Chapter 4
Characterization of Climate Risks for Rice Crop in Casamance, Senegal

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Abstract This chapter contributes to a global reflection on climate change and its implications for agricultural production. We present a case study aiming to quantify trends of climate risks for rice crop in Casamance (Senegal). We evaluate the recurrence of drought and extreme rainfall conditions in the most sensitive phases of plant life and identify trends in the rainy season distribution. To overcome the low quality of climate records from gauge stations in the Region we use the rainfall estimation Climate Hazards group with InfraRed Precipitation Stations (CHIRPS), a daily gridded dataset with 0.05′ resolution over the period 1981–2013. The analysis is centered on the critical aspects that determine rice final yield such as: availability of water in the (i) plant germination and (ii) flowering phases, and (iii) the dynamics of the rainy season. We use the return period method to identify extreme events probability in rice crop's sensitive phases. Lastly, we identify the dynamics of the three parameters of the growing season: start, end and length by highlighting significant changes recorded in the study period (1981–2010). These outputs aim to support strategic agronomic choices in the Region.

Keywords Climate change · Rural development · Rice crop · Casamance

4.1 Introduction

Casamance Region is an enclave territory in southern Senegal (Fig. 4.1). The historical sociopolitical instability of the Region contributed to a regression of its rural development process (Evans 2003). Nowadays, the changes in the social and economic context of the country and the more secure conditions in Casamance lead the Region to a new rural development phase. According to the National Program

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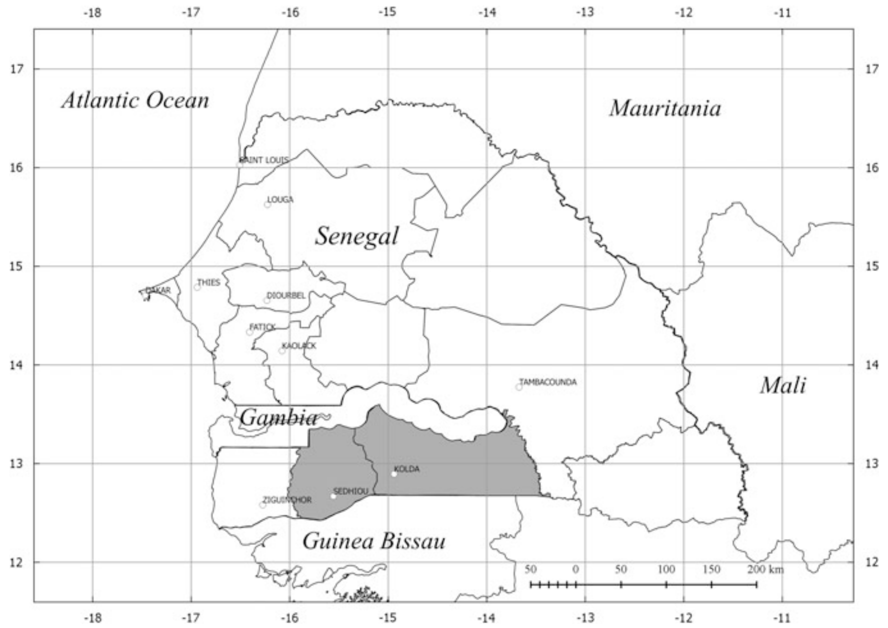

Fig. 4.1 Senegal. The Mid-Upper Casamance, the Sédhiou and Kolda regions (*grey*)

for Self-Sufficiency of Rice (PNAR) of Senegal, Ministerial Act No. 5042 dated June 8th, 2010, the goal of which is to help Senegal to achieve rice self-sufficiency and reduce poverty, the lowland rice cropping system of Casamance Region is designated as the one of the priority zones for an increase in rice productivity.

The climate of the Region is favorable to agriculture. Rains reach an average amount of 1000–1200 mm/year distributed in one rainy season from June till October. This allows the production of several rainfed crops; among these the most important are millet, sorghum, peanuts, maize and rice. Nowadays the agricultural production of the Region is far from reaching its potentials for different reasons.

These include the slow mechanization process in local agriculture that would be difficult to make sustainable and the limited market access for smallholders that discourages economic investments in the production process (Manzelli et al. 2015).

