Agricultural Climate Atlas for Kajiado and Kiambu Counties, Kenya

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Contents

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Abstract

Crop production in Kenya takes place mostly under rain-fed conditions, with weather fluctuations having a high impact on productivity. Significant changes in the climate are expected between now and the end of the century, while many smallholder farmers are ill-equipped to cope with climate-related risks. These challenges are exacerbated by the fact that agricultural investment decisions and policy aspects for systemic adaptation require long-term planning. Therefore, there is a need to know what kind of climate change to expect. A climate atlas was developed as an interactive and user-oriented tool to provide a first insight into the projected impact of climate change on the agricultural sector in Kajiado and Kiambu Counties in Kenya. The information is provided on a web-based platform and is easy to access by farmers, farmer organizations, agri-food businesses, policymakers, and investors for climate decisions and planning. The information results from downscaling global climate change models to the Kenyan context, combined with the local agricultural sector's vulnerability information. Via graphs and interactive maps, projected climate impacts are presented. The climate atlas also comprises an expert tool that allows exploration of climate impacts for a tailored situation to evaluate particular crops and/or varieties' suitability in a specific location. The climate atlas is critical for starting a dialogue on the climate challenges that affect the two counties. Results can be translated into investment portfolios for climate-proofing agribusinesses and accelerating investments due to the potential to mitigate climate-related risks.

Keywords

Adaptation · Agriculture · Climate atlas · Climate change · Expert tool · Storylines

Introduction

Intergovernmental Panel on Climate Change (IPCC) defines climate change as an adjustment in the state of the environment that can be statistically quantified by changes in the mean as well as the variance of its properties and that persists for a comprehensive period, normally decades or longer beyond expected climate inconstancy (Kim et al. 2014; IPCC 2014). Considering the United Nation's Commodity and Development Report (2019), Kenya is entirely vulnerable (31st most vulnerable country) to, yet unready (37th least prepared country) to battle, climate change effects. The current projections show that temperature will rise to 2.5 °C in the scope of 2000 and 2050, while precipitation will turn out to be more intense and less predictable (Funk 2010). As indicated by the 2000–2009 yearly averages of the most disaster-prone countries globally as far as populace influenced by the climate change-related calamities, Kenya was positioned sixth among all nations and first among East African nations. In 2012, Kenya was ranked seventh by the number of victims caused by disasters relating to floods and drought occasions. Subsequently, the slightest increase in the frequency of droughts will introduce major challenges for food security and water accessibility, especially in arid and semiarid lands (ASALs). Likewise, parts of the Kenyan Rift Valley region are vulnerable to climate change due to increasing extreme dry spells and floods, combined with landslides. Coastal areas and lake basins will experience rising sea levels and associated floods and saltwater interruption (Funk 2010).

Cumulative impacts of climate change threaten to adversely affect social and economic development and endanger Kenya from achieving its development goal as described in vision 2030 of becoming a prosperous country with a high quality of life for all its citizens (King et al. 2018; Kebeda 2019). This change will lead to significant challenges in the economy, human life, and the environment. According to the Government of Kenya (GoK), as indicated in the Kenya National Adaptation Plan 2015–2030, Kenya is most vulnerable to climate change since its key economic sectors (agriculture, livestock, tourism, forestry, and fisheries) are climate-sensitive (GoK 2016).

The Food and Agriculture Organization (FAO) acknowledged that climate change presents one of the greatest challenges to Kenya's agricultural sector's productivity and sustainable development of Kenya's agricultural sector due to extreme events such as more frequent droughts during long rains, irregular rainfall that is unpredictable, severe floods during short rains, and temperature changes (FAO 2016; Patrick et al. 2020). Despite the ever-growing demand for agricultural produce, which contributes 26% of the gross domestic product (GDP), crop production mostly occurs under rain-fed conditions. The effects of climate change are already felt, with weather fluctuations having a high impact on productivity (Omoyo et al. 2015). Droughts are regularly cross country with the greatest economic effect of 8% of GDP every 5 years. However, they have the most extreme effects in the ASALs. Floods are more confined than dry spells, achieving an average loss of 5.5% of GDP every 7 years (Funk 2010).

Horticultural crops are particularly sensitive to climate change because of their high water demand and strict temperature requirements (Luo 2011; Cairns et al. 2013). Increased or decreased rainfall and increased temperature (Fedoroff et al. 2010) result in drought or flooding and lack of water for irrigation that could affect growing specific horticultural crops. Pests and diseases may also emerge that affect the yields. Arid and semiarid areas are severely affected by these climate change hazards, therefore putting agriculture at risk.

Significant changes in the climate are expected to aggravate between now and at the end of the century, affecting farmers' resilience (Lipper et al. 2014; Campbell et al. 2014). The projected impact of climate change on smallholder farmers is a reduction in yield (Cairns et al. 2013). Rising temperatures, higher occurrence of drought events, and changing rainfall patterns (Dolan and Humphrey 2000; FAO 2008; Gourdji et al. 2012) are likely to result in changes in production and the suitability of current crops, affecting people's nutrition security and income generation potential (Bryan et al. 2013). For instance, using worldwide temperature and yield trends, maize reported an 8.3% decrease in yield per 1 °C to rise above average (Adhikari et al. 2015). Coupled with the country's low adaptive capacity to climate change, Kenya experiences a high vulnerability level. Therefore, climate change will severely test farmers' adaptive capacity (Adger et al. 2003), considering they are ill-equipped to cope with risks (Rao et al. 2008). Smallholder farmers, who make up a large share of the world's poor and undernourished people, could suffer the most from the more frequent weather extremes (Maxwell 2010). The situation can be dire across Kenya because of its high exposure of farmers and their low coping capacity (Sönke et al. 2019).

