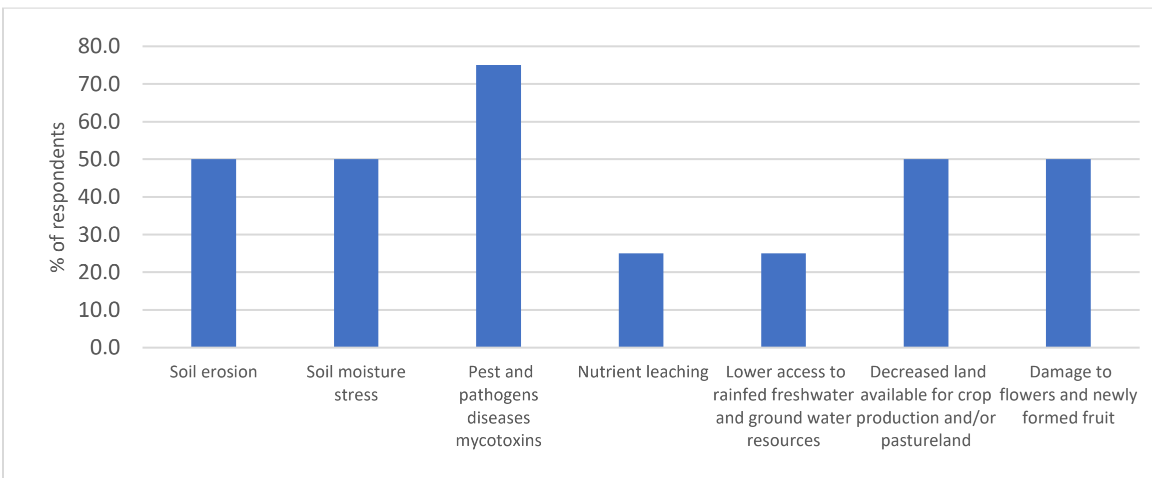

Figure 33. Perceived climate impacts on coffee production.

71. Direct linkages between observed and projected climate hazards and impacts on coffee yields as well as at post-harvest stages of the value chain in the LREB are further highlighted below.

Extreme temperatures

72. Higher temperatures than the optimal requirements hasten the development and ripening of the cherry, affecting quantity and quality of yields, particularly of Arabica beans[150]. Due to projected increasing temperatures, suitable areas for coffee growing are projected to shift from 1600 to 1700masl as well as to shrink from 50-70% of the areas to 30-50% by 2050 under the Business-as-Usual scenario, particularly due to coffee berry borer outbreaks[151]. The suitability of coffee growing

[150] FAOSTAT. 2022. Crops and livestock production. https://onlinelibrary.wiley.com/doi/full/10.1002/fes3.61

[151] Adhikari, U. et al. 2015. Climate change and eastern Africa: a review of impact on major crops. Food and Energy Security. 4(2). https://doi.org/10.1002/fes3.61

areas will significantly reduce by 2050 due to projected increasing temperatures by 2°C. Jaramillo et al. (2009[152], 2010[153]) demonstrates that coffee- growing areas in most of Kenya, Uganda and Rwanda would decrease due to the prevalence of the coffee berry borer favored by the temperature rise. Furthermore, while open lands in East Africa at higher altitudes are projected to become more suitable for coffee production, key barriers might arise from conflicts with lands occupied for other agroecological activities, as well as due to more limited roads and infrastructure to reach those areas, as well as possible unsuitability of soils[154].

Changes in rainfall patterns, dry spells, and heavy rainfall events

73. Combined changing rainfall patterns, shorter and delayed rainy seasons, increase the probability of pest and disease attacks (e.g., coffee berry disease and leaf rust), negatively affecting coffee pollinators and thus, undermining flowering and berry growth stages[155]. The effectiveness of pest and disease management and coffee harvesting are also compromised due to uncertainties in the timing of fertilizer and fungicide application, and in the timing of cherry ripening and drying. A decrease in precipitation of driest month, an increase in precipitation of the coldest quarter, and an increase in minimum temperatures of the coldest month are main negative impacts on coffee suitability[156]. Farmers have reported uneven coffee tree flowering due to increasing dry spells, resulting in reduced yields (in terms of quality and quantity) and increased costs of production[157]. Furthermore, heavy rainfall events negatively affect coffee yields by causing soil erosion, nutrient leaching, and soil infertility, as well as by directly damaging flowers.

7.3.2. Climate hazards and impacts on post-harvest stages of the coffee value chain

74. Once cherries are harvested, these are delivered by farmers by truck to collection centers or millers for the primary processing step[158]. Climate impacts to coffee beans are therefore driven by unsuitable environmental conditions of storage and transportation facilities. Green coffee is transported to storage units in jute bags, which may pose contamination risks due to external factors and thus quality degradation. Storage lasts for 6 months after which coffee is transported to millers for the final processing. Farmers mainly make use of communal storage facilities operated by cooperatives. At the same time, storage facilities often lack adequate technologies for preventing climate impacts, such as poor ventilation and insulation for controlling relative humidity exchanges[159]. Furthermore, heavy

[152] Jaramillo J, Chabi-Olaye A, Kamonjo C, Jaramillo A, Vega FE, Poehling HM, Borgemeister C. Thermal tolerance of the coffee berry borer Hypothenemus hampei: predictions of climate change impact on a tropical insect pest. PLoS One. 2009 Aug 3;4(8):e6487. doi: 10.1371/journal.pone.0006487. PMID: 19649255; PMCID: PMC2715104.

[153] Jaramillo J, Muchugu E, Vega FE, Davis A, Borgemeister C, Chabi-Olaye A. Some like it hot: the influence and implications of climate change on coffee berry borer (Hypothenemus hampei) and coffee production in East Africa. PLoS One. 2011;6(9):e24528. doi: 10.1371/journal.pone.0024528. Epub 2011 Sep 14. PMID: 21935419; PMCID: PMC3173381.

[154] Pham et al., 2019. The impact of climate change and variability on coffee production: a systematic review. Climatic Change. https://doi.org/10.1007/s10584-019-02538-y

[155] https://www.globalcoffeeplatform.org/wp-content/uploads/2021/03/Kenya-Coffee-Platform-Coffee-Economic-Viability-Study-Report-F.pdf

[156] CIAT, 2010. Climate Change Adaptation and Mitigation in the Kenyan Coffee Sector. Final Report. Cali

[157] Kenya Coffee Platform through research by Coffee Management Services. Coffee Economic Viability Study. https://www.globalcoffeeplatform.org/wp-content/uploads/2021/03/Kenya-Coffee-Platform-Coffee-Economic-Viability-Study-Report-F.pdf

[158] Aragie, E. (2018). Identifying opportunities for value chain development in the Kenyan coffee sector: A modelling approach. Outlook on Agriculture, 47(2), 150–159. https://doi.org/10.1177/0030727018766956

[159] FEEM. 2020. FEEM Approach to Supply Chain Analysis The coffee sector in Kenya. https://feem-media.s3.eu-central-1.amazonaws.com/wp-content/uploads/968-rpt-supplychainanalysis-cofee-kenya.pdf

rainfall and flooding may cause the re-wetting and moisture absorption of coffee bags if these are not properly raised from the ground as well as away from walls. High relative humidity in the storage facility contributes to coffee moisture content. Ochratoxin A (OTA) contamination, which is a key risk for coffee during storage, is driven by high temperature and relative humidity conditions, as well as presence of insects within the storage facility which may increase relative humidity and thus mold growth and mycotoxins through insect respiration[160]. Overall, climate hazards affecting each stage of the coffee value chain from production to storage, processing, and transportation, indirectly affect coffee sales through reduced quantity and quality of coffee beans available at markets, as well as increased costs and reduced final prices.

7.4. Fruit trees (Avocado, Banana)

75. Fruit trees are mainly grown as alternative sources of food and income. Major challenges to fruit trees production revolve around limited superior varieties or planting materials, pests and diseases (beetles and thrips for bananas) with a large proportion of harvest losses (e.g., in the case of avocado).

7.4.1. Observed and projected climate hazards and impacts on banana production

As reported in the Feasibility Study (part B, chapter 1.5), the fruit trees value chain was prioritized by the following counties: Bomet, Kericho, Kisii, Kisumu, Nandi, Siaya, and Vihiga.

76. The following figures show historical simulations and future projections using AEZ for maximum banana yields under rainfed and net irrigated conditions at the county level. Generally, potential banana yields simulated during the historical period (1981-2010) are high in central counties and those closest to the Lake Victoria with an average low elevation (Figure 34, a). Counties at higher altitudes from northernmost to southern-easternmost areas including Nandi, Kericho, and Bomet are simulated to experience low-medium yield potential. Future projections indicate that counties with the lowest yield potential under historical climatic conditions are experiencing an increase in yields in the mid-term (2031-2060) to the long-term (2061-2090) future under both RCP2.6 and RCP8.5, thus delimiting more suitable climatic conditions, particularly for Nandi and Bomet counties (Figure 34, b). At the same time, counties with medium to high yield potential under historical rainfed conditions are projected to experience a yield decrease by 5% under RCP2.6 by end-century, and a decrease from 10% to 15% by mid-century, and by up to 30% by end-century under RCP8.5. Therefore, climate change is projected to impact the counties with the highest historical yield potential the most (including Kisumu and Siaya), thus highlighting the need for the adoption of tailored climate-resilient practices, as well as provide more suitable climatic conditions for counties with historical low yield potential.

77. Irrigation has the potential to increase yields by 50% compared to rainfed conditions in all counties in the LREB according to historical simulated conditions (1981-2010) (Figure 34, c). Projections indicate that yields will likely remain stable under RCP2.6 by end-century and increase in Bomet. Under RCP8.5, yields are projected to decrease by less than 10% by end-century, whereas in Bomet they are projected to increase by mid-century (2031-2060) and stabilize by end-century (2061-2090) (Figure 34, d). Therefore, all counties would particularly benefit from irrigation in terms of increased yields compared to rainfed conditions. Overall, the maximum banana yield potential under irrigated conditions will remain above the projected values under rainfed conditions particularly under RCP2.6,

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[160] FAO. 2006. Storage of Coffee: Good Hygiene Practices along the coffee chain. Rome. www.ico.org/projects/ Good-Hygiene-Practices/cnt/cnt_sp/sec_3/docs_3.3/ Storage.pdf.

suggesting a comparative advantage, of irrigating banana. However, decreasing yield trends as a result of compounded increasing temperatures under RCP8.5 and irrigated conditions suggest how these negatively influence banana yields (Figure 35).

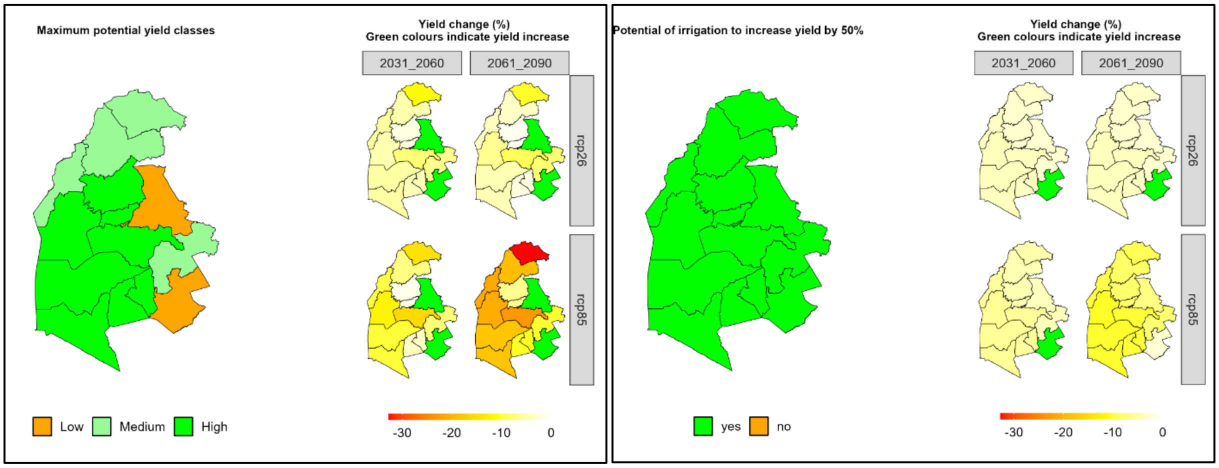
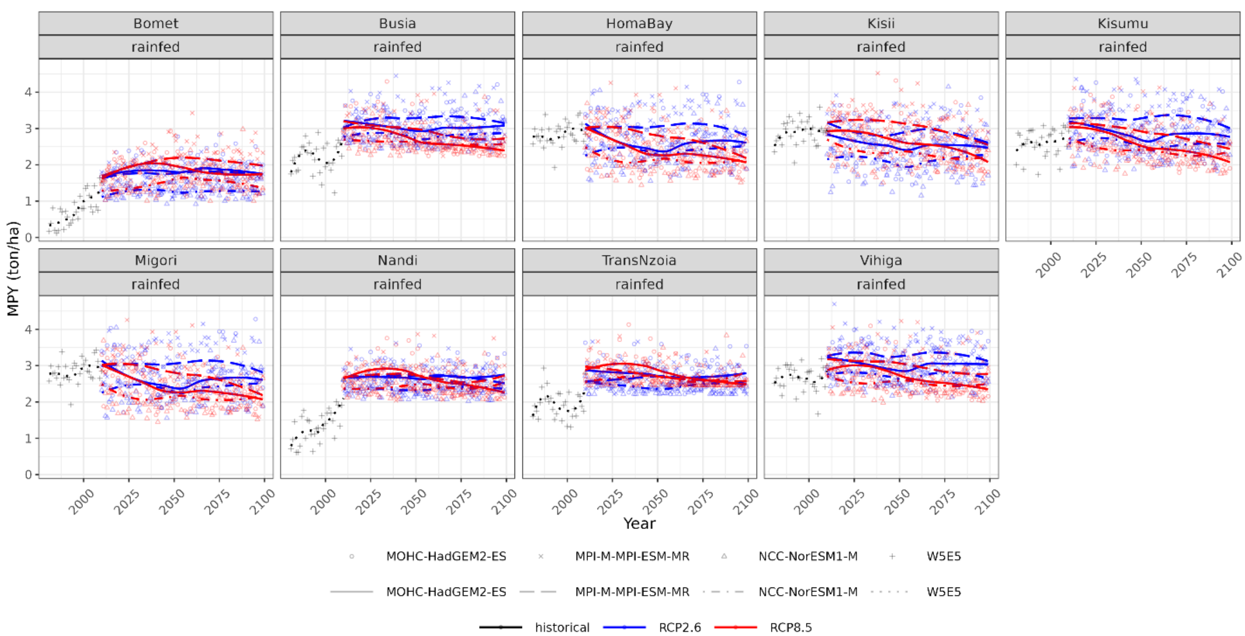


Figure 34. From left to right: a) maximum potential yield classes (baseline); b) projected yield changes (future) under rainfed conditions; c) potential of irrigation to increase banana yields (baseline); d) yield changes (future) under irrigated conditions.[161]



[161] The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

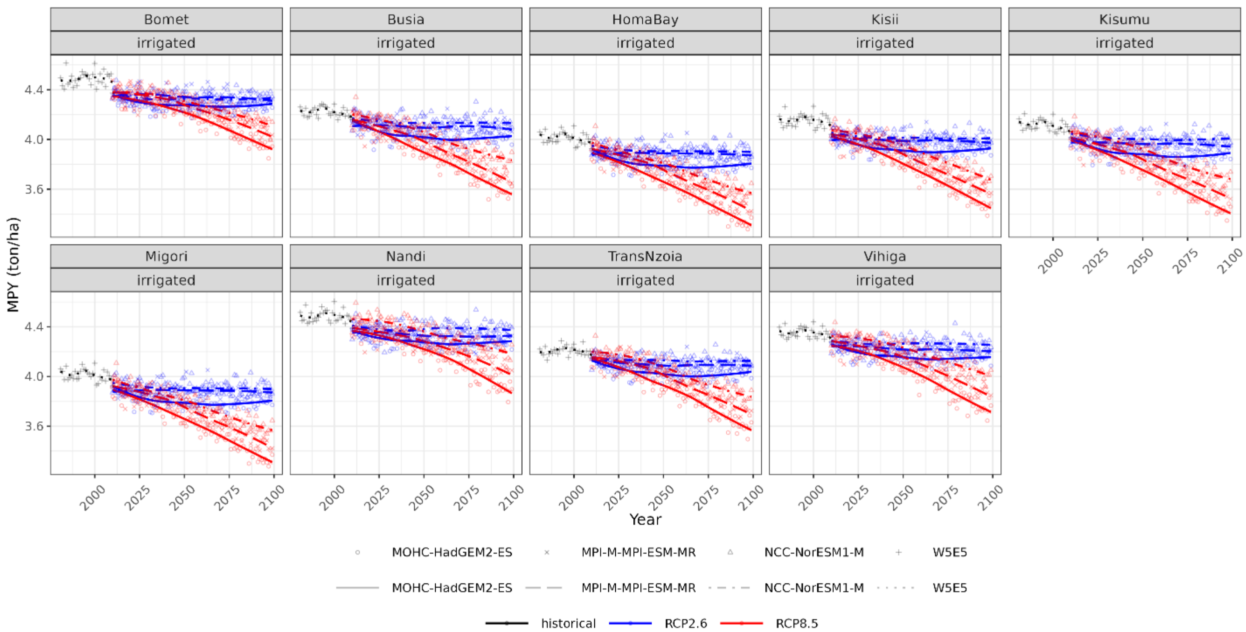


Figure 35. Maximum Potential Yield (MPY) for banana under net irrigated and rainfed conditions over the 2010-2099 period in representative LREB counties. Future yield simulations are based on 3 GCMs, while historical yield simulations on W5E5 dataset.

78. Direct linkages between observed climate hazards such as rainfall variability and weather extremes and impacts on banana and avocado yields along the value chain in the LREB are further highlighted below.

7.4.1.1. Banana production

Rainfall variability and drought

79. Changes in seasonal rainfall patterns, increased dry periods and soil moisture stress have negative effects on banana production[162], resulting in reduced effectiveness of agricultural inputs such as fertilizers as well as manure. The dry soils challenge land preparation, planting, and weeding and primarily impact small-scale farmers with limited capacities to access equipment for facilitating soil water infiltration. Since fruit crops are mainly rainfed, prolonged dry spells have negative effects on banana yields causing sun scorching, stunted growth, dried leaves, and tissue death in new plants resulting in reduced quantity and size of fruits at harvest as well as increasing chances of fruit spoilage at post-harvest stages of storage and transportation. Drought-induced yield reduction on rain-fed bananas can reach up to 65% compared to wetter areas[163]. Low soil moisture and extended exposure

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[162] Sabiiti et al., 2016. Empirical Relationships between Banana Yields and Climate Variability over Uganda. 7:03-13. Journal of Environmental and Agricultural Sciences (ISSN: 2313-8629)

[163] Van Asten, Piet J.A. & Fermont, Anneke & Taulya, G.. (2011). Drought is a major yield loss factor for rainfed East African highland banana. Agricultural Water Management. 98. 541-552. 10.1016/j.agwat.2010.10.005.

to temperatures above 35°C reduce banana production[164]. Areas where production is currently limited by low temperatures may become suitable due to increasing temperatures, but some areas currently suitable may become unsuitable due to rainfall variability[165]. Higher temperatures combined with dry spells will result in increased water demand, limiting banana cultivation to the areas projected to receive increased rainfall. Every 100mm yr−1 decrease in rainfall reduces bunch yields by 9% by reducing the number of banana fingers more than finger weight[166]. Additionally, higher temperatures than optimal conditions (around 20°C) during post-harvest storage may increase the probability of diseases incidence such as stem end rots and body rots[167].

Heavy rainfall and hailstorms

80. Heavy rainfall and hailstorms directly damage the growth and harden the fruit, alongside indirect effects such as nutrient leaching, waterlogging, and limited access to fields by farmers. Impacts are mostly felt among women and youth groups which lack financial resources to address such impacts, as well as small-scale farmers using organic manure which is less effective than inorganic fertilizers[168].

7.4.1.2. Avocado production

81. Respondents to the online survey involved in fruit trees production reported avocado as the main fruit tree produced in the LREB. There is an overall agreement among the respondents in terms of the perceptions of climate and weather-related hazards highly affecting avocado production, including drought (selected by 62% of the respondents), hailstorms (44%), extreme heat (37,5%), heavy rainfall events (37,5%) and pests and diseases (37,5%) (Figure 36). The identified hazards were reported to contribute to soil erosion, the spread of pathogens, and the damage to flowers and newly formed fruit (Figure 37).

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[164] Thornton, Philip K. and Laura Cramer. "Impacts of climate change on the agricultural and aquatic systems andnatural resources within the CGIAR's mandate. CCAFS Working Paper No. 23." (2012).

[165] Ramirez, J., Jarvis, A., Van den Bergh, I., Staver, C. and Turner, D. (2011) Changing Climates: Effects on Growing Conditions for Banana and Plantain (Musa spp.) and Possible Responses. Crop Adaptation to Climate Change, 19, 426-438. https://doi.org/10.1002/9780470960929.ch29

[166] P.J.A. van Asten, A.M. Fermont, G. Taulya. 2011. Drought is a major yield loss factor for rainfed East African highland banana, Agricultural Water Management, Volume 98, Issue 4.

[167] Yahia, E. 2012. Avocado. In: Crop Post-Harvest: Science and Technology. https://www.researchgate.net/publication/277697648

[168] MoALF. 2017. Climate Risk Profile for Bomet County. Kenya County Climate Risk Profile Series. The Ministry of Agriculture, Livestock and Fisheries (MoALF), Nairobi, Kenya.

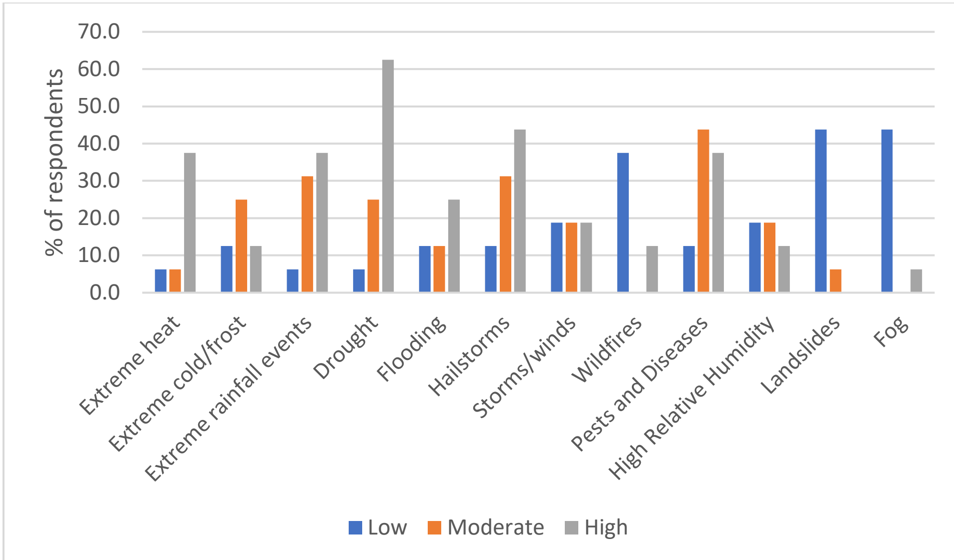

Figure 36. Perceived climate hazards affecting avocado production.

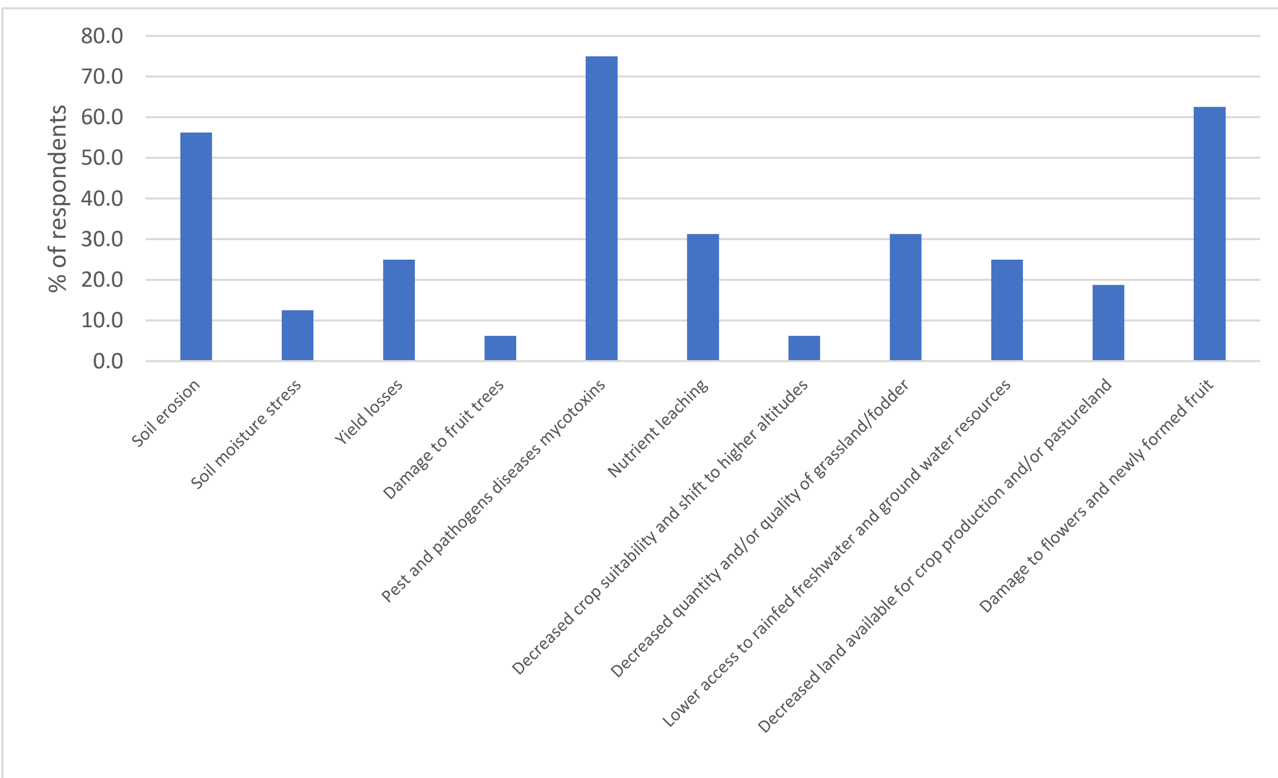

Figure 37. Perceived climate impacts on avocado production.

Extreme temperatures and drought

82. Extreme temperatures cause sunburns as well as increase the avocado plant's exposure to pathogens and pests such as fruit spotting bugs, overall reducing the size of the fruits and causing early spoilage. Dry conditions lead to flower desiccation[169].

Heavy rainfall and flooding

83. Avocado production is particularly vulnerable to flooded, waterlogged areas with high salinity and fertility degradation. Poorly drained soils in combination with warmer temperatures cause root damage from de-oxidation and contribute to the spread of Avocado root rot (*Phytophthora cinnamon*). Furthermore, heavy rainfall and storms may directly damage avocado trees and fruits. Avocados are vulnerable to thrips, moth insects, and other fungal diseases (anthracnose, root rot, cercospora, scab), which may develop already after 2 consecutive heavy rainfall events[170].

7.4.2. Climate hazards and impacts on post-harvest stages of the fruit trees value chain

84. Once harvested, bananas are subject to rapid ripening under extreme temperatures, thus reducing their shelf life as well as their quality before reaching the markets. Processing only occurs at small-scale, with women and youth being highly involved compared to production stages due to lower control on the land[171]. Heavy rains may also affect the ripening process as well as damage storage and transportation facilities, impeding farmers' access to collection centers and markets. Dry periods negatively affect the quality of peeling and slicing, as well as reduce the availability of freshwater for product cleaning, thus contributing to reduced quality of the product.

7.5. African Leafy Vegetables

7.5.1. Observed and projected climate hazards and impacts on cowpea production

85. As reported in the Feasibility Study (part B, chapter 1.5), the ALV value chain was prioritized by the following counties: Bungoma, Busia, Kakamega, Kisii, Migori, Nandi, Nyamira, and Trans-Nzoia.

86. The following figures show historical trends and future projections of AEZ simulations for maximum cowpea yields (legumes) under rainfed and net irrigated conditions at county level. In the case of cowpea, Nandi and Bomet counties are not represented in the maps due to missing statistically significant data. among the counties targeting ALV production, Figure 38 (a) shows an overall high yield potential under rainfed conditions across the LREB counties with an average low elevation, in the historical period (1981-2010). Bungoma and Kericho show low yield potential, and Trans-Nzoia and Kakamega show medium yield potential. Under RCP2.6, projections show an increase in yields, from the mid-term (2031-2060) to long-term (2061-2090) future, in counties with low yield potential under historical conditions (Bungoma, Kakamega, Kericho) (Figure 38, b). Under RCP8.5, the counties with higher historical yield potential (except for Nyamira and Kisii) show a decrease in yield by 10% in the mid-term, and up to 20% in the long-term. At the same time, potential yield trends follow an

[169] Howden et al. 2005. Climate Change – Risks and Opportunities for the Avocado Industry. New Zealand and Australia Avocado Grower's Conference '05. 20-22 September 2005. Tauranga, New Zealand. Session 1. Introduction. 19 pages.