Yield is strictly dependent on the rainfall distribution and climate change impacts directly on farmers' activity. Knowledge of these changes support the adaptation strategies to face climate risk.

Risk is a clear concept for farmers and decision makers, they have to face a risk in every choice they make. But, how much climate risk? The answer depends on the local climate conditions that Climate General Circulation Models or information produced at national level cannot describe. To bridge this gap the study aims to produce a quantification of climate risks for rice crops in the Region.

The results are mainly addressed to the entire agricultural community, from decision makers to smallholders, who must receive clear and pertinent information for their agronomic choices.

In this paper attention is placed on the analysis of the agrometeorological conditions that most influence the rice yield in the Region. In Mid-Upper Casamance there are two different types of rice crop: (i) upland rainfed rice (*plateau*) and (ii) lowland rainfed rice (*vallée*).

The upland rice is a rainfed crop grown on dry soil without any water management. This activity is carried out by men and mechanization is sometimes used to aid their labor.

The lowland rainfed rice is grown in the natural depression near Casamance River. This activity uses traditional practices by which farmers, mostly women, seek to support the family's food balance. So this essentially remains a subsistence crop where women try reduce economic risks rather than intensify productivity. The effects of climate on this farming system are linked to the poor management of water in the field. Heavy rains and dry spells in some specific periods of the plant growing cycle could cause stress to plants and reduce yield potentials.

The other important factor, determining a good or bad harvest, is the dynamics of the West African Monsoon. In other words how an early or delayed start and end of the growing season impacts on yield. Each crop and variety is characterized by an optimal cycle length, so if there is no water available to complete the crop cycle there is a risk of the loss of the entire harvest (Roudier et al. 2011; Sultan et al. 2005). Indeed seasonality influences farmers' decisions about when to sow and harvest, and ultimately the success or failure of their crops (Graef et al. 2001).

The labor organization in the field is dependent on rainfall distributions, in the case of a late start to the season farming could be in competition with other activities and farmers risk not having enough time for field preparation and sowing, leaving some plots uncultivated (Manzelli et al. 2015b).

A longer growing season allows farmers to diversify crops or, as in this case, rice varieties. Instead, a shorter growing season and delayed start to the season reduce available options. Traditional agriculture is characterized by local varieties that women select in the years, mostly ecotypes naturally adapted to the local environment, but in the case of rapid climate change they aren't able to independently adjust seeds selection to new conditions.

Based on the observed climate, we try to identify local climate trends aiming to support the evaluation process of risk in agricultural production and the climate change adaptation process in the region. A set of synthetic indicators useful for the local community has been defined based on local knowledge, trying to highlight the factors most influencing final yield. A collaborative approach with the local agricultural service allowed us to select the following risk indicators: the presence of extreme events, both rainfall and drought, in (i) the germination and (ii) flowering period, and (iii) the dynamics of the growing season.

The probability of negative events is immediately comprehensible by decision makers and the results of the study can support strategic choices in the short- and mid-term.

Raw climatic data from the ground measurement network are poor and unevenly distributed, so we chose for the analysis a daily rainfall estimation images dataset: the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS). The selected dataset has a spatial resolution of 0.05°, sufficient to describe dynamics of rainfall in the Region with more of 30 years of data available to define a climatic index. This approach has the advantage of describing phenomena over the entire domain and producing hazard maps capable of intercepting criticalities at a very local level (i.e. municipality level).

4.2 Materials and Methods

The rainfall estimation dataset used in this work is the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) v1p8 by the U.S. Geological Survey and Earth Resources Observation and Science (Funk et al. 2015). CHIRPS is a quasi-global daily dataset spanning 50°S–50°N, starting in 1981 to near-present. CHIRPS incorporates 0.05° resolution satellite imagery with in situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring.

CHIRPS rainfall estimation daily images are distributed in NetCDF (Network Common Data Form) format, one of the most common climatic gridded data formats. We used the Climate Data Operators (CDO) to deal with this dataset. CDO is a large open source tool set for working on climate and model data. Using this tool we selected the domain over Casamance Region from the original dataset and computed the different indexes starting from the CHIRPS daily data.