To enhance investment that aims to reduce vulnerability and build the resilience of the society and in line with the provisions of the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, the Government of Kenya launched the National Climate Change Response Strategy (NCCRS) in 2010, which recognized the importance of climate change impacts on country's development (GoK 2010). In 2012, Kenya developed a National Climate Change Action Plan (NCCAP) that provides means for implementing NCCRS by highlighting options for a low-carbon climate-resilient development pathway as Kenya adapts to climate impacts and mitigates growing emissions. The Plan also addresses the enabling aspects of finance, policy and legislation, knowledge management, capacity development, technology requirements, monitoring, and reporting (GoK 2018). The focus of these initiatives was at the national level. However, Kenya's agricultural sector is devolved to counties; thus, policies relevant to it are expected to be implemented at the county level. Analysis of the County Integrated Development Plans showed that horticulture is prioritized as a high-value sector that plays a significant role in generating county development revenue. Yet, it is unknown how counties position themselves to deal with climate change threats to this sub-sector. Climate change significantly affects crop production systems; hence counties need to be better prepared to address these effects at the local level and the priority sectors.

These challenges are exacerbated by the fact that agricultural investment decisions and policy measures do not incorporate climate change, affecting farmers' adaptive capacity. Agricultural investments require relevant information on both long- and short-term climate changes to inform adaptation and investment planning decisions. Since devolution took effect in Kenya in 2010, county governments have positioned themselves to support agri-food sector development and integrate the Kenya National Adaptation Plan (KNAP) 2015–2030 into county-specific development plans (Kilelu et al. 2020). Therefore, the county governments have the responsibility to incorporate long-term climate changes into their decision-making. Apart from the county government, farmers and researchers would highly benefit from tailored information regarding climate changes through specific indicators showing the impacts of climate change on crop production now and in the future. Hence, there is a need to bridge the gap between climate information and these users (Hewitt et al. 2012). Understanding the impacts of climate for a given crop under specific conditions is key to further developing the agricultural sector.

This chapter describes the development of the agricultural climate atlas for Kajiado and Kiambu Counties in Kenya as an information tool to bridge the aforementioned information gap. The counties are experiencing climate change as a threat to the horticulture sector (Matui et al. 2016). Climate atlas is an integrated approach of climate-smart agriculture to transform and reorient county agricultural development under the new local climate change realities (Lipper et al. 2014; Campbell et al. 2014; Kebeda 2019). The atlas is aimed at sustainably increasing agricultural productivity, building resilience to changing climate, guiding mitigation, and enhancing the achievement of both national and county food security and sustainable development goals (Dinku et al. 2010; Tubiello et al. 2013; FAO 2014). Agricultural productivity, climate change adaptation, and mitigation are the three interlinked pillars fundamental for accomplishing food security and sustainable development (Tubiello et al. 2013; FAO 2014; Lipper et al. 2014) in the counties. Through the atlas systems, organizations, households, or people will build the adaptive capacity to prevent, mitigate, or adapt (Tubiello et al. 2013) to climate change by providing the first insight into the impact climate change may have on the agricultural sector, therefore ensuring adverse effects of climate change do not have long-term adverse development impacts on the agricultural industry.

The strength of the tool is that it is built in close co-production with the potential users. In this way, the tool is an easy-to-use and fit-for-purpose way for spatial planning and support adaptation in Kajiado and Kiambu Counties. The approach comprises a web-based platform that gives local users access to the required information, such as interactive maps and graphs, which are easy to use in their decision-making. The climate atlas brings climate research to use by developing attractive visualizations, communication tools, and training approaches. Understanding what kind of changes are projected is the first step in adapting to climate change. The information could be used in developing strategies in the county development plans and investment portfolios for climate-proofing agribusinesses.

The Design of the Climate Atlas

As a proof of concept, the climate atlas was developed for two Kenyan counties: Kiambu and Kajiado. These counties were selected as they both have the potential for agricultural production but vary in their agroecology. They are major horticultural crop-producing areas for the capital city of Nairobi. Kiambu County is in the central region of Kenya. It borders Nairobi to the north, while Kajiado County is in the southeastern part of Kenya and borders Nairobi to the south. Both counties experience changing weather patterns characterized by rising temperature, flooding, drought, erratic rainfall, and pattern (Fig. 1).