[170] George et al. 2019. An analysis of socioeconomic factors affecting avocado production in saline and flooded areas around Lake Victoria Basin of Western Kenya. African Journal of Agricultural Research. Vol. 14(35), pp. 2048-2061. DOI: 10.5897/AJAR2019.14153

[171] MoALF. 2017. Climate Risk Profile for Bomet County. Kenya County Climate Risk Profile Series. The Ministry of Agriculture, Livestock and Fisheries (MoALF), Nairobi, Kenya.

increasing pathway compared to the low-emissions scenario (Figure 39), particularly in counties with low historical yield potential such as Bungoma, Kakamega, and Trans-Nzoia counties. It is evident that climate change is projected to impact the counties with the highest historical yield potential the most, as well as provide more suitable climatic conditions for counties with historical low yield potential.

87. Figure 38 (c) highlights the counties where irrigation would have the potential to increase yields by 50% in the historical period (1981-2010) compared to rainfed conditions. Counties with low-medium yield potential under rainfed conditions and an average high elevation such as Trans-Nzoia, Bungoma, and Kakamega, are likely to benefit the most from irrigation. Future projections (Figure 38, d) indicate a very low yield decrease (less than 5%) by end-century both under RCP2.6 and RCP8.5.

88. Among the counties that prioritized the African Leafy Vegetables value chain, results indicate that climate change is projected to cause higher negative impacts on rainfed cowpea production in Busia, Migori, and Trans-Nzoia, therefore highlighting the need for the adoption of tailored climate-resilient practices. Cowpea production in Bungoma and Kakamega instead has the potential to increase under rainfed conditions, whereas irrigation has the potential to reduce the projected negative impacts particularly in Bungoma, Kakamega, and Trans-Nzoia.

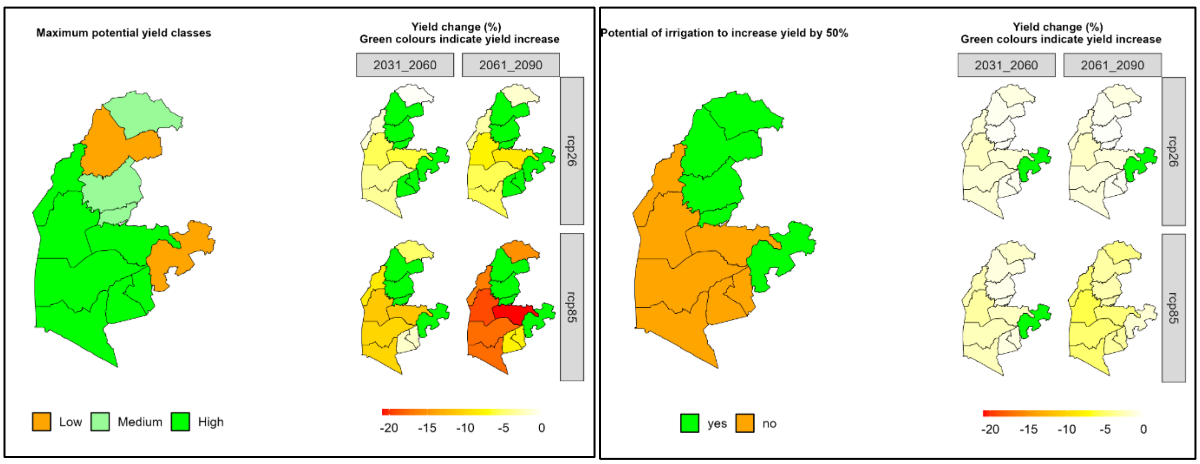

Figure 38. From left to right: a) maximum potential yield classes (baseline); b) projected yield changes (future) under rainfed conditions; c) potential of irrigation to increase cowpea yields (baseline); d) yield changes (future) under irrigated conditions.[172]

[172] The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

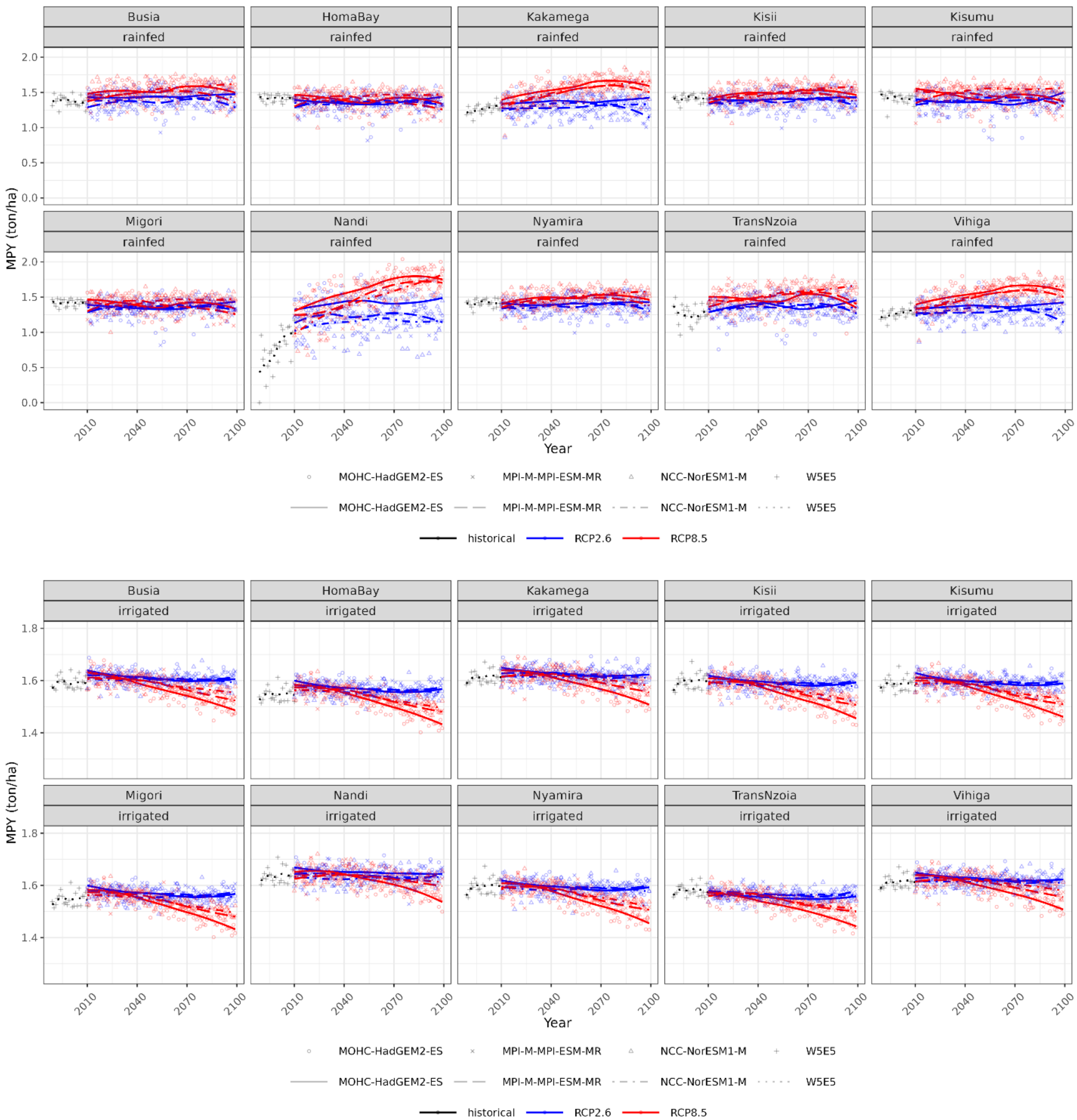

Figure 39. Maximum Potential Yield (MPY) for cowpea under rainfed and net irrigated conditions over the 2010-2099 period in representative LREB counties. Future yield simulations are based on 3 GCMs, while historical yield simulations are based on the W5E5 dataset.

89. Cowpea producers involved in the online climate survey reported the key climate hazards having the highest impact on cowpea production particularly in Bungoma, Busia, Kisumu, Migori, Nandi, and Vihiga counties, as drought, pests and diseases, extreme heat, and heavy rainfall events and flooding (Figure 40). The most perceived climate impacts include the spread of pests and pathogens, followed by soil erosion (reported by 65% of respondents) and nutrient leaching driven by heavy rainfall events

(49%) and flooding. Droughts are perceived to lower the access to rainfed and groundwater resources (40%) (Figure 41).

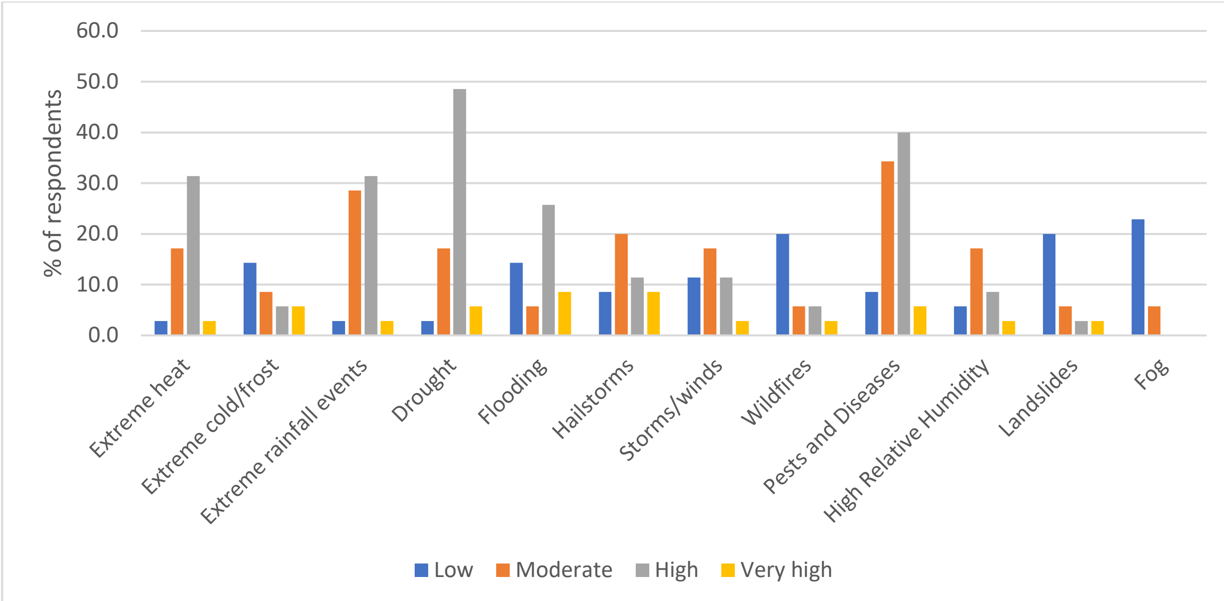

Figure 40. Perceived climate and weather-related hazards affecting ALVs production.

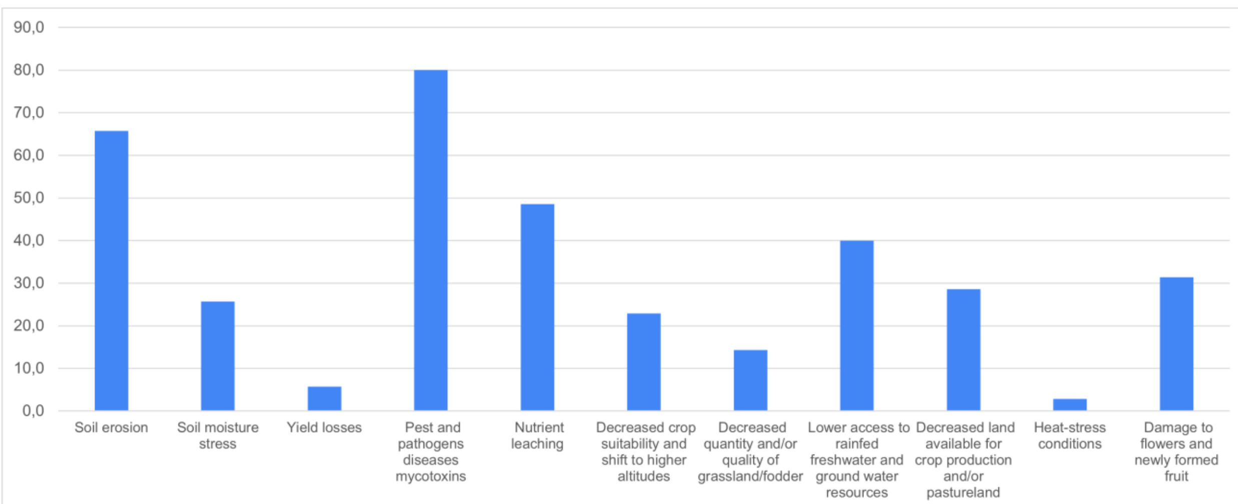

Figure 41. Perceived climate impacts on ALVs production.

90. Direct linkages between observed climate hazards and impacts on cowpea yields along the African Leafy Vegetables value chain in the LREB are further highlighted below.

Rainfall variability and drought

91. Observed climate changes include delayed onset of the rainy season and decreasing precipitation during the months of February, March, and April by up to 9mm per month. An increasing number of dry days and moisture stress reduces the availability of seeds and manure, consequently increasing the prices of agricultural inputs and negatively affecting seed germination. Land preparation is also affected due to the presence of hard pans which discourage farmers from planting due to intensive labor requirements. Farmers in Kakamega County reported that decreased rainfall caused a reduction of yields and toughening of the vegetable leaves reducing their quality and caused a moderate to high incidence of pests like spider mite and white flies as well as diseases such as bacterial wilt and powdery mildew[173]. Observed low cowpea production trends are because of prolonged droughts, increasing temperatures reducing soil fertility, soil Ph, increasing pest attacks combined with farmers' limited access to improved seeds as well as suitable pesticides and herbicides[174].

92. Drought and water stress in Amaranthus reduces its vegetative growth, the leaf area is reduced by 18-20%, as well as the plant's height, number of leaves and root length, with yields for both Spider plant and African nightshades beginning to decline with soil moisture deficit of 60% compared to the plant's optimal soil water requirements[175].

Heavy rainfall events

93. ALVs farmers' local traditional and environmental knowledge and perceptions of climate and weather changes for agricultural decision making is a valuable source of information to identify the most appropriate climate change adaptation measures. In Kakamega County, farmers reported that too much rain moderately increased the incidences of pests, highly increased the incidences of black spot and blight in cowpeas and nightshade respectively and promoted rapid growth of weeds necessitating frequent weeding. Heavy unpredictable downpours reduced yield and quality of cowpeas by causing yellowing and falling of leaves[176]. Extreme rainfall and hailstorms in Kisii and Nyamira were reported to impede farmers from using roads to transport inputs to the farm, as well as vegetable to market sites, and increasing the time needed to handle and prepare vegetables for markets. Costs for processing and transportation also increase.

94. Extreme rainfall has a significant impact on input application in Kisii and Nyamira due to difficulties with field preparation, the fixation of nutrients and leaching, as well as the proliferation of microorganisms that cause soil illnesses. In addition, heavy rains wash away seeds and cause waterlogging leading to seeds to rot. As a result, farmers are compelled to purchase additional seeds, raising the cost of replanting. Severe rainfall that is usually accompanied by hailstorms, which is bad for the growth of vegetables[177]. Such incidents frequently result in flooding in lowlands and mudslides in hilly places.

7.5.2. Climate hazards and impacts on post-harvest stages of the ALVs value chain

95. Once cowpea is harvested, it is collected and bulked and transported to market centers. During storage and transportation, high relative humidity may cause vegetables to rot and reduce the overall quality of the product, forcing farmers to lower their prices. Dry spells that negatively affect pre-

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[173] Winifred Chepkoech, Nancy W. Mungai, Silke Stöber, Hillary K. Bett and Hermann Lotze-Campen. Impact of climate change on African indigenous vegetable production in Kenya. International Journal of Climate Change Strategies and Management Vol. 10 No. 4, 2018 pp. 551-579 Emerald Publishing Limited 1756-8692 DOI 10.1108/IJCCSM-07-2017-0160

[174] Erana Kebede & Zelalem Bekeko | (2020) Expounding the production and importance of cowpea (Vignaunguiculata (L.) Walp.) in Ethiopia, Cogent Food & Agriculture, 6:1, 1769805

[175] Masinde et al. 2007. Scaling up Production of Traditional Green Leafy Vegetables in Kenya: Perspectives on Water and Nitrogen Management. Dynamic Soil, Dynamic Plant. Global Science Books.

[176] Winifred Chepkoech, Nancy W. Mungai, Silke Stöber, Hillary K. Bett and Hermann Lotze-Campen. Impact of climate change on African indigenous vegetable production in Kenya. International Journal of Climate Change Strategies and Management Vol. 10 No. 4, 2018 pp. 551-579 Emerald Publishing Limited 1756-8692 DOI 10.1108/IJCCSM-07-2017-0160

[177] CGIAR-CIAT. Ministry of Agriculture, Livestock, Fisheries and Cooperatives. 2022. Kenya County Climate Risk Profiles. https://ccafs.cgiar.org/resources/publications/kenya-county-climate-risk-profiles

harvest stages of the value chain, at post-harvest stages may create opportunities for increasing solar drying and ease vegetable transportation[178].

96. At post-harvest stages of ALVs value chains, perceived climate hazards affecting value-adding activities are more indirect than the identified ones at production stages, thus expected to have low and moderate direct impacts on post-harvest activities. Moderate impacts were identified by 80% of respondents by pests and diseases which can attack stored vegetables in warehouses and markets contributing to food spoilage and contamination through mold, bacteria, and pathogens spread, thus decreasing overall product quality and shelf-life for consumption. 50% of respondents also reported extreme rainfall events, high relative humidity, and hailstorms having a moderate impact on post-harvest activities contributing to moisture and mold increase, as well as directly damaging storage, transportation, and market infrastructures. Furthermore, extreme temperatures cause pre- and post-harvest losses in vegetables production, including early flowering, flower abscission, decreased photosynthetic capacities in cowpeas[179],[180], and vegetables spoilage, thus decreasing shelf-life. Post-harvest, high temperatures may lead to rapid spoilage of ALVs if they are not immediately sold or processed. At the processing stage, sun drying is the most popular method used to preserve vegetables. This processing is hindered during extreme rainfall and hailstorm events, whilst drier periods favor the effectiveness of the practice.

97. According to the survey respondents, all this eventually results in changes in food prices and increased needs for food importation (Figure 42 and Figure 43). Overall, adequate, and climate-proofed road networks are fundamental to enable farmers to timely reach markets with low food losses and transport costs, as happens in Kericho county. At the same time, extreme rainfall, and hailstorms in Kisii and Nyamira impede farmers to use roads to transport inputs to the farm, as well as vegetable to market sites, combined with more time needed to handle and prepare vegetables for markets.

[178] CGIAR-CIAT. Ministry of Agriculture, Livestock, Fisheries and Cooperatives. 2022. Kenya County Climate Risk Profiles. https://ccafs.cgiar.org/resources/publications/kenya-county-climate-risk-profiles

[179] Mohammed et al., 2021. Effect of climate variation on the yield of cowpea (Vigna unguiculata). Vol. 17(3), pp. 456-462, March, 2021 DOI: 10.5897/AJAR2020.14960 Article Number: A77ACC766334 ISSN: 1991-637X

[180] Barros et al. 2021. Selection of cowpea cultivars for high temperature tolerance: physiological, biochemical and yield aspects. Physiol Mol Biol Plants (January 2021) 27(1):29–38 https://doi.org/10.1007/s12298-020-00919-7

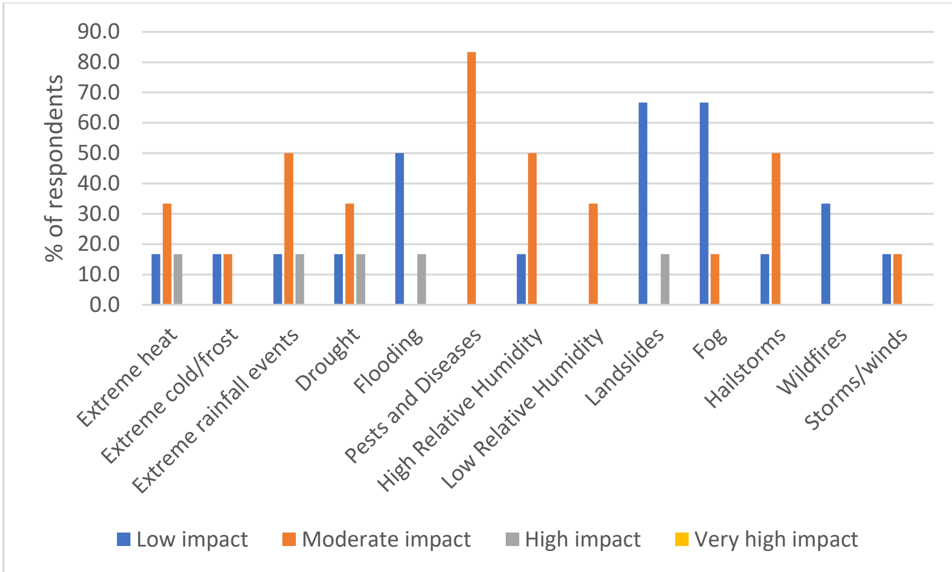

Figure 42. Perceived climate and weather-related hazards affecting post-harvest stages of ALVs value chains.

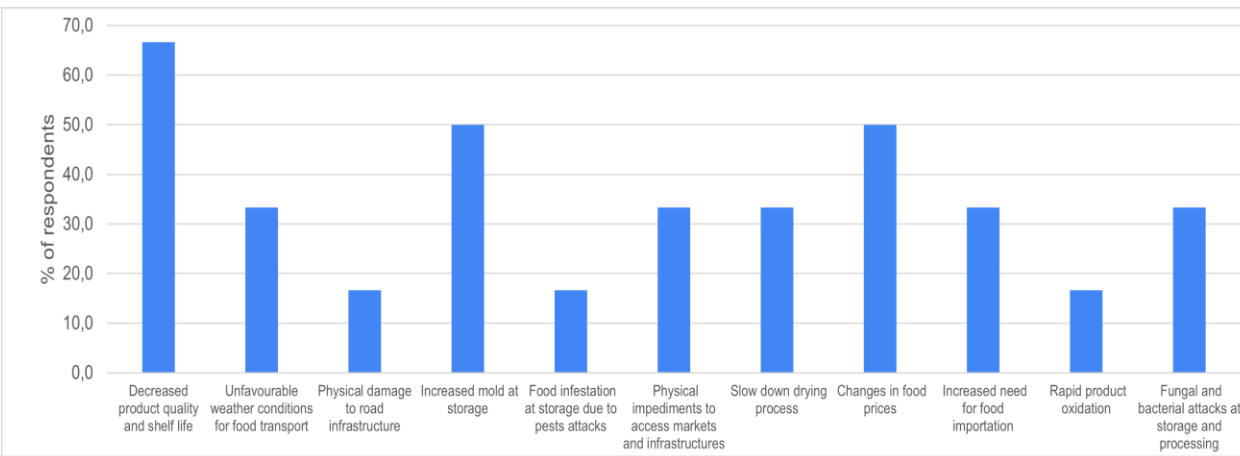

Figure 43. Perceived climate impacts on post-harvest stages of ALVs value chains.

Table 5. Summarized impacts of climatic variables on targeted crop value chains.

	Optimum conditions		Climate impacts		
Crop	Total rainfall and rainfall distribution	Optimal growth temperatures	Precipitation	Extreme maximum/minimum temperatures	Other climatic variables
Tea	1150-1400mm/yr., well distributed (150 mm/month)	18–30°C. 13-14°C for shoot growth	Drought: 14–20% loss in yield and 6– 19% plant mortality Heavy rainfall: fungal diseases, soil erosion, poor bud break	Extreme maximum temperatures (Tmax>30°C): Shoot growth restricted, directly damaged leaves Frost: leaf scorching	Hailstorms: 30% of harvest losses and delays; damaged mother bushes
Coffee	Rainfall - >1000 mm/yr., well distributed with a 2-month dry spell	18 – 21ºC	- Prolonged rainfall: high incidences of coffee Berry disease, Coffee Leaf Rust and Coffee bacterial wilt -erratic rains: year-round coffee flowering -Changes in rainfall patterns: drying and processing activities negatively affected	Extreme maximum temperatures: -Tmax>23°C, the development and maturation of coffee berries are hastened -Tmax>25ºC - Photosynthesis is reduced -Tmax>30ºC - Yellowing of leaves - Growth of tumors at the base of the stem - Abortion of flowers Large variations in temperature: increase bean defects, modify bean biochemical composition and the final quality of the beverage	Increased winds causing branches to break. Hail: flower loss
Banana	1000mm/yr. (100mm/month)	28°C	- Drought/moisture stress: reduced quantity and size of fruits; pests and diseases - Heavy rainfall: rotting, pests and diseases, damage to trees - every 100 mm yr−1 decrease in rainfall reduces bunch yields by 9%		Hailstorms and strong winds causing banana stems to break
African leafy vegetables	1000-1600mm/yr.	25°C	- Heavy rainfall and unpredictable downpours: moderately increased incidence of pests, highly increased incidences of black spot and blight in cowpeas and nightshade, respectively; promoted rapid growth of weeds necessitating frequent weeding; reduced yield and quality of cowpeas by causing yellowing and falling of leaves	Extreme temperatures (Tmax>35°C): early flowering and flower abscission in cowpeas	

	Optimum conditions		Climate impacts		
Crop	Total rainfall and rainfall distribution	Optimal growth temperatures	Precipitation	Extreme maximum/minimum temperatures	Other climatic variables
			- Dry spells: reduction of yields and toughening of the leaves (reduced quality) and moderated to high incidences of pests like spider mite and white flies, and diseases such as bacterial wilt and powdery mildew		

7.6. Climate impacts on livestock

98. Impacts of climate change on livestock are both direct (by impacting the health and productivity of the animal) and indirect (through disruptions to feed and fodder value chains and water availability). The same constraints apply to livestock products, with meat and milk production affected by higher temperatures and increased heat waves, precipitation-related increases in diseases, and a decline in fodder production. Other livestock impacts to consider are the prevalence of livestock storing and herding occurring in urban and peri-urban environments in Kenya, greatly increasing the potential for livestock parasites to interact with human populations[181].

Observed and projected extreme temperature impacts on livestock

99. Increased heat waves and temperatures directly affect animal health through the emergence of pathogens. In a 2010 cattle study in Kenya's LREB, two-thirds of all cattle contained at least one parasitic community suggesting that increasing temperatures and rainfall were the main climatic variables triggering the expansion and distribution of parasites[182]. Increased ambient temperature and concurrent changes in heat exchanges cause heat stress which influences growth, reproduction performance, milk production, and animal health and welfare. High temperatures may also cause heat stress on animals and weight loss, leading to increased need for larger spaces for poultry houses and open pastures lacking enough space and trees for shading. Extreme temperatures also increase the demand for energy to maintain the products fresh during storage and transportation. The latter results in reduced quantity and quality of final products available for selling, reduced prices and income for producers[183]. Increasing maximum temperatures influence the quantity and quality of pastures, fodder crops, and grains, highlighting the need for a crop-livestock value chain approach. Nonetheless, the Lake Basin Commission strategy and action plan (2013-2023) indicated that a 1°C temperature rise above optimal levels (10–30°C) for livestock might reduce their feed intake by 3–5% [184].

Observed drought and flooding impacts on livestock

100. Livestock production and the dairy value chain in the LREB are highly exposed and vulnerable to the occurrence of drought and flooding events. Drought periods have direct negative impacts on quantity and quality of fodder supply and pasture and water availability, resulting in poor animal body conditions, and with negative effects on the quality of milk produced and sold and poor market prices. Flooding, on the other hand, increases the incidences of vectors (such as ticks, mosquitoes and tsetse and vector-borne diseases such as trypanosomiasis, Rift valley fever and East coast Fever). There is also an increased incidence of internal parasite infestations such as flukes and worms. Other negative impacts of floods include increases in foot rot and other fungal infections. Increased frequency and intensity of heavy rainfall events and extreme heat are expected to impact the cattle and poultry value

[181] P.W.N. Kanyari, J.M. Kagira, J.R.L. Mhoma. 2010. Prevalence of endoparasites in cattle within urban and peri-urban areas of Lake Victoria Basin, Kenya with special reference to zoonotic potential. *Scientific Parasitology*, 11(4): 171-178.

[182] Kanyari, Kagira, and Mhoma, 2010. Prevalence of endoparasites in cattle within urban and peri-urban areas of Lake Victoria Basin, Kenya with special reference to zoonotic potential. Sci Parasitol, 11(4). http://erepository.uonbi.ac.ke/handle/11295/33352

[183] MoALF. 2016. Climate Risk Profile for Busia. Kenya County Climate Risk Profile Series. The Kenya Ministry of Agriculture, Livestock and Fisheries (MoALF), Nairobi, Kenya.

[184] USAID. 2018. Climate Risk Profile. Kenya. Fact Sheet. https://www.climatelinks.org/sites/default/files/asset/document/2018_USAID-ATLAS-Project_Climate-Risk-Profile-Kenya.pdf

chain in the LREB from input supply to marketing stages, leading to increased demand combined with reduced access to agricultural inputs due to damaged roads and input storage infrastructures.

7.7. Dairy

7.7.1. Observed and projected climate hazards and impacts on dairy production

101. While dairy products provide consumers with high-quality nutrients including calcium, protein, vitamin D, they require a substantial use of natural resources including freshwater and land, as well as energy and crops to feed animals. The dairy value chain is susceptible to compounded climate hazards and impacts as highlighted below, which directly affect cows' well-being and performance in producing milk[185]. Respondents of the climate survey involved in dairy production reported drought (43,5%), pests and diseases (52%), and extreme heat (30%) as the climate hazards having a high impact on cattle and dairy production (Figure 44). The most perceived impacts include pest and pathogens, diseases and mycotoxins spread (60%), as well as indirect impacts on the quantity and quality of fodder produced (42%), and overall decreased land available for crop and livestock production (48%) (Figure 45).