4.2.1 Climate Extremes

Climate extremes may be time averages or frequencies of events above a given threshold of a single meteorological variable. In this case study we focused on detecting climatic stress in rice yield through the likelihood of recurrence of extreme events in the most vulnerable crop stages. The proposed approach identified criticalities supporting agronomic strategic choices that involve short- to medium-term economic investment. In Casamance, according to rice plant physiology and local knowledge, the most critical periods for rice yield are during emergence and flowering. We therefore chose the months of June-July and October as the most critical stages. In both periods we evaluated a set of indexes describing drought and extreme rainfall phenomena, these are:

- the maximum consecutive dry days, i.e. the greatest number of consecutive days per time period with daily precipitation below 1 mm; and the number of dry periods of more than 5 days to assess drought periods;
- the number of days when rainfall rate is at least 10 and 20 mm plus the highest one day precipitation amount per time period to assess heavy rainfall.

Using the yearly index in the time series it is possible to produce statistics and trends. The approach is useful in describing climate context as it gives a quantification of the probability that an extreme event will occur.

We evaluated the probability at a given threshold applying the return period analysis approach for each selected climatic index.

The return period is defined as the estimated time interval between events of a similar size or intensity, normally it is used to estimate the probability that a hazardous event such as a flood, drought or extreme rains will occur. The method proposed in this study was formulated by Gumbel (1954). The Gumbel equation is given by:

$$F(x) = \exp\left[-\exp\left(-\frac{x-u}{\alpha}\right)\right]$$

where F(x) is the probability of an annual maximum and u and α are parameters. Denoting the mean of the distribution by $\bar{x}$ and the standard deviation by s then the parameters u and α are given by the following:

$$\alpha = \frac{\sqrt{6}s}{\pi}$$
$$u = \bar{x} - 0.5772\alpha$$

In order to estimate the T-year extreme events it is possible to reverse the procedure to estimate the annual maximum for a given return period. So giving:

$$y_T = -\ln\left[\ln\left(\frac{T}{T-1}\right)\right]$$

It is possible to apply to the substitution to the original formula calculating u and α using the sample mean and standard deviation, as estimates of the population values, then the estimates of x_T may be obtained by:

$$\begin{aligned} x_T &= u + \alpha y_T \\ &= \bar{x} - 0.5772\frac{\sqrt{6}}{\pi}s + \frac{\sqrt{6}}{\pi}s\left\{-\ln\left[\ln\left(\frac{T}{T-1}\right)\right]\right\} \\ &= \bar{x} - \frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left[\ln\left(\frac{T}{T-1}\right)\right]\right\}s \end{aligned}$$

So we can simplify in the following formula:

$$x_T = \bar{x} + K_T s$$

where:

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left[\ln\left(\frac{T}{T-1}\right)\right]\right\}$$

K_T is the frequency factor, which is a function only of the return period T. Thus if an estimate of the annual maximum consecutive dry period for a return period of 20 years is required, if T = 20 years in the formula the result is an estimate of the likelihood of an event with 20 years return period. In synthesis, it is a statistical measurement based on historic data denoting the average recurrence interval over an extended period of time, and it is usually used for risk analysis, especially flood risk analysis. The associated yearly probability is the inverse of the Return Period (RP). For instance the probability (P) of an event with 10 years return period is P = 1/RP = 10%, this means that each year there is a 10% chance of recording a value greater than or equal to the indicated value of extreme event.

Whilst the method generally relies on using gauged rainfall records, in this case we applied the method on the CHIRPS gridded rainfall estimation dataset. For each single gridded point in the domain we quantify the probability of an extreme event removing incertitude by surface interpolation methods. It is clear that rainfall estimation by models implies bias errors, but the representation of dynamics of the phenomenon over space is not warped by systematic errors of the model.

4.2.2 Growing Season

Being part of the sub-humid regions of West Africa, the rainfall distribution in the Casamance area is typically unimodal from May-June till October–November.