On the one hand, the approach to developing the climate atlas is by downscaling global climate models to the Kenyan context and specifically to Kiambu and Kajiado

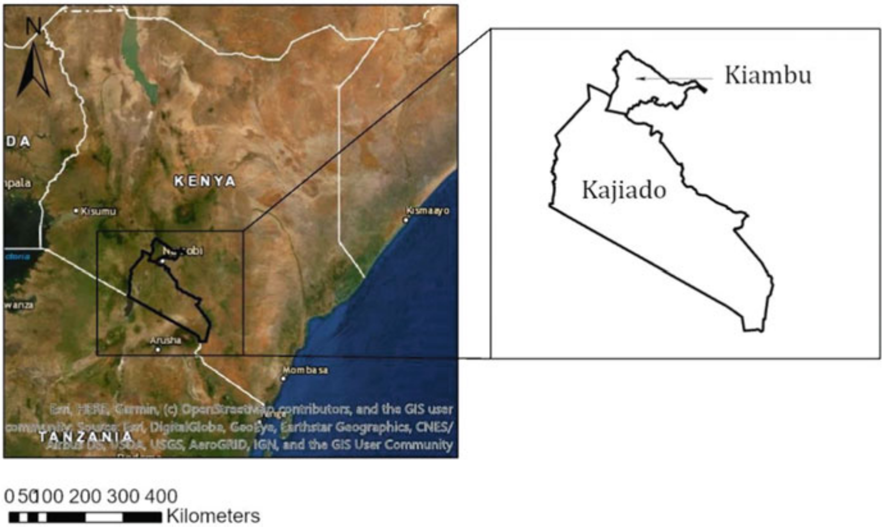


Fig. 1 The location of Kiambu and Kajiado Counties, Nairobi City, is indicated with the red star

and developing an information interface that meets the users' needs. The co-production of the climate atlas was at the core of the methodological approach. This means that users are involved in the development of the atlas to meet their information demands and expectations. An agile and interactive approach was used to develop the expert toolkit through "sprints": short feedback loops around continuously developed content (Thépaut 2014).

The county extension officers and county meteorologists were identified and subsequently involved in the climate atlas design. Furthermore, there was a close collaboration between food security and climate change researchers, IT developers, and the Kenya meteorological department that has resulted in the co-produced climate atlas.

Inventory of the Information Needs of Farmers and Agricultural Extension Workers

A survey among smallholder farmers and agricultural extension workers in both counties was done to identify information needs. Their preferences for access to information were carried out through key informant interviews followed by focus group discussions. The survey focused on observations of changes in cropping, temperature, rainfall and water availability, soils, and pests' occurrence. Respondents were also asked about their knowledge of climate change and if they take adaptation measures and receive government support. Lastly, they were asked for their preferred mode of receiving more localized information on the climate.

Agroclimatic Indicators for Crop Suitability

The relevant agroclimatic indicators for two reference crops, tomato and maize, were extracted from the literature and seed companies. Suitability information for Kiambu and Kajiado Counties was explored based on temperature and precipitation, taking the interest of smallholder horticulture farmers into account. The selected indicators for temperature and precipitation were then used in projected climate impact analyses under the Representative Concentration Pathway (RCP) 4.5, a stabilization scenario, and RCP 8.5, a high-emissions scenario, for the years 2050 and 2080. Temperature thresholds for maize and tomato in the area were identified.

Technical Description of Modeling to Develop the Climate Change Atlas

Climate data were accessed through the Copernicus Climate Data Store (CDS), which offers open, free, and quality-assured data and a toolbox to promote exploitation supporting adaptation and mitigation policies. Data from the CDS was extracted, processed, and downscaled to the appropriate geospatial level to bridge the gap between the CDS and farmers on the ground. The information was then interpreted and visualized before being disclosed via an online, map-supported storyline platform (Fig. 2).

Climate data was extracted from the CDS using CDS API client (the Climate Data Store Application Program Interface), a Python-based library. The retrieved NetCDF files were used to calculate the agroclimatic indicators. The visualizations focused on the selected agroclimatic indicators for crop suitability. Information from field research was used to improve knowledge of the critical agroclimatic indicators, namely, maximum, minimum, average temperature, precipitation, soil moisture, runoff, temperature days, and potential evapotranspiration for the climate atlas. The future projections were based on the ERA5-Land reanalysis dataset and a selection of five models (IPSL-CM5A-MR, HadGEM2-ES, MPI-ESM-LR, NorESM1-M, and GFDL-ESM 2) from the Coupled Model Intercomparison Project 5 (CMIP5) climate models ensemble (Jones et al. 2011; Brands et al. 2013; Samuelsson et al. 2015; McSweeney and Jones 2016; King et al. 2018) for RCP 8.5. To harmonize between the 9 km resolution of the reanalysis product and the much coarser climate projections, the climate signal was regridded to the ERA5-Land grid using the nearest neighbor on the historical data (superimposed change). This allowed a comparison between the current climate, upcoming period (~ 2035), midcentury (~2050), and end of century climates (~2085) (Thépaut 2014).

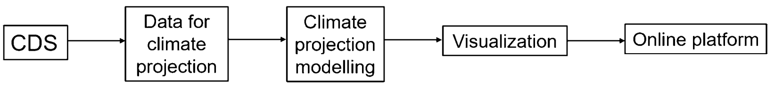


Fig. 2 Visualization of the information flow of the climate atlas

To ensure maximum uptake and dissemination of information, the results were put together into an interactive atlas (https://www.climate-atlas.ke), allowing the user to select different variables.

Validation of the Concept

The climate atlas is designed to cater for different user groups. From a series of field visits and workshops, it became clear that the following groups can be distinguished:

- Expert users, e.g., academia and meteorologists
- Agricultural users, e.g., farmers, extension workers, and county agricultural experts
- External stakeholders, e.g., nongovernmental organizations and policymakers

To provide information to expert users, an interactive tool to explore temperature and precipitation changes was developed. For the external stakeholders and agricultural users, a more accessible interface was needed. Therefore the climate atlas features storylines for two key crops (maize and tomatoes). The storylines explain how climate change could affect these crops and which measures can be taken. Such a storyline is focused on a particular location and crop; hence it is a useful tool for creating awareness.