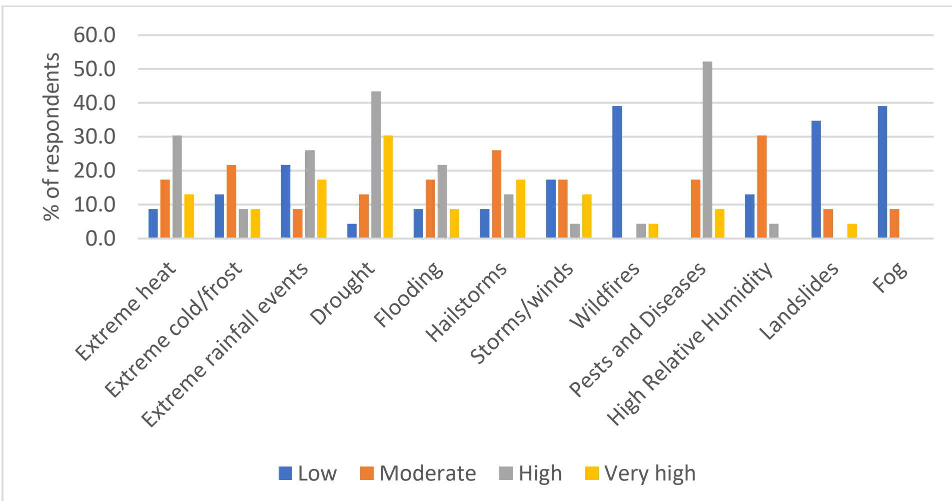

Figure 44. Perceived climate and weather-related hazards affecting dairy production.

185 Guzmán- Luna et al., 2021. Analysing the interaction between the dairy sector and climate change from a life cycle perspective: A review. Trends in Food Science & Technology. 126.

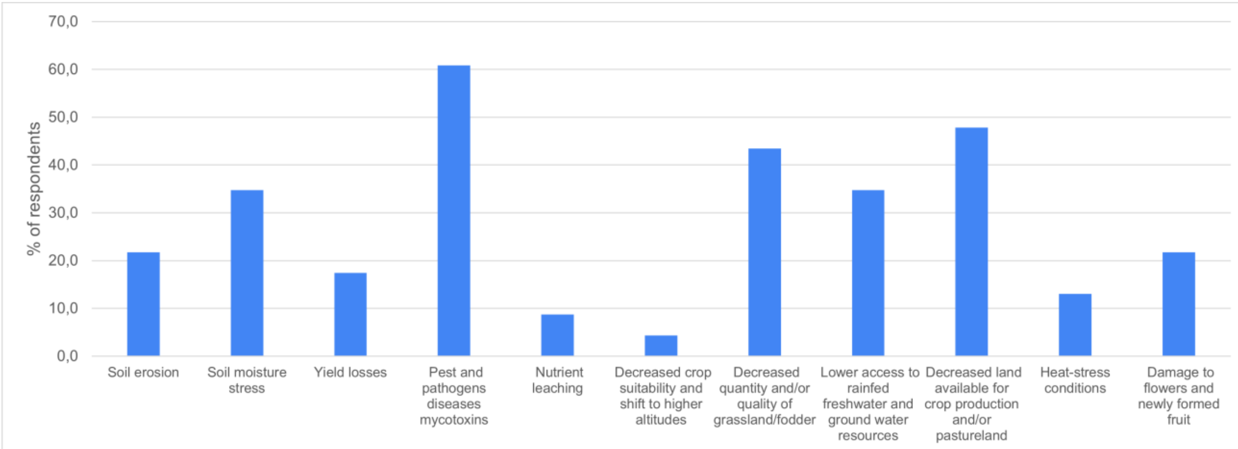

Figure 45. Perceived climate impacts on dairy production.

102. Direct linkages between observed climate hazards and impacts on dairy production as well as along the value chain in the LREB are further highlighted below.

Extreme temperatures and drought

103. In tropical and sub-tropical regions, extreme temperatures have negative impacts on livestock well-being. Temperatures above 35°C lead to heat stress which reduces fertility and milk yields and increases animal mortality[186]. Temperature and humidity conditions above average normal resting state of a cow negatively affect its productivity and physiological conditions, including weakening of immune functions thus increasing vulnerability to mastitis and infections, decreasing feeding rates, body growth and weight, and increasing oxidative stress. Such stresses have direct negative impacts on raw milk's microbiology, yields, and physicochemical properties such as lower fat levels, milk protein and casein content, which negative impacts on the techno-functional properties for producing cheese blocks and bio-functional properties of antihypertensive and hypolipidemic activities, and for the absorption of bioactive compounds in foods during digestion[187],[188].

104. A study by Rahimi et al. (2021)[189] assessed historical trends of heat stress impacts on dairy cattle in East Africa during 1981-2010, using the Temperature-Humidity Index (THI). THI is a fundamental indicator of climate-driven stress to livestock. For a Holstein cow with average yields (up to 35kg/day) the THI threshold is 68-72 if it has no access to shade, and 78 with access to shade and sprinkler systems, corresponding to ±25 °C and ±15% relative humidity[190],[191]. For each unit in the THI exceeding

[186] Rahimi, J., Mutua, J.Y., Notenbaert, A.M.O. *et al.* Heat stress will detrimentally impact future livestock production in East Africa. *Nat Food* **2**, 88–96 (2021). https://doi.org/10.1038/s43016-021-00226-8
[187] Tadesse, G. and Dereje, M. 2018. Impact of Climate Change on Smallholder Dairy Production and Coping Mechanism in Sub-Saharan Africa-Review. Advances in Life Science and Technology. ISSN 2224-7181 (Paper) ISSN 2225-062X (Online) Vol.65, 2018.
[188] Feliciano, R.J.; Boué, G.; Membré, J.-M. Overview of the Potential Impacts of Climate Change on the Microbial Safety of the Dairy Industry. *Foods* **2020**, *9*, 1794. https://doi.org/10.3390/foods9121794
[189] Rahimi, J., Mutua, J.Y., Notenbaert, A.M.O. *et al.* Heat stress will detrimentally impact future livestock production in East Africa. *Nat Food* **2**, 88–96 (2021). https://doi.org/10.1038/s43016-021-00226-8
[190] Guzmán- Luna et al., 2021. Analysing the interaction between the dairy sector and climate change from a life cycle perspective: A review. Trends in Food Science & Technology. 126.
[191] Tadesse, G. and Dereje, M. 2018. Impact of Climate Change on Smallholder Dairy Production and Coping Mechanism in Sub-Saharan Africa-Review. Advances in Life Science and Technology. ISSN 2224-7181 (Paper) ISSN 2225-062X (Online) Vol.65, 2018.

such threshold, a 0.2-0.41kg decrease in milk yield per cow is expected[192]. In the LREB, results mostly indicate no heat-stress and optimal productive and reproductive performance of livestock, to "Mild" conditions (THI between 72-79), which indicates the presence of heat stress that is bearable for the animal through chemical and physical means (from 40% to >50%). However, mild THI conditions already pose uncomfortable stress in cattle and decreased milk yields. Furthermore, "Moderate" conditions (THI between 80-89), were observed within counties closer to the LVB, which correspond to heat stress increasing animals' body temperature and reducing productive and reproductive performances.

105. Changes in temperature and precipitation patterns, extreme temperatures, and dry spells, also have detrimental effects on crop and grass growing seasons[193], on the spatial distribution of pastureland and water availability, impacting on the availability of feed for livestock. Overall, higher milk yields are expected during the rainy seasons compared to the dry seasons due to higher quantity and quality of pasture[194]. Poor pasture conditions result in overgrazing, pressure on water resources, and land degradation[195].

106. A projected increase in the number of consecutive extreme heat days in the LREB is likely to pose substantial heat stress on livestock. According to results from Samy and Peterson (2016)[196]', analysis of past and future global distribution of the bluetongue virus, a high concentration of bluetongue virus in the LREB was detected as compared to the rest of Kenya both for the present and future scenarios under RCP2.6 and RCP8.5, because of suitable climatic conditions. The occurrence of mastitis outbreaks due to farmers' maladaptation practices of poor feed storage, lack of feed and milking equipment hygiene and sanitation on-farm and at storage[197],[198] is expected to be exacerbated by climate change, particularly by increasing temperatures and drought conditions.

Heavy rainfall and flooding

107. Increasing rainfall and flooding is expected to decrease breeding activities and animal mortality due to higher exposure and vulnerability to water-borne diseases. As most livestock production in the LREB is consumed domestically, a decrease in productivity as a result of heavy rains and flooding stress on animals would reduce food access and availability 199. Heavy rainfall and flooding indirectly reduce livestock production, as run-off carries away fodder, influencing the quantity and quality of pastures and grains. Such climate hazards are exacerbated by overgrazing and vegetation degradation in the

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[192] Feliciano, R.J.; Boué, G.; Membré, J.-M. Overview of the Potential Impacts of Climate Change on the Microbial Safety of the Dairy Industry. *Foods* **2020**, *9*, 1794. https://doi.org/10.3390/foods9121794

[193] Tadesse, G. and Dereje, M. 2018. Impact of Climate Change on Smallholder Dairy Production and Coping Mechanism in Sub-Saharan Africa-Review. Advances in Life Science and Technology. ISSN 2224-7181 (Paper) ISSN 2225-062X (Online) Vol.65, 2018.

[194] Guzmán- Luna et al., 2021. Analysing the interaction between the dairy sector and climate change from a life cycle perspective: A review. Trends in Food Science & Technology. 126.

[195] Tadesse, G. and Dereje, M. 2018. Impact of Climate Change on Smallholder Dairy Production and Coping Mechanism in Sub-Saharan Africa-Review. Advances in Life Science and Technology. ISSN 2224-7181 (Paper) ISSN 2225-062X (Online) Vol.65, 2018.

[196] Samy AM, Peterson AT. 2016. Climate Change Influences on the Global Potential Distribution of Bluetongue Virus. PLoS ONE 11(3): e0150489. https://doi.org/10.1371/journal.pone.0150489

[197] Guzmán- Luna et al., 2021. Analysing the interaction between the dairy sector and climate change from a life cycle perspective: A review. Trends in Food Science & Technology. 126.

[198] Feliciano, R.J.; Boué, G.; Membré, J.-M. Overview of the Potential Impacts of Climate Change on the Microbial Safety of the Dairy Industry. *Foods* **2020**, *9*, 1794. https://doi.org/10.3390/foods9121794

[199] Mwongera, C., Nowak, A., Notenbaert, A.O.M., Grey, S., Osiemo, J., Kinyuwa, I., Lizarazo, M. & Girvetz, E. 2019. Climate-Smart Agricultural Value Chains: Risks and Perspectives. In: Rosenstock T., Nowak A., Girvetz E. (eds) *The Climate-Smart Agriculture Papers*. Springer, Cham. https://doi.org/10.1007/978-3-319-92798-5_20

LREB because of higher livestock density and grassland consumption compared to the estimated available grassland200. Milk productivity is also indirectly affected by climate change impacts to grasslands and to livestock feed production. Changes in temperature and precipitation patterns, extreme temperatures and dry spells, have detrimental effects on crop and grass growing seasons201, on the spatial distribution of pastureland and water availability, thus on the final availability of feed for livestock. The safety of milk products may be compromised by the growth of fungi and mycotoxins (including Geobacillus stearothermphilus, Micrococcus, Bacillus cereus, Anoxybacillus flavithermus, Pseudomonas fluorescens, Enterobacter faecium and E. faecalis, and occasionally pathogenic microorganisms such as Salmonella and Listeria monocytogenes) in cows' feed due to increasing temperatures, rainfall, and humidity.

7.7.2. Climate hazards and impacts on post- production stages of the dairy value chain

108. In Kenya, the national daily capacity of milk cooling centres is not fully reached in every season due to climate impacts exacerbating the instability of milk production, storage, and processing activities. These include higher than optimal temperatures, drought and flooding events which cause dairy products' spoilage, reducing their shelf-life as well as safety through the proliferation of spore forming bacteria and milk evaporation[202]. In addition, flooding events may damage road infrastructure and reduce access to milk storage, processing, and marketing facilities, leading to milk spoilage, thus reducing sales and dairy farmers' income[203].

109. According to FAO (2011), post-harvest losses in the milk value chain mainly occur at handling and storage, and distribution. Losses are higher during the wet season due to the proliferation of mold and fungi, as well as the challenges to use roads impacted by extreme rainfall. Milk is lost due to quality controls which reject milk at collection and bulking centers for the presence of contaminants. In western Kenya, such losses were estimated at 1.1% within cooling centers (7% or 336 million liters of milk were assumed to be lost at national level at the expense of 23.5 billion KES assuming a milk price of KES 70 per liter). During transportation, milk losses as a result of bacterial growth occur due to the use of improper plastic containers that are hard to sterilize as well as limited cold chain practices, weak infrastructure, long distances from the farm to the bulking and cooling center[204]. Infrequently milk is precooled before transportation and precious time to avoid raw milk spoilage is also lost to manage milk collection from farmers as well as on the management of cooling centers. Milk losses due to poor management practices are expected to be exacerbated by increasing temperatures[205]. According to 60% of the respondents to the online climate survey, extreme heat and

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[200] Yamane, Y. et al. 2015. Influence of Livestock Farming on Vegetation in a Degraded Soil Area on the East Coast of Lake Victoria in Western Kenya: A Case Study of Jimo East Sub-Location in Nyando Sub-County. Journal of Environmental Protection. 6.

[201] Tadesse, G. and Dereje, M. 2018. Impact of Climate Change on Smallholder Dairy Production and Coping Mechanism in Sub-Saharan Africa-Review. Advances in Life Science and Technology. ISSN 2224-7181 (Paper) ISSN 2225-062X (Online) Vol.65, 2018.

[202] International Livestock Research Institute. 2020. Food safety landscape analysis: The dairy value chain in Kenya. https://cgspace.cgiar.org/bitstream/handle/10568/108989/Food%20safety%20Kenya%20dairy%20value%20chain.pdf?sequence=1

[203] Mwongera, C., Nowak, A., Notenbaert, A.O.M., Grey, S., Osiemo, J., Kinyuwa, I., Lizarazo, M. & Girvetz, E. 2019. Climate-Smart Agricultural Value Chains: Risks and Perspectives. In: Rosenstock T., Nowak A., Girvetz E. (eds) *The Climate-Smart Agriculture Papers*. Springer, Cham. https://doi.org/10.1007/978-3-319-92798-5_20

[204] International Livestock Research Institute. International Livestock Research Institute (ILRI). 2020. Food safety landscape analysis: The dairy value chain in Kenya. https://cgspace.cgiar.org/bitstream/handle/10568/108989/Food%20safety%20Kenya%20dairy%20value%20chain.pdf?sequence=1

[205] Guzmán- Luna et al., 2021. Analysing the interaction between the dairy sector and climate change from a life cycle perspective: A review. Trends in Food Science & Technology. 126.

drought have a high impact on the dairy value chain (Figure 46), particularly through the increased risk of milk spoilage through the proliferation of contaminants (Figure 47).

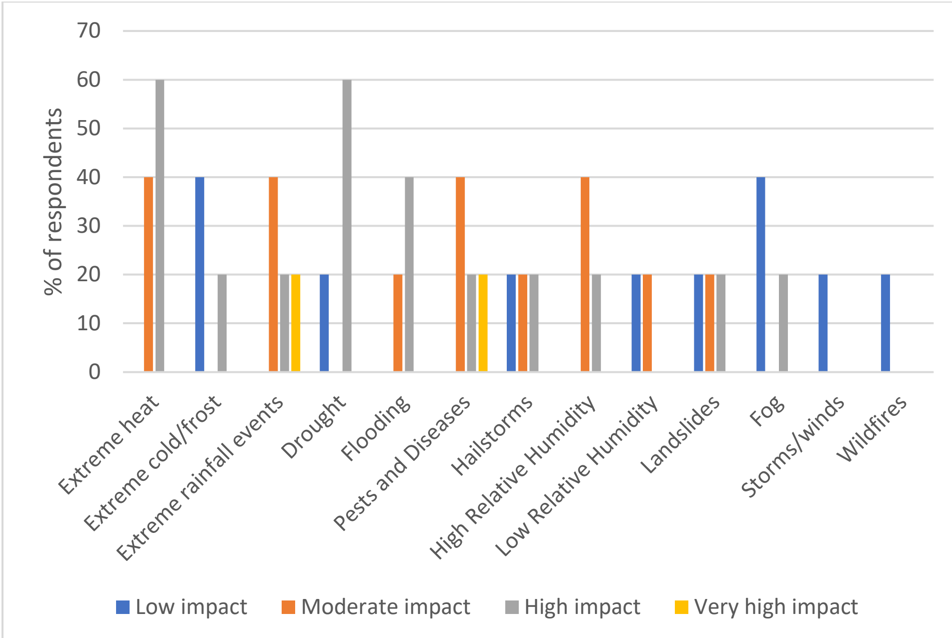

Figure 46. Perceived climate and weather-related hazards affecting the dairy value chain.

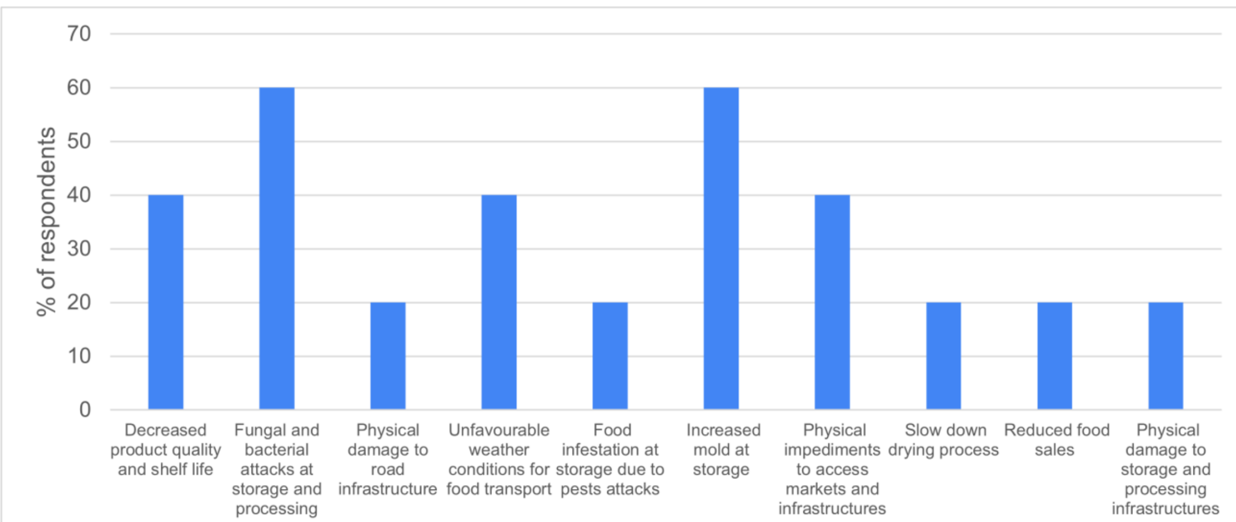

Figure 47. Perceived climate impacts on the dairy value chain.

7.8. Poultry

7.8.1. Observed and projected climate hazards and impacts on poultry production

110. According to the results of the online climate survey, producers selected pests and diseases (41%), drought and flooding (29%) as the hazards having a high impact on poultry production (Figure 48) through the spread of pathogens (75%) as well as soil erosion (50%) (Figure 49). Extreme rainfall events (41%) were perceived to moderately impact poultry production.

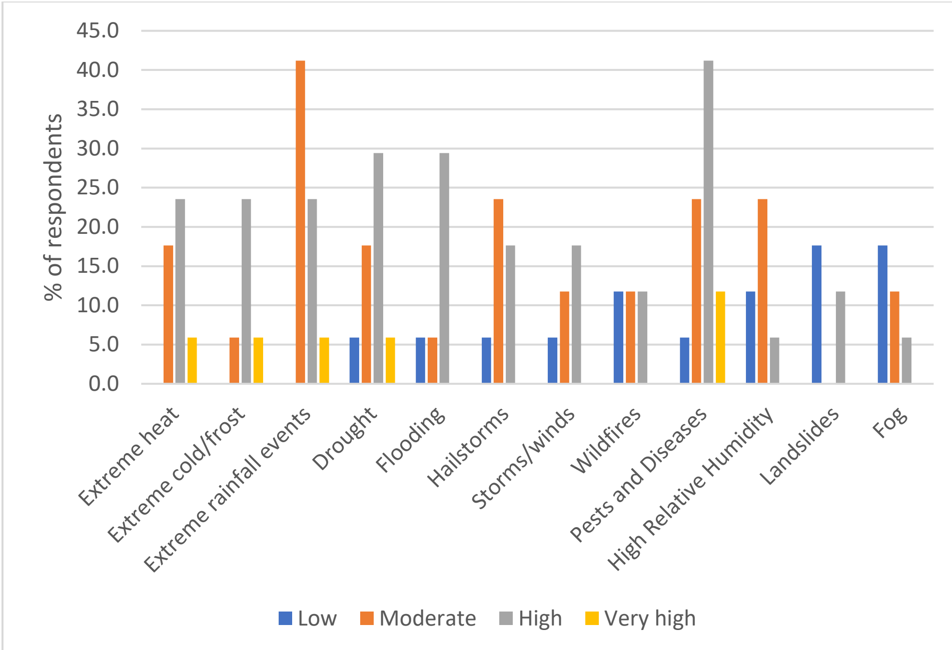

Figure 48. Perceived climate and weather-related hazards affecting poultry production.

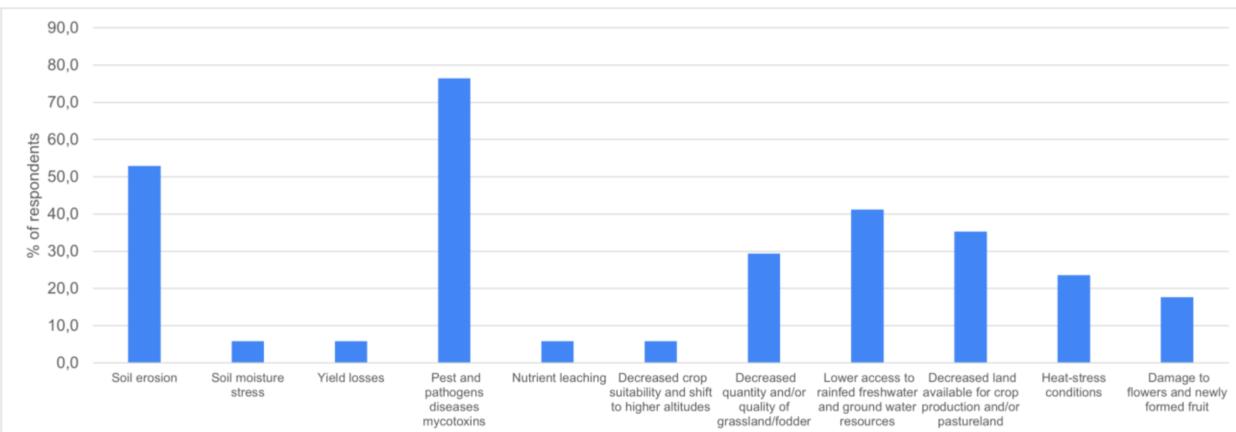

Figure 49. Perceived climate impacts on poultry production.

Direct linkages between observed climate hazards and impacts on poultry production as well as along the value chain in the LREB are further highlighted below.

Heat stress

111. Most poultry production losses occur with sudden temperature changes, particularly in intensive units. Temperatures above 21°C reduce voluntary feed intake, and hence growth rates are reduced. The consecutive exceeding of such threshold year-round is likely to pose substantial heat stress on poultry, which can suffer from acute heat stress when temperatures above 35°C are exceeded, as well

as chronic heat stress after 3 consecutive days of maximum temperatures above 35°C [206]. High temperatures associated with drought conditions make chicken production unprofitable due to poor productivity as birds shift their energy uses to cooling to the disadvantage of muscle development and egg production; it also increases chick's mortality[207]. Extreme temperatures during production directly reduce the quality of meat products on the market as well as the weight of chicken sold[208]. Dry spells also increase the risk of pest and disease attacks.

Poultry diseases

112. The main observed viral diseases affecting local chicken production include Newcastle Disease (NCD) and fowl pox, which are driven by both wet and dry weather and climatic conditions[209]. The likelihood of disease transmission is influenced by changes in temperature through changing pathogen viability and risk of transmission.

7.8.2. Climate hazards and impacts on post-production stages of the poultry value chain

113. The occurrence of heavy rainfall events may hinder the collection of eggs as well as chicken and egg transportation to collection and market facilities due to damage to road infrastructures. The risk of egg spoilage during storage and transportation is also high[210]. Small-scale farmers in the LREB are discouraged from travelling to selling points during heavy rains, therefore missing income opportunities, due to poor roads and infrastructure, thus causing market shortages and higher prices[211]. Transportation also poses higher discomfort among animals when temperatures are high and chicken storage spaces are narrowed. Post-production losses in eggs and meat where cold storage is not available also increase. Overall, value chain respondents to the online climate survey identified extreme heat (75%) as having a high impact on the post-production stages of the poultry value chain (Figure 50) particularly contributing to decreased product quality and shelf-life and thus reduced food sales and prices.

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[206] Srikanth K, Kumar H, Park W, Byun M, Lim D, Kemp S, te Pas MFW, Kim J-M and Park J-E (2019) Cardiac and Skeletal Muscle Transcriptome Response to Heat Stress in Kenyan Chicken Ecotypes Adapted to Low and High Altitudes Reveal Differences in Thermal Tolerance and Stress Response. Front. Genet. 10:993. doi: 10.3389/fgene.2019.00993

[207] Kennedy et al. 2022. Review Article : Heat stress and poultry: Adaptation to climate change, challenges and opportunities for genetic breeding in Kenya. Journal of Agriculture, Science and Technology. DOI: 10.4314/jagst.v21i1.6

[208] Ngigi, M.W., Mueller, U. & Birner, R. Livestock Diversification for Improved Resilience and Welfare Outcomes Under Climate Risks in Kenya. Eur J Dev Res 33, 1625–1648 (2021). https://doi.org/10.1057/s41287-020-00308-6

[209] MoALF. 2017. Climate Risk Profile for Bomet County. Kenya County Climate Risk Profile Series. The Ministry of Agriculture, Livestock and Fisheries (MoALF), Nairobi, Kenya.

[210] Mwongera, C., Nowak, A., Notenbaert, A.O.M., Grey, S., Osiemo, J., Kinyuwa, I., Lizarazo, M. & Girvetz, E. 2019. Climate-Smart Agricultural Value Chains: Risks and Perspectives. In: Rosenstock T., Nowak A., Girvetz E. (eds) *The Climate-Smart Agriculture Papers*. Springer, Cham. https://doi.org/10.1007/978-3-319-92798-5_20

[211] Kennedy et al. 2022. Review Article : Heat stress and poultry: Adaptation to climate change, challenges and opportunities for genetic breeding in Kenya. Journal of Agriculture, Science and Technology. DOI: 10.4314/jagst.v21i1.6

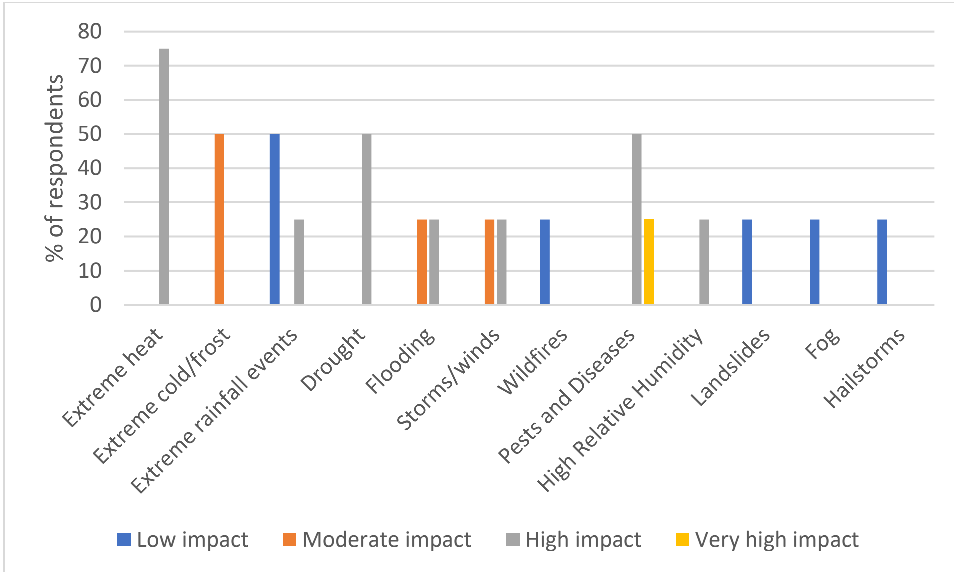

Figure 50. Perceived climate and weather-related hazards affecting the poultry value chain.

Table 6. Summarized impacts of climatic variables on targeted livestock value chains.

Optimum conditions			Climate impacts	
Livestock	Optimal temperatures	Temperature-Humidity Index	Precipitation	Extreme maximum/minimum temperatures
Dairy	5°C-25°C	68-72 (without shade); 78 (with access to shade and sprinkler systems)	Drought: reduced immunity to diseases, animals' emaciation, lower quality of feed Heavy rainfall: water-borne disease risks, reduced milk quantity and quality	Extreme maximum temperatures (Tmax>35°C): 0.2 to 0.41kg decrease in milk yield per cow for each unit in the THI exceeding the threshold
Poultry	15°C-20°C	70-78	Drought: disease risks, decline in production Heavy rainfall: water-borne disease risks, decreased breeding activities, increased animal mortality and feed spoilage	Extreme maximum temperatures (Tmax>35°C): malnutrition and weight loss, increased vaccination needs and flock mortality

7.9. Climate impacts on water resources

114. Climate change, variability, and extremes, including temperature increases and increased evaporation rates, heavy rainfall events and dry days, compounded with anthropogenic drivers of population growth and increased pressure on water resources through agricultural expansion, negatively affect the spatiotemporal availability of water resources. Land conversion to agriculture and deforestation also have negative impacts on increased heavy rainfall and associated landslide risks due to lower trees' capacity to slow water flow within slopes[212]. Research was conducted among climate and water experts, decision-makers, and stakeholders in three counties along the Nzoia River Basin (Busia, Kakamega, and Trans-Nzoia) to define the main climate hazards and levels of impacts on water resource management[213]. The results show high levels of drought risk and consequent water scarcity and degradation throughout the basin. The risks of water runoff, soil erosion, and sediment load associated to heavy rainfall and river flooding instead were rated as high in the lower catchment of the river, and moderate and low towards the upper catchment. Mwangi et al. (2020)[214] also demonstrate how observed and projected decreasing total precipitation during the MAM and JJAS seasons in the mid- to long-term future under both RCP2.6 and 8.5 is expected to cause a decrease in stream flows, as well as how increasing total precipitation during the OND season is likely to exacerbate the frequency and intensity of flooding events, in most rivers in the LREB including Nzoia, Nyando, Sio, Sondu, and Yala.

[212] Parry et al. 2012. Climate Risks, Vulnerability and Governance in Kenya: A review. UNDP.

[213] Odwori, E. 2022. Adapting Strategies for Water Supply Management to Climate Change in Nzoia River Basin, Kenya. Asian Journal of Environment & Ecology. 18(1): 24-52, 2022; Article no.AJEE.86325 ISSN: 2456-690X

[214] https://www.scirp.org/journal/paperinformation.aspx?paperid=103280

8. Mapping of the National Framework on Climate Services in Agriculture

115. Climate services at county level are provided by the county meteorological offices present in all counties. The Kenya Meteorological Department (KMD) under the Ministry of Environment and Forestry (MEF) is the main department collecting and disseminating climate information services (CIS) to the population and key sectors in Kenya including transportation, agriculture, water, and health. The mandate of the KMD is to provide timely early warning weather and climate information for safety of life, protection of property and conservation of the natural environment. At county level the KMD operates through the County Meteorological Office (CMO) which is the sub-national weather service of KMD. Each CMO is headed by a County Director of Meteorological Services (CDMS) who is charged with implementing national policies at the county level and delivering CIS[215].

116. In addition, there are several other actors, such as Ag-tech start-ups, global non-profits and regional centres that also contribute to the county level CIS. These actors work closely with government counterparts to deliver CIS. One example is Precision Agriculture for Development (PAD), an Ag-tech start up that ensures CIS is relevant at the county level. In addition, the global non-profit Precision for Development (PxD) offers mobile-phone based agricultural extension services and the regional centner IGAD Climate Prediction and Application Centre (ICPAC), a specialized regional centre of the Intergovernmental Authority on Development (IGAD) supports on climate monitoring, prediction, early warning, and applications for the reduction of climate-related risks.

8.1. Data collection and monitoring of weather forecasting and agronomic information

117. To monitor and evaluate the weather patterns in Kenya, the KMD operates, and controls 40 synoptic stations spread across the country and about 600 rain gauge stations operated by private observers. Overall, the weather observation network is sparse compared to the World Meteorological Organization's (WMO) recommended practice regarding the spacing between neighboring stations of 1 station every 50 km for measuring temperature and 10 km for precipitation. Although the KMD has in the last few years installed several Automatic Weather Stations (AWS), the data is not yet fully integrated into meteorological applications or shared globally through the Global Telecommunication System (GTS) of the WMO as required. This is mainly because the quality of storage and reporting of the AWS datasets is not yet well known[216].

118. With regards to the agricultural sector, KMD carries out observations of air maximum and minimum, wet bulb, dry bulb, dew point and soil temperature, sunshine duration, radiation, wind speed and direction, humidity at synoptic times, pan evaporation in mm per day, calculated potential evapotranspiration in mm per dekadal (10-day period) and rainfall in mm per day. Other important products issued to the farmers include the onset and cessation of the rainy season, and the expected seasonal rainfall amounts. The KMD through its agrometeorological section prepares the 10 day (dekadal) agrometeorological bulletin, which is available on its website for public use. The bulletin normally has updates on weather evolution and crop development and contains forecast on crop performance, advisory services on adverse effects of weather on crops as well as on harvest and post-

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[215] County Meteorological Services. Kenya Meteorological Department. Accessed at: https://meteo.go.ke/services/county-meteorological-services

[216] Muita, Richard & Kucera, Paul & Aura, Stella & Muchemi, David & Gikungu, David & Mwangi, Samuel & Steinson, Martin & Oloo, Paul & Maingi, Nicholas & Muigai, Ezekiel & Kamau, Mwaura. (2021). Towards Increasing Data Availability for Meteorological Services: Inter-Comparison of Meteorological Data from a Synoptic Weather Station and Two Automatic Weather Stations in Kenya. American Journal of Climate Change. 10. 300-316. 10.4236/ajcc.2021.103014

harvest operations[217]. For seasonal to sub-seasonal (S2S) forecasts, ICPAC is involved in research and testbed activities to integrate scientific research and operational forecasting testbeds, piloting the provision of real-time, bespoke S2S forecast products to decision-makers in Kenya[218].

8.2. Co-design and co-production of tailored products

119. Kenya has a decentralized National Meteorological Hydrological Services (NMHS) which presents an advantage in terms of engaging farmers on issues related to climate information. KMD, and a Ministry of Agriculture Agricultural Sector Development Support Programme (ASDSP) support at county level. The government is supported through pilots and projects such as ACREI and WISER East Africa which utilize the Participatory Advisory Planning (PSP) and Participatory Integrated Climate Services (PICSA) approaches to co-design and co-produce advisories at the local level. These projects have involved multiple entities such as ICPAC, FAO, WMO, local government departments and CBOs[219].

8.3. Communication of services to the last mile

120. In Kenya, farmers receive climate information from extension services, daily radio, television, newspapers and through community interactions. Experience has shown that most farmers prefer indigenous forecasting knowledge more than contemporary forecasting[220]. CIS is mainly disseminated to farmers through television and radio, as well as advisories in short messages. Information is also disseminated through sub-county specific climate advisories to farmers; however, issues of illiteracy affect last-mile information.

121. According to the results of the climate survey to actors involved in the targeted value chains (Figure 51), WhatsApp SMSs (63%) and TV (49%) are the two mostly used tools to receive climate and weather-related information across the LREB counties, followed by radio (45%) and meteorological service websites (42%). Value chain actors highlighted how information received from weather applications (39%), agrometeorological bulletins (36%), and WhatsApp SMSs (35%), should be improved.

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[217] Ongoma, Victor and Shilenje, Zablon W. (2016). The effectiveness of agrometeorological information in the realization of Kenya's vision 2030; lessons learnt from China. Italian Journal of Agrometeorology. 21. 2016.

[218] Linda Hirons, et al. 2021. "Using co-production to improve the appropriate use of sub-seasonal forecasts in Africa" Climate Services, Volume 23, 100246, ISSN 2405-8807, https://doi.org/10.1016/j.cliser.2021.100246.

[219] Carter, S., Steynor, A., Vincent, K., Visman, E., and Waagsaether, K. (2019) 'Co-production of African weather and climate services'. Second edition. Manual, Cape Town: Future Climate for Africa and Weather and Climate Information Services for Africa (https://futureclimateafrica.org/coproduction-manual)

[220] FAO (2021). Global Outlook on Climate Services in Agriculture: Investment Opportunities to Reach the Last Mile. Accessed at: https://www.fao.org/3/cb6941en/cb6941en.pdf

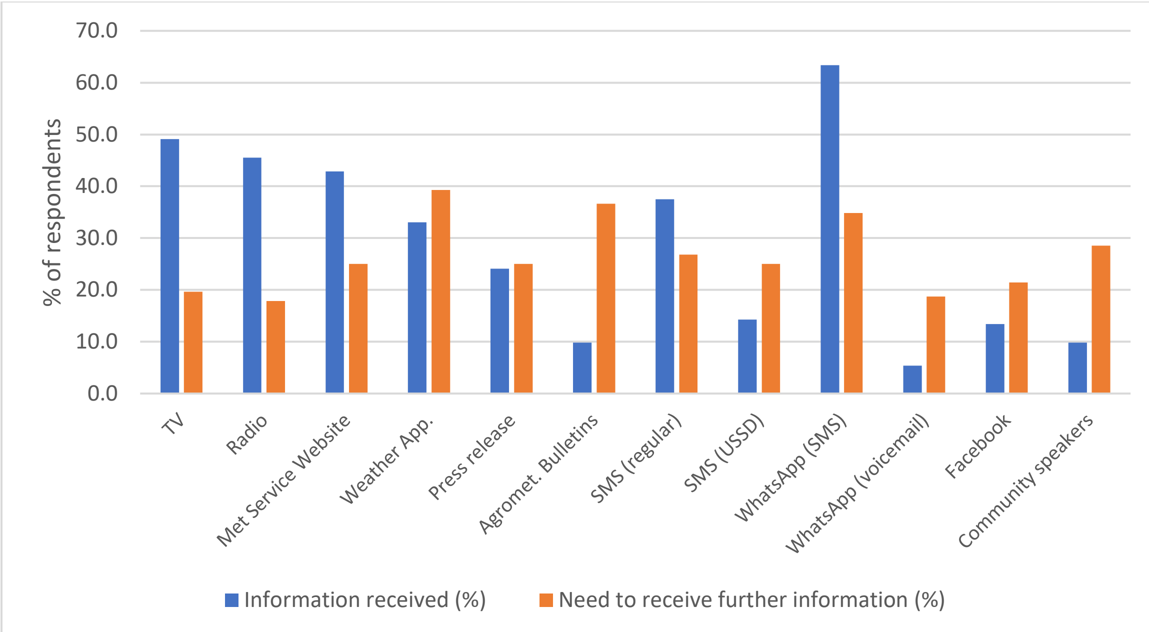

Figure 51. Information and communication means used and recommended by users to receive climate and weather information across the value chain.

122. According to the results of the climate-sensitive value chain conducted (Figure 52), most actors involved in the input supply, production, and harvesting stages of the targeted value chains receive information from governmental sources (particularly the Kenya Meteorological Department-KMD and county-level meteorological departments, from weekly (60%) to seasonal (37,5%) levels. 30% and only 9% of respondents receive climate and weather-related information on a monthly and daily scale, respectively. Other supporting institutions involved in the communication of agrometeorological services include research institutions (e.g., the Kenya Agricultural and Livestock Research Organization-KALRO, the Kenya Agricultural Observatory Platform, the Trans-African Hydro-Meteorological Observatory-TAHMO, the Tea Research Institute, as well as IGAD Climate Prediction and Application Centre-ICPAC), non-governmental organizations (e.g., PAFID, DACCA programme, SOFDI-Sustainable Organic Farming and Development Initiatives), and private companies (including agriBORA, Yara, Sauti East Africa).

123. At post-harvest stages of the value chain (Figure 53), surveyed actors mainly receive climate and weather-related services by governmental institutions, such as KMD and county-level meteorological departments, as well as the National Drought Management Authority, from daily and weekly, to monthly and seasonal scales. Daily information by actors involved in the distribution stage is also retrieved by private companies such as Yara through the FARMGO app as well as weekly information from the Coffee Research Institution.

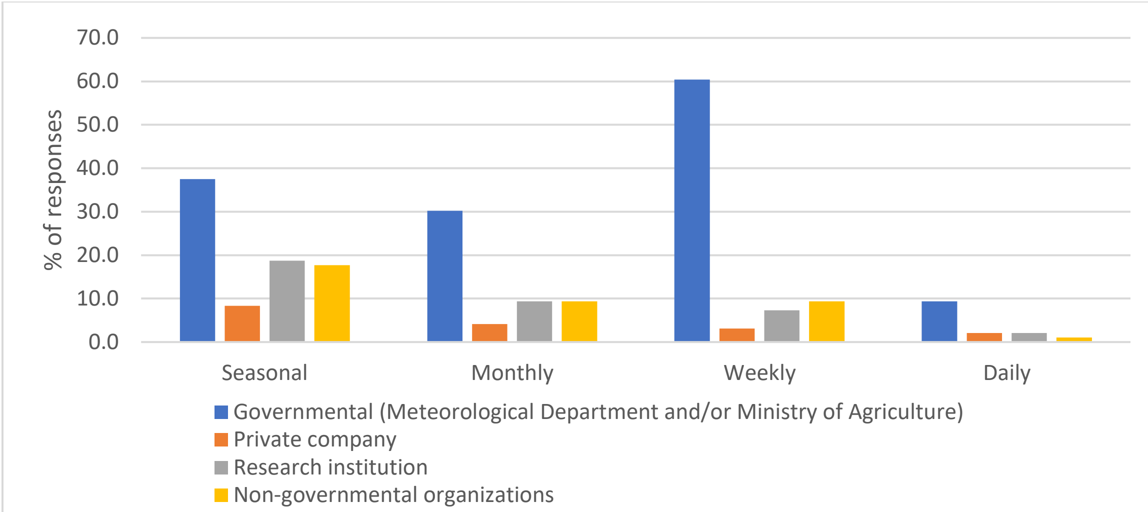

Figure 52. Institutions providing climate and weather-related information to food producers by timescale. Figure produced by FAO.

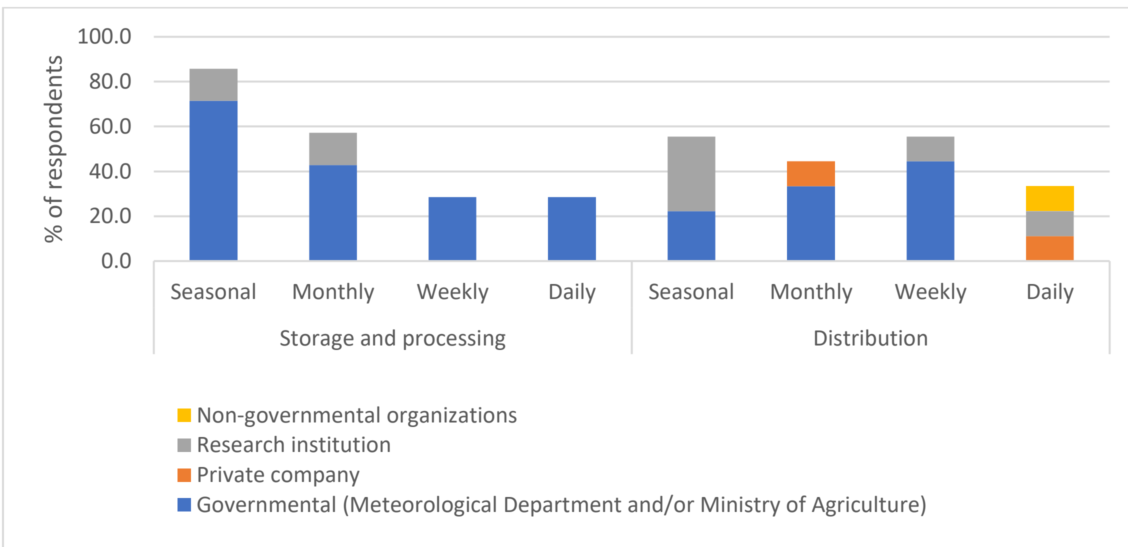

Figure 53. Institutions providing climate and weather-related information to value chain actors by timescales.

8.4. Participatory engagement of the last mile

124. KMD has been conducting Participatory Scenario Planning (PSP) in several counties, as well as issuing warnings on disasters and advisories and weather updates. KMD also supports farm-activity planning. The activities vary county by county in the LREB, whereby some counties have PSP, some benefit from farm-activity planning, and some mainly only get information.

8.5. Barriers and opportunities

125. Figure 54 shows the most used climate and weather-related information by food producers in the LREB, including information on the onset and offset of the rainy seasons (61,5%), precipitation forecasts (58%) and extreme rainfall advisory (56%), as well as dry spells forecasts (54%). Furthermore, food producers highlighted the need for receiving additional information on pest and disease forecasts (52%), and soil moisture information (41%). In terms of climate and weather-informed

agricultural advisory services for crop and livestock production (Figure 55), producers reported information on climate-resilient varieties (53%) and land preparation (52%) and planting dates (47%). 52% of respondents also reported the need to receive improved recommendations on the use of climate-resilient varieties. Furthermore, 50% of respondents highlighted the need for receiving additional and improved advisory on water management and irrigation, fertilizer, pesticide, and herbicide management practices.

126. At post-harvest stages of the selected food value chains (Figure 56), the most accessed and used climate information and agricultural advisory services include precipitation forecasts (37,5%) and flooding advisory (31%), as well as temperature advisory services (25%). 25% of respondents also use forecasts on relative humidity, particularly relevant for storage facilities and activities, as well as thunderstorms, visibility, and overall weather-informed transportation advisory. A potential for up-scaling the communication of the already most received climate and weather-informed agricultural advisory services is derived from the highest interest reported by respondents in improving temperature (31%) and precipitation (25%) advisory services for storage and processing stages, as well as transportation advisory (25%) services tailored to weather conditions.

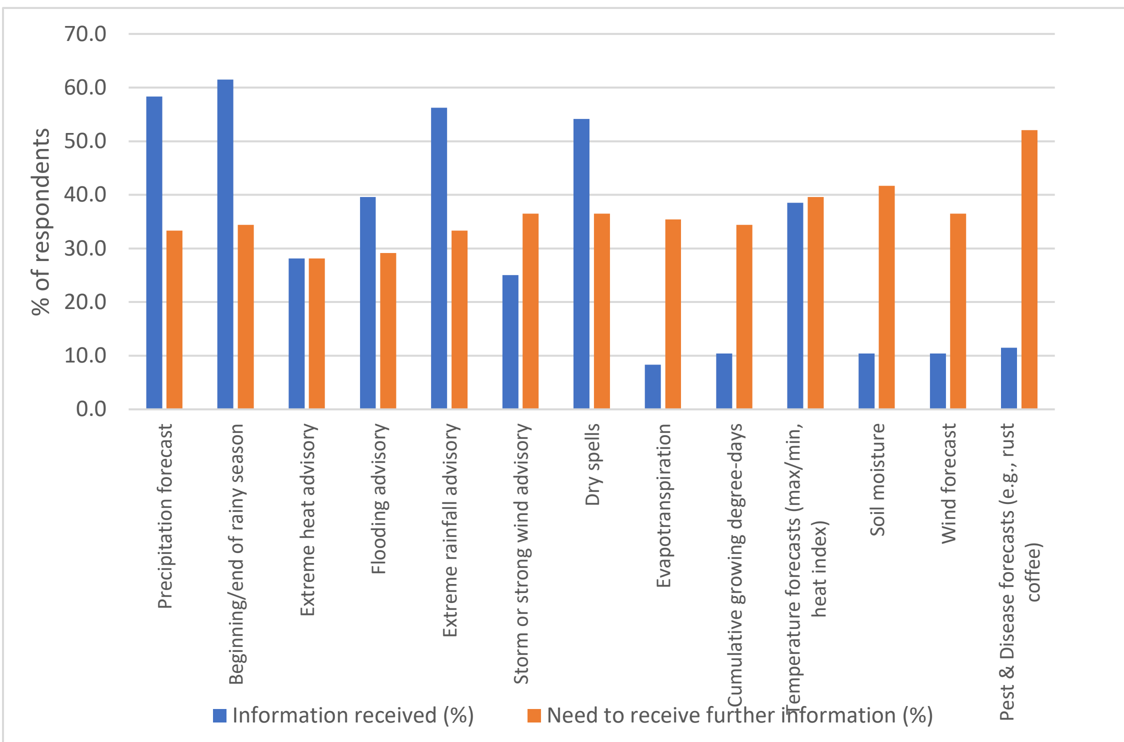

Figure 54. Climate information services for crop and livestock production.

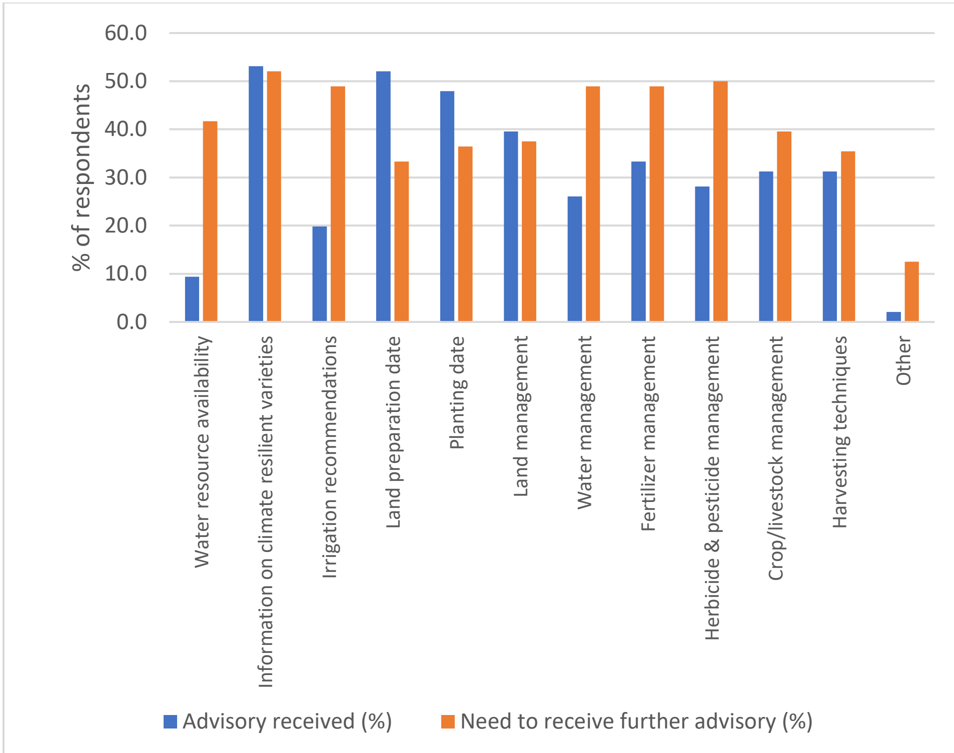

Figure 55. Agricultural advisory services for crop and livestock production.

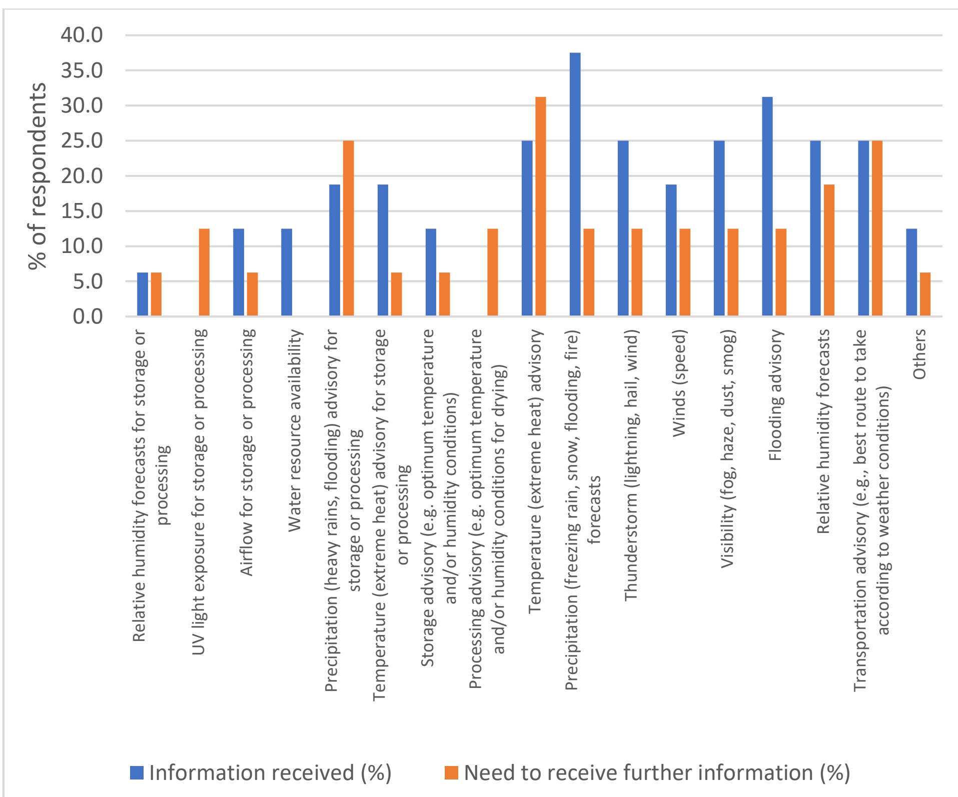

Figure 56. Climate information and agricultural advisory services for crop and livestock value chains.

127. Overall, major barriers to climate services development for reaching agricultural users and particularly small-holder farmers and local communities in the LREB in Kenya are identified in Table 7 (FAO, 2021). To effectively produce and deliver weather-informed agricultural advisories it is essential to improve every step of the climate services framework[221].

Table 7. Barriers and opportunities to climate services development in the LREB.

Barriers	Opportunities
Data collection, monitoring and forecasting	
- Insufficient and often declining agrometeorological observation network - Station network is sparse	- Improve data collection and monitoring of meteorological and agricultural information. - Install and fully integrate more Automatic Weather Stations (AWS), and enhance the quality of available observational datasets
Task force and data-sharing	
- The connection between local, county, and national levels is impeded by unclear mandates, lack of capacity at local and county level and sectoral budgeting processes. - Lack of harmonization of national and county goals	- The formal institutional climate change response set-up is sophisticated, but needs strengthened and clear mandates, capacity-building for local counterparts and new budget processes. - Harmonize goals through coordinating climate change activities and reinforcing the institutional set-up
Co-production of tailored agrometeorological advisories	
- Monetary restrictions to share and access the data.	- Support the co-production, co-development and co-design of actionable services by engaging not just governmental institutions, but also the private sector, community-based organizations and NGOs.
Communication of services to the last mile	
- Modern forecasting tools are not trusted or understood to a large enough degree - Lack of ICTs in some areas and for certain farmers as well as lack of information uptake	- Identify appropriate timing, language, and format for farmers, and enable its access to increase information uptake, through co-production and co-designing so as to deliver services in a language that is easily understood by rural communities - Invest in strengthening the capacities of agricultural extension services
Participatory engagement of last mile	
- KMD issues warnings and offers advisory, as well as supporting planning of farm activities in most counties in the LREB, but deliberate operational planning is still limited and varied county by county	- Action and engage deliberate operational planning for climate change by conducting and expanding Participatory Scenario Planning (PSP) programs
Climate-informed actions	
- Use of scientific language that is not easily understandable and tailored to farmers needs - Gaps between multiple sectors users' needs and available weather and seasonal climate forecasts	- Promote learning and knowledge exchange between farmers and other stakeholders - Translate technical weather, climate, and agronomic information into actionable services for agricultural users, and ensure appropriate use of socio-economic and social science information

[221] FAO (2021). Global Outlook on Climate Services in Agriculture: Investment Opportunities to Reach the Last Mile. Accessed at: https://www.fao.org/3/cb6941en/cb6941en.pdf

9. Recommended climate adaptation actions for each food value chain

9.1. Tea

9.1.1. Climate services development

128. Results from the online survey showed that stakeholders receive climate information from the Kenya Meteorological Department on daily, weekly, monthly, and seasonal timescales, as well as from the Government Meteorological Departments at County level at a seasonal scale.

129. At the distribution stage, stakeholders receive and have most interest in further receiving the following key climate-related information and agricultural advisory services:

- Temperature forecasts (max/min, heat index) and extreme heat advisory
- Wind forecast
- Overall information from the Kenya Agricultural and Livestock Research Organization – KALRO
- Information on climate resilient varieties
- Fertilizer management
- Herbicide & pesticide management
- Precipitation (freezing rain, snow, flooding, fire) forecasts
- Visibility (fog, haze, dust, smog) for transportation
- Transportation advisory (e.g., best route to take according to weather conditions)

9.1.2. Climate resilient practices

130. Results from the survey conducted to the tea value chain actors highlighted key practices implemented from the production to distribution stages. To address the identified climate hazards and related impacts on the tea value chain, the following climate-resilient practices were selected by tea value chain actors as already implemented as well as to be further implemented and improved:

- Cold chain practices
- Use of Early Warning Systems
- Use of alternative/organic agricultural inputs
- Immediate drying techniques

131. A summary of identified climate hazards, impacts, and tailored climate resilient practices along the tea value chain is highlighted in Table 8.

Table 8. Climate hazards, impacts, and climate resilient practices for the Tea value chain. Readapted from [222].