The definition of start of the growing season is debated in the literature. Regional and local onset determine a different approach and analysis (Fitzpatrick et al. 2015). Despite an accurate review of the existing method, in this case we focused on determining dynamics and trends over a specific territory for a specific crop. We chose the method proposed by Sivakumar (1988) as analyzed in Ati et al. (2002) where the onset is defined as the first date after May 1st when three consecutive days accumulated rainfall exceeds 20 mm with no seven days dry spell in the subsequent 30 days.

The end of the growing season is the date after September 1st when the soil water content (set to 100 mm) is nil with a daily ETP of 5 mm (Maikano 2006; Traoré et al. 2000). The season length is derived from these two dates.

The limit of this method is its reliance on the threshold approach chosen by the two agronomic definitions of start and end of the season. Rain estimates incur sampling and retrieval errors that affect the accuracy of the satellite-inferred rain information provided to users. In this case the method, based on a rainfall threshold, could introduce an error in defining the date due to the uncertainty linked to the rainfall amount recorded on that day. Studies in the literature on similar gridded datasets (Ficher 2007) demonstrate that error is randomly distributed in rainfall estimation images so it is possible to assume that statistics in the trend analysis are not significantly biased by this kind of error.

The dates of the start and end of the rainy season were determined for each year applying the methods to the CHIRPS daily rainfall estimation dataset. We used the resulting time series from 1981 to 2013 as input in growing season parameters trend analysis.

The linear regression coefficient evaluated from the three values for each grid point in the domain allowed us to plot current dynamics in the modulation of the growing season in the Casamance Region.

4.3 Results

Germination and flowering periods are the most vulnerable to rainfall anomalies. In the plants' installation stage, the roots are weakly developed and they are not able to absorb moisture in the deepest part of the ground to avoid water stress. Flowering time is a critical stage of development in the life cycle of most plants because seed number is determined. Abiotic stresses of temperature and water deficit, and biotic (pest and disease) constraints could reduce the number and quality of seeds. Hence drought or very wet conditions in these stages mainly influence the rice crop final yield.

4.3.1 Rice Crop Germination

Historical data for Casamance region show high inter-annual variability with a heterogeneous distribution of dry and wet periods (Fig. 4.2). The graph has been produced averaging values from CHIRPS gridded dataset over the Mid-Upper Casamance using a mask.

Until the early 1990s a very prolonged dry period was recorded with extreme events beyond the normal statistical distribution, particularly 1981 and 1986 are the years characterized by the greatest length of consecutive dry days and the number of episodes of more than 5 consecutive dry days respectively. The second part of the 1990s until 2010 was characterized by wet conditions with a substantial absence of prolonged drought periods in the early stages of the rainy season. Decision makers are normally very interested in the quantification of the probability of negative events. To meet this need we determined drought risk through the evaluation of several return periods (2, 5, 10 and 20 years) for the two indexes in this study: (i) the maximum consecutive dry days and (ii) the number of dry periods of

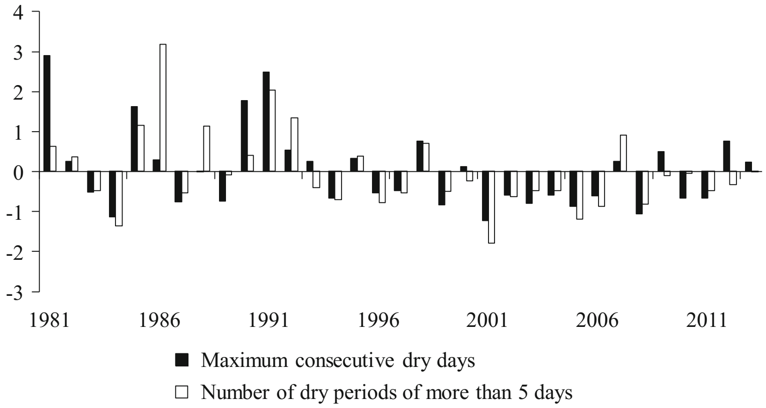

Fig. 4.2 Standardized distribution of maximum consecutive dry days and the number of dry periods of more than 5 days over Mid-Upper Casamance in June and July (CHIRPS data)

more than 5 days recorded in June–July over 1981–2013 period. The values are calculated and presented as a set of comparison maps with the plots of the dry periods' probability distribution over the area (Fig. 4.3).

As shown in the maps, there is a southeast northwest gradient, with a significant likelihood of a long series of consecutive dry days near the Gambia. In the eastern part of the Kolda region it seems that very long episodes of drought conditions never normally occur.

Regarding the distribution of the average number of periods with at least 5 consecutive dry days it can be observed how the distribution is irregular and follows a south north gradient.

The maximum number of consecutive dry days per year in the Region is expected to be from 6 to 10 but there is a 5% probability of recording 10–18 days, which is almost double.

July is when seedlings emerge. This is a critical stage for the plant development. Heavy rains can cause prolonged submersion of small plants and soil erosion phenomena. A graph is presented in Fig. 4.4 with a yearly distribution of rains in July over Mid-Upper Casamance.

July seems to have a downward trend in extreme events of rain. 1984 and 2004 were the years with the most intense rain phenomena and maximum variability. Starting from 2006 the maximum value distribution recorded has been quite regular reducing risks for crop submersion.

A map of the return period of the maximum daily amount of rain in the month of July has also been produced (Fig. 4.5). The map shows that values of over 80 mm/day can be reached in 1 year every 20 in the central part of the Mid-Upper Casamance. This high amount of daily rainfall might also create problems in well-drained valleys. The distributions of rainfall extremes do not follow the normal north south gradient. It is possible to observe a cone of maximum values between the eastern part of the Sédhiou Region and western part of the Kolda Region.

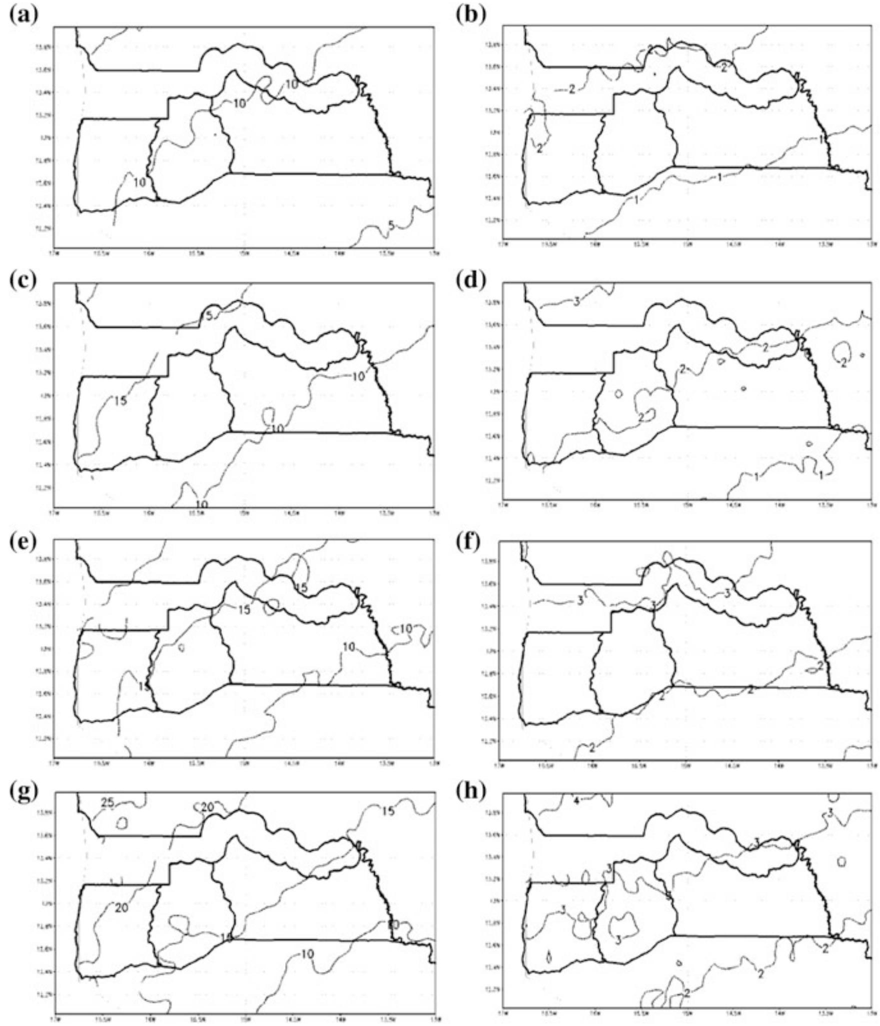

Fig. 4.3 Maximum consecutive dry days in June-July **a**, **c**, **e**, **g** 2, 5, 10 and 20 years return period respectively; Number of dry periods of more than 5 days **b**, **d**, **f**, **h** 2, 5, 10 and 20 years return period respectively

4.3.2 Rice Crop Flowering

Regarding flowering, the other vulnerable stage of rice crop, in Casamance this normally occurs in October. At this stage it is very important that plants receive a sufficient amount of rain. In fact drought stress in this period could generate 80% of yield loss. The characterization of drought risk in the flowering period was

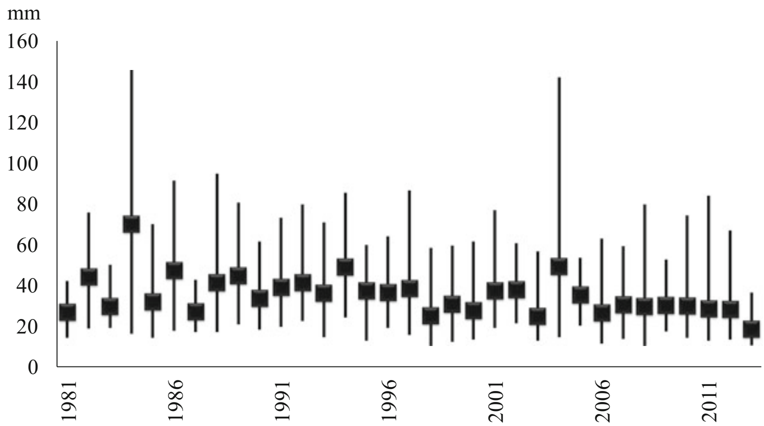

Fig. 4.4 Maximum daily rainfall distribution—minimum, maximum and average recorded over Middle and Upper Casamance (CHIRPS data)

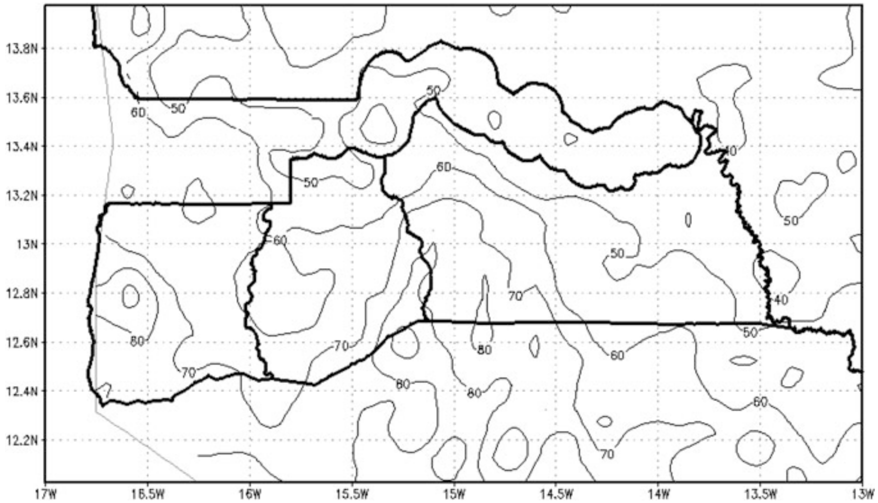

Fig. 4.5 Distribution of extreme values of rainfall (mm) with return period of 20 years in July (CHIRPS data)

produced by the evaluation of dry spells distribution in October through the analysis of the maximum consecutive dry days and the number of dry periods of more than 5 days recorded in October over 1981–2013 (Fig. 4.6).

The probability of having an average of 1.2–1.4 periods of 5 consecutive dry days per year is almost normal, while over 20 years 2.4–2.8 dry periods per year can be expected with an uneven distribution over the Middle and Upper Casamance Region.

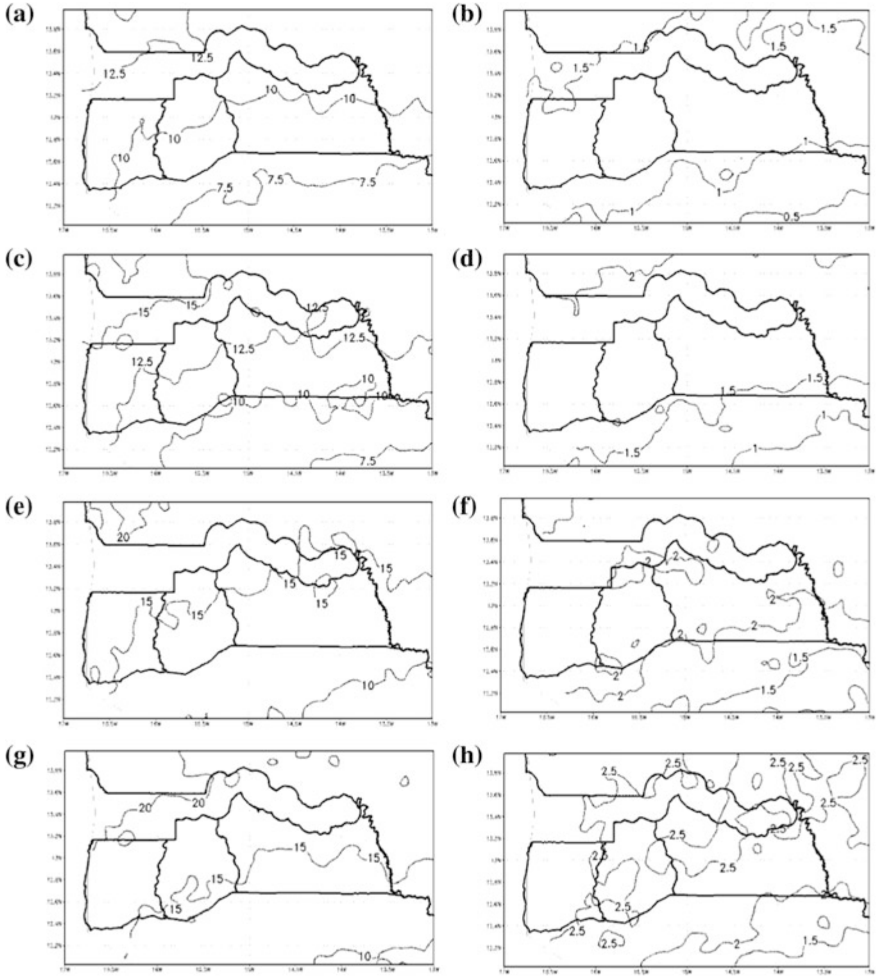

Fig. 4.6 Maximum consecutive dry days in October **a**, **c**, **e**, **g** 2, 5, 10 and 20 years return period respectively; Number of dry periods of more than 5 days **b**, **d**, **f**, **h** 2, 5, 10 and 20 years return period respectively

Episodes of consecutive dry days gives a chance of 9–11 consecutive days as a normal condition, while with a 20-year return period it is possible to arrive at 14–20 days. In both cases the distribution will follow isohyets with a north south gradient from wetter conditions to the driest.

4.3.3 Growing Season

Using CHIRPS daily images over the period 1981–2010 the yearly onset and cessation of the growing season was calculated according to Sivakumar and Traoré definitions. Averaging the 30 yearly images we obtained the mean conditions recorded in the area describing the growing season. The trend linear regression coefficient was then calculated to evaluate the distribution of the patterns in the Region (Fig. 4.7). In the Region the average start of the growing season in the 1981–2010 period was between June 5th (corresponding to the 156th Julian day) and June 25th (176th Julian day), with variability that reached, as in the case of 2014, mid-July with a very late onset of the rains. The trend analysis on the date of the start of the growing season shows an unclear signal. The values of linear regression coefficients are between −0.2 and +0.2 with a very uneven distribution over the territory, so there is not a clear configuration of the tendency of the phenomenon.

The average end of the growing season is in October and farmers normally start the harvest in November. However the average length of the growing season is

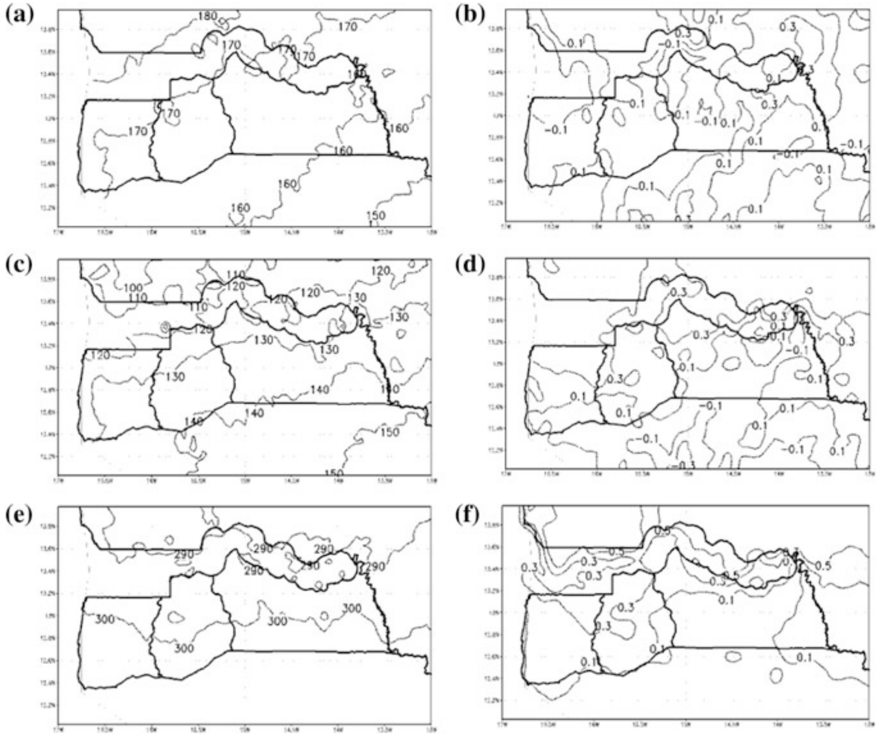

Fig. 4.7 Average start (Julian day), length (days) and end (Julian day) of season, **a**, **c** and **e** respectively with the relative linear regression coefficient, **b**, **d** and **f** respectively, 1981–2010

120–140 days. The result is a consistent pattern to a shift towards November for the end of the cropping season. In general for Casamance there is a slight increasing tendency in the length of the growing season. Especially in Sédhiou Region maximum values are observed arriving at a ratio of increase in length of the growing season by 0.3 days a year.

4.4 Discussion

Rain distribution is one of the main factors that cause problems for rice crops in Mid-Upper Casamance. Poor valleys water management, soil degradation and erosion phenomena, the lack of proper management of water in the plot and inappropriate agricultural practices are all factors creating a risk for crop yield.

To improve land and drainage management in the Region, the measure of climate change risks is necessary to assist this development process. Indeed, where the agricultural system is very vulnerable to natural hazards, adaptation measures are urgently required, such as the reorganization of hydraulic management in the valleys, with an evaluation of alternative cropping systems and/or introduction of new rice varieties and the risk to achieve all of this must be quantified.

The probability of dry spells or extreme events in the most critical stages of rice crop supports alternative strategic choices and it is possible to evaluate the best options in terms of crops and varieties combination for the Casamance Region. In fact, each crop, and consequentially each variety, has a particular sensitivity to drought spells. Using the probability maps of extreme events produced in this study it is possible to select the most appropriate combination of crops and varieties considering future climatic conditions.

We want to stress the fact that using a high resolution daily precipitation gridded dataset it is possible to describe phenomena at a very local scale, giving tailored climatic information also at municipality level.

The study characterized some crucial agro-climatic hazards impacting on the Region rice crop production; this paper presents the most important findings. First of all we found that in the last decade the good rainfall distribution in the initial phase of the growing season determined a low probability of unfavorable conditions for crