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CLIMATE VULNERABILITY ASSESSMENT FOR SELECTED CROPS IN SENEGAL

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Climate Vulnerability Assessment for selected crops in Senegal

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Alliance



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ABSTRACT

The Adaptation and Valorization of Entrepreneurship in Irrigated Agriculture (AVENIR) project aims to improve the socioeconomic well-being and resilience of farming households in the regions of Sédhiou and Tambacounda, Senegal. The project focuses on smallholder-irrigated systems through promotion of climate-adapted irrigation and agricultural practices, particularly for women and young people. AVENIR seeks to promote crop diversification through the integration of rice, agroforestry, and horticulture. In Goudiry and Tambacounda Departments within Tambacounda Region, the project focuses on rice, baobab and horticulture value chains. In Bounkiling and Goudomp departments within Sédhiou Region, the project focuses on rice, mango, cashew, and horticulture value chains. Among the important associated crops prioritized in the two regions are ditakh (*Detarium senegalense*), madd (*Saba senegalensis*), onion, okra, and pepper.

The vulnerability assessment for the selected crops in Senegal is based on the interaction of sensitivity to change, exposure, and adaptive capacity. We use the conceptual framework of climate-related risk from the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) Working Group II (WGII) to examine the impacts that climate change is likely to have on agriculture and food security. The ultimate purpose of this study is to assess if the future climate has a neutral (no change), negative (decreasing), or positive (increasing) impact on crop productivity, and to identify regions of concern and opportunities for climate change adaptation. We used the Maxent ecological models under intermediate and high-emission climate scenarios – Representative Concentration Pathways (RCPs) 4.5 and 8.5, respectively – to assess the sensitivity of nine crops to climate change: rice, baobab, cashew, mango, okra, onion, pepper, madd and ditakh. To produce a crop-specific vulnerability index and a final accumulative score, we combined the components of vulnerability using equal weighting. We have also mapped the hotspots of climate change vulnerability and identified the underlying driving indicators. For example, we found that the south, east, and southeastern regions are most vulnerable, especially Tambacounda, Kaffrine, Sédhiou, Kolda, and Kedougou regions. There is a high vulnerability for baobab trees and cashew to the north, as well as cashews, ditakh, okra, onions, and rice to the northeast. This study highlights how the adaptive capacity of the farming population can be enhanced by augmenting access to education and health services, improving nutrition, and developing infrastructure for marketing, transportation, and irrigation.



1. INTRODUCTION

Senegal is in western Africa on the Atlantic Coast between the latitudes of 12°30' and 16°30'N and the longitudes of 11°30' and 17°30'W. The southern region of Senegal has a sub-tropical climate, while the northern region lies in a sub-tropical, semi-arid belt called the Sahel (Mcsweeney et al., 2008). Rainfall is mainly controlled by the movement of the Intertropical Convergence Zone (ITCZ) (Lucio, 2012). The movement of the ITCZ determines the onset and duration of the rainy season (Salack et al., 2011). For example, the south has more rainy days and a longer rainy season than the drier north.

Temperatures in Senegal exhibit an east-to-west gradient, such that inland temperatures are normally higher than along the coastline, with the highest temperatures occurring in the northeastern parts of the country (Fall et al., 2006). Matam region located in the northeast, for instance, experiences a maximum temperature of above 40°C in the hottest month of May. The coastal regions, on the other hand, experience cooler temperatures between 25°C to 28°C (Mcsweeney et al., 2008). In the cooler seasons, average temperatures can fall below 25°C at the coast but still climb to 30°C in the east (Fall et al., 2006).

Rainfall begins in the southeast around May or June, and spreads northwest throughout the summer months through September (Marteau et al., 2009). August accumulates the highest amount of rainfall (Camberlin and Diop, 2003). The dry season, on the other hand, lasts for about six months in the south and eight months in the north. The highest seasonal rainfall is received in the southern parts of the country, measuring approximately 1000 mm, while the northern parts receive less than 400 mm (USAID, 2017, 2015). The rainy season ceases with the migration of the ITCZ to the south around October (Nicholson, 2018).

The agricultural sector of Senegal contributes about 17% of the country's gross domestic product (GDP), employing more than 70% of the workforce (World Bank, 2018). Senegal is one of the most stable and promising countries in West Africa with great potential to increase its agriculture-led economic growth (USAID, 2015). However, a large portion of Senegal's landmass lies within the Sahel, which is arid and highly prone to droughts (Mcsweeney et al., 2008). This location makes rain-fed agricultural production highly variable, a situation that climate change is exacerbating (D'Alessandro et al., 2015).

Senegal is divided into six agro-ecological zones (Figure 1) based on biophysical and socioeconomic characteristics (Alessandro et al., 2015; CIRAD, 2015). Moving from north to south, these are the following:

1. The Senegal River Valley characterized by alluvial plains and sandy uplands with irrigated rice production; it covers a surface area of 9,658 km². Most agricultural production occurs with irrigation (Alessandro et al., 2015). Although salinity is a problem in some areas, much of the land has high fertility levels because of regular flooding and siltation.
2. The Niayes on the Atlantic coast features a temperate climate and produces fruits and vegetables (CIRAD, 2015). This 100km - 280km strip occupies 2,759 km². Niayes is a densely populated area and faces challenges including soil and water salinity and coastal erosion (Alessandro et al., 2015).
3. The sylvo-pastoral zone of north-central Senegal supports extensive livestock production and covers 55,561 km² (CIRAD, 2015).
4. The Groundnut Basin of south-central Senegal is a zone of savannah dominated by groundnut and millet production (CIRAD, 2015). It covers an area of 46,367 km² and is densely populated. Ecosystem degradation and depletion of land resources, mainly soil fertility and timber resources, affect the area (Alessandro et al., 2015). Because of upland soil acidification and lowland salinity, soil regeneration has declined.
5. Eastern Senegal is characterized by savannah with trees. Its agricultural production involves primarily cotton and livestock. It covers an area of 56 529km² (Tappan et al., 2004) and is subject to rampant rural poverty because of extreme population pressure on natural resources, despite its robust agro-pastoral potential (Alessandro et al., 2015). La Casamance est caractérisée par des forêts et des savanes arborées (CIRAD, 2015). Sa production agricole comprend principalement le riz pluvial ainsi que diverses autres cultures. Avec une superficie totale de 28 324 km², elle est divisée en trois zones - basse, moyenne et haute. La région est confrontée à des défis tels que l'acidification des sols au niveau des zones basses, l'érosion de l'eau, la perte de la diversité forestière, la salinisation accrue des sols, la toxicité ferreuse et la dégradation aiguë des mangroves (Alessandro et al., 2015).

6. The Casamance is characterized by forests and savannah with trees (CIRAD, 2015). Its agricultural production includes mainly rain-fed rice along with diverse other crops. With a total surface area of 28,324 km², it is divided into three zones—lower, middle, and upper. The region faces challenges such as lowland soil acidification, water erosion, a loss of forest diversity, increased soil salinization, iron toxicity, and acute mangrove degradation (Alessandro et al., 2015).

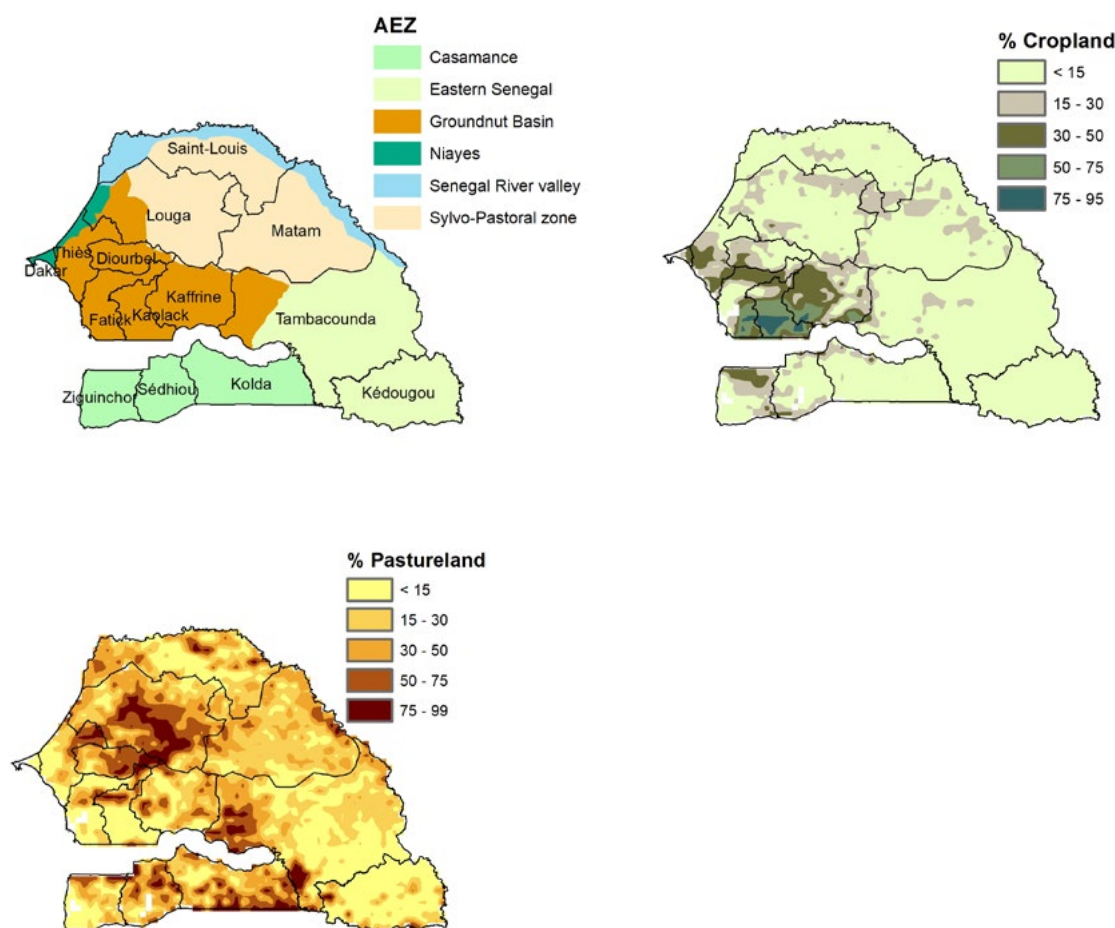


FIGURE 1: Agro-ecological zones of Senegal (left), cropped areas (center), and areas with pastures (right). Data for the left panel were adapted from the Directorate of Water, Forests and Hunting Conservation, and the center and right panels were taken from Ramankutty et al., 2008.

The topography of Senegal is generally flat with rolling sandy plains but rises to hills in the southeast. Most areas have elevations of less than 100 m above sea level. Senegal encompasses over 19 million ha of land, of which only about 20% or 3.9 million ha are suitable for arable crops. The rest comprises undeveloped bush and arid areas used for livestock grazing (Alessandro et al., 2015). Around 40% of the arable land is constantly cultivated, although 10% receives less than 500 mm of rainfall per year, which limits crop production. Only 10% of the cultivated land is under irrigation, mainly along the Senegal River and in the Casamance (Peterson et al., 2006). This challenge aligns with the goal of the AVENIR project, which aims to improve access for irrigation technologies and improve the governance and management of water resources, working with government, civic groups, and market actors in Sédhiou and Tambacounda regions.

Population increases have led to land pressure (Place and Otsuka, 2000), which in turn has brought about soil degradation and declining soil fertility due to many years of unsuitable agricultural practices such as tillage practices, mono-cropping, and incorrect use of chemical inputs (Doso Jnr, 2014; Sow et al., 2015). Soils in most areas have low percentages of clay and organic matter and therefore low cation exchange capacities, resulting in increased vulnerability to nutrient depletion (Mahé et al., 2002; Matlon, 1987).

Millet, rice, maize, and sorghum are the major food crops grown in Senegal. Other crops such as groundnuts, sugarcane and cotton are important cash crops. A wide variety of fruits and vegetables are grown for local and export markets. Cowpeas and cotton are also cultivated. Because food production does not meet domestic demand, the country imports rice and wheat (Diagne et al., 2013). Senegal exports cotton, groundnuts, and horticultural products, mainly green beans, tomatoes, cashew and mangoes (D'Alessandro et al., 2015).

Crop production in Senegal falls into several categories: subsistence smallholders, commercial smallholders, and pure commercial producers (D'Alessandro et al., 2015). Subsistence smallholders produce food mainly for consumption with occasional surplus for sale, while commercial smallholders produce cash crops for sale and some food crops for their own consumption. About 90% of the rural population of Senegal are involved in livestock production, which accounts for 30% of the country's GDP (Diagne et al., 2013). Livestock includes cattle, goats, sheep, and poultry farming. The cattle provide plowing power which is used in cropped lands (D'Alessandro et al., 2015).

Senegal is highly vulnerable to risks associated with climate change (USAID, 2017). Years of erratic rainfall patterns and rising sea level has led to increased soil erosion, agricultural soil salinization, and the destruction of infrastructure. Droughts and floods associated with climate change have increased the country's vulnerability to food security (Fall, 2020). In the Senegal River Valley, the Niayes, and the Casamance, agriculture and fisheries are some of the main economic activities, and they are highly vulnerable to reductions in rainfall, coastal erosion, salt water intrusion, and flooding (Fall, 2020).



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2. CLIMATE VULNERABILITY ASSESSMENT METHODOLOGY

The methodology used to prepare this report hinges on the conceptual framework of climate-related risk from the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) Working Group II to explore the potential consequences of climate change for agriculture and food security (Adger, 2006; O'Brien et al., 2007; Sharma and Ravindranath, 2019). The IPCC defines vulnerability as “the extent to which a natural or social system is susceptible to sustaining damage from climate change impacts, and is a function of exposure, sensitivity and adaptive capacity”. The impact of climate change on agriculture and livelihoods therefore can be conceptualized as the aggregation of these components (Foden et al., 2013).

Exposure refers to the amount of climate variation to which a system could be subjected by hazards. Sensitivity, meanwhile, is the degree to which the system could be affected by that exposure. Finally, adaptive capacity is the ability to adjust, cope with, or benefit from expected climate variations. The analysis was implemented by obtaining indicators relevant to Senegal for each dimension of vulnerability. These indicators were then aggregated as shown in equation 1 below to compute the vulnerability of each crop and administrative unit or arrondissement.

In the vulnerability framework we use here, the vulnerability of each crop is calculated using crop-specific sensitivities, exposure to natural hazards, and a series of indicators of adaptive capacity (equation 1), and the results are then summed up to obtain overall vulnerability (Parker et al. 2019).

$$\text{Overall vulnerability} = \sum_{i=1}^n \left[\frac{1}{2} \left(\left(\frac{1}{2} \left(\frac{\text{Growing area}_i}{\text{Total area}} * S_i + E_i \right) \right) - AC \right) \right]$$

[Equation 1]

Where i denotes each crop; *Growing area* refers to the extent of suitable area for the crop i ; *Total area* pertains to all crops; S_i is the sensitivity of the value chain i ; E_i represents the exposure of each crop; and AC is the adaptive capacity.

Sensitivity index, S_i , was determined by computing the difference between the future and current crop suitability followed by normalizing the values to a scale ranging from -1 and 1. Exposure indices, E_i was determined by obtaining the variables representing the value chains exposure such as aridity, flood etc. and extracting the values for each arrondissement. The resulting values were then normalized to a scale ranging from 0 and 1. Adaptive capacity, AC on the other hand was determined by obtaining the variables that enhance the adaptive capacity of Senegal such as literacy rate, health, poverty etc. and extracting the values for each arrondissement. The resulting values were also normalized to a scale ranging from 0 and 1. Crop suitability was modelled for nine selected crops: baobab, cashew, ditakh, madd, mango, onion, okra, pepper, and rice, using the Maxent suitability model package in R Statistical software (Figure 2). These crops were selected from a value chain study conducted for the AVENIR project in February to March 2020, which identified these as the most promising crops for socio-economic progress in the regions of Tambacounda and Sedhiou. To obtain one index for each variable in the equation e.g., one index for AC in calculating total vulnerability for a specific crop, all indices were added and normalized to a scale between 0 and 1.

Crop suitability determines the effectiveness of a specific area for the production of a particular crop within a defined system of agricultural production based on agro-climatic conditions related to temperature and moisture, and on agro-edaphic conditions pertaining to soils and landforms (Kassam et al., 2012; Nisar Ahamed et al., 2000).

We carry out a Maxent suitability model using available crop presence data and gridded climate data for current and future scenarios pertaining to the 2050s, and for two Representative Concentration Pathways (RCPs): RCP 4.5 and RCP 8.5. The RCPs describe various climate futures whose likelihood of occurring depends upon the volume of anthropogenic greenhouse gases (GHG) emitted over the years. RCP 4.5 is an intermediate scenario premised on the employment of a range of technologies and strategies for reducing GHG emissions. RCP 8.5 is a high-end scenario characterized by increasing GHG emissions over time. Our value chain presence data were derived from two sources; the Global Biodiversity Information Facility public database (<http://www.gbif.org>) as well as on farm observations of value chain presence obtained from local extension officers. The variables we use include climate data with bio-climatic variables relating to temperature in addition to slope, soil texture, soil pH, and waterlogging. We obtained current climate data from WorldClim 2.0 (Fick and Hijmans, 2017), whereas we downloaded future climate data from CCAFS-Climate (Navarro-Racines et al., 2020). We calculated slope data from a digital elevation model obtained from the United States Geological Survey's Earth Explorer and determined soil texture and pH from the International Soil Reference and Information Centre World Soil Information database. Finally, information on waterlogging is obtained from the United Nations Food and Agriculture Organization (FAO) Global Assessment of Soil Degradation (Fischer et al., 2008).

We present this information in two ways: (1) the current (baseline) magnitude of suitability; (2) the magnitude of change under future climate projections. The magnitude of change reflects whether crop suitability will increase or decrease relative to the baseline period. In the following section, we show agreement maps that rank the current suitability from zero, meaning areas are projected to be climatically unsuitable for production of the crop, to one, where the area presents greatest climatic conditions suitable for crop production.

3.0 RESULTS

3.1 Crop suitability

The current suitability of the selected crops in the project areas, show that, cashew, ditakh, madd, mango, and rice have overall high suitability under current climate in Sedhiou, while pepper will have moderate to high suitability. In Tambacounda, pepper has moderate suitability. Baobab, onion and rice show high suitability to the northeastern areas bordering Mali, and low suitability in other areas of the region. Madd shows high suitability in the southern part. Rice in Tambacounda is suitable along the Senegal River to the east as well as to the south near Kolda region. Okra shows low suitability in both regions. Baobab and onion show very low suitability in Sédhiou while ditakh and cashew show low suitability in Tambacounda.

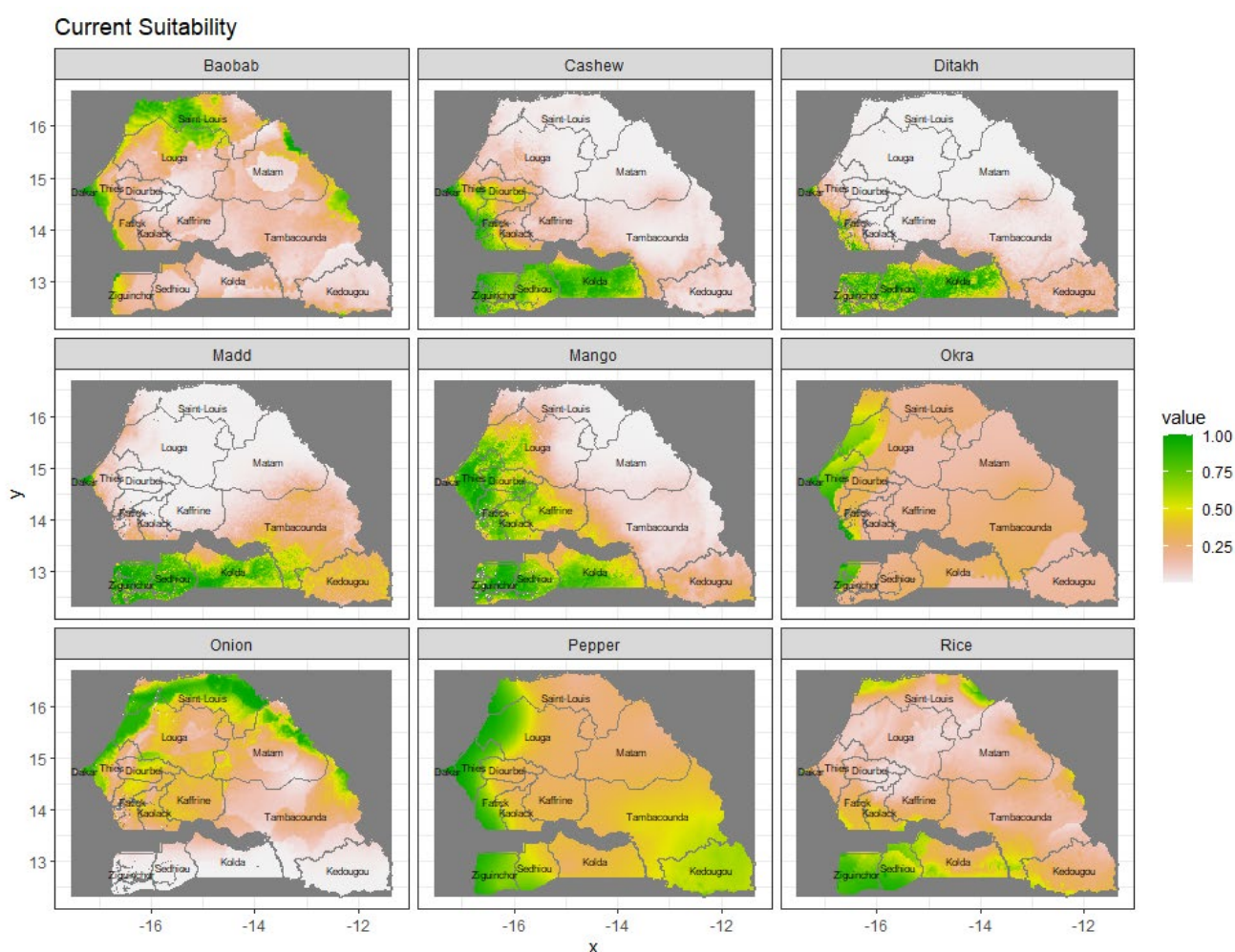


FIGURE 2: Current crop suitability in Senegal

3.2 The sensitivity of value chains to climate change

Sensitivity expresses the relationship between human-induced emissions and the temperature changes that will result from these emissions. It is the amount of warming caused by increases in atmospheric carbon dioxide (CO₂) (Hawkins and Forster, 2019). Frequently, sensitivity is defined as the change in temperature resulting from a doubling of the concentration of CO₂ in the atmosphere. In this case, we calculated sensitivity using crop suitability such that we understood sensitivity as the change in suitability. Therefore, we computed the difference between the future and current crop suitability.

We analyzed the sensitivity of all crops under future climate projections for 2050s under RCP 4.5 (Figure 3). All the selected crops experience some degree of sensitivity, either an increase or decrease. Increasing sensitivity infers that climate change will affect productivity patterns for the crop. The change in suitability maps range from -1 meaning areas with 100 percent crop suitability loss, to +1 representing areas where there are 100% suitability increases. By the 2050s under RCP 4.5, cashew, pepper, and rice are the most sensitive crops, while baobab, mango, okra and onion are least sensitive. In this scenario, increasing suitability is strongly exhibited by baobab and okra in most areas of Senegal, cashew and ditakh towards central Senegal and madd to the southeast and central Senegal. The suitability of onion along the Senegal river valley and in the Casamance especially Kolda region is seen to increase with the suitability decreasing to the west of the country. Decreasing suitability is likely for rice along the Senegal River valley as well as in Sédhiou with increase in suitability in the Casamance areas shifting to Kolda region to the east of Sédhiou. There is a decreasing suitability for pepper in the Casamance, Tambacounda, Kedougou and the western part of the country with an increasing suitability in the central areas.

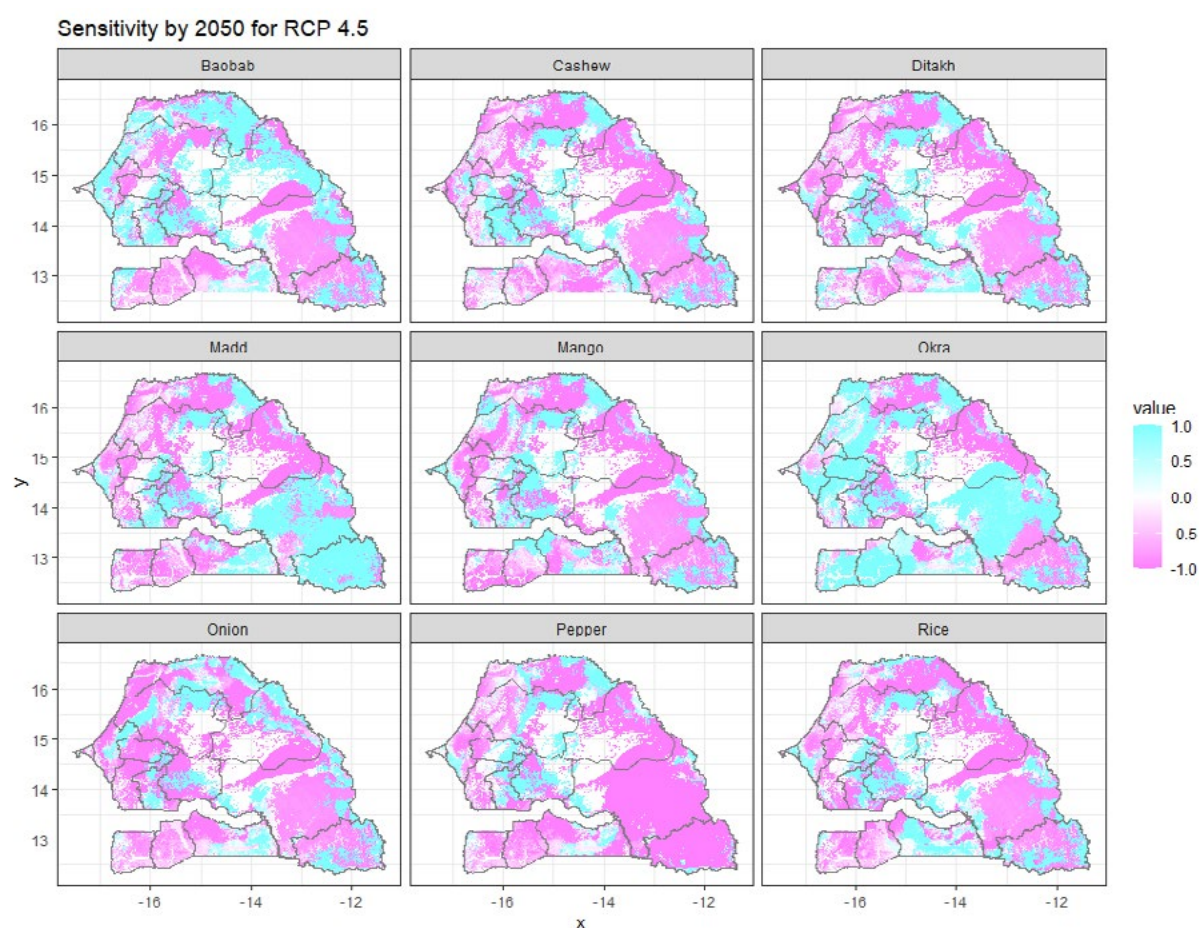


FIGURE 3: Changes in suitability for selected value chains by the 2050s for RCP 4.5. 1.0 denotes increasing suitability and -1.0 a loss in suitability.

For the AVENIR project areas, there is a likelihood for a decreasing suitability in rice, pepper, madd, cashew and ditakh in Sédhiou with an increasing suitability for mango to the north and okra. Pockets of increasing suitability for Cashew and ditakh are seen across the region. Although baobab is not currently suitable in this region, further reduction in suitability is exhibited in this scenario. In Tambacounda, there is a likelihood for an increase in suitability in okra, baobab to the east, cashew and ditakh to the west and east and mango and onion to the east which could lead to an increase in production by 2050 for RCP 4.5. Cashew and ditakh however, show decreasing suitability in central Tambacounda while madd, pepper and rice show a high decrease in suitability by 2050 for RCP4.5.

Results for RCP 8.5 for 2050s are shown in the supplementary figures in the Annex. The results show an increasing suitability for baobab and okra with increases in the suitability of cashew, ditakh, and madd towards the east. The suitability of mango, okra and onion shifts towards the north of Senegal, while pepper suitability increases towards central, east and south eastern parts of the country. The suitability of rice on the other hand, decreases along the Senegal river valley but increases towards the central parts of the country and in the Casamance and more so in Sédhiou. This shows a high probability of these value chains shifting from the current production areas which might lead to a decrease in production in the areas currently under production and consequently food insecurity. This calls for production consideration of these new areas.

3.3 Exposure to natural hazards

Senegal remains vulnerable to climatic shocks including natural hazards that are predicted to increase in magnitude and extent because of climate variability (Simonet and Jobbins, 2016). These hazards include droughts and floods, which recur seasonally, affecting livelihoods. Increasing precipitation and rising sea level pose a great risk to people living in coastal, urban areas, who account for approximately 67% of Senegal's population (Croitoru et al., 2019; USAID, 2011). Variation in the start of the growing season, meanwhile, increases the vulnerability of farmers who lack access to irrigation because they are unable to schedule the timing of cropping activities such as planting and harvesting. In assessing vulnerability, we mapped natural hazards as shown in Table 1 below.

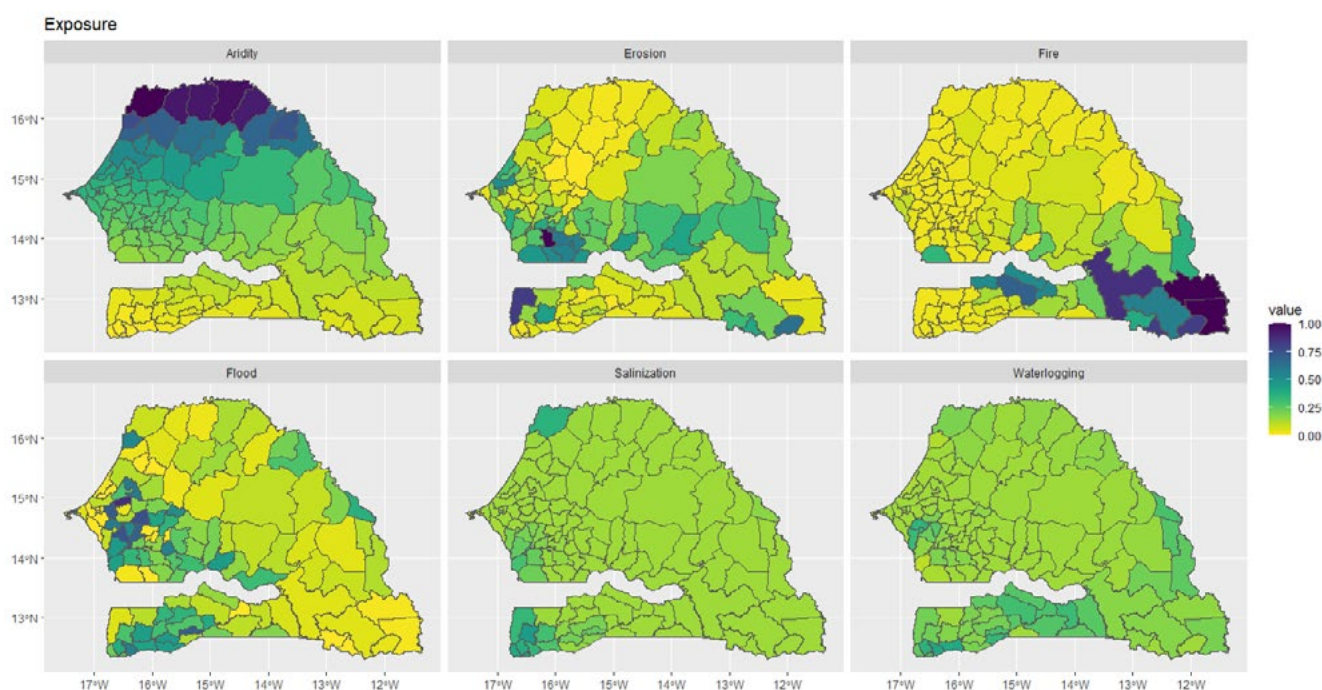
Droughts experienced in the 1970s and 1980s contributed to food insecurity in Senegal and the Sahel in general (USAID, 2017). Recent drought events in 2000 led to a 74% decline in groundnut revenues and diminished revenues for millet and sorghum by 60% (World Bank, 2011). More droughts occurred in 2002, affecting 284,000 people; in 2006/2007; and 2011, affecting 806,000 people (WFP, 2013). Droughts in 2014, 2017, and in 2018 impacted 245,000 people (Bhaga et al., 2020).

Floods, on the other hand, have become frequent due to increasing heavy rainfall events (USAID, 2017). Between 2000 and 2012, damages resulting from floods occurred in at least 8 years. In 2002, 179,000 people were affected; in 2008, 250,000 people; and in 2009, 360,000 people (WFP, 2013). The 2012 floods along the Senegal River and in low-lying areas of Greater Dakar affected over 265,000 people, exacerbating the flood-induced food security crisis of 2011/2012 (WFP, 2012). More recently, 2020 received higher-than-normal rainfall that led to flooding (ReliefWeb, 2020). In the absence of mitigation practices, consecutive floods and droughts can cause severe land degradation, worsening the crisis of food insecurity. Land degradation in Senegal is linked to the salinization of agricultural land, especially of rice paddies; water erosion that causes stripping and gullyng; and to wind erosion that removes the surface layer of soils and destroys its potential for production (Sow et al., 2016).

TABLE 1: Key natural hazards in Senegal

Hazard	References	Data link
Drought	(Epule et al., 2014) (Sall et al., 2015) (USAID, 2017)	https://bit.ly/2pgeN0p
Soil erosion	(Sow et al., 2016)	https://bit.ly/2JBU0eC
Flooding	(USAID, 2017) (WFP, 2013)	https://bit.ly/34kl9ux
Fires	(Sow et al., 2016)	https://go.nasa.gov/3200nPc
Salinization	(Sow et al., 2016) (Thiam et al., 2019) (Diack et al., 2019) (Wopereis et al., 1998)	http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v12/soil-qualities-data/en/
Waterlogging	(Komivi et al., 2018) (Diack et al., 2017)	http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v12/soil-qualities-data/en/

We extracted the data in raster format as an average for each arrondissement of Senegal and then normalized to a scale from 0 to 1. Senegal is subdivided into regions, which are further subdivided into departments and arrondissements. For each arrondissement, this data was later used to calculate vulnerability by applying equation 1. Figure 4 shows the spatial distribution of the six natural hazards considered: aridity, erosion, fire, flood, salinization, and waterlogging. Aridity affects the northern areas of Senegal, fire the southeastern areas, and erosion the central areas. Flooding and salinization are particularly impactful in the southwestern areas of Ziguinchor and Sedhiou and in areas close to the coast. Waterlogging is mostly experienced in the southern areas of Senegal, such as the Casamance, which also receives high levels of rainfall. Exposure to arid conditions is particularly acute in the north and less severe in the south.

**FIGURE 4:** Spatial distribution of natural hazards across Senegal

We calculated changes in temperature for the four scenarios to show the rate at which temperatures in Senegal are projected to increase (Figure 5). By the 2050s for RCP 4.5, temperatures are projected to increase slightly in eastern and southeastern Senegal, with the highest increase in Tambacounda Region. In some parts of Thiès and Louga Regions, temperatures will remain similar to the present conditions. Even greater temperature changes are projected under RCP 8.5 for the 2050s, particularly for the east, south, and southeastern areas of Senegal. Some arrondissements in Tambacounda Region will experience the greatest increases in temperature. Changes in temperature signify heat stress, which negatively impacts agriculture, particularly for livestock.

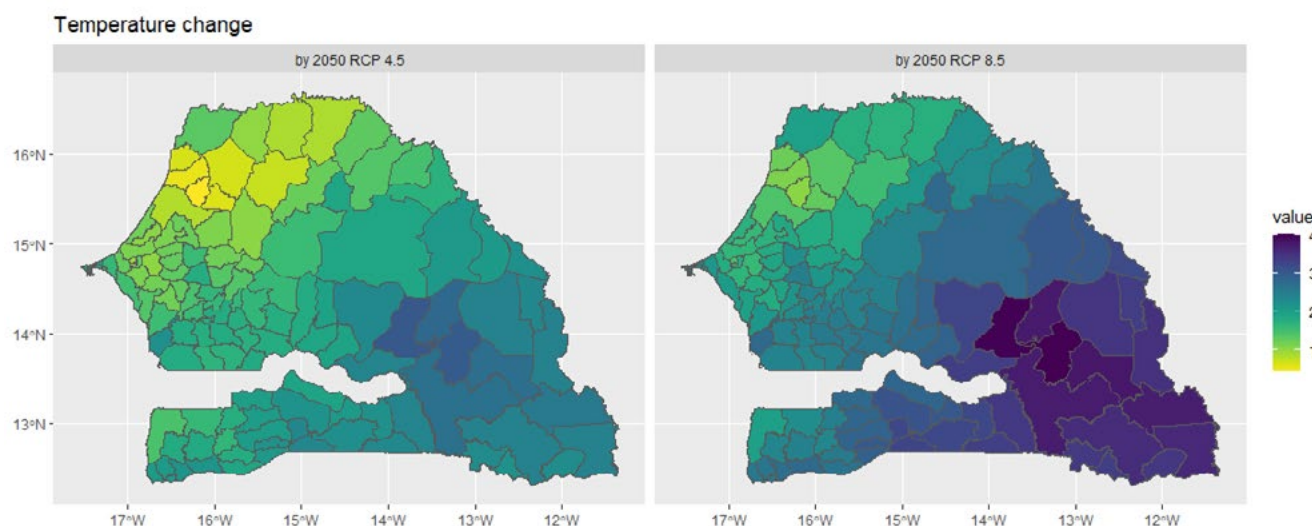


FIGURE 5: Temperature changes under RCPs 4.5 and 8.5 for the years 2050s

3.4 Adaptive capacity

Adaptive capacity refers to the ability of a system to prepare for climate stresses and changes in advance (Smit et al., 2003) or the ability to adjust and respond to the effects caused by climate change (IPCC, 2014). Increased adaptive capacity means better opportunities for systems to manage climate impacts of varying magnitudes (IPCC, 2012). For this vulnerability analysis, we gathered geospatial data on the variables that enhance adaptive capacity in Senegal (Table 2). We then normalized these variables so that 0 indicates lack of adaptive capacity and 1 corresponds to absolute adaptive capacity. For example, poverty was reciprocated so that a higher value shows low adaptive capacity.

TABLE 2: Adaptive capacity variables used in the vulnerability assessment for Senegal

Variable	Description
Crop diversification	Obtained by counting the total number of crops that are growing in each arrondissement. Crop distribution areas were taken from MapSPAM(You et al., 2017).
Literacy rate	The percentage of the population in each age group that can read and write. The adult literacy rate was obtained from the proportion of adults who had accessed primary education.
Dependency ratio	The ratio of the number of children aged 0-14 years and older persons aged 65 years or above, to the working-age population between 15 and 64 years old (UN, 2006).
Access to health care	Distance to health care facilities (Maina et al., 2019).
Institutional capacity	The institutional capital index relates to the “governance index”, “conflictuality index”, and “environmental management index” of an institution (ClimAfrica, 2014).
Access to markets	Travel time to major cities is used as a measure of the accessibility to markets.
Poverty index	The proportion of the population living in households below the international poverty line, where the average daily consumption or income per person is less than \$1.25 a day measured at 2005 international prices adjusted for purchasing power parity.
Stunting	The percentage of children under 5 years old whose standard score (z-score) falls below -2 standard deviations from the median height-for-age according to the World Health Organization (WHO) Child Growth Standards.

Variable	Description
Wasting	The percentage of children under 5 years old whose standard score (z-score) falls below -2 standard deviations from the median weight-for-height according to the WHO Child Growth Standards.
Underweight children	The percentage of children under 5 years old whose standard score (z-score) falls above +2 standard deviations from the median weight-for-age according to the WHO Child Growth Standards.
Technological capacity	A combination of two underlying indexes: the “household technology index” and the “infrastructure index”. Technological capacity is linked with the diffusion of basic life technology and infrastructure, is linked to transportation networks.
Access to water	Distance to the nearest water body. This variable represents access to irrigation and water for household consumption.
Under-5 mortality	Refers to the probability of dying between birth and exactly five years of age, expressed per 1,000 live births.
HIV prevalence	Percentage of the population living with HIV per 1000 people.
Food insecurity	People experiencing insufficient food consumption. This variable is expressed as poor or borderline food consumption, according to the Food Consumption Score.
Irrigable areas	Areas considered to have high potential for irrigation by their closeness to water sources, and areas with soils containing more clay are also more suitable for irrigation because clay improves soil's water holding capacity.
Malaria mortality	Under-5 mortality from malaria infections.
Access to electricity	Access to electrical energy (Falchetta et al., 2019).
Residual water irrigation potential	Areas where water is predicted to remain on the soil longer after rainfall. This variable is estimated using data such as slope and soil's water-holding capacity, clay, and organic carbon content.
Soil fertility	Soil fertility index (Lu et al., 2002).
Phone access	Number of households owning a mobile phone.

The indicators of adaptive capacity represented here varied greatly across Senegal's various regions and arrondissements. For instance, some arrondissements had very low adaptive capacity associated with poverty, but high adaptive capacity associated with crop diversification and access to hospitals, markets, and irrigable areas. Rates of stunting, underweight children, wasting, malaria, and poverty are generally high in the western parts of the country. In addition, access to health care, water, markets, and soil fertility are low in western areas. These variables improve in the east and toward Dakar. Regions around Dakar and Ziguinchor have lower rates of stunting, underweight children, and wasting, and better access to health care, water, and markets. These regions are also characterized by low poverty rates and higher levels of soil fertility. In comparison to western Senegal, eastern regions face high rates of HIV prevalence and low access to electricity (Figures 6a and 6b).

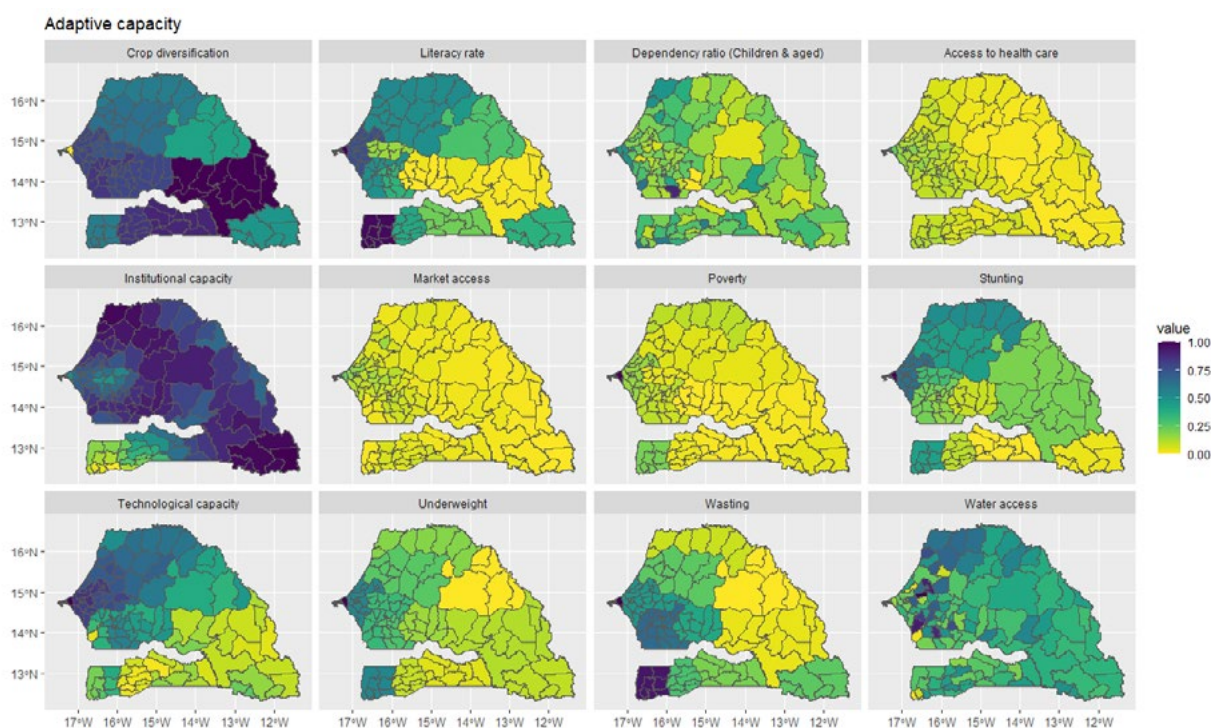


FIGURE 6a: Spatial distribution of adaptive capacity indicators for Senegal. A value of zero indicates no adaptive capacity, and a value of 1 indicates absolute adaptive capacity.

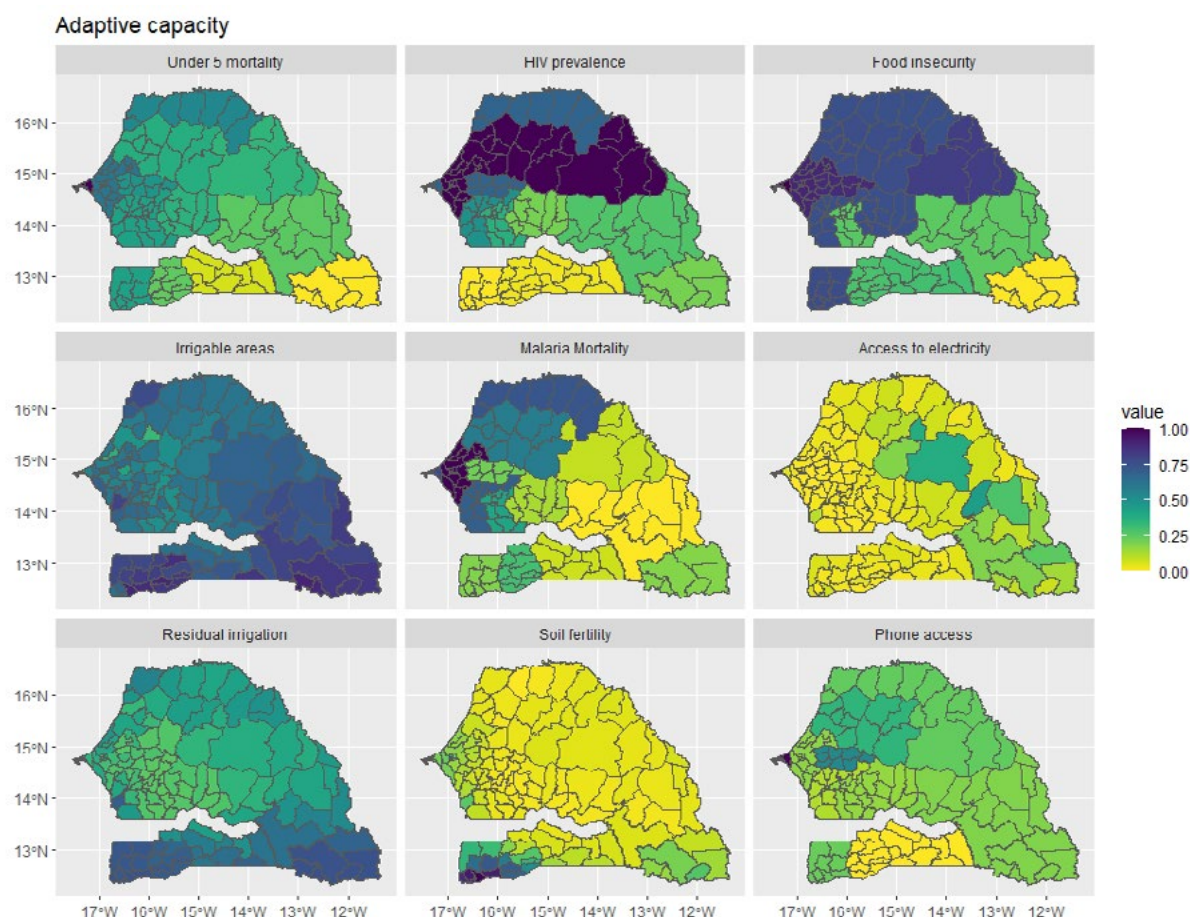


FIGURE 6b: Spatial distribution of adaptive capacity indicators for Senegal. A value of zero indicates no adaptive capacity, and a value of 1 indicates absolute adaptive capacity.

3.5 The vulnerability of the Senegalese agricultural sector to climate change

By applying equation 1 using all the indicators for sensitivity, exposure, and adaptive capacity, we computed the vulnerability of the Senegalese agricultural sector to climate change. Our analysis focused on the future climate for RCP 4.5, an intermediate scenario that assumes partial implementation of the Paris Agreement, and RCP 8.5, the business-as-usual scenario, for the 2050s.

Overall crop vulnerability in the 2050s under RCP 4.5 is greatest in the regions of Kaffrine, Tambacounda, Sedhiou, Kolda, and Kedougou, which are mainly in the central, southern, and southeastern parts of Senegal. There are also other specific arrondissements with high vulnerability elsewhere across the country (Figure 7a). On the other hand, vulnerability is lowest in areas near Dakar and Thiès. Some areas in the north, especially in the regions of Thiès and Louga, have lower vulnerability to climate change, probably because of the ease of access to markets, high technological and institutional capacity.

For RCP 8.5 in the 2050s, vulnerability to climate change increases as compared to RCP 4.5 (Figure 7b) but remains higher in the regions of Kaffrine, Tambacounda, Sedhiou, Kolda, and Kedougou. Under RCP 8.5 for the 2050s, climate change will lead to increased vulnerability especially in the northeastern areas of Senegal on top of the areas that already have high vulnerability (Figure 7b).

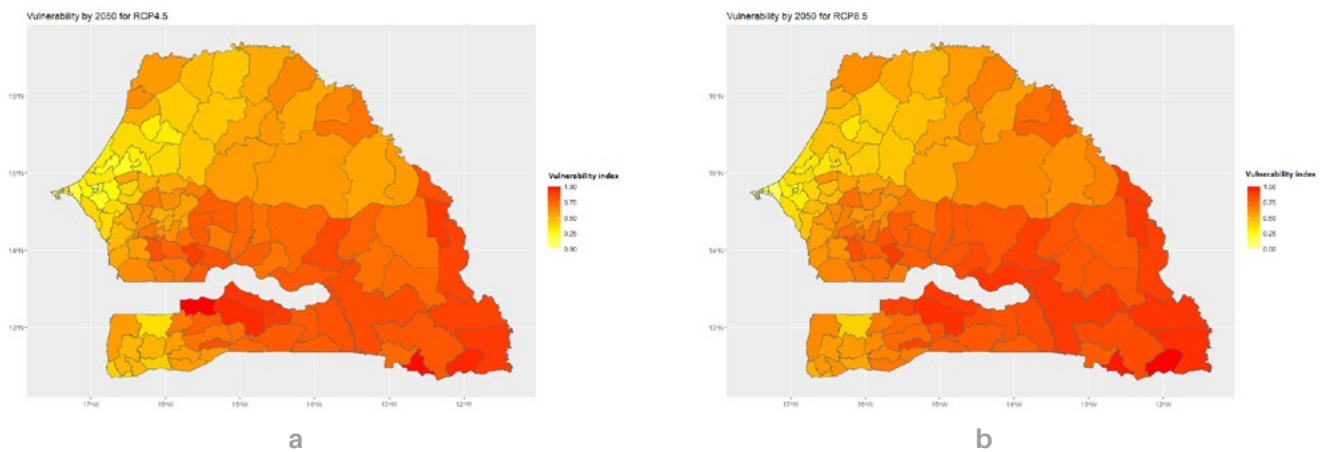


FIGURE 7: Overall vulnerability of Senegalese agriculture to climate change

Vulnerability comparison between RCP 4.5 and RCP 8.5 show an increase in vulnerability for all regions of Senegal for RCP8.5 compared to RCP4.5 (Figure 8). This shows that in the RCP 8.5, which is an unlikely high-risk future, Senegal regions will be more vulnerable to the effects of climate change compared to RCP 4.5, which gives a more optimistic future. The highest increase in vulnerability is exhibited in the arrondissements of Sédhiou except one to the north while the lowest is seen in most arrondissements of Kedougou and Tambacounda. Other regions with lower increase in vulnerability include Ziguinchor, Kaolack, Fatick and Thiés.

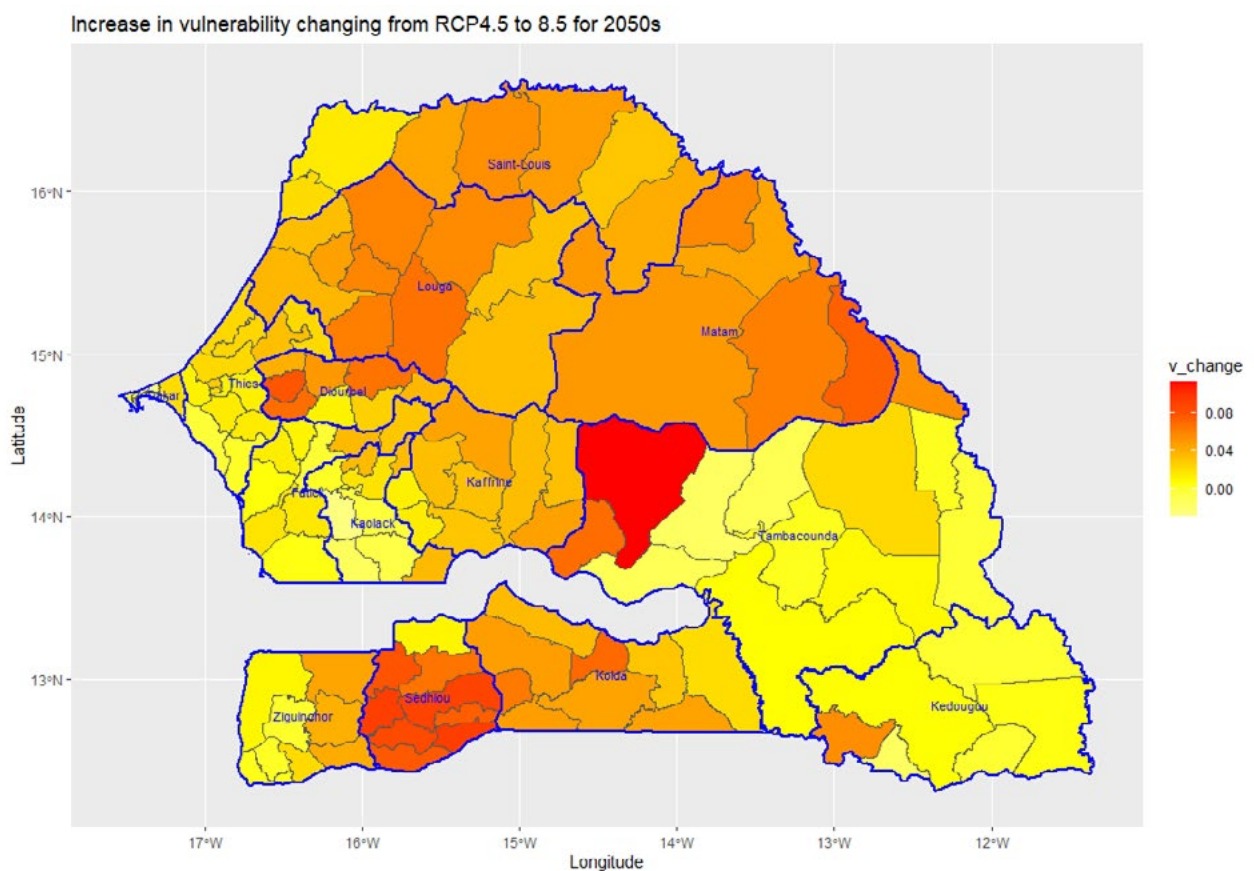


FIGURE 8: Vulnerability difference between RCP 4.5 and RCP 8.5 for 2050s

In the areas of greatest vulnerability, that is, the central, southern, and southeastern parts of Senegal, most of the crops under analysis faced a significant reduction in suitability. These areas also experience heightened poverty rates, limited access to health facilities, high rates of stunted, wasted, and underweight children, and elevated malaria mortality. In additions, these areas have limited access to markets, depressed literacy rates, significant food insecurity, and low technological capacity. However, these areas also promise the greatest opportunity for farming using irrigation and residual soil moisture.

All nine crops under analysis are most vulnerable towards southeastern Senegal, in the regions of Tambacounda, Kaffrine, Sedhiou, Kolda, and Kedougou but with madd exhibiting a lower value of vulnerability compared to other value chains. In the north, baobab trees are slightly vulnerable. Okra is slightly vulnerable to the northwest; onion to the northeast and rice to the northeast along the Senegal river valley. Mangoes, madd and pepper are the least vulnerable crops in Senegal (Figure 9). This situation is attributed to heightened climatic variations in the east and south of Senegal that leads to overall declines in crop suitability.

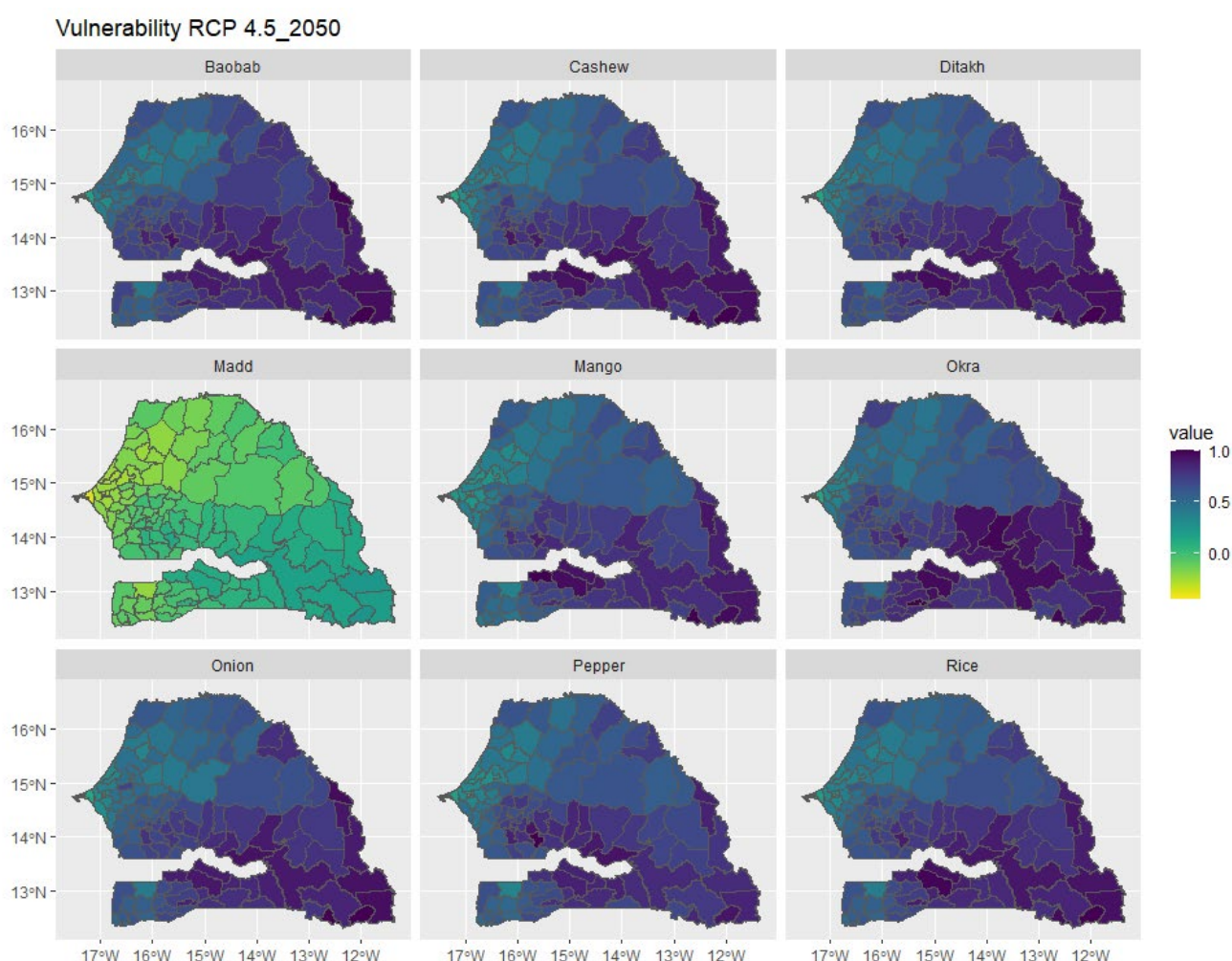


FIGURE 9: Contribution of different agricultural value chains to overall climate change vulnerability by the 2050s for RCP 4.5. Supplementary Figure S4 in the Annex show results for RCP 8.5 by the 2050s.

CONCLUSION

More than 70% of Senegal's population depend on agriculture, especially in the rural areas. With increasing youth populations, it is essential to empower young people with technical skills for profitable entrepreneurship and employment opportunities in agricultural value chains. The lack of economic opportunities is a key driver for outmigration in Senegal. Despite having about 1.5 million hectares of cultivated land and the potential to irrigate up to 240,000 hectares, at present the country irrigates only 10 percent of the cultivated area.

The vulnerability assessment for the selected crops in Senegal is based on their sensitivity to climate change, exposure, and adaptive capacities. We identified drought, soil erosion, flooding, fires, salinization and waterlogging as the main natural hazards representing exposure to climate change in Senegal. The adaptive capacity of the farming population can be enhanced by boosting literacy rates; increasing access to educational institutions and health facilities; improving nutrition outcomes to reduce the rates of stunted, wasted, and underweight children; and developing marketing, transportation, and irrigation infrastructure. Priority areas for ameliorating crop vulnerability include the eastern, southern, and southeastern areas of Senegal, which encompass Kaffrine, Tambacounda, Sedhiou, Ziguinchor, Diourbel, Fatick, Kolda, and Kedougou Regions.

Under climate change, there will be a decline in crop suitability for all the nine value chains especially in the regions to the south and the southeast of Senegal. There is also a notable shift in suitability for cashews, ditakh and madd towards the east and okra and onions towards the north. Various climate smart interventions will therefore be of most importance to reduce the effects of climate change on the selected value chains. Adoption of practices such as reforestation as well as technologies that increase crop cover and reduces erosion could enhance soil water retention. Other opportunities include irrigation and the harvesting of flood waters for cultivation.

Agricultural interventions for improved nutrition including diversifying crops for healthier diets, increasing production for food and nutrition security and communication strategies to promote positive changes in knowledge, attitudes, norms, beliefs and behaviors will enhance the ability to adjust, cope or benefit from the expected climate variations across the country.

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ANNEX: SUPPLEMENTARY FIGURES

1. Crop suitability

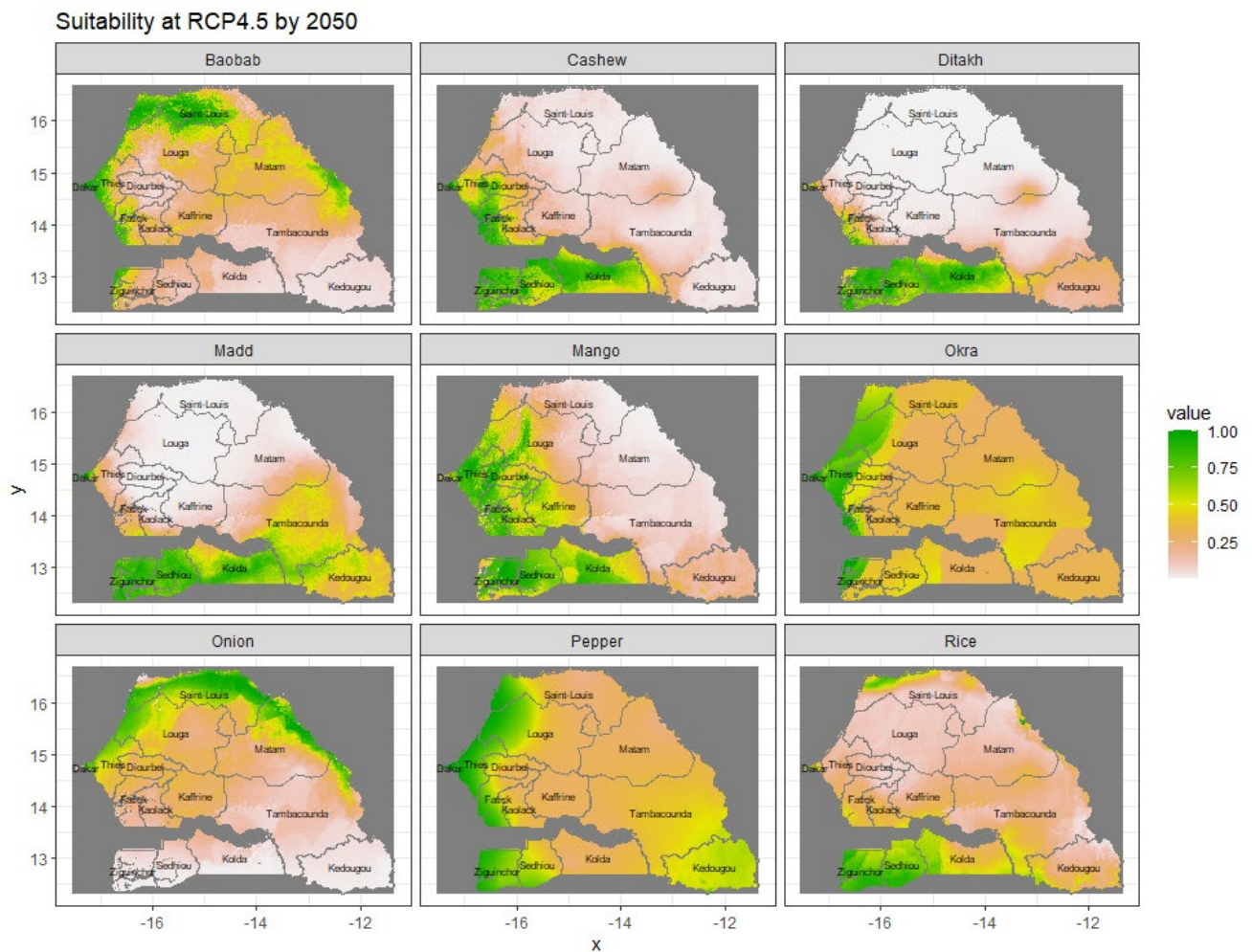


FIGURE S1. Crop suitability of the nine value chains by the 2050s for RCP 4.5

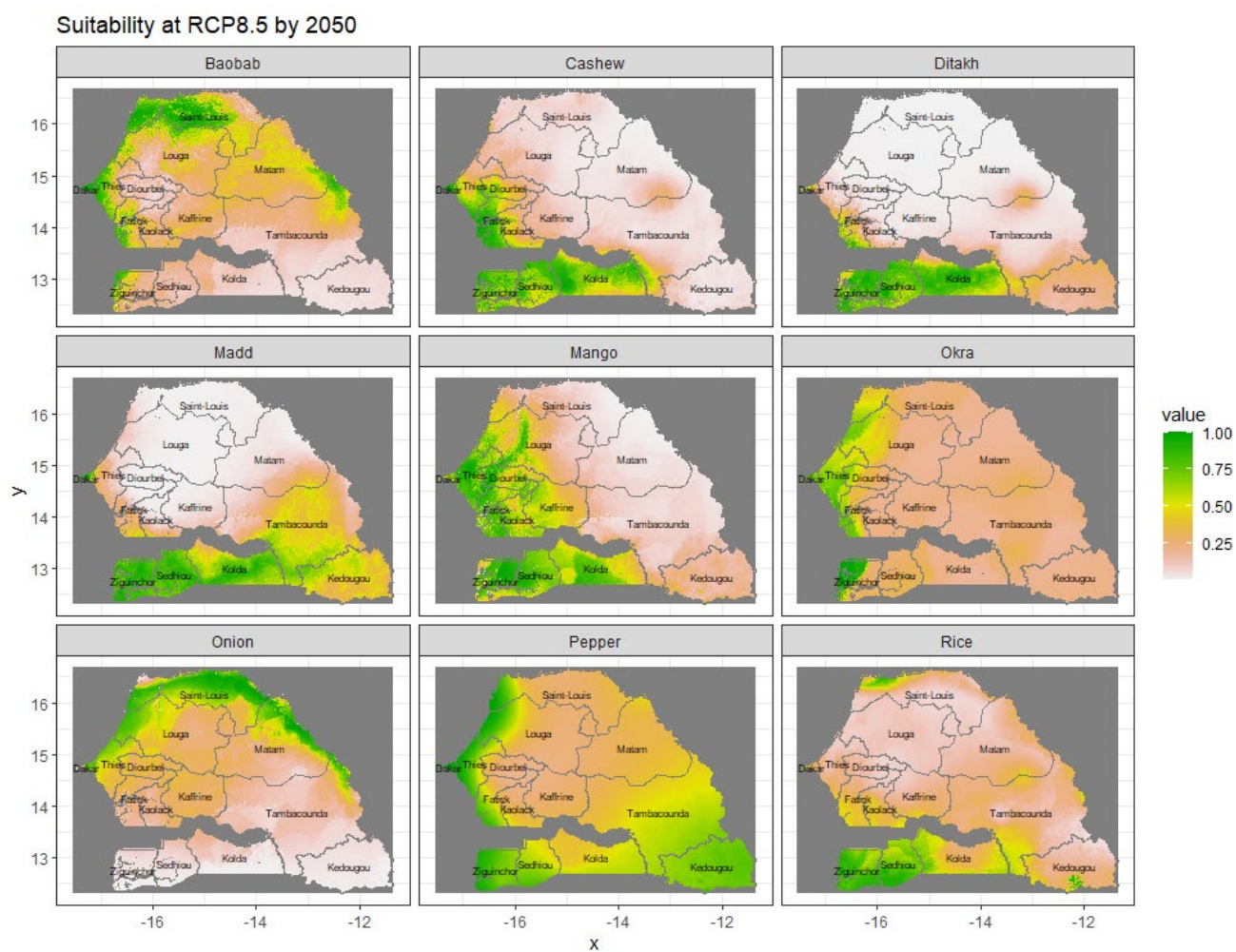


FIGURE S2. Crop suitability of the nine value chains by the 2050s for RCP 8.5

2. Sensitivity

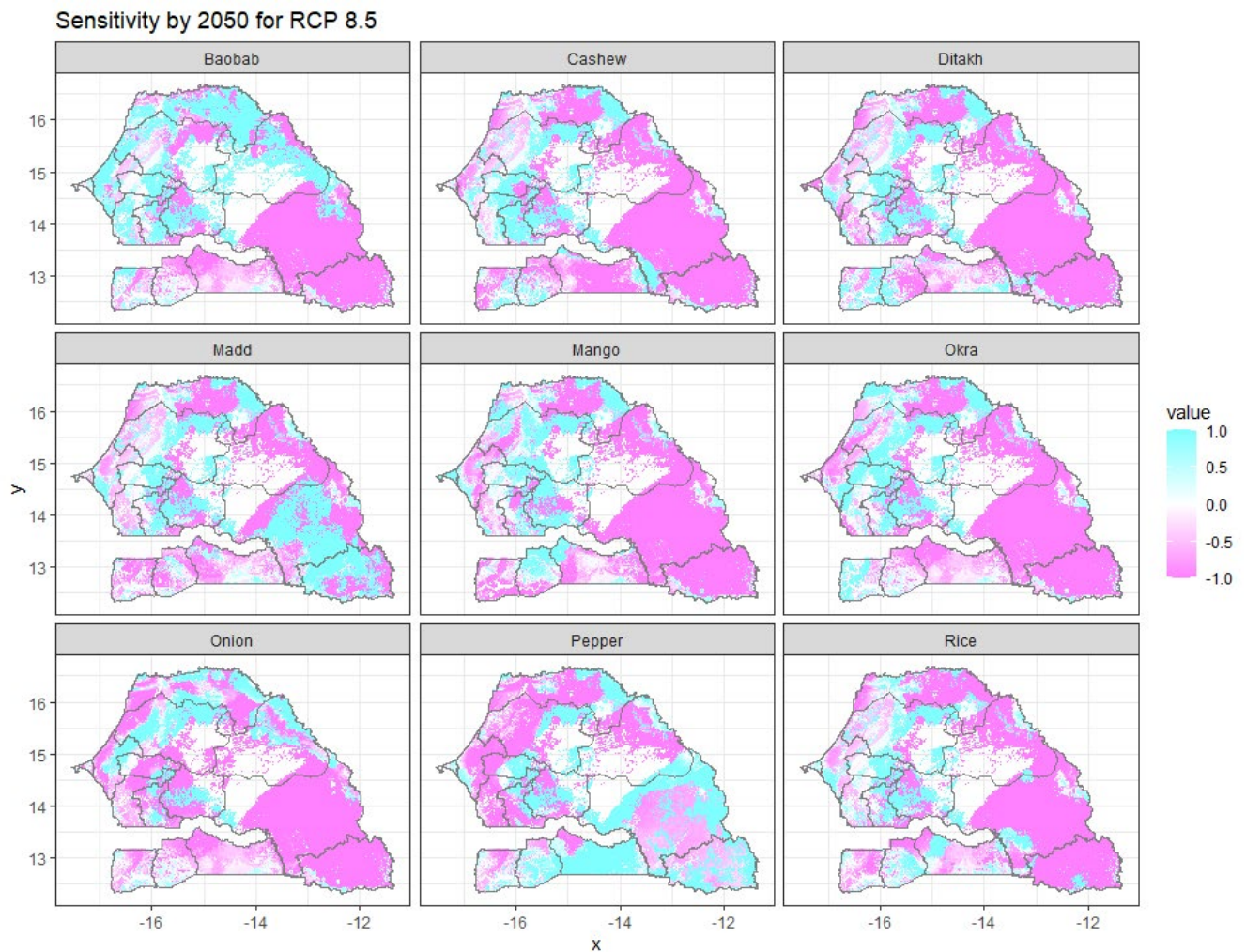


FIGURE S3. Sensitivity of the nine value chains to climate change by the 2050s for RCP 8.5

3. Vulnerability

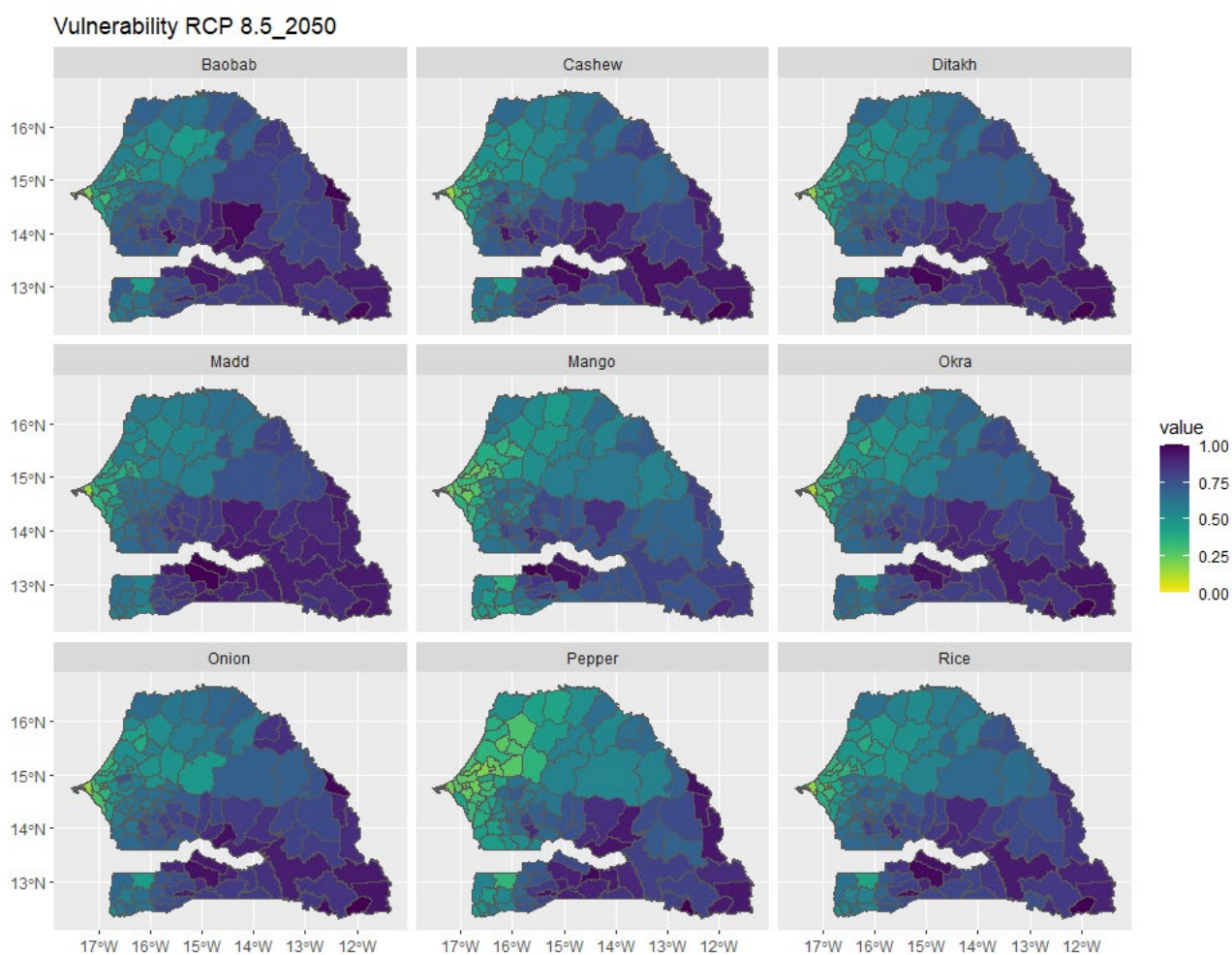


FIGURE S4: Contribution of the nine value chains to overall climate change vulnerability by 2050 for RCP 8.5



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