VALUE CHAIN STEP	CLIMATE HAZARD	CLIMATE IMPACTS	ADAPTATION RECOMMENDATIONS	SELECTED PRACTICES TO BE IMPROVED
Input supply	**Heavy rainfall and hailstorms**	- Ineffective fertilizer application; - reduced mother bushes' capacity to generate new planting material for nurseries; poor soil nutrients.	- Optimization of fertilizer application according to climate conditions (e.g., higher K+ to reduce drought stress); - reutilization of residues for mulching, green manure, compost tea application	- Use of alternative/organic agricultural inputs (e.g., bio-fertilizers) - Use of Early Warning Systems for weather-informed fertilizer application
	Drought and reduced moisture	- Increased costs of nurseries maintenance; - reduced effectiveness of fertilizers application and labor	- Establish water-harvesting and irrigation systems for nurseries; - use of drought-tolerant and high-yielding varieties; - develop policy frameworks for labor stability and diversification - Climate services: advisory on herbicide and pesticide management	- Advisory on climate resilient varieties - Use of alternative/organic agricultural inputs (e.g., bio-fertilizers) - Use of Early Warning Systems for weather-informed fertilizer application - Advisory on herbicide and pesticide management
Production	**Heavy rainfall and hailstorms**	- Crop damage and failure over three consecutive months after occurrence; - destroyed green leaves; - leaf drying; - fungal diseases and pests; - poor drainage; - soil erosion; - poor bud break and shoot growth.	- Shift to drought, heat and frost, hailstorm, pests and disease resistant tea clones (e.g., purple tea); - tea pruning; conservation agriculture (crop cover, mulching); - promote crop diversification in low production areas; agroforestry practices (e.g., grevilleas plantation); - rainwater harvesting; preventative frost monitoring and forecasting and risk insurance schemes; planting of indigenous trees.	- Use of precipitation forecasts and Early Warning Systems to avoid green leaves damages
	High temperatures, drought, and reduced moisture	- Increased weeding; - reduced green leaf production and harvest; - water loss and evapotranspiration; - increased need for pruning; - poor bud break; bud scorch; leaf and bark desiccation	- Improve farmers' access to drought Early Warning Systems and climate information; - introduction of drought-tolerant varieties; - use of herbicides for weeding management; - enhance tea extension services to promote efficient irrigation technologies; - increase farmer collaboration and linkages to promote use of drought-tolerant varieties	- Cold chain practices (e.g., misters, sprinkles, tree shade)
Harvesting, storage, and processing	**Heavy rainfall and hailstorms**	- impediments to harvesting; damaged infrastructure and packaging processes; - reduced grading of tea leaves damaged by hailstorms	- Use of insurance schemes; small-scale processing; road maintenance -	- Use of Early Warning Systems to avoid food spoilage and contamination - Immediate drying techniques
	Drought and reduced moisture	- Reduced yields; reduced green leaves production, collection, and transportation; - delays in fermentation; reduced performance of withering;	- Capacity-building on post-harvest technologies and techniques for tea value-adding practices; - ensure optimal air temperatures for withering, fermentation, and processing;	- Cold chain practices (e.g., air temperature monitoring for processing)

[222] CGIAR-CIAT. Ministry of Agriculture, Livestock, Fisheries and Cooperatives. 2022. Kenya County Climate Risk Profiles. https://ccafs.cgiar.org/resources/publications/kenya-county-climate-risk-profiles

VALUE CHAIN STEP	CLIMATE HAZARD	CLIMATE IMPACTS	ADAPTATION RECOMMENDATIONS	SELECTED PRACTICES TO BE IMPROVED
		- reduced tea quality and flavor; deterioration of leaves	- provide financial and technical resources to processors; - support strategic processing plants to maximize capacity to process tea and provide value addition products; - use of electronic machinery for temperature regulation and tea drying; solar air heating technologies.	
Trade	**Droughts and reduced moisture**	- Increased costs and prices; reduced quantity available for markets	- improve tea transport system management through use of energy-efficient trucks and vehicles, and increased access to weather advisory for transportation; - Promotion of value addition activities (e.g., processing) for tea to counteract low availability of green leaf tea; - Promote new tea marketing channels (e.g., e-marketing); - establishment of new tea processing plants to process excess tea and sell/market during period of low product availability; - transportation and selling of other products; strengthen market networks and farmer linkages	- Improve food management practices and cold chains (e.g., new tea marketing channels, climate-informed planning of excess tea processing during periods of low product availability)

9.2. Coffee

9.2.1 Climate services development

132. It is fundamental to ensure equitable access to climate and market-based information among all coffee value chain actors, particularly farmers, through the support of cooperatives, as well as providing sellers with adding-value mechanisms such as sustainable certifications for ensuring coffee quality which include climate adaptation standards. This should be combined with ensuring timely and adequate payments to farmers to maintain a stable return on investment in coffee plantations. Results from the online survey (Figure 57) highlighted that stakeholders primarily receive climate information from the Kenya Meteorological Department from weekly to monthly, and seasonal timescales. They also receive information from private companies, research institutions (e.g., Coffee Research Institute), and non-governmental organizations primarily at a seasonal scale. Drought and flooding advisory, combined with recommendations on land preparation and planting dates (75%) are the most accessed and used climate and weather-informed agricultural advisory services. At the same time, in accordance with the results from all the value chains combined, coffee value chain actors expressed interest in receiving information on the use of climate-resilient varieties, however such type of advisory is not already accessed nor used by the respondents. Additional most requested types of climate and weather-informed agricultural advisory services include extreme heat and evapotranspiration advisory, as well as information on soil moisture, pest, and disease forecasts (e.g., on rust coffee), water resource availability and irrigation recommendations, in order to improve land management including herbicide and pesticide management practices (75%).

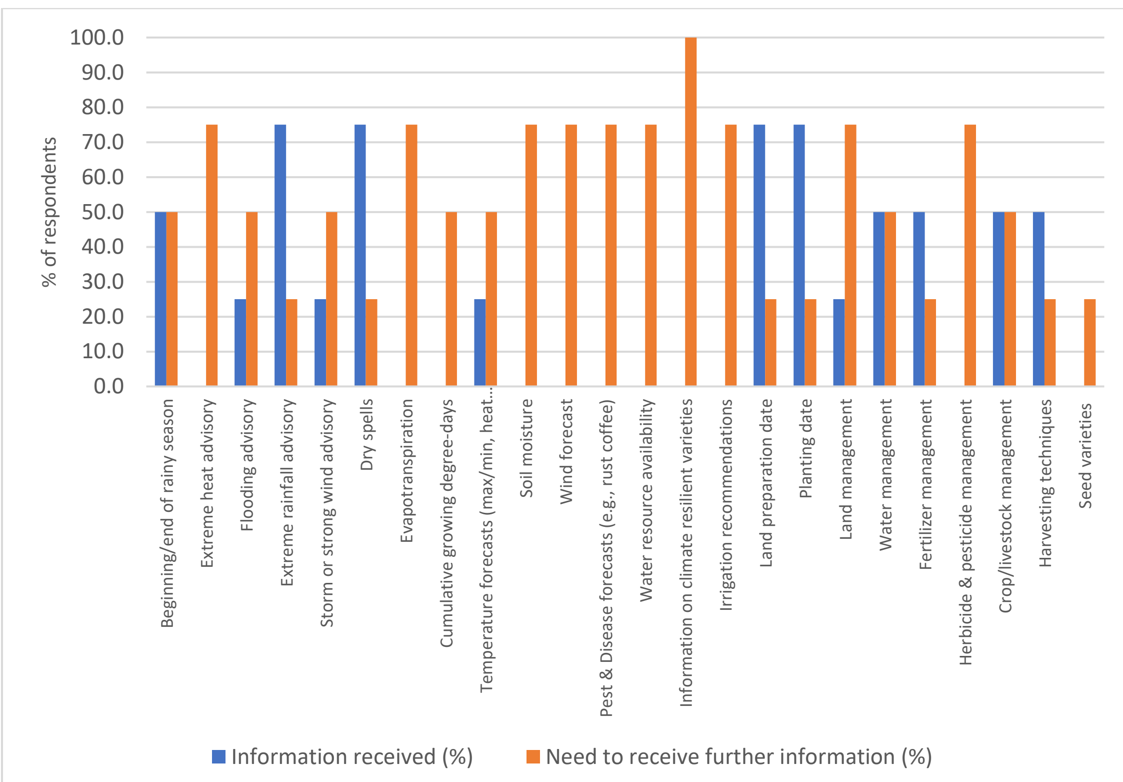

Figure 57. Climate information and agricultural advisory services for coffee production.

9.2.2. Climate resilient practices

133. Additional processing activities should be promoted to enhance market opportunities, such as coffee roasting. According to the results from the survey conducted by the County Government representatives (Figure 58), key practices implemented from production to storage stages include use of organic agricultural inputs, use of early-maturing, shorter-duration crop varieties, as well as integrated land management practices such as agroforestry and crop rotation systems, and greenhouse production. At the same time, respondents reported a spread interest in implementing further climate-resilient practices along the value chain, without one specific practice emerging from the results.

134. Therefore, a summary of identified climate hazards, impacts, and tailored climate resilient practices along the coffee value chain is highlighted in Table 9.

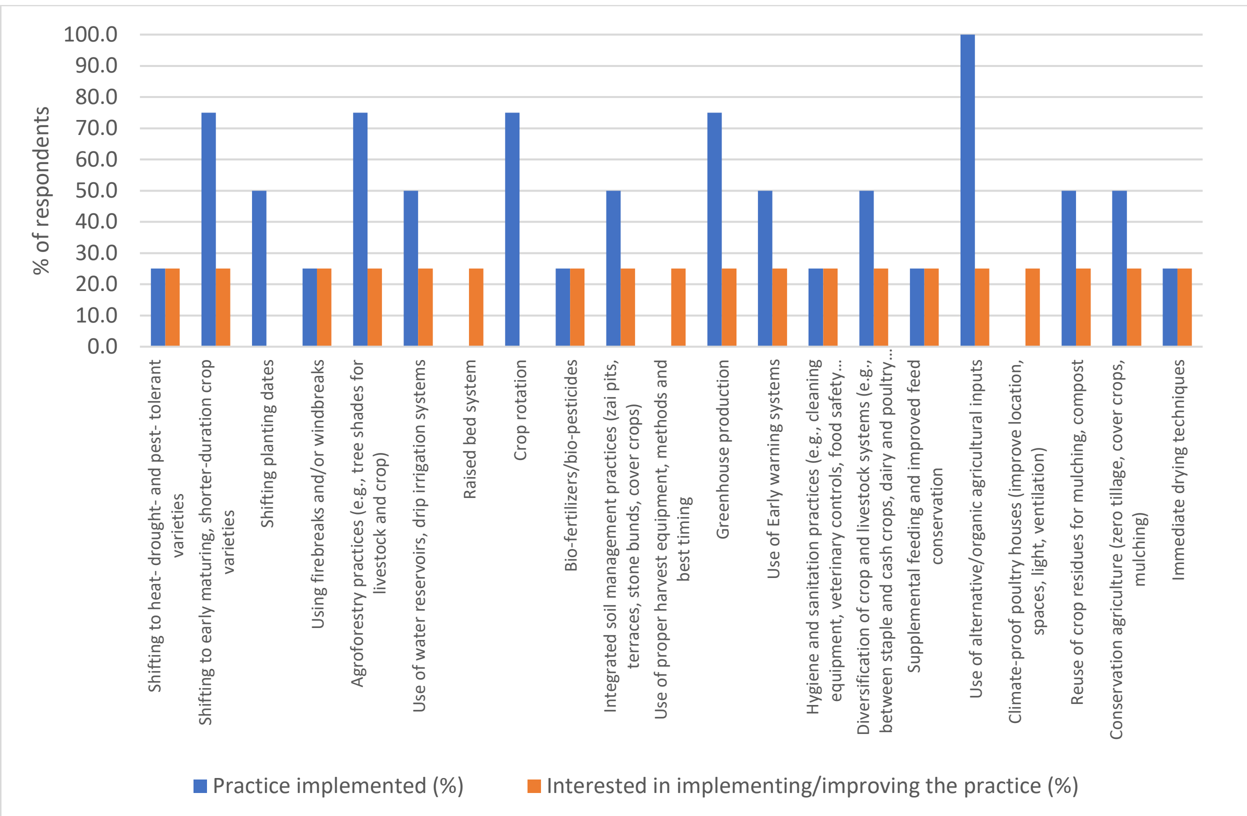

Figure 58. Climate-resilient practices for coffee production.

Table 9. Climate hazards, impacts, and resilient practices along the Coffee value chain [223,224,225].

VALUE CHAIN STEP	CLIMATE HAZARD	CLIMATE IMPACTS	ADAPTATION RECOMMENDATIONS	SELECTED PRACTICES TO BE IMPROVED
Input supply and production	**High temperature and relative humidity**	- Significant reduction of suitability of coffee growing areas by 2050; - shifted production to higher altitudes. - Pests and diseases attacks; - rapid ripening of cherries; - water loss and evapotranspiration.	- Integrated soil, water, and pest management practices. - Balanced application of fertilizers, establishment of cover crops, optimization of crop calendars. - Agroforestry practices (plant shade trees to regulate temperature, wind protection, and water use). - Shift to pest and disease-resistant varieties. - Climate services: extreme heat, evapotranspiration, and soil moisture information and advisory; pest and disease forecasts (e.g., on rust coffee); land management advisory (herbicide and pesticide management); water resource availability and irrigation recommendations.	- Shifting to heat- drought- and pest- tolerant varieties - Shifting to early maturing, shorter-duration crop varieties - Use of water reservoirs, drip irrigation systems - Agroforestry practices (e.g., tree shades for livestock and crop) - Climate services: extreme heat, evapotranspiration, and soil moisture information and advisory; pest and disease forecasts (e.g., on rust coffee); land management advisory (herbicide and pesticide management); water resource availability and irrigation recommendations.
	Heavy rainfall and hailstorms	- Ineffectiveness of cherry ripening and drying	- Selective picking techniques. - Appropriate timing for drying according to suitable weather conditions. - Agroforestry practices. Balanced application of fertilizers, herbicides and fungicides, and pesticides according to forecasted weather conditions. - Climate services: flooding advisory	- Agroforestry practices (e.g., tree shades for livestock and crop) - Using firebreaks and/or windbreaks
Harvesting, storage, and processing	**High temperature and relative humidity**	- Mold and mycotoxins spread (e.g., ochratoxin A - OTA contamination from unsuitable temperatures, high relative humidity, and presence of insects.	- Use appropriate moisture-measuring equipment, temperature and relative humidity forecasts tailored to VC actors; - Reduce time of storage; - Facilitate ventilation through fans and use of jute bags; Pests control and infrastructure inspections.	- Immediate drying techniques
	Heavy rains, hailstorms, and flooding	- Disruption of storage infrastructure, coffee beans re-wetting, stagnant humidity;	- Adequate ventilation, relative humidity control, rainwater drainage systems; - Access to cooperative storage structures; Pile bags on pallets or similar structures and away from walls to prevent re-wetting;	- Immediate drying techniques

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[223] FAO. 2006. *Storage of Coffee: Good Hygiene Practices along the coffee chain.* Rome. (also available at: www.ico. org/projects/Good-Hygiene-Practices/cnt/cnt_sp/sec_3/ docs_3.3/Storage.pdf).

[224] Palacios-Cabrera H., Taniwaki M.H., Menezes H.C. & Iamanaka, B.T. 2004. *The production of OTA by Aspergillus ochraceus in raw coffee at different equilibrium relative humidity and under alternating temperatures*, Elsevier Ltd, p. 531–535.

[225] Getachew WeldeMichael, Demelash Teferi, "The Impact of Climate Change on Coffee (Coffea Arabica L.) Production and Genetic Resources" International Journal of Research Studies in Agricultural Sciences (IJRSAS), 2019; 5(11), pp. 26-34, http://dx.doi.org/10.20431/2454-6224.0511004

VALUE CHAIN STEP	CLIMATE HAZARD	CLIMATE IMPACTS	ADAPTATION RECOMMENDATIONS	SELECTED PRACTICES TO BE IMPROVED
		- Coffee moisture content growth, mold and mycotoxins spread - water entrance in storage facilities and re-wetting of coffee, stagnant humidity.	- Use real-time weather forecasts, extreme rainfall and flooding advisory tailored to VC actors.	
Transportation and markets	**High temperature and relative humidity**	- Reduced quantity and quality of coffee beans available at markets. Increased costs and reduced final prices.	- Development of sustainable certifications that include climate adaptation standards; - Ensure equitable access to information to value chain actors; - Monitor activities to improve performance of cooperatives; Promote coffee processing and market opportunities, organization through cooperatives	- None of the recommended practices were selected for improvement
	Heavy rainfall and flooding	- Reduced quantity and quality of coffee beans available at markets. - Increased costs and reduced final prices.	- Development of sustainable certifications that include climate adaptation standards; Ensure equitable access to information to value chain actors; - Monitor activities to improve performance of cooperatives; Promote coffee processing and market opportunities, organization through cooperatives	- None of the recommended practices were selected for improvement

9.3. Fruit trees

9.3.1. Climate services development

135. According to the results of the online climate survey (Figure 59), 75% of the respondents in the value chain receive information on the onset and offset of the rainy seasons, followed by 68% receiving flooding advisory as well as irrigation recommendations. Furthermore, 62,5% of respondents use extreme rainfall advisory for fruit tree production, as well as land management advisory (56,3%). Among the most selected climate information and agricultural advisory services, 50% of respondents expressed their interest in receiving additional pests and disease forecasts, as well as recommendations on irrigation, land preparation, herbicide, and pesticide management practices.

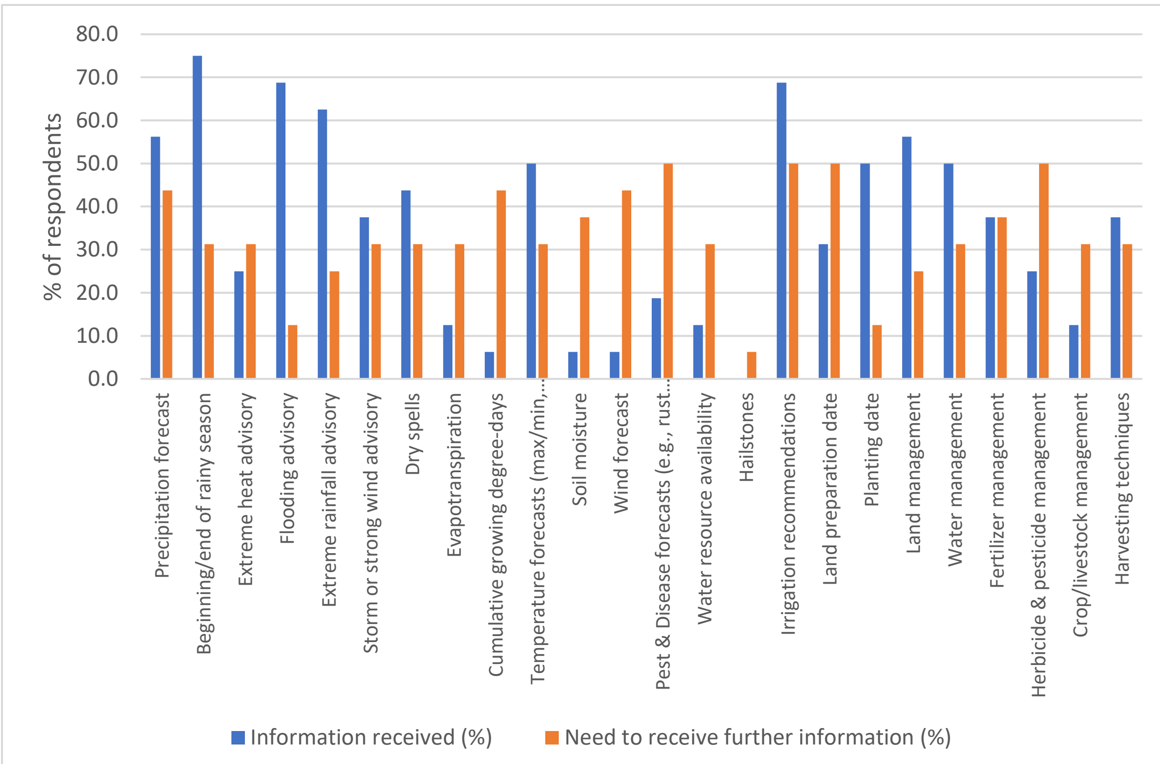

Figure 59. Climate information and agricultural advisory services for fruit trees production.

9.3.2. Climate resilient practices

136. According to the results from the survey conducted to multiple stakeholders including Bungoma County Department of Agriculture representatives, community-based organizations, non-profit and agricultural focused organizations, agricultural services, and local businesses (Figure 60), key practices implemented along the fruit trees value chain include integrated soil management practices (such as zai pits, terraces, stone bunds, cover crops) (81%), conservation agriculture (zero tillage, cover crops, mulching) and agroforestry practices (62,5%). At the same time, respondents reported an interest in implementing additional practices which are particularly relevant to strengthen the resilience of the harvest stage to the identified climate and weather-related hazards, such as immediate drying

techniques (31%), use of proper harvest equipment, methods and best timing combined with early warning systems, as well as cold chain practices (e.g., misters, sprinklers, fans, roofing, shade, use of cold/ice boxes, cold rooms) (25%). Therefore, a summary of identified climate hazards, impacts, and tailored climate resilient practices along the fruit trees value chain is highlighted in Table 10.

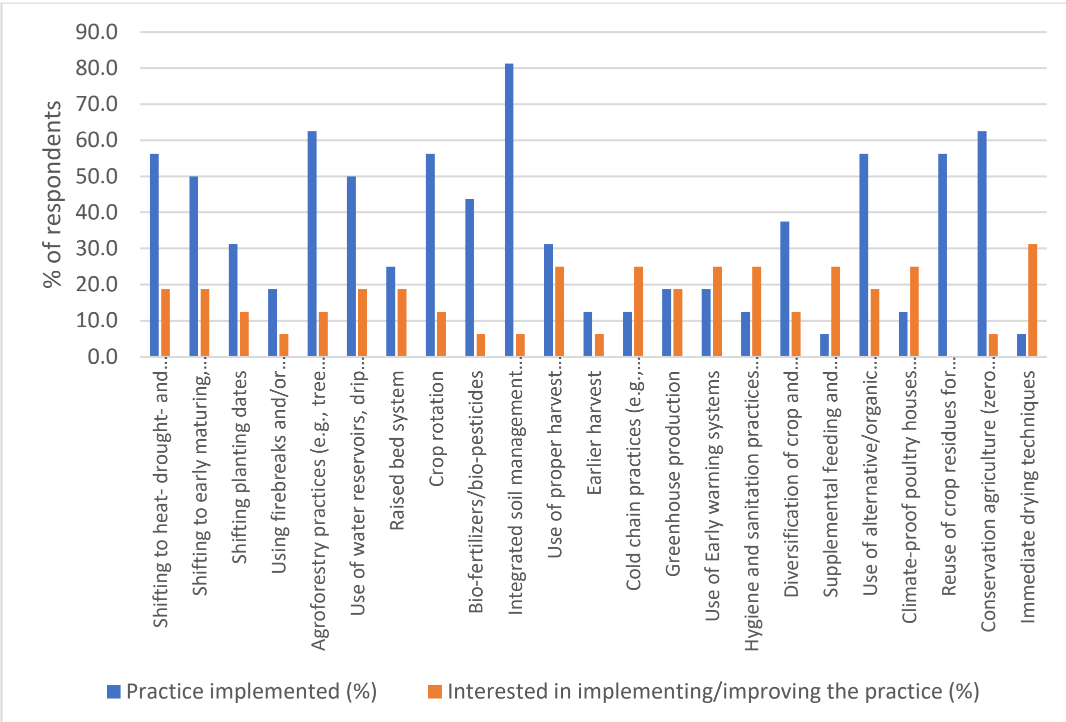

Figure 60. Climate-resilient practices for fruit trees production.

Table 10. Climate hazards, impacts, and resilient practices along the fruit trees (Banana and Avocado) value chain. Readapted from [226].

VALUE CHAIN STEP	CLIMATE HAZARD	CLIMATE IMPACTS	ADAPTATION RECOMMENDATIONS	SELECTED PRACTICES TO BE IMPROVED
Input supply	**Drought and reduced moisture**	- Delayed access to agricultural inputs; - challenges to digging holes due to soil pan for land preparation	- Application of organic matter as mulch to conserve soil moisture and protect seeds and seedlings; - improve mechanized and early land preparation; use tissue culture bananas; - integrate irrigation systems and water purification - Climate services: irrigation and land preparation recommendations.	- Use of Early warning systems - Land preparation recommendations
	Seasonal rainfall variability	- Increased wilting; delayed access to inputs; - increased storage costs for inputs	- Application of organic matter as mulch to conserve soil moisture and protect seeds and seedlings; - mechanized and timely land preparation according to agro-meteorological information and advisory - Climate services: information on the onset and offset of the rainy season.	- Use of Early warning systems - Land preparation recommendations
	Strong winds, heavy rainfall and hailstorms	- Loss of topsoil and nutrients, increased demand for fertilizers/manure; - damage to suckers; - nutrient leaching; - water logging and limits to planting holes and manure application	- Use of net sheds, green-grey infrastructure to prevent runoff - Climate services: flooding advisory, land preparation recommendations.	- Agroforestry practices (e.g., tree shades for livestock and crop) - Greenhouse production - Land preparation recommendations
Production	**Drought and reduced moisture**	- Reduced quantity and size of fruits; delays in planting after the dry spell; - increased vulnerability to pests and diseases	- Introduction of early maturing, drought- and pest-tolerant varieties such as purple banana. - Promote crop diversification with poultry. - Use of low-cost irrigation systems such as drip, flood, and sprinkler irrigation; - use of water and soil moisture conservation practices (e.g., pits, mulching, minimum tillage); - cover bananas while on the tree; removal of excess shoots to reduce water competition - Climate services: pest and disease forecasts; advisory on herbicide and pesticide management practices; water availability information and irrigation recommendations.	- Shifting to heat- drought- and pest-tolerant varieties - Use of water reservoirs, drip irrigation systems - Integrated soil management practices (zai pits, terraces, stone bunds, cover crops) - Conservation agriculture (zero tillage, cover crops, mulching) - Diversification of crop and livestock systems (e.g., between staple and cash crops, dairy and poultry production) - Climate services: pest and disease forecasts; advisory on herbicide and pesticide management practices; water availability information and irrigation recommendations.

[226] CGIAR-CIAT. Ministry of Agriculture, Livestock, Fisheries and Cooperatives. 2022. Kenya County Climate Risk Profiles. https://cgspace.cgiar.org/discover?query=ministry+of+agriculture+vihiga&filtertype=author&filter_relational_operator=equals&filter=Ministry+of+Agriculture%2C+Livestock%2C+Fisheries+and+Cooperatives%2C+Kenya

VALUE CHAIN STEP	CLIMATE HAZARD	CLIMATE IMPACTS	ADAPTATION RECOMMENDATIONS	SELECTED PRACTICES TO BE IMPROVED
	Seasonal rainfall variability	- Increased soil pan and challenges to land preparation; - reduced soil moisture, delayed planting and weeding	- Introduction of early maturing varieties - Climate services: information on the onset and offset of the rainy seasons.	- Shifting to early maturing, shorter-duration crop varieties
	Strong winds, heavy rainfall and hailstorms	- Delays in planting and manure decomposition; - rotting of bananas, water logging, water-borne pests and diseases; - damage to trees	- Introduction of wind lodging-resistant varieties. Agroforestry practices with grevilleas plantation; - climate risk-based crop insurance; - optimization of drilling pits and planting; construction of dams and canals; use of packaging and crates; - solar drying and refrigeration practices; cover bunches with banana leaves to protect from scorching - Climate services: extreme rainfall and flooding advisory; land management advisory	- Agroforestry practices (e.g., tree shades for livestock and crop)
Harvesting, storage, and processing	**Drought and reduced moisture**	- Reduced quantity and quality of products; - increased food spoilage and post-harvest losses; - higher transportation costs; - rapid ripening of bananas	- Improved cold storage facilities and use of moisture and relative humidity monitoring systems; - increase support by cooperatives to promote storage in common facilities; increase de-handling and processing practices (drying, frying) for value addition	- Immediate drying techniques - Use of proper harvest equipment, methods and best timing - Cold chain practices (e.g., misters, sprinklers, fans, roofing, shade, use of cold/ice boxes, cold rooms)
	Seasonal rainfall variability	- Product spoilage due to changes in relative humidity during storage	- Strengthen climate-proofed packaging and storage facilities for farmers to wait for better market prices while preserving shelf-life; - use moisture and relative humidity monitoring systems; - increase support by cooperatives to promote storage in common facilities	- Immediate drying techniques - Use of proper harvest equipment, methods and best timing
	Strong winds, heavy rainfall and hailstorms	- Rapid ripening of bananas, reduced quality; - damage to storage, processing, and transportation facilities; - need for premature harvesting	- Use banana leaves to cover banana products; use of ripening chambers; - improve water harvesting practices and technologies	- Use of proper harvest equipment, methods and best timing
Markets	**Drought and reduced moisture**	- Rapid fruit ripening and spoilage during transportation; - reduced quality and quantity of final products at market; - changes in food prices; irregular, low supply and income for producers	- Improved storage, product preservation techniques, and transportation to reduce food spoilage; - increase cooperatives' support to collect products and increase marketing opportunities	- Immediate drying techniques
	Seasonal rainfall variability	- Irregular food supply, marketing opportunities, and income due to irregular seasons	- Link food production and marketing timing according to agro-meteorological information and market advisory; - increase support by cooperatives to promote storage in common facilities	- None of the recommended practices were selected for improvement

VALUE CHAIN STEP	CLIMATE HAZARD	CLIMATE IMPACTS	ADAPTATION RECOMMENDATIONS	SELECTED PRACTICES TO BE IMPROVED
	Strong winds, heavy rainfall and hailstorms	- Damage to market facilities, impediments to accessing markets; - reduced shelf-life at markets and quality for sorting; reduced prices	- Improved market infrastructure with shelter; increase farmers' coordination on prices and volumes at markets through cooperatives; - optimize transportation timing to markets according to weather advisory; policy support for climate-resilient market regulation	- None of the recommended practices were selected for improvement

9.4. African Leafy Vegetables

9.4.1. Climate services development

137. In alignment with the overall results on survey respondents' statistics on the use of climate information and agricultural advisory services at the production stage, advisory on land preparation and planting dates emerge as the most used services (65%), together with information on the onset and offset of the rainy seasons (60%). Information on precipitation forecasts and extreme weather events such as extreme rainfall and dry spells is also mostly used by respondents. At the same time, the results highlight the key services for which there is high interest in receiving further information and advisory to improve climate-resilient ALVs production, including recommendations on climate-resilient varieties (60%), water management and irrigation recommendations (57%), herbicide and pesticide management practices (60%) (Figure 61). At post-harvest stages of ALVs value chains (Figure 62), survey respondents primarily receive flooding advisory and relative humidity forecasts (50%), which is fundamental to avoid product spoilage from mold and fungal spread from storage to market stages. Furthermore, precipitation advisory tailored to storage and processing steps, as well as overall weather-informed transportation advisory (33%) are the most selected advisory services the respondents are interested in receiving further.

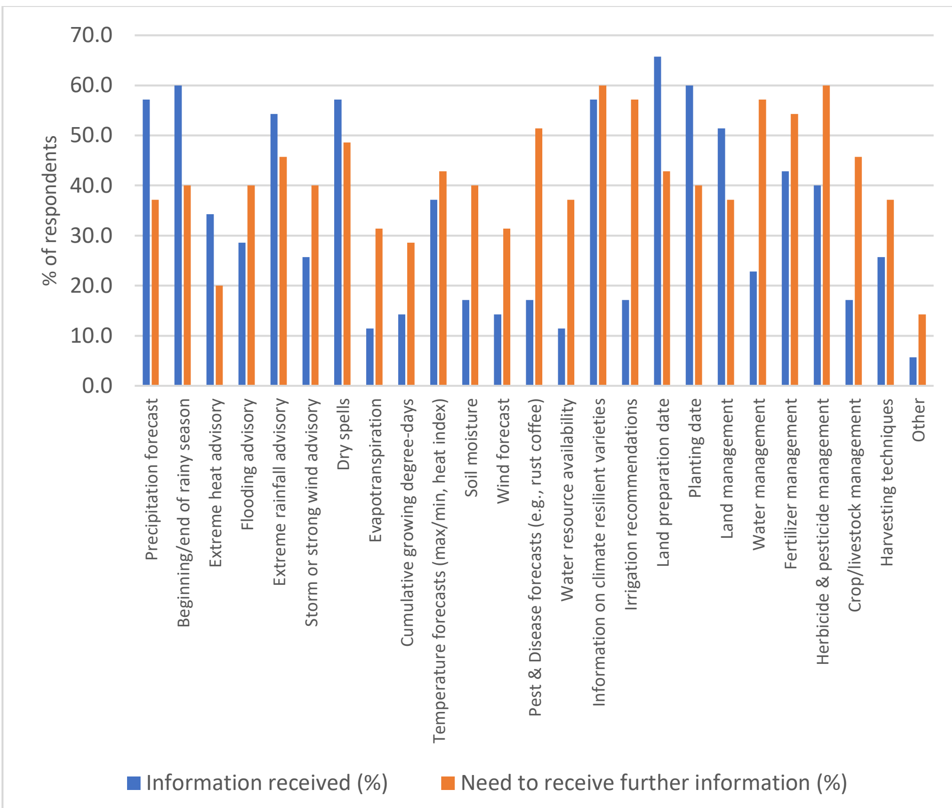

Figure 61. Climate information and agricultural advisory services for ALVs production.

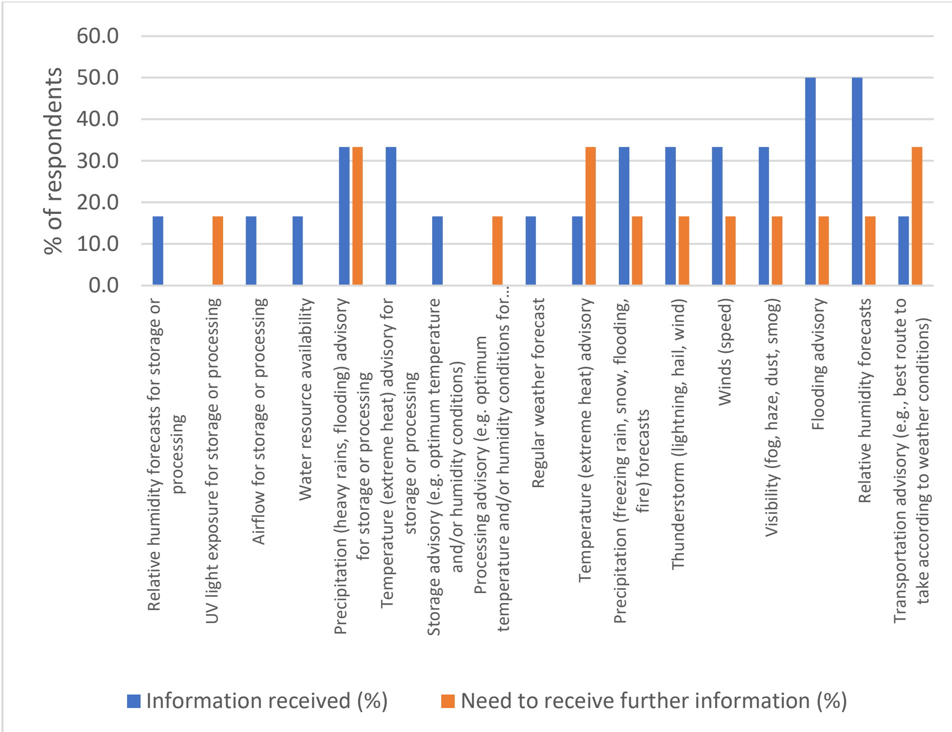

Figure 62. Climate information and agricultural advisory services for ALVs value chains.

9.4.2. Climate resilient practices

138. According to the results from the climate-sensitive value chain survey (Figure 63, Figure 64, and Figure 65), most implemented climate-resilient practices at the production stage are crop rotation measures (71%), as well as the use of early-maturing and short-duration vegetable varieties (65,7%), and conservation agriculture practices such as zero tillage, cover crops, and mulching (57%). It is important to highlight that the shifting to early-maturing and short-duration crop varieties as also selected by 28,6% of respondents as a practice that they would be interested in implementing and improving further. Since there is already a high rate of adoption of such practice, there is a potential for scaling it up among all stakeholders. Other selected practices to further improve include agroforestry (28,6%) as well as diversification of crop and livestock systems (25,7%).

139. At post-harvest stages of the ALVs value chain, most respondents implement immediate drying techniques such as dun drying to preserve food quality and increase its shelf-life, as well as apply work hygiene and sanitation practices during storage, processing, and distribution stages. Sun-drying and boiling are key traditional practices which need to be further up-scaled, as well as grading and packaging for value addition. At the same time, respondents reported a spread interest in implementing further climate-resilient practices along the value chain, without one specific practice emerging from the results. Therefore, a summary of identified climate hazards, impacts, and tailored climate resilient practices along the ALVs value chain is highlighted in Table 11.

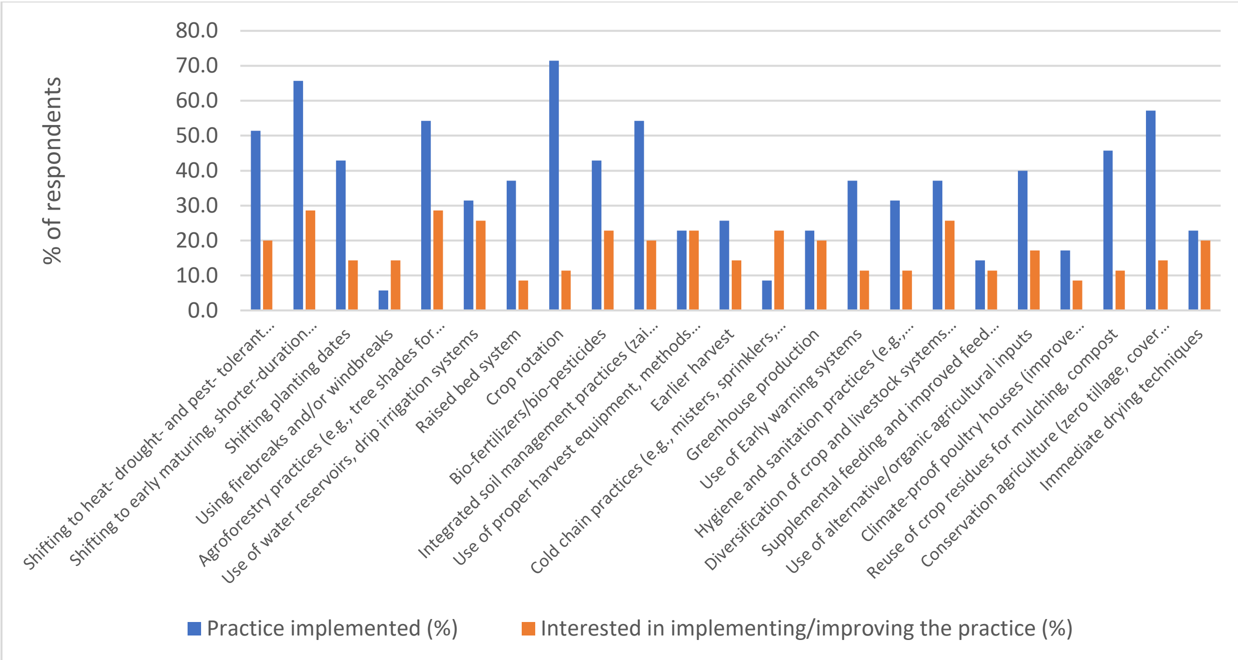

Figure 63. Climate-resilient practices for ALVs production.

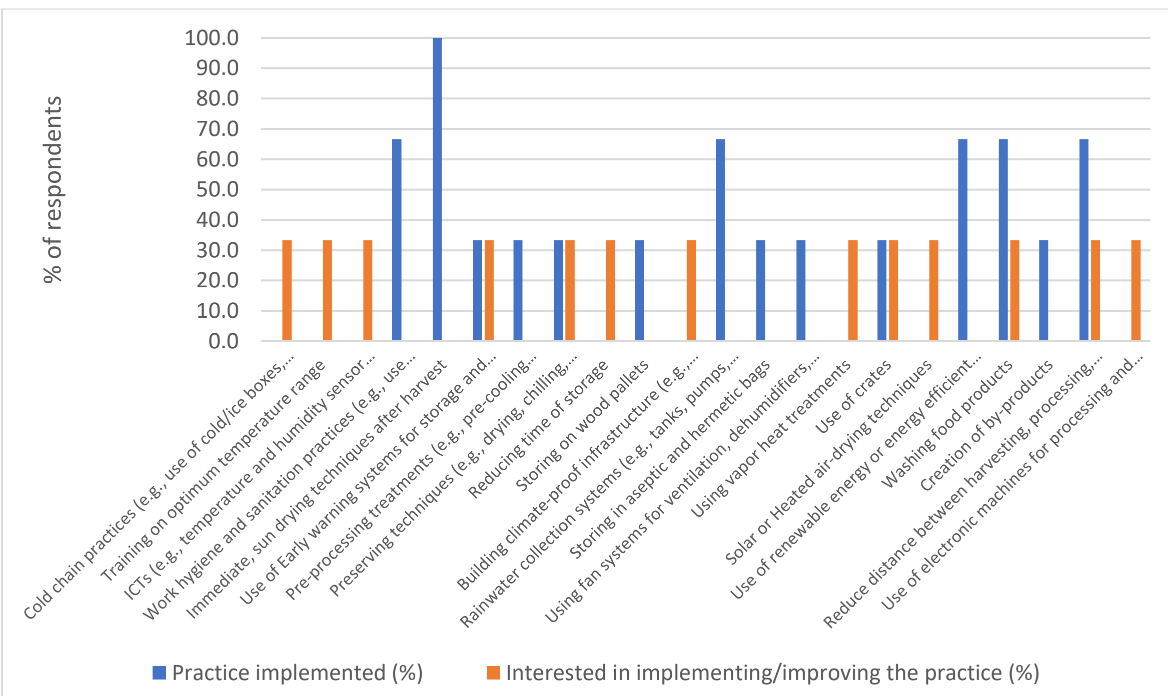

Figure 64. Climate-resilient practices for ALVs storage and processing.

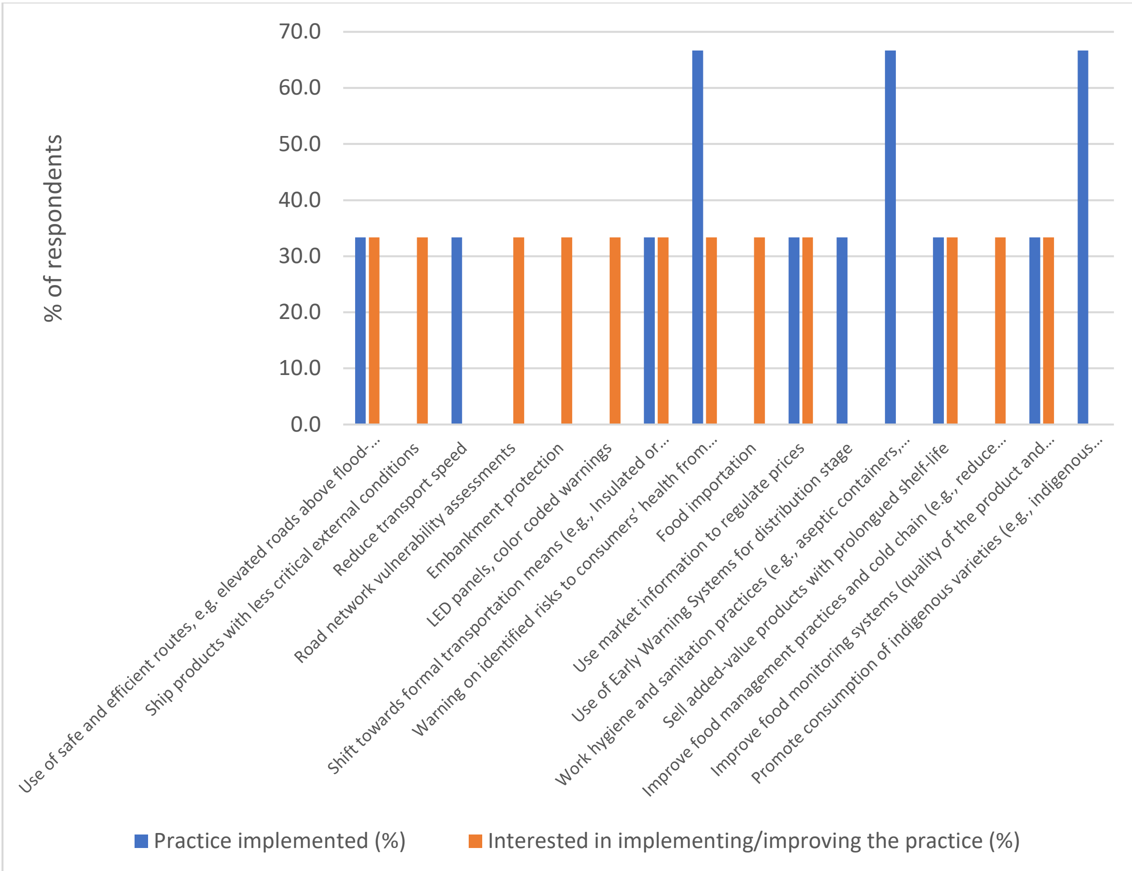

Figure 65. Climate-resilient practices for ALVs distribution.

Table 11. Climate hazards, impacts, and resilient practices along the Vegetables value chain. Readapted from [227].

VALUE CHAIN STEP	CLIMATE HAZARD	CLIMATE IMPACTS	ADAPTATION RECOMMENDATIONS	SELECTED PRACTICES TO BE IMPROVED
Input supply	**Heavy rainfall and hailstorms**	- Leaching of nutrients and washing away of seeds and topsoil; - seed rotting and destruction; mudslides; - proliferation of microorganisms bringing soil diseases; - delays in land preparation; additional costs of inputs	- Integrated soil and water management and conservation practices; - climate risk crop insurance; - shade nets and greenhouse production; - Climate services: advisory on herbicide and pesticide management practices; land preparation and planting dates. Precipitation and extreme weather events forecasts.	- Integrated soil management practices (zai pits, terraces, stone bunds, cover crops) - Conservation agriculture (zero tillage, cover crops, mulching) - Use of alternative/organic agricultural inputs - advisory on herbicide and pesticide management practices.
	Drought and reduced moisture	- Wilting and death of seedlings. - Reduced availability of seeds and dry manure	- Introduction of drought, pest tolerant varieties; - agroforestry practices; - Climate services: recommendations on water management and irrigation; land preparation and planting dates.	- Shifting to heat- drought- and pest-tolerant varieties - Recommendations on water management and irrigation.
	Seasonal rainfall variability	- Damage to seedlings and wilting	- Promotion of early maturing varieties; - local seed production and increased manure and seed commercialization, storage, and processing. - Climate services: information on the onset and offset of the rainy seasons.	- Shifting to early maturing, shorter-duration crop varieties - Diversification of crop and livestock systems (e.g., between staple and cash crops, dairy and poultry production)
Production	**Drought and reduced moisture**	- Reduced seedling germination success rates; - formation of soil pans and reduced tillage capacity; - increased water and labour requirements; - increased incidence of pests and diseases (aphids, termites)	- Use of mechanical tilling equipment and small-scale, drip irrigation systems; - investing in water harvesting and canals; capacity building on manure management and use. - Greenhouse production; - integrated water management practices (ZAI pit systems, water dams, irrigation)	- Integrated soil management practices (zai pits, terraces, stone bunds, cover crops) - Greenhouse production - Bio-fertilizers/bio-pesticides - Crop rotation - Reuse of crop residues for mulching, compost
	Seasonal rainfall variability	- Poor seedling germination success rates; soil moisture stress; - difficulties in planning farm operations according to changing weather conditions	- Develop water harvesting and drip irrigation systems; - capacity-building on integrated pest and disease management; - Climate services: improve access to agro-meteorological information and advisories for vegetable production planning and practices; information on the onset and offset of the rainy seasons.	- Use of water reservoirs, drip irrigation systems - Use of Early warning systems
	Heavy rainfall and Hailstorms	- Delays in land preparation and planting; nutrient leaching, water logging, less time-efficient labor; - direct damage to vegetables	- Optimize early timing for planting, use of drainage systems; - agroforestry practices and greenhouses to protect vegetables from hail - Climate services: precipitation and extreme weather events forecasts	- Shifting planting dates - Raised bed system

[227] CGIAR-CIAT. Ministry of Agriculture, Livestock, Fisheries and Cooperatives. 2022. Kenya County Climate Risk Profiles. https://ccafs.cgiar.org/resources/publications/kenya-county-climate-risk-profiles

VALUE CHAIN STEP	CLIMATE HAZARD	CLIMATE IMPACTS	ADAPTATION RECOMMENDATIONS	SELECTED PRACTICES TO BE IMPROVED
Harvesting, storage, and processing	**Drought and reduced moisture**	- Reduced quantity and quality of harvested vegetables due to withering; - reduced shelf life; - reduced biomass for processing practices; - rapid spoilage during transportation	- Organize cooperatives for vegetables to coordinate on storage and transportation facilities; - training for capacity building on value addition activities; - use early warning systems to reduce harvest losses; - training on solar drying, use of insulated containers and cold chain practices (e.g., refrigeration within vans and packaging)	- Cold chain practices (e.g., misters, sprinklers, fans, roofing, shade, use of cold/ice boxes, cold rooms)
	Seasonal rainfall variability	- Reduced food quality; - higher storage and transportation costs; - delays between harvest and aggregation-storage	- Training on vegetable storage strategies and timing, and value addition activities	- Hygiene and sanitation practices (e.g., cleaning equipment, veterinary controls, food safety controls) - Use of proper harvest equipment, methods and best timing
	Heavy rainfall and hailstorms	- Delays in harvesting, increased risk of contamination, rotting, and spoilage.	- Store vegetables in climate-proofed, dry facilities; solar drying, optimize timing of transport. - Climate services: precipitation, flooding, and relative humidity information for storage and processing advisory.	- Immediate drying techniques; - Precipitation and flooding information for storage and processing advisory.
Markets	**Drought and reduced moisture**	- Reduced food available at markets and increased prices for consumers	- Improve access to roads; establishment of contract marketing	- None of the recommended practices were selected for improvement
	Seasonal rainfall variability	- Irregular quantity and quality of food supply to markets compared to market demand; - reduced prices, value-addition and market opportunities	- Capacity-building initiatives for cooperatives to support farmers with exploring different vegetable marketing opportunities; - Contract farming and marketing of vegetables; - increase communication of climate- and market-based information for farmers to optimize selling practices and profits	- None of the recommended practices were selected for improvement
	Heavy rainfall and hailstorms	- Difficulties in accessing roads and storage facilities, increased food spoilages.	- Climate services: weather-informed transportation advisory; precipitation, flooding, and relative humidity advisory for storage and markets. - Combine climate- and market information and research through most suitable communication tools to optimize vegetables marketing as well as connection between value chain actors through e-marketing	- Weather-informed transportation advisory.

9.5. Dairy

9.5.1. Climate services development

140. According to the results on climate information and agricultural advisory services for the dairy value chain, at the production stage, respondents reported to have access to and use precipitation forecasts and extreme rainfall advisory (65%), as well as dry spells forecasts and information on the onset and offset of the rainy seasons (60%). In terms of services to be improved and received further, respondents primarily selected recommendations on water resource availability, soil moisture and water management, as well as pest and disease forecasts (56%) (Figure 66). Along the dairy value chain, respondents primarily use information on precipitation and thunderstorm forecasts (40%), however they would be particularly interested in receiving further advisory on storage and processing tailored to precipitation forecasts (40%) (Figure 67).

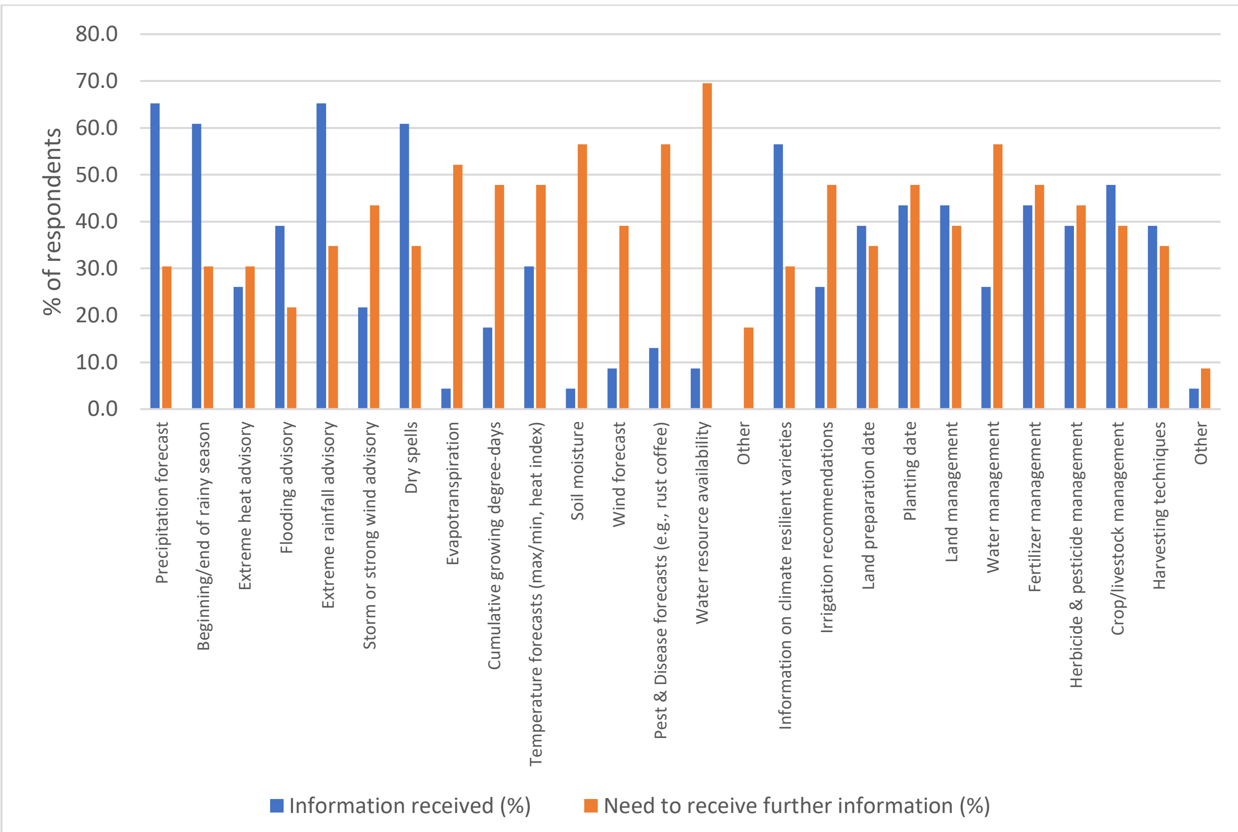

Figure 66. Climate information and agricultural advisory services for dairy production.

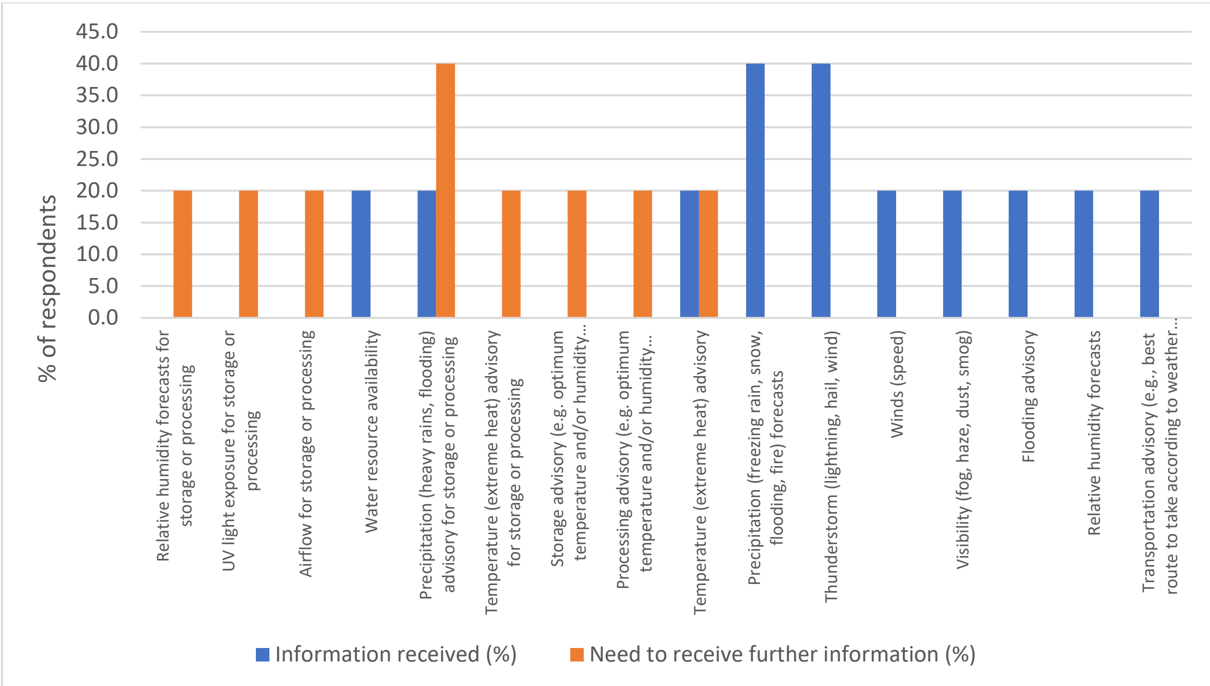

Figure 67. Climate information and agricultural advisory services for the dairy value chain.

9.5.2. Climate resilient practices

141. In high-temperature environments, milk is subject to rapid deterioration, therefore processing into yogurt and fermented products can increase its shelf life to reach markets by at least one-week[165]. Pre-processing treatments, which include milk filtration and thermalization, are necessary to remove dangerous microorganisms in the raw milk. Processing treatments include cream separation from skimmed milk and pasteurization to remove or reduce pathogens to safe levels[228].

142. According to the results from the climate-sensitive value chain survey (Figure 68 and Figure 69), respondents mostly apply agroforestry practices to provide tree shade to livestock and crops, as well a diversification of crop and livestock systems (e.g., between staple and cash crops, dairy and poultry production) (65,2%). Furthermore, a common interest among 30% of the respondents results in the Shifting to early maturing, shorter-duration pasture varieties and dairy breeds, the improvement of proper harvest and handling equipment, methods, and timing, combined with cold chain practices including the use of cold/ice boxes, cold rooms, refrigerated cooler tanks for milk handling and storage, the latter being also reported to be implemented by actors involved in dairy value-adding activities. Other practices stakeholders reported to be particularly interested in implementing further include training on optimum temperature range through ICTs for temperature and relative humidity controls, as well as increasing the efficiency of milk storage, combined with the use of vapor heat treatments, while ensuring work hygiene and sanitation practices. Therefore, a summary of identified climate hazards, impacts, and tailored climate resilient practices along the dairy value chain is highlighted in Table 12.