Capacity Building

To safeguard the platform and information's uptake and usability, the information and communications technology center for climate change adaptation was established at Jomo Kenyatta University of Agriculture and Technology (JKUAT) to train and take over the further development of the climate atlas. This ensures that the climate atlas is effectively utilized, maintained, and enhanced. During the design and implementation, climate field schools were organized to train users to work with climate information. The county agricultural and meteorologists receive training on climate change and hands-on experience working with the climate atlas.

The Use of the Climate Atlas

Perception and Information Needs About Climate Change by Farmers and Agricultural Extension Workers

Farmers and agricultural officers in Kiambu and Kajiado unanimously agreed that weather extremes and climate variability affect farming practices. The challenges they face include erratic and unpredictable rainfall patterns, prolonged dry periods, frost, and new and intense pest and disease attacks on crops. Some emerging pests, such as the tomato leaf miner, *Tuta absoluta,* and the fall armyworm, *Spodoptera frugiperda*, were indicated as possible climate change outcomes. In Kajiado, respondents noted that prolonged dry periods and the emergence of new and increased pest and disease outbreaks on crops are the primary challenges, while in Kiambu, unreliable rainfall is the major threat to farming. None of the farmers or agricultural extension workers had had training about climate change and its effects. The support by county governments regarding adaptation is minimal (Patrick et al. 2020). Smallholder farmers indicated that they required weather information to optimize their seasonal crop yield and, in the long term, climate information to alter their practices if required. Therefore, the atlas should integrate both weather and climate information. Background information of the interviewed smallholder farmers in Kiambu and Kajiado is given in Table 1.

Table 1 The summary of the interview results in the exploratory study (Patrick et al. 2020)

Characteristic/ county	Kiambu	Kajiado
Number of farmers interviewed	13	6
Male	6	4
Female	7	2
Age	31–60	41–60
Education: primary school level	38%	0%
Education: secondary school level	38%	0%
Education: collage and above	23%	100%
Land size	1–5 acres	<10 acres
Income	<200$/month	n/a
Crops	Tomatoes, cabbage, maize, beans, kales, potatoes	Onions, tomatoes, cabbage, kales, capsicum, cucumber
Need for climate information	100%	100%
Trained in climate change	0%	0%
Changes in climate noticed	Higher temperature, exacerbated precipitation extremes, increased pests	Increase in pests, drought, higher temperature, unclear seasonality
Possesses mobile phones	100%:50% smartphone	100% smartphone

The Climate Atlas

The agricultural climate atlas (https://www.climate-atlas.ke) is an online platform using maps and an expert tool as the primary support for the story, which provides the first insight into climate change effects on agriculture in Kajiado and Kiambu. Storylines guide navigation within the atlas with informative maps and figures, providing further information. The climate atlas provides an integrated perspective on climate change by putting together the diverse information on different climate change impacts to address questions relating to agriculture, rising temperature, drought conditions, and water resources tailored to specific crops. The story section and the key agroclimatic indicators are based on the investigated farmer's needs. The five sections of the climate atlas outlook are the introduction, climate change impacts, the future of maize in Kiambu and tomatoes in Kajiado, and an expert tool. The "introduction" page shows the general information on usage and content the climate atlas provided in a short and easily understandable tutorial (Fig. 3).

The "climate change effects" page contains annual averages of climate change indicator maps across Kenya based on five ensemble global climate models (MOHC-HadGEM2-ES, IPSL-IPSL-CMSA-MR, CCCma-CanESM2, MPI-MPI-ESM-LR, and RCA4) (Jones et al. 2011; Brands et al. 2013; Samuelsson et al. 2015; McSweeney and Jones 2016; King et al. 2018). The climate impact results clearly and distinctly show that climate change will affect many agrometeorological indices across Kenya. To illustrate these findings to the public and sensitize decision-makers for the challenges and opportunities of climate change, the climate impact indicators were designed and implemented in an interactive toolbox embedded in the climate atlas. For both temperature and precipitation indicators, projections are available under RCP 4.5 and RCP 8.5 for 2050 and 2080 (Fig. 4).

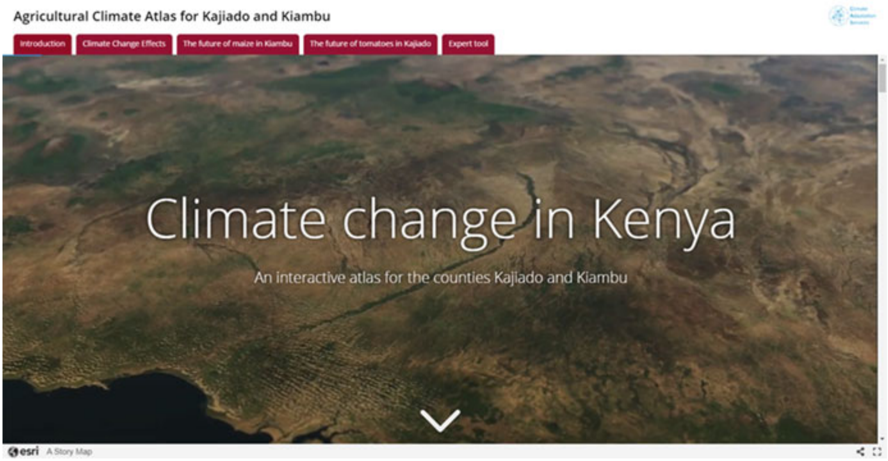


Fig. 3 The introduction chapter of the interactive climate atlas

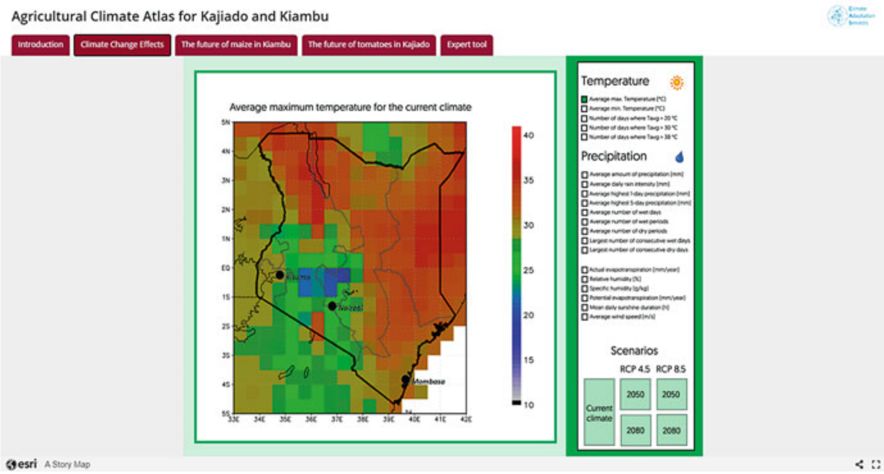


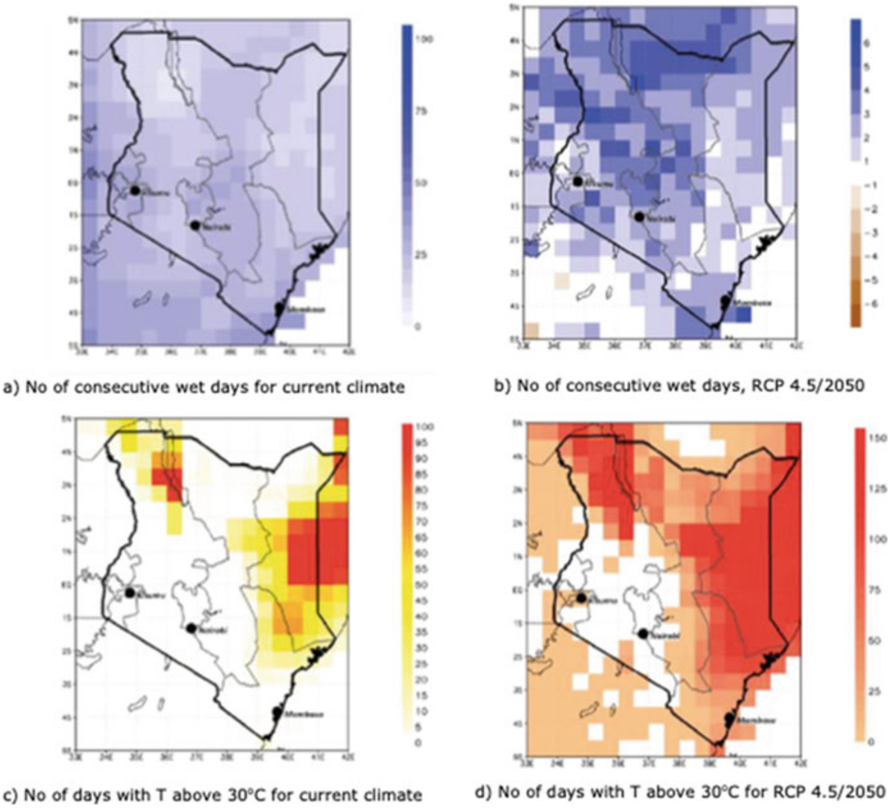
Fig. 4 Climate change effects section of the climate atlas

The climate atlas provides detailed information to address the current knowledge gap by presenting the current and future suitability maps for key crops in Kiambu and Kajiado Counties. Projected changes include the increased maximum and minimum temperature, an increase in frequency and intensity of heavy rainfall events, and an increase in severity and duration of dry spells (Fig. 5).

Implications for Crop Production in Kiambu and Kajiado

Based on projections, both Kiambu and Kajiado will become warmer, and extreme temperatures are expected to cause major losses in crop yields. The reduced crop yields and quality could result from damage to crops and land due to increased crop water requirements and rising temperature. Therefore, crops in most locations will experience enhanced water stress. Agricultural extension workers and farmers in Kajiado and Kiambu were involved in developing the climate change storylines for two specific locations from generic climate change indicators toward crop-specific climate change outlooks, as shown by the two examples for maize and tomato (Fig. 6).

Maps and graphical information indicate the location-specific suitability of growing conditions for selected crops under current and projected future climate conditions. The future of maize in Kiambu features a storyline that illustrates how rising temperatures and changing rainfall patterns may impact maize farming. The growing season for maize in Kiambu County is usually between March and July during the long rains. In the current climate, temperatures rarely exceed the harmful threshold (30 °C) for maize during the growing season. Increased maximum (day) temperature has a more significant, negative impact on yield compared to increased minimum (night) temperatures (Lobell et al. 2011). Average optimum temperatures for



a) No of consecutive wet days for current climate

b) No of consecutive wet days, RCP 4.5/2050

c) No of days with T above 30°C for current climate

d) No of days with T above 30°C for RCP 4.5/2050

Fig. 5 Changes in climatic indices (RCP 4.5, current and 2050 climate projections)

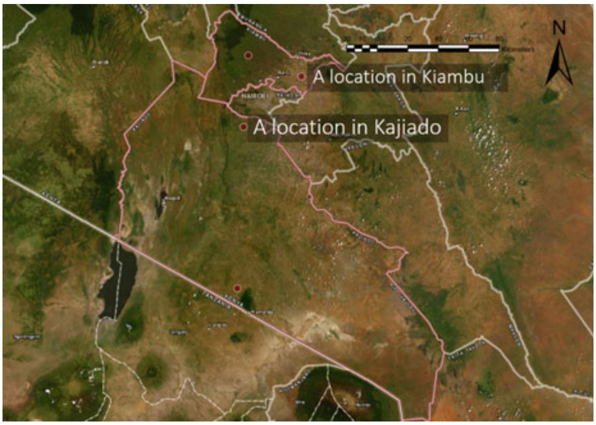


Fig. 6 Sample locations in Kiambu and Kajiado Counties

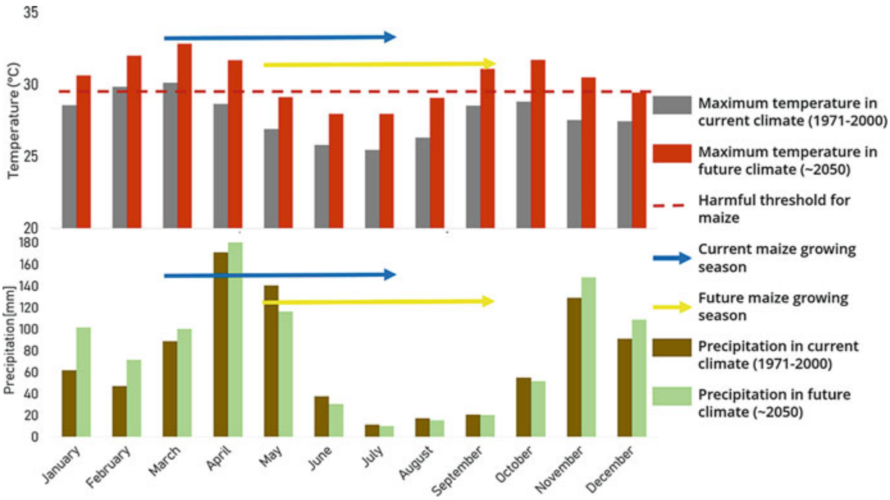


Fig. 7 Indicative projection of effects of climate change on maize production, RCP 8.5

temperate, highland tropical, and lowland tropical maize lie between 20 and 30 °C, 17 and 20 °C, and 30 and 34 °C, respectively (Cairns et al. 2013). However, due to climate change, the projected maximum temperature exceeds the lowland tropical threshold and could reduce maize yields by 2050. Therefore, looking at the temperature throughout the year, it would be important to shift the maize growing season from March to July to cooler months of May to September when the projected maximum temperature is below 30 °C (Fig. 7).

For Kajiado, a storyline was developed for tomato that illustrates how rising temperatures and changing rainfall patterns may impact tomato farming in a particular location within Kajiado County. The growing season usually starts in March at the onset of the long rains, and tomatoes are harvested in June. In the current climate, temperatures sometimes exceed the threshold (28 °C) for tomatoes (Luo 2011). However, due to climate change, maximum temperatures will increase, exceeding the threshold for tomatoes regularly by 2050. Therefore, looking at the temperature throughout the year, an option would be to shift the tomato growing season from March to July to cooler months of May to September when the projected maximum temperature is below 28 °C (Fig. 8).

Precipitation projections suggest monthly rainfall patterns will change in all locations (King et al. 2018); however, the direction and magnitude of change vary with location. Additionally, there is little change in the total rainfall amount during the maize and tomato growing seasons. Rainfall is also projected to decrease during the maize and tomato cropping period. For both maize and tomato, it is clear that the temperature will rise above the production threshold during the traditional growing months when rainfall is high, while rainfall will be too low for growing the crops in the month when the temperature is cooler. Therefore, it would be important to explore the option of harvesting water during long rains (from May to July) and

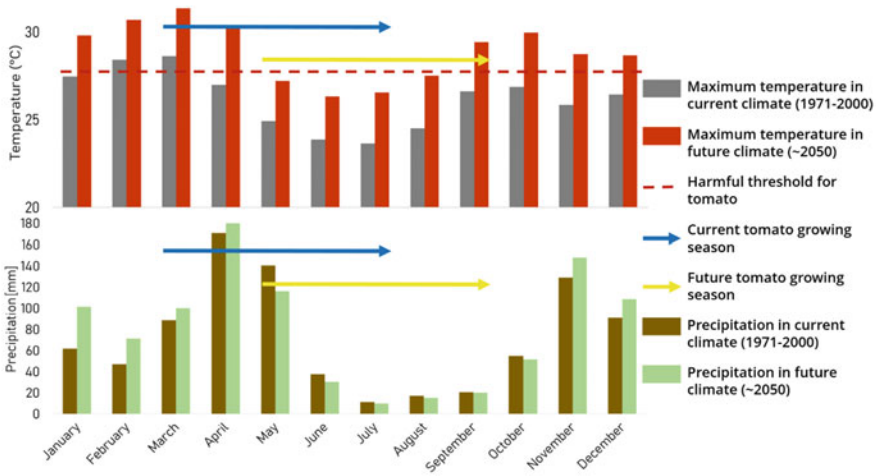


Fig. 8 Indicative projection of effects of climate change on tomato production, RCP 8.5

utilizing it to grow crops during the short rain period when the temperature is favorable. Shifting the growing seasons for both maize and tomatoes to months with a lower temperature will mean that more water for irrigation is needed to meet the crop water requirements. Hence, water retention, storage, and irrigation could provide more flexibility in the growing season (Klein Holkenborg 2020). Agroforestry and shade nets could be implemented as a way to mitigate heat as far as possible.

Expert Tool

The expert tool is a climate information tool that allows exploration of climate impact for a tailored situation. The tool discloses Copernicus climate data to a wide range of users who do not have the resources to support such developments. Technical data at a high abstraction level were translated to easily accessible and visually attractive map-supported storylines that appeal to Kenyan smallholder farmers' experience and daily practice. Using the information, users can generate a storyline about a particular crop's future in a particular location within Kiambu and Kajiado Counties. The climate atlas will help users identify key adaptation challenges in their areas of interest by combining the effects and visualizing the main conclusions in risk maps, highlighting areas where adaptation is more urgent (Fig. 9). Further development of the atlas will make this information available for other counties as well.

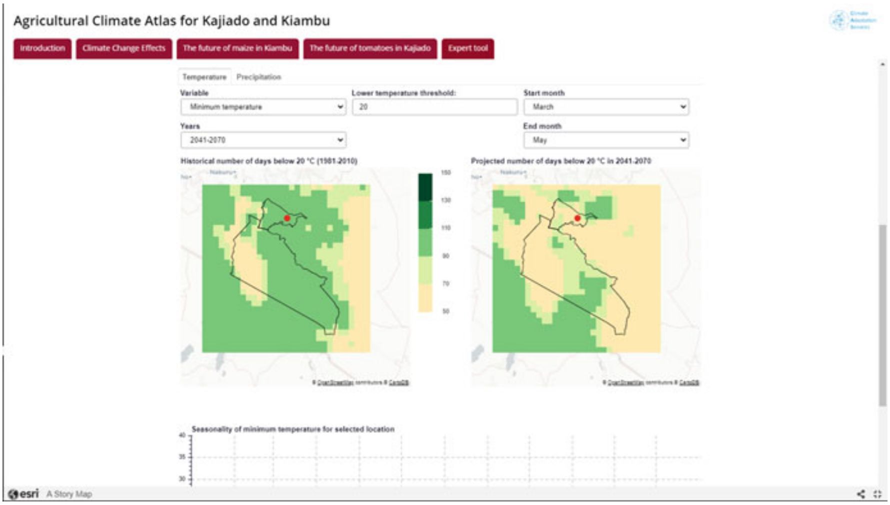


Fig. 9 Illustration of the expert information tool for Kiambu and Kajiado Counties

Discussion

Climate Atlas to Foster Dialogues on Adaptation

It is assumed that climate change induces rising temperatures, extreme drought events, changing rainfall patterns, and floods (Gourdji et al. 2012). These assumptions originate from scientific findings published in technical reports and sophisticated scientific papers. The problem is that the information in these reports is not easy to access due to scientific jargon or useful due to a lack of tailored indicators for people who want to deal with climate change. There is also a lack of information on the regional diversity of climate change effects in Kenya. Projected changes differ with geographical locations and microclimatic parameters. Also, future climate change cannot be separated from trends and patterns in the historical climate. Therefore, it is essential to realize that climate change consists of a continuous record of variable weather patterns extending from the past into the future. However, the trend is clear: in most areas, heat will become problematic during the traditional growing months, while rainfall is too low for growing crops in the colder periods. This brings across and the subsequent discussions and awareness is an essential step toward the next stages in climate adaptation.

Developing an easily accessible, visual, interactive, and living agricultural climate change atlas is critical to provide information about future climate change impact, adaptation, and response planning in Kiambu and Kajiado Counties. Based on CDS, the climate atlas contains climate projections potentially extremely relevant for farmers' daily practice. The atlas can significantly contribute to decision-making in county planning and climate change management strategies required to build resilience (Cairns et al. 2013). If done at various levels such as farm, county, and national, adaptation can create weather- and climate-resilient agriculture in Kenya.

According to IPCC (2014), adaptive capacity refers to governments or individual farmers' ability to prepare for threats and exploit beneficial opportunities by adjusting to actual or expected climate and its effects (IPCC 2014) while protecting the ecosystem services and maintaining agricultural productivity. Therefore, farmers should be motivated to adopt practices that will make their farms more resilient to climate change. This could mean adopting local adaptation strategies such as diversification of farming and cropping systems, adopting heat or drought-resistant varieties, building asset diversity (Kim et al. 2014), and adjusting the cropping calendar.

The proposed adaptation strategies consist of small-scale, affordable, and on-farm soil and water conservation measures that promote sustainable intensification. Experience has shown that the utilization of new crop varieties with increased tolerance to abiotic stresses, including heat and drought stress (Fedoroff et al. 2010), alongside acceptable management practices, can counterbalance agricultural yield losses by up to 40% (Thornton et al. 2009, 2014; Vermeulen et al. 2013). Given the time lag between the advancement and the dissemination and adoption of improved crop varieties, current research must focus on developing varieties adapted to the forecasted climate. More considerable attention should be directed at facilitating farmers' access to these varieties (Cairns et al. 2013).

The climate atlas emphasizes the need for improving farm risk management, information flows, and local institutions to support adaptive capacity. Therefore the atlas is a critical smart agriculture technology that promotes sustainable intensification (Campbell et al. 2014) to sustainably increase overall agricultural productivity without negatively impacting the ecosystem services and enhancing future agricultural production. This, in turn, will raise food and nutritional security (FAO 2014; Vanlauwe et al. 2014; Mahashin and Roy 2018).

Information Needs of the Climate Atlas

The Copernicus Climate Data Store contains seasonal forecasts and climate projections with the Kenyan smallholder farmers' information. Fortunately, the information is available, *albeit* not in a form that corresponds to farmers' needs. Therefore, such climate information does not reach the people at the community level who need it most. The project built an application that translates the technical data from the CDS to a form accessible to the end user and connects to their experience and daily practice. The development of the agricultural climate atlas required an intensive co-creation process, hands-on training, gaining a mutual understanding of what is needed on the ground, and what is possible from a climate modeling perspective. To safeguard uptake and usability, the project built the local actors' capacity to utilize, maintain, and enhance sustainable climate data visualization tools.

Given that the cropping calendar in both counties is very seasonal, annual averages of precipitation and temperature are of little help in assessing whether a particular crop will perform well in the future climate. This led to a shift in focus toward the seasonality of temperature and rainfall patterns, cropping calendars, and critical thresholds for crops. To assess how crops will perform under certain climatological circumstances, running a crop model is required. A crop model incorporates the exposure-damage relationship and allows for exploring different adaptation measures, such as new varieties or cropping calendars. However, running such a crop model for different crops and scenarios is an intensive and lengthy process and would yield very detailed results based on numerous assumptions. Running crop models is therefore recommended at a later stage in adaptation. As it is very detailed, it might deter the less technical stakeholders from engaging in the initial discussion on how to deal with climate change. Instead, we used indicative crop thresholds as a more intuitive basis for subsequent discussions. However, it proved extremely hard to decide on which thresholds to use for which crops. Different maize varieties have different water requirements and heat tolerance. Also, the exposure-damage relationship cannot be expressed clearly without running a crop model. A discussion has been started, and the general scope of impacts is emerging. However, at this point, the data is insufficient to draw "hard" conclusions.

Upscaling the Use of the Climate Atlas

With climate change becoming a reality, national government, counties, and nongovernmental organizations are increasingly involved in strategic initiatives to adapt and respond to the risks posed by climate change. Direct access to climate information (climate change impact, adaptation, and response planning) improves agricultural planning at national, county, and local scales in a localized, scientific manner to understand and solve agricultural production system problems. The climate atlas provides information at various levels. Expert users such as academia and specialized consultancies can make use of the expert tool. Policymakers, extension workers, and other nonexpert users can use the storylines, which feature interpreted and comprehensive examples of climate impacts.

The information is critical for starting a dialogue on the climate challenges that affect the counties. It can help counties understand the uncertainty ranges in the future to plan and invest in different adaptation options for the sector's long-term sustainability. For example, using the atlas, irrigation, and agricultural planners can identify rain-fed agriculture's potential and improve irrigation planning and management. Furthermore, the agricultural climate atlas could be used in climate field schools to train farmers and "farmer" organizations to translate climate information into daily practices. The application will help policymakers visualize the impacts of climate change and, consequently, lead to the formulation of policies that are better aligned with climate change and support adaptation.

The climate atlas can potentially be translated into investment portfolios for climate-proofing agribusinesses and accelerating investments and green bonds initiatives due to the potential to mitigate climate-related risks. The financial and insurance providers may also benefit as they will better visualize the climate change risks. This will unlock finances to support the smallholder farmers to improve their production.

Conclusion

Based on the overall project results, the climate atlas is an interactive, user-oriented, self-explaining, and intuitive tool that allows different users to find tailored information about the expected climate change effects on agriculture in Kiambu and Kajiado Counties in Kenya. Using a multi-model ensemble of both climate and impact projections, it is possible to define ranges of impacts and quantify some uncertainty around future climate and climate impact projections. The expert tool allows users to explore the future of a particular agricultural production system in a particular location. This climate atlas can bridge the gap between the climate information and the needs of users. The strength is the bottom-up co-development of the atlas, involving farmers, agricultural extension workers, meteorological experts, and policymakers. The online platform offers the possibility to present map-based information in a visually attractive way and provides a down-to-earth explanation in text, translating climate science into information that users could work with.

Knowing what kind of change is ahead is the first step in adapting to climate change. By presenting a wide variety of potential climate change impacts, the climate atlas aims to serve various audiences in gathering information to develop recommendations on possible adaptation strategies in both Kiambu and Kajiado Counties in Kenya.

The climate atlas is designed to be a living document that will continue to grow as different topics and stories are added in the future. The atlas comprises of stepwise guidance explaining and demonstrating (i) how relevant data from the CDS can be extracted and tailored toward relevant agroclimatic indicators, (ii) how this information can be communicated toward farmers and agricultural extension workers through storylines and insightful visualization, and (iii) how to ensure maximum uptake and dissemination by developing an online, living platform that can be easily updated and is accessible to anyone.

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