[228] Guzmán- Luna et al., 2021. Analysing the interaction between the dairy sector and climate change from a life cycle perspective: A review. Trends in Food Science & Technology. 126.

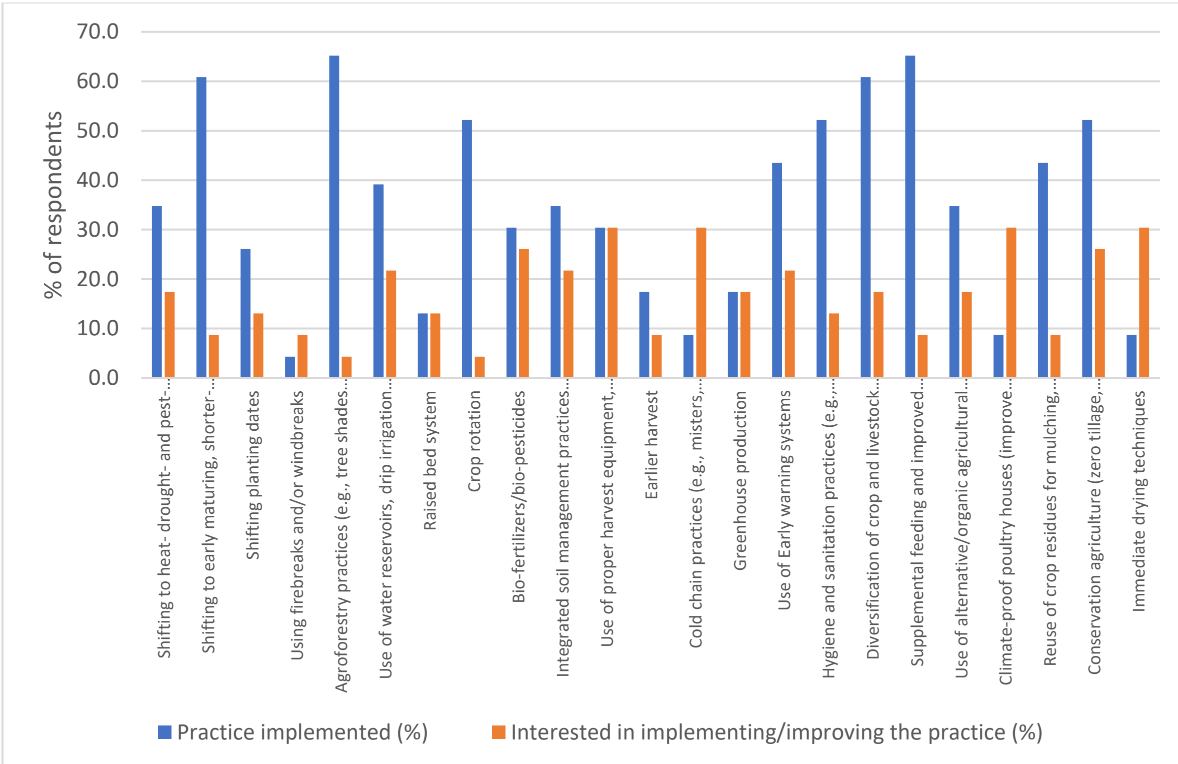

Figure 68. Climate-resilient practices for dairy production.

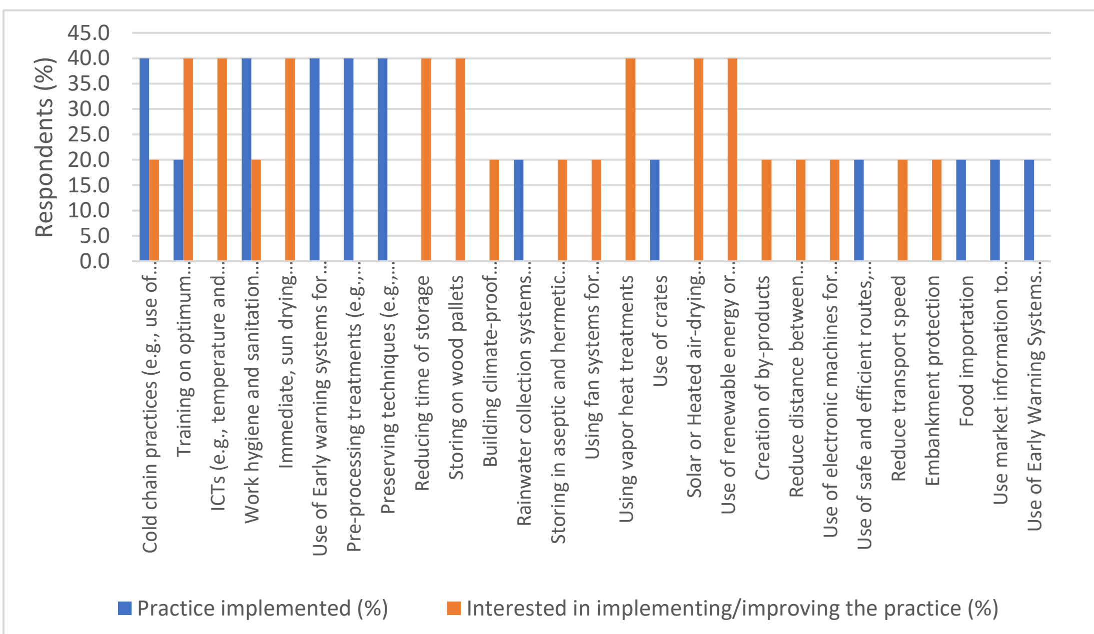

Figure 69. Climate-resilient practices for the dairy value chain.

Table 12. Climate hazards, impacts, and climate resilient practices along the dairy value chain. Readapted from [229].

VALUE CHAIN STEP	CLIMATE HAZARD	CLIMATE IMPACTS	OVERALL ADAPTATION RECOMMENDATIONS	SELECTED PRACTICES TO BE IMPROVED
Input supply	**Extreme heat and Drought**	- Reduced quality and quantity of pasture and fodder; - increased infertility and costs of breeding; - reduced access to credit for agricultural inputs	- Introduction of drought tolerant pasture; - development of feed storage facilities; training on fertility cycle monitoring and input subsidies to farmers; - establishment of emergency fund to insure producers; - introduction of drought- and disease-tolerant breeds; - use of fresh or dried fodder; - training farmers on mastitis prevention veterinary practices; agroforestry practices - Climate services: dry spells forecasts and information on onset/offset of the rainy seasons; information on water resource availability, soil moisture and water management.	- Shifting to early maturing, shorter-duration pasture varieties and dairy breeds - Supplemental feeding and improved feed conservation - Agroforestry practices (e.g., tree shades for livestock and crop). - Climate services: information on water resource availability, soil moisture and water management.
	Heavy rainfall and Flooding	- Limited access to inputs due to negative effects to input transport, storage, and marketing facilities; - reduced quality of pasture and feed	- Improve infrastructure to facilitate access to inputs; government provision of dairy inputs (e.g., drugs, feed; concentrates); - capacity building in fodder production and conservation strategies - Train farmers on flooding-resistant practices for fodder conservation - Climate services: precipitation forecasts and extreme rainfall advisory	- Conservation agriculture (zero tillage, cover crops, mulching) - Embankment protection.
Production	**Extreme heat and Drought**	- Increased vulnerability to pests and diseases due to reduced immunity and poor feeding; - emaciation of livestock; - drought stress on animals	- Improved access to veterinary services and insurance schemes; improved pests and disease control systems; - agroforestry practices and integrated water management - Climate services: dry spells forecasts and information on onset/offset of the rainy seasons; information on water resource availability, soil moisture and water management; pest and disease forecasts.	- Use of water reservoirs, drip irrigation systems - Climate services: information on water resource availability, soil moisture and water management; pest and disease forecasts.
	Heavy rainfall and Flooding	- Increased pests and water-borne diseases risk; - reduced milk production due to lower quality of animal feed	- Improved pest and disease control systems and advisories; capacity building in soil and water conservation and on improved drainage systems; - training farmers on milk antimicrobial treatments and standards - Climate services: precipitation forecasts and extreme rainfall advisory; pest and disease forecasts.	- Climate services: pest and disease forecasts.
Handling, storage, and processing	**Extreme heat and Drought**	- Increased costs for collection of milk and pastures/fodder; - increased milk spoilage;	- Establishment of climate-proofed milk processing plants (e.g., for milk powder and long-life milk) and cold chain facilities combined with systemic electricity provision (e.g., milk coolers).	- Training on optimum temperature range - ICTs (e.g., temperature and humidity sensor systems) - Reducing time of storage

[229] CGIAR-CIAT. Ministry of Agriculture, Livestock, Fisheries and Cooperatives. 2022. Kenya County Climate Risk Profiles. https://ccafs.cgiar.org/resources/publications/kenya-county-climate-risk-profiles

VALUE CHAIN STEP	CLIMATE HAZARD	CLIMATE IMPACTS	OVERALL ADAPTATION RECOMMENDATIONS	SELECTED PRACTICES TO BE IMPROVED
		- reduced water resources	- Training farmers on hygiene and sanitation practices for milk handling. Rapid milk cooling practices and technologies right after milking	- Hygiene and sanitation practices (e.g., cleaning equipment, veterinary controls, food safety controls) - Work hygiene and sanitation practices (e.g., use of aseptic containers)
	Heavy rainfall and Flooding	- Damage to road infrastructure and reduced access to storage and processing facilities; - damage to fodder and milk storage infrastructure; - rapid food spoilage.	- Establishment of climate-proofed milk collection and processing plants; - Climate services: strengthen use of flooding early warning systems; precipitation and thunderstorm forecasts; advisory on storage and processing tailored to precipitation forecasts.	- Climate services: strengthen use of flooding early warning systems; precipitation and thunderstorm forecasts; advisory on storage and processing tailored to precipitation forecasts. - cold chain practices (e.g., use of cold/ice boxes, cold rooms, refrigerated cooler tanks)
Distribution and Markets	**Extreme heat and Drought**	- Higher costs for milk traders in milk sourcing and reduced quantity of milk at markets	- Improve access to high-end markets; - increase farmers' access to insurance products and contract milk farming	- None of the recommended practices were selected for improvement
	Heavy rainfall and Flooding	- Reduced access to market facilities and damage to infrastructure; - reduced income from milk production; - reduced market activities and opportunities, job losses for processors and transporters; - delays in delivering milk due to impacts on road infrastructure	- Establishment of community-based milk collection and storage facilities; - improved dairy farmers' access to insurance product and contract milk marketing. - Use of specialized milk trucks. Investments in refrigeration facilities for milk marketing and retail, use of aluminum containers for transportation and cleaning procedures. - Improve milk delivery timing. - Training on sanitation and contamination control requirements.	- Cold chain practices (e.g., use of cold/ice boxes, cold rooms, refrigerated cooler tanks) - Work hygiene and sanitation practices (e.g., use of aseptic containers) - Reduce distance between harvesting, processing, and distribution facilities to avoid food recontamination

9.6. Poultry

9.6.1. Climate services development

143. Respondents to the online survey involved in poultry production reported accessing and using precipitation forecasts, as well as information on the onset and offset of the rainy seasons (52%) to inform their agricultural activities (Figure 70). Dry spells forecasts (47%) followed by temperature forecasts (41%) are also mostly used. Poultry producers also highlighted the need to strengthen access to information on climate resilient poultry breeds (53%), as well as pest and disease forecasts (47%). Furthermore, advisory on land, water, and integrated crop and livestock management was also selected by 35% of the respondents as types of weather-informed agricultural advisory services to be improved further. Along the poultry value chain, other key advisory services the respondents expressed interest in receiving further (50%) include temperature and relative humidity forecasts relevant to storage, processing, transportation, and market stages, as well as overall weather-informed transportation advisory services (Figure 71).

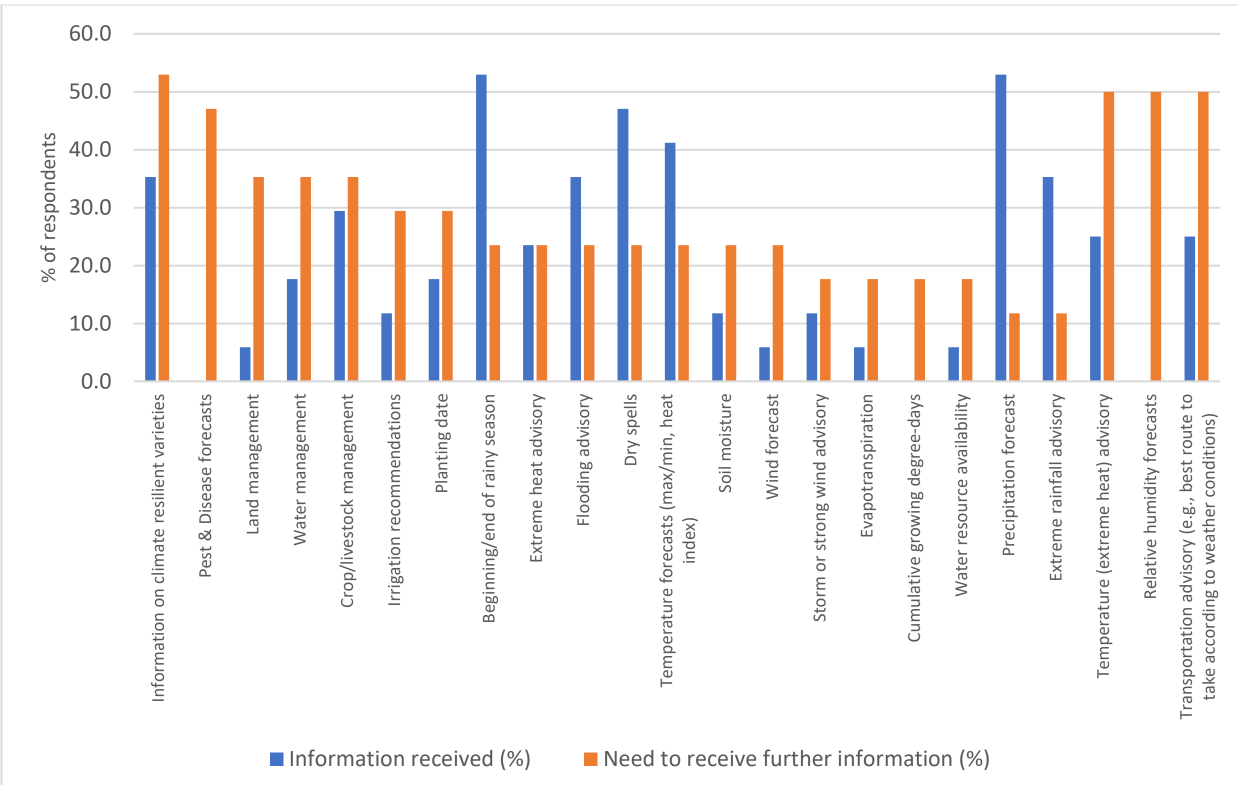

Figure 70. Climate information and agricultural advisory services for poultry production.

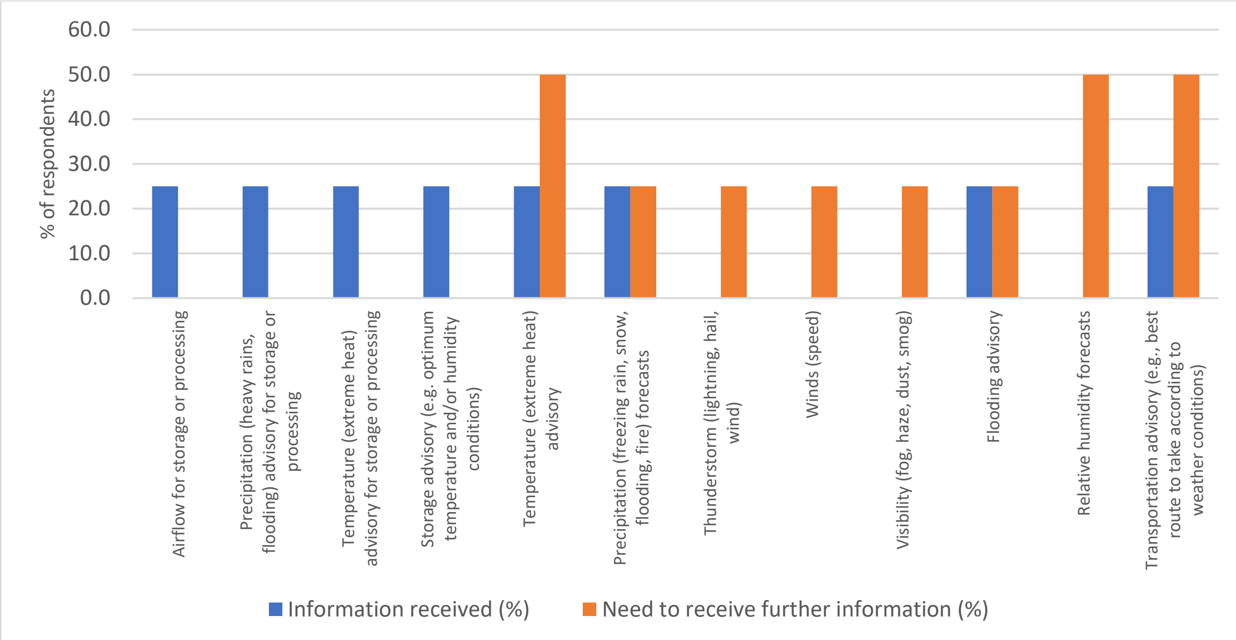

Figure 71. Climate information and agricultural advisory services for the poultry value chain.

9.6.2. Climate resilient practices

144. Overall, there is a need for enhancing the market opportunities for indigenous poultry products by promoting information on consumption which is healthier due to higher nutritional qualities than the commercial options, as well as the market profitability to farmers due to the lower inputs needed to support poultry's adaptation to heat stress and diseases[230]. In addition, since poultry is generally more resistant to climatic shocks than cattle, it is important to promote diversification within livestock producers, in order to increase household's income and food and nutrition security especially during the occurrence of climatic shocks and crop failures, and in the absence of food safety nets and insurance, to act as a risk management strategy. Some factors such as small distance to markets, access to safety nets programmes which prioritize small livestock, and larger sizes as well as higher ages of the households are positive for farmers to invest in poultry due to lower labor, water, and feed requirements[231]. Cooperatives can substantially support farmers with accessing climate and market-based information to set appropriate prices, increase their empowerment at the market and selling stages, and accessing credit and agricultural insurance.

145. According to the results from the climate-sensitive value chain survey (Figure 72), most respondents reported the diversification of crop and livestock systems (e.g., between staple and cash crops, dairy and poultry production) as a key practice implemented (53%), supported by agroforestry and hygiene and sanitation practices along the poultry value chain (47%), which also show a common interest (23,5%) in further adoption and improvements. The construction of climate-proofed poultry houses, for example by improving the location, spaces, light, ventilation, was also reported as a common resilient practice by 41% of the respondents. Across the value chain, poultry producers

[230] Kennedy, g. et al. 2022. Review Article : Heat stress and poultry: Adaptation to climate change, challenges and opportunities for genetic breeding in Kenya. Journal of Agriculture, Science and Technology. 21(2).

[231] Ngigi, M.W., Mueller, U. & Birner, R. Livestock Diversification for Improved Resilience and Welfare Outcomes Under Climate Risks in Kenya. Eur J Dev Res 33, 1625–1648 (2021). https://doi.org/10.1057/s41287-020-00308-6

highlighted the need to improve the use of early warning systems relevant to the distribution stage, such as weather-informed food monitoring systems to ensure quality of the products. Therefore, a summary of identified climate hazards, impacts, and tailored climate resilient practices along the poultry value chain is highlighted in Table 13.

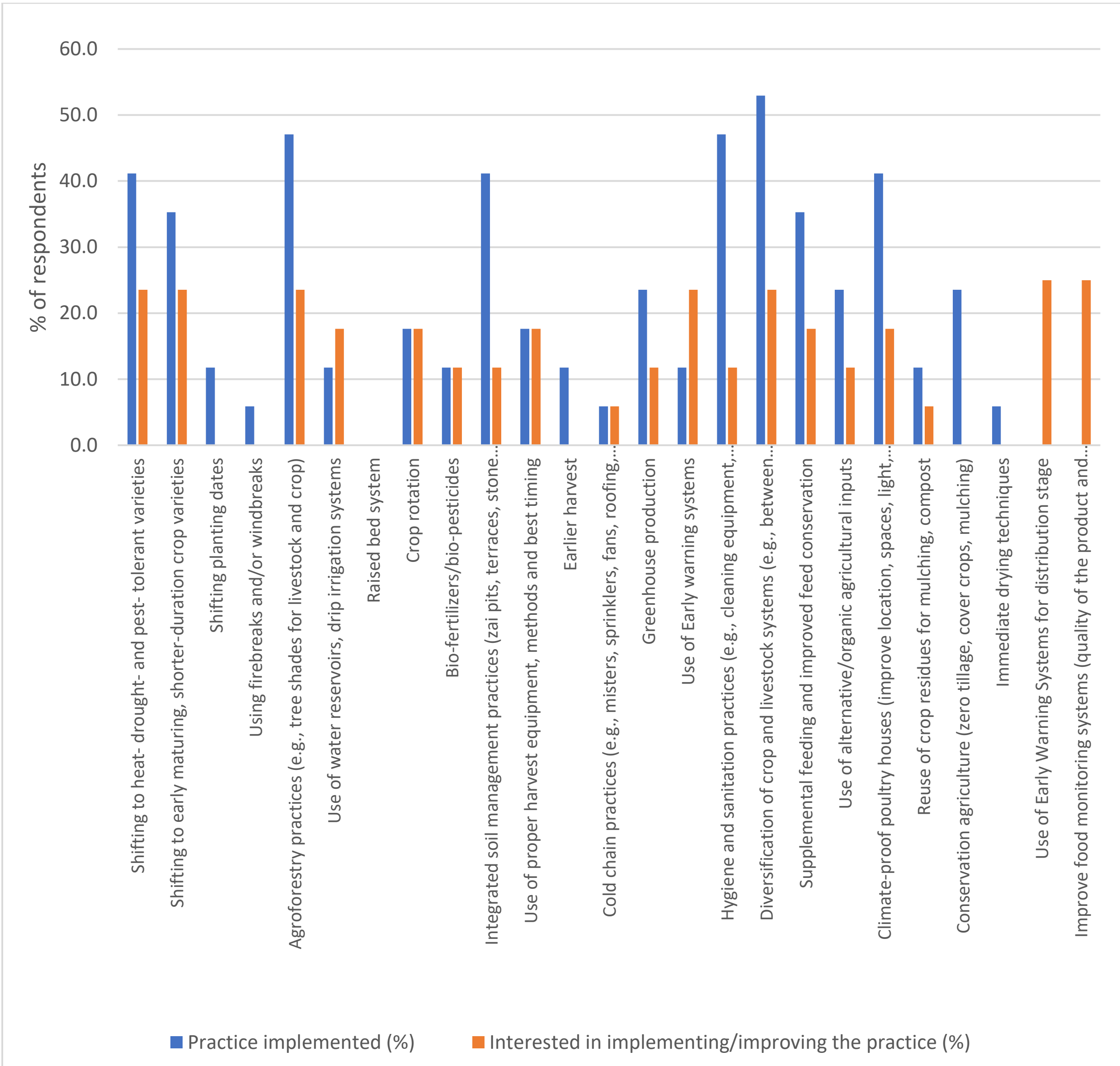

Figure 72. Climate-resilient practices for the poultry value chain.

Table 13. Climate hazards, impacts, and climate-resilient practices along the Poultry value chain. Readapted from [232].

VALUE CHAIN STEP	CLIMATE HAZARD	CLIMATE IMPACTS	ADAPTATION RECOMMENDATIONS	SELECTED PRACTICES TO BE IMPROVED
Input supply	**Heavy rainfall and flooding**	- Increased demand and prices, and reduced access to agricultural input; - damage to input storage infrastructure, feed spoilage	- Train farmers on building climate-proofed poultry and input storage facilities using local resources (e.g., timber, stone). - Diversification of feed - Climate services: precipitation forecasts and information on the onset and offset of the rainy seasons.	- Climate-proof poultry houses (improve location, spaces, light, ventilation
	Extreme heat	- increased prices and reduced access to agricultural inputs (feed sources, water requirements, vaccines due to storage constraints)	- Insulation of infrastructure through iron sheet to regulate temperature. - Diversification of feed. - Climate services: temperature forecasts; weather-informed advisory on land, water, and integrated crop and livestock management.	- supplemental feeding and improved feed conservation - Climate services: weather-informed advisory on land, water, and integrated crop and livestock management.
	Drought	- Increased costs of inputs, feed shortages	- Diversification of feed and fodder crops, training on homemade feed and supplements - Climate services: dry spells forecasts; weather-informed advisory on land, water, and integrated crop and livestock management.	- Shifting to heat- drought- and pest-tolerant varieties - Shifting to early maturing, shorter-duration pasture varieties - Climate services: weather-informed advisory on land, water, and integrated crop and livestock management.
Production	**Heavy rainfall and flooding**	- Decreased breeding activities; increased animal mortality and feed spoilage; - increased pest and water-borne disease attacks (e.g., fowl typhoid); - increased demand for extension services; - contamination of chicken enclosures	- Promote work hygiene and sanitation practices, disinfecting feeding/water equipment; increase access to early warning systems and agricultural advisory; - build climate-proofed poultry houses - Climate services: precipitation forecasts and information on the onset and offset of the rainy seasons; pest and disease forecasts.	- Use of Early warning systems - Climate-proof poultry houses (improve location, spaces, light, ventilation) - Hygiene and sanitation practices (e.g., cleaning equipment, veterinary controls, food safety controls) - Climate services: pest and disease forecasts.

[232] CGIAR-CIAT. Ministry of Agriculture, Livestock, Fisheries and Cooperatives. 2022. Kenya County Climate Risk Profiles. https://ccafs.cgiar.org/resources/publications/kenya-county-climate-risk-profiles

VALUE CHAIN STEP	CLIMATE HAZARD	CLIMATE IMPACTS	ADAPTATION RECOMMENDATIONS	SELECTED PRACTICES TO BE IMPROVED
	Extreme heat	- Decreased breeding activities; increased pest and disease attacks (mites) in poultry houses; - malnutrition and weight loss; - increased vaccination needs; - need for larger spaces for poultry houses; - increased flock mortality	- Increase production of poultry feeds (e.g., sunflowers, soybean, millet); - promote insect feed supplements and synchronized hatching to facilitate farm operations - Climate services: temperature and pest and disease forecasts. - Climate resilient poultry breeds.	- Shifting to heat- drought- and pest-tolerant varieties - Shifting to early maturing, shorter-duration pasture varieties - Improve feed monitoring systems (quality of the product and weather advisory) - Climate resilient poultry breeds. - Climate services: pest and disease forecasts.
	Drought	- increased risk of diseases (e.g., Newcastle), parasites (e.g., flies and mites). - Decline in production (eggs and meat)	- improve access to hatcheries and chicken enclosure; increase use of on-farm and diversified feeds - Climate services: dry spells and pest and disease forecasts. - Climate resilient poultry breeds.	- Shifting to early maturing, shorter-duration pasture varieties - Climate resilient poultry breeds. - Climate services: pest and disease forecasts.
Post-breeding, storage, and processing	**Heavy rainfall and flooding**	- Delays in collecting eggs and transporting products to collection facilities; lower quantity of eggs available; - increased egg spoilage due to moisture and dirt; power shortages to cold storage facilities	- Organize farmer cooperatives to render transport means more accessible and affordable; establish local collection points; increase access to cages and boxes for markets - Climate services: relative humidity forecasts relevant to storage and processing.	- Climate services: relative humidity forecasts relevant to storage and processing.
	Extreme heat	- Increased food spoilage, reduced egg and meat quantity and quality; - increased storage and refrigeration, energy, and transportation costs	- Use of ventilated cages for transportation and storage to promote air circulation; improve communal storage to reduce transport costs and to standardize processing systems; - train farmers on optimum temperatures for storage - Climate services: temperature and relative humidity forecasts relevant to storage and processing.	- Climate services: temperature and relative humidity forecasts relevant to storage and processing.
	Drought	- Lower grading of the eggs, reduced eggs' shelf-life and quality	- Value addition practices such as eggs grading, packaging, boiling, chicken de-feathering, boiling, salting, packaging. - Climate services: temperature and relative humidity forecasts relevant to storage and processing.	- Climate services: temperature and relative humidity forecasts relevant to storage and processing.

VALUE CHAIN STEP	CLIMATE HAZARD	CLIMATE IMPACTS	ADAPTATION RECOMMENDATIONS	SELECTED PRACTICES TO BE IMPROVED
Distribution, markets	**Heavy rainfall and flooding**	- Limits to access markets due to impairment to roads and delayed delivery; - increased costs and reduced prices set by farmers; increased transportation costs	- Build/repair infrastructure and roads; promote innovative and local marketing channels (e.g., e-platforms, supermarkets; tourist hotels, schools); - create farmer associations for collective farmer negotiations - Climate services: weather-informed transportation advisory	- Climate services: weather-informed transportation advisory
	Extreme heat	- Increased final products' prices, reduced demand for poultry	- Promote electronic marketing, contracted marketing, promote value adding activities such as sale of differentiated chicken parts to reduce food loss and waste; use of cold storage systems during transportation of meat and ventilated cages. - Climate services: temperature and relative humidity forecasts relevant to transportation and markets.	- Climate services: temperature and relative humidity forecasts relevant to transportation and markets.
	Drought	- poorer product quantity and quality, lower trade, increasing prices	- facilitate collective marketing, contract farming, improve market information systems linked to climate information; - increase local product sale. - Climate services: temperature and relative humidity forecasts relevant to transportation and markets.	- Climate services: temperature and relative humidity forecasts relevant to transportation and markets.

9.7. Summary of climate-resilient practices for crop and livestock value chains and adaptation benefits

146. Table 14 and Table 15 provide a list of climate-resilient practices and technologies which are expected to provide adaptation benefits, based on the results on the observed and projected climate hazards and impacts along the 6 selected value chains, as identified in this study's climate hazard and climate impact assessments.

Table 14. Climate-resilient practices for crop and livestock production and adaptation benefits.

Climate-resilient practices for crop/livestock production	Description and adaptation benefits
Shifting to heat- drought- and pest-tolerant varieties	• Coffee: promote the use of Ruiru 11 variety which is resistant to pests and diseases, although with lower quality of coffee berries, or the Batian variety which also has higher yields in all agro-ecological zones, lower costs of fungicide application and higher income opportunities due to its resistance to coffee berry disease and leaf rust, its early maturity and ripening timing, while providing high yields and quality. • The introduction of heat-tolerant cow breeds and cross breeding with local genetics (e.g., with the indigenous Zebu cattle, bred in Kisii and Nyamira) would render water use as well as cooling systems more efficient, such as Holstein dairy cow and feedlot cattle. The use of breeds with lower water intake requirements can reduce animal mortality and optimize the use of water resources by minimizing animal's exposure and ensure high productivity under heat and drought stress conditions. • The introduction of heat- and drought-tolerant varieties would enhance food security by providing high nutrients to low-income households' diets, environmental sustainability for their ability to grow in drier and hostile areas with high salinity, and contribute to land rehabilitation and soil erosion control, eliminate poverty by allowing farmers to diversify products sold to markets.
Shifting to early maturing, shorter-duration crop varieties; high-nutrition feed options	• According to a study in Makueni and Siaya through a sample of 237 farmers, the adoption of Brachiaria grass was reported to increase milk production by about 27.6% and related income, to increase feed sufficiency and reduce time spent in feeding activities particularly for women and during the dry seasons when fodder is scarce. Other improved feeds include Rhodes grass, Lucerne, maize stover, and tree shrubs. • The use of early maturing and short-duration crop varieties reduce the effect of heat stress at key phenological phases (germination and flowering) and improve final yields; reduce plants' exposure to heat by shortening the growing cycle, and the total water requirements during the growing season.
Shifting planting dates	• Select crop practices and planting dates based on timing of sensitive stages and critical damage temperature relative to the probability and risk of extreme high temperatures. It is important to detect critical temperature thresholds at early growing stages. • Optimal crop calendars based on historical climate data and seasonal forecasts support decision-making, avoiding heatstress conditions at crop's sensitive phenological phases, and increasing yields. • Use of crop models to support climate-informed cropping decisions.
Using firebreaks and/or windbreaks	• Windbreak acts as a barrier lowering the wind speed near the ground surface, deviating, and splitting the air stream. Dry winds may damage the grass plants through loss of water from evapotranspiration, wind erosion when vegetation cover is sparse, and the soil is dry. Rows of trees can protect crops by breaking strong winds, reducing soil erosion, increasing crop yields, and protecting livestock from heat and cold conditions. Also important in coffee and banana fields to prevent breakages. • Firebreaks limit the spread and impact of wildfires on crops, reduce social, environmental, and economic losses deriving from wildfires, and decrease air pollution by reducing black carbon emissions.

Climate-resilient practices for crop/livestock production	Description and adaptation benefits
Agroforestry practices (e.g., tree shades for livestock and crop)	• Shaded coffee production compared to monoculture helps remove pests, maintains soil fertility, provides farmers with diversified income, and reduces impacts from extreme weather events such as hailstorms, as well as from dry spells impacts on reduced soil water content, and solar radiation impacts on sun scorching. reduce hailstorm and strong wind impacts on tea shrubs and leaves, as well as to store plucked tea (as well as harvested bananas, vegetables) under the shade, to reduce sun scorch, reduce weed growth, act as frost and soil erosion protection. • Reduce animals' heat stress particularly during the dry seasons, enhance milk productivity and optimize land and resource use. Shades for protecting farm animals in hot climates: trees, partially or totally enclosed shelters. • Root systems stabilize the ground and reduce soil erosion. • Improves soil health by increasing soil organic matter, nutrient availability and microbial activity. • Leaves from trees enrich the soil and help keep soil moisture, contributing to efficient and self-sufficient use of water. • Canopy cover reduces evaporation from direct sunlight and by decreasing air and soil surface temperature. • Other co-benefits of agroforestry include fodder for animal feeding. Fodder trees can also be grown as a substitute or supplement to a basal diet including crop residues. • Tree shelterbelts can reduce the exposure of livestock to heat-stress conditions and therefore reduce animal mortality. • Fruit trees such as mango and avocado can be introduced to increase the source of income and improve nutrition.
Use of water reservoirs	• Increase crop yields. • Small-scale reservoirs increase water availability to counteract the impacts of drought shocks. • Provide supplemental irrigation on rainfed fields. • Wastewater management brings additional nutrients to the plants and enhances yields; increases water use efficiency and promotes sustainable withdrawal and supply of freshwater to address water scarcity. • Water reservoirs optimize water resources by reducing the exposure to drought and heat-stress conditions; limit the movement of cattle and reduce overgrazing; reduce transhumance time by placing water along transhumance corridors.
Drip irrigation systems	• Increase water-use efficiency by providing sufficient water according to the crop. Partial-root zone drying (PRD) maximizes water use efficiency by adding water only on half of the root zone. • Reduce soil erosion and macronutrient losses from leaching. • Promote weed control as water is locally applied. • Reduce the risk of diseases that occur under damp conditions. • Programmed irrigation uses water resources more efficiently and avoids permanent wilting point as well as field capacity. It reduces losses from direct evaporation by providing water when evaporation rates are lowest (dawn and/or dusk). • Promoting irrigation at dawn and dusk reduces direct soil evaporation, making better use of water resources.
Raised bed system	• Removes excess water during plant growth by better draining the water retained in the soil. • Promotes optimal growth of root systems through soil aeration. • Improves soil structure by limiting the compaction from human feet.
Crop rotation	• Increases soil fertility as each crop has different nutrient requirements and plant-soil dynamics. • Increases crop yields with the diverse nutrient availability. • Reduces soil erosion and prevent nutrients from being washed away by wind or water (through an increase in crop cover). • Limits concentration of pests and diseases and lower selective pressure on pathogens (as each crop has different pathogens).

Climate-resilient practices for crop/livestock production	Description and adaptation benefits
	• Reduces fertilizer use and associated pollution by improving nutrient cycling. • Increases soil carbon sequestration. • Limits concentration of pests and diseases and lowers selective pressure of pathogens (as each crop has different pathogens).
Bio-fertilizers/bio-pesticides	• Fertility improvements; use of manures as fertilizer (compost, animal manures). • Natural enemies (insects) can be introduced in the environment and sustain themselves by feeding from pests affecting the crop. • Use beneficial entomopathogens to reduce the need for chemical pesticides, fertilizers, as well as herbicides and pesticides. • Reduce the environmental impacts as they are organic and biodegradable. • Reduce the negative effect on human health associated with chemical pesticides.
Integrated soil management practices (zai pits, terraces, stone bunds, cover crops)	• In-field water harvesting and storage within the soil profile addresses changes in rainfall distribution while improving soil water content. • Improve the efficiency of fertilizers by adding the required amount of nutrients to a planting hole instead of spreading them over the entire field area. • Reduce soil erosion, increase macronutrient deposition and infiltration by reducing surface runoff. • Increase water infiltration rates as water is trapped in the pits close to the root systems of crops. • Terracing Reduces soil erosion, increases macronutrient deposition and infiltration by reducing surface runoff.
Proper crop husbandry	• Crop protection measures such as under-tree sprinkles. Pruning protects bushes from climate and pest and diseases impacts while maintaining green leaf quality.
Use of proper harvest equipment, methods, and best timing; earlier harvest	• Ensure high quality coffee cherries are harvested. • Timely harvest according to the planned processing/marketing of fruit to increase fruit quality (e.g., harvesting less mature harvest for fresh fruit, and more mature harvest for processing into oil). • Minimize losses caused by falling of fruit and food spoilages. • Cover perishables to preserve them until they reach maturity.
Cold chain practices (e.g., misters, sprinklers, fans, roofing, shade, use of cold/ice boxes, cold rooms)	• Tea: to address frost impacts, apply cold air drainage and diversion. • Preserve fruit quality, ensure that products are intact and mature to ripen at room temperatures. • Fruit trees: pre-cooling practices by covering bananas with banana leaves (to protect from sun-scorching and moisture stress). • Implement cold chains and ice cooling to remove heat from fresh fruit and vegetables quickly after harvest, reducing food loss.
Greenhouse production	• Low or walk-in tunnel greenhouses warm the soil and protect plants from hailstorms and wind. • Reduces crop damage and loss by buffering the impact of hail on crops. • Protection from bird predation and insect pests.
Use of Early warning systems	• Tea: enhance preventative frost monitoring and forecasting by the Tea Research Institute in collaboration with the Regional Centre for Mapping, Finlays, Unilever, and Sotik, and communication to farmers through adequate information and communication tools (e.g., radio and TV). • Coffee: enable more informed decisions at the production site and improve the quality and quantity of coffee production. • Combined weather and market information increase knowledge sharing and farmers' capacity building to negotiate prices and contracts with middlemen, as well as requests for improved technologies and practices tailored to farmers' needs.

Climate-resilient practices for crop/livestock production	Description and adaptation benefits
	• Enable farmers to make informed decisions on land preparation, input supply, and cropping based on forecasted onset and duration of the growing season.
Hygiene and sanitation practices (e.g., cleaning equipment, veterinary controls, food safety controls)	• Practice sustainable hygiene and sanitation practices (e.g., cleaning the udder of the cow, milking equipment, and surfaces prior to milking, use of probiotics and other disinfectants), veterinary health controls and practices (shifting feeding and drinking regimes to cooler times of the day, and using raw feed during extreme weather events), and food safety controls (GAP, GHP, Good Veterinary Practices) would support animal health and comply with dairy products' microbiological specifications. • Promote animal health and reduce mortality. For instance, installing door sweeps, store feed bags on pallets, screening materials, caulk, vermin traps and disinfectant are among the most effective measures for controlling/preventing and/or eliminating the presence of pests in the animal's environment.
Diversification of crop and livestock systems (e.g., between staple and cash crops, dairy and poultry production)	• Focus on degraded land for avocado production as means of afforestation and reforestation. • Increases product and income diversification among farmers. • Diversification of income and nutrition for small-scale farmers, higher nutritional qualities than the commercial options, as well as the market profitability to farmers due to the lower inputs needed to support poultry's adaptation to heat stress and diseases. • Increase household's income by avoiding the reduction in prices due to the selling of the same livestock breeds between farmers, and by rendering water and other natural resources use more efficient, to provide a more varied food consumption regime, especially during the occurrence of climatic shocks and crop failures, and in the absence of food safety nets and insurance, to act as a risk management strategy.
Supplemental feeding and improved feed conservation	• Appropriate poultry feeding regimes during extreme heat events to lower metabolic heat production, reduce mycotoxins contamination during rainy season. • Preservation of feed as hay and silage
Use of alternative/organic agricultural inputs	• Climate resilient seeds: ensure farmers' income from alternative, climate-resilient products, and tea by-products (e.g., green tea instead of black CTC tea) against decreased crop suitability under changing climatic conditions and market fluctuations. • Reduce use of chemical fertilizers and costs for farmers, as well as biomass to produce bioethanol, or as coffee flour, which has high nutritional and gluten-free values, thus generating income for farmers and millers.
Climate-proof livestock houses/shelters (improve location, spaces, light, ventilation)	• Improved housing (orientation and size) for the livestock and poultry to shield from both excessive heat and rainfall. Better ventilation, resistance to flood, and cleaning, reduce heat-stress and cold-stress. • Open shelters recommended for tropical climates because the increased natural air velocity and sanitation. • Reduce animals' heat stress particularly during the dry seasons. Use of zero-grazing and stall feeding to enhance milk productivity and optimize land and resource use.
Cover crops, mulching	• Mulching in combination with no-tillage reduces the exposure of crops to heat-stress conditions. It also increases soil moisture by reducing direct soil evaporation. • Increase water availability for crop production by improving infiltration and evaporation from the top layer and improving soil structure and moisture. • Increase soil organic matter content and microbial activity present in the soil. • Reduce soil evaporation as plant residues increase soil moisture. • Mulching Increases soil moisture by reducing losses from direct evaporation; reduces weed growth by keeping light from reaching the soil surface; moderates soil temperatures by keeping the soil warmer during cold nights and cooler in hot days; reduces irrigation requirements by reducing losses from direct evaporation.

Climate-resilient practices for crop/livestock production	Description and adaptation benefits
Zero tillage	• Zero tillage promotes minimum disturbance of soil structure and organic matter found in the soil by increasing the decomposition of plants in-situ. • Higher infiltration caused by the vegetation present in the soil. Organic matter increases and enhances the cycling of nutrients. • Less resistance to root growth due to improve structure, allowing crops to germinate and develop faster with additional soil moisture. • Reduces soil evaporation as plant residues increase soil moisture.
Immediate drying techniques	• Ensure high quality tea leaves. • Increase processed, high-value coffee domestic and exportation marketing. • Increase automatization of coffee processing using electronic weighing machines and electronic moisture control systems to increase time- and cost-effectiveness of sorting and grading. • Better storage thus opportunity for additional marketing and value addition. • For farmers to wait for better market prices while preserving shelf-life. • Improved fodder production and conservation. • Sun drying or heated-air drying to prevent spread of pests and diseases and reduce food moisture.

Table 15. Climate-resilient practices at post-harvest/handling and distribution stages of crop and livestock value chains, and adaptation benefits.

Climate resilient practices at post-harvest/handling and distribution stages	Description and adaptation benefits
Cold chain practices (e.g., use of cold/ice boxes, cold rooms, refrigerated cooler tanks)	• Ice cooling to remove heat from fresh fruit and vegetables quickly after harvest, reducing food loss. • Use cold rooms to prevent biological degradation, support temperature-controlled storage. • Improve insulation of refrigerated trucks while reducing energy consumption of vehicles.
Training on optimum temperature range	• Enhance food and nutrition security as well as resilience to climate impacts through diversification at production, and increased shelf-life through processing practices. • Temperature and humidity controls of feedstuff and use of preservatives to avoid fungal and bacterial growth.
ICTs (e.g., temperature and humidity sensor systems)	• Use temperature and humidity sensors to prevent food loss from heat or humidity.
Work hygiene and sanitation practices (e.g., use of aseptic containers)	• Ensure food safety standards and food quality controls. • Improve the monitoring and assessment of microbial risks to ensure food safety across the dairy value chain from production to consumption. • Increased worker safety and health.
Immediate, sun drying techniques after harvest	• Reduce steps between farm and trade levels to avoid multiple handling within the chain and higher risk of exposure to microbial contamination.
Use of Early warning systems for storage and processing	• Strengthen early warning systems to prevent flooding impacts to storage infrastructure and food products.

Climate resilient practices at post-harvest/handling and distribution stages	Description and adaptation benefits
	• Increase income opportunities for farmers planning and taking up climate-informed, adding-value activities such as collection, grading, bulking, and transportation. • Strengthen early warning systems to prevent impacts to food products caused by pests and rodent attacks, as well as spread of mycotoxins.
Pre-processing treatments and preserving techniques	• Pre-cooling fruits and milk, cream separation and pasteurization for milk enhance availability of nutrient-rich food products and beverages. • Drying, chilling, freezing, heating, salting, product fermentation, etc.); washing food products increase the value of the product as well as its shelf-life and maintain its physical and nutritional quality, reduce chemicals contamination.
Reducing time of storage	• Reduce steps between farm and trade levels to avoid multiple handling within the chain and higher risk of exposure to microbial contamination.
Storing on wood pallets	• Prevents water intrusion, increased relative humidity and food moisture content.
Building climate-proof infrastructure (e.g., appropriate location, dimensions, type and slope of the roof, etc.)	• Meet sustainable structural requirements and standards to prevent water entrance in storage facilities, increased relative humidity, and food moisture content. • Disaster risk reduction; reduced cost of damages and repairs.
Rainwater collection systems (e.g., tanks, pumps, purifiers, drainage systems and infrastructures etc.)	• Deploy rainwater collection systems such as rainwater tanks, pumps, purifiers; use drying hangers and storm drain maintenance for efficient water use and drainage.
Storing in climate-proof packages	• Store in jute bags to let the air circulate, or hermetic bags to decrease food contamination and spread of mold. • Ensure food safety standards. • Use large or small packaging, containers, aseptic packaging, impermeable to moisture and oxygen bags. • Implement modified atmosphere packaging and pulsed electric field techniques. • Dry and package food right after harvesting to prevent food spoilage.
Using fan systems for ventilation, dehumidifiers, ventilators	• Improve storing conditions (e.g. fan systems for ventilation in temperate climates or reduced moisture and temperature in warm, humid environments); use dehumidifiers, roof ventilators and wall air vents to reduce relative humidity in closed environment and prevent mold spread.
Using vapor heat treatments	• Implement vapor heat treatment/hot water treatment to conserve food products.
Use of crates	• Reduces food spoilage and losses during storage and transportation by allowing air to circulate.
Solar or Heated air-drying techniques	• Use UV lamps to preserve food quality and safety. • Switch from sun drying to solar drying techniques (e.g., using solar cabinet dryer technologies). • Use mechanical dryer techniques such as heated air-drying.
Use of renewable energy or energy efficient infrastructure and technologies (e.g., for milling, drying, grating)	• Install efficient and renewable energy infrastructures to support temperature-controlled storage, contribute to offsetting GHG emissions from fossil-fuel based sources of energy, increase productivity, time and cost effectiveness of labor work and operations. • Efficient use of natural resources (land, water, energy).

Climate resilient practices at post-harvest/handling and distribution stages	Description and adaptation benefits
Utilization of by-products	• Enhance modern processing techniques (e.g., optimum thermal processing conditions, utilization of by-products such as coffee husks, use of food dehydrators) to increase value chain actors' alternative market and income opportunities during high-impact weather-related events. • Increased monetary value of the food product, increased access to premium markets and revenue; reduced waste.
Reduce distance between harvesting, processing, and distribution facilities to avoid food recontamination	• Enhance market linkages, product diversification at markets, and collaboration between value chain actors (producers and industries). • Improve milk transportation monitoring systems, both for the quality of the product, and of external factors such as extreme weather events forecasting and enhancing real-time data gathering on extreme weather events and litres of milk lost, as well as on consumers' perspectives on use of refrigeration practices to address increasing extreme temperatures.
Use of electronic machines for processing and sorting	• Install sustainable, safe, and energy efficient machines (e.g., for milling, drying, grating) to increase productivity, time and cost effectiveness of labor work and operations.
Use of safe and efficient routes, e.g., elevated roads above flood-prone areas, appropriate lightning	• Reduce road traffic when external conditions for drivers' safety are critical to avoid hailstorm impacts on road accidents and food losses.
Ship products with less critical external conditions	• Strengthen transportation-focused early warning systems to prevent impacts to road infrastructure and reduce food losses from heavy rainfall events.
Reduce transport speed; Road network vulnerability assessments; embankment protection; LED panels, color coded warnings; Shift towards formal transportation means (e.g., Insulated or refrigerated trucks)	• Reduce transport speed and implement more efficient planning of transport routes. for transportation of fresh, perishable food to reduce time, food losses, and energy use. • Avoid hailstorms and frost impacts. • Conduct road network vulnerability assessments tailored to specific means of transport.
Warning on identified risks to consumers' health from contaminated food products and removal from the market	• Provide warning to prevent spread of illnesses, linked to product-specific consumption. Ensure immediate removal of the product from markets, stopping further distribution and informing all other actors along the value chain about its non-compliance with health safety requirements.
Use market information to regulate prices	• Provide seasonal advisory on climate impacts on yields and changes in food availability within national and international production to enable value chain actors to set transparent and competitive food prices for both domestic markets and food exportation. • Optimize information exchange on climate risks and knowledge on most suitable climate-resilient practices from production to processing and markets. set appropriate prices, increase farmers empowerment at the market and selling stages, and accessing credit and agricultural insurance. • Increase knowledge sharing and farmers' capacity building to negotiate prices and contracts with middlemen, as well as requests for improved technologies and practices tailored to farmers' needs.
Use of Early Warning Systems for distribution stage	• Strengthen early warning systems to avoid shipment of products when external conditions for drivers' safety are critical.

Climate resilient practices at post-harvest/handling and distribution stages	Description and adaptation benefits
Sell added-value products with prolonged shelf-life	• Relevance to household consumption and dietary diversification, as well as their suitability to dry and hot conditions.
Improve food management practices and cold chain (e.g., reduce distance and value chain steps from handling to markets)	• To comply with sustainable and climate-resilient standards and obtain related certifications, for example through access to more suitable technologies and packaging products.
Improve food monitoring systems (quality of the product and weather advisory)	• Reducing uncertainties in climate impacts to the agricultural sector and increase availability of products at markets.
Promote consumption of indigenous varieties (e.g., indigenous leafy vegetables and poultry)	• Diversification of income and nutrition for small-scale farmers, higher nutritional qualities than the commercial options, as well as the market profitability to farmers due to the lower inputs needed to support poultry and ALVs's adaptation to heat stress and diseases. • Increase household's income by avoiding the reduction in prices due to the selling of the same product between farmers, and by rendering water and other natural resources use more efficient, to provide a more varied food consumption regime, especially during the occurrence of climatic shocks and crop failures, and in the absence of food safety nets and insurance, to act as a risk management strategy. • Awareness raising on high nutritional qualities of African leafy vegetables (vitamins A, C, calcium, zinc, iron) as a result of climate-resilient, organic production and proper post-harvest handling and tailored market strategies.

A2. GHG emissions profile

147. In 2000, Kenya was reported to use 15.1 million tons of fuelwood and 16.5 million tons of wood for charcoal (processed in kilns with only 10% efficiency), making up most of the biomass energy that provides 68% of Kenya's national energy requirements.[233] Biomass is expected to remain the main source of energy until 2050. In 2015, the agriculture sector was the leading source of GHG emissions in Kenya, with the livestock sub-sector contributing about one-half of the emissions. As noted in Kenya's Updated NDC (2020), GHG emissions are projected to reach 143 MtCO2e by 2030; an increase of 152% from 93.7 MtCO2e in 2015[234].

148. According to Kenya's Second National Communication[235], agriculture emissions (the largest source of GHG emissions in Kenya) are likely to increase from 30 MtCO2e in 2010 to 39 MtCO2e in 2030, primarily driven by livestock Methane emissions (18.8 MtCO2e in 2030) and in agricultural soils (16.2 MtCO2e by 2030). The sector also contributes Carbon Dioxide (CO2), Methane (CH4) and Nitrous Oxide (N2O) emissions through activities such as conventional tillage, burning of the savannah and crop residues.

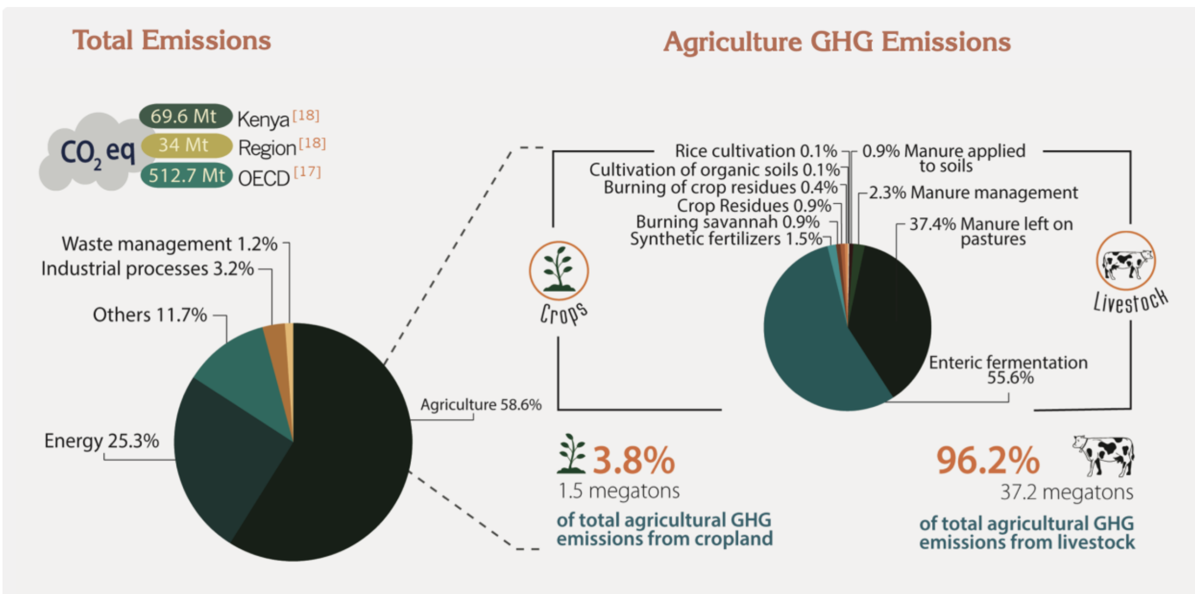

Figure 73:Emissions from agriculture In Kenya, compared to region and OECD (World Bank)

149. The steps that emit the largest proportion of GHG in the crop sub-sector is land management (including land clearing), post-harvest processing, where energy-inefficient technologies are used, inadequate post-harvest handling and conservation, leading to food waste. Crop residues are still often burnt, emitting significant levels CO_2 into the atmosphere. In the livestock sub-sector, methane emissions are due to enteric fermentation ([236]). Increasing the number of cattle heads (driven by the need to increase production) will expectedly lead to increased CH4 emissions; however, productivity

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[233] S. Reppin et al. February 2020. Contribution of agroforestry to climate change mitigation and livelihoods in Western Kenya. Agrofestry Systems, 94(3): 203 –220.

[234] https://unfccc.int/sites/default/files/NDC/2022-06/Kenya%27s%20First%20%20NDC%20%28updated%20version%29.pdf

[235] https://unfccc.int/sites/default/files/resource/Kennc2.pdf

[236]

and efficiency in the livestock sub-sector is low in LREB region. Current estimates of carbon intensity conducted using the Global Livestock Emissions Assessment Methodology (GLEAM)[237] for Kenya are 164.5 kg CO2-eq per kg of protein (please refer to Annex 22 for further detail). By comparison, emissions intensity per Kg of protein in European countries varies between less than 50 and 100. pointing to areas for improvement leveraging better technologies across the value chain, including land use and feed[238]. In Kenya, the emissions profile in the livestock sub-sectors is as indicted in Table 16 and Table 17.

Table 16: emissions profile for dairy sub-sector (GLEAM)

Emission Source	Emissions [%]
Feed-CO2	2%
Feed-N2O	8%
Land Use Change	1%
Pasture Expansion	5%
Enteric Fermentation	73%
Manure-CH4	2%
Manure-N2O	6%
Direct On Farm Energy	1%
Embedded On Farm Energy	0%
Post-farm	1%

Table 17: Poultry sub-sector emissions profile (GLEAM)

Emission Source	Emissions - Extensive[%]	Emissions - Intensive[%]
Feed-CH4	1%	
Feed-CO2	6%	45%
Feed-N2O	85%	19%
Land Use Change		12%
Manure-CH4	2%	2%
Manure-N2O	6%	4%
Direct On Farm Energy		8%
Embedded On Farm Energy		0%
Post-farm		10%

150. Smallholder farming also utilizes woody biomass for charcoal production thus resulting in deforestation, land degradation, biodiversity loss, and loss of soil organic matter. According to findings from the cooperative census undertaken in 2022 for the development of this proposal, farmers appear to use a semi-diversified energy basket that varies according to costs, accessibility, and needs of each value chain. Initial findings of the cooperative census indicate that only 41% of cooperatives use exclusively hydro-electricity, while the rest use a combination of hydroelectricity

[237] https://www.fao.org/gleam/en/
[238] https://storage.googleapis.com/fao-maps-catalog-data/uuid/5ff39b53-073a-42c3-ac9f-3557944cabe3/resources/Map1.jpg

and other sources (solar, firewood, LPG and kerosene). This isn't a comprehensive census of energy uses, but it does provide a representative snapshot of the current situation in the LREB region. There is evidence in the area that hydro-electricity supply varies when rainfall is lower or there is a drought, highlighting the need to ensure adequate access to energy under projected climate conditions.

151. Finally, the region is also seeing increasing emissions trends from deforestation, land degradation, and the expansion of agricultural land into forests. The annual rate of forest loss is estimated at 6% since 2000[239]. As noted by Global Forest Watch, "between 2001 and 2021, forests in Kenya emitted 8.56MtCO_2e/year and removed -13.7MtCO_2e/year. This represents a net carbon flux of -5.09MtCO_2e/year", with a significant proportion of forest emissions coming from the western region. Although Kenya is not a net emitter, there is a need to decouple agricultural growth from land expansion and deforestation and the Government of Kenya has recently implemented legal reforms to that effect, including a ban on charcoal.

152. Unsustainable land use management also releases carbon emissions into the atmosphere, including for example total land clearing, deep tillage, uncontrolled fires, and excessive application of fertilizers. Global Forest Watch also reports a decreasing soil carbon intensity in the areas near Lake Victoria. Local data on emissions from deforestation and land use change are not available, due to the lack of county capacity to conduct decentralized carbon accounting.

[239] https://www.globalforestwatch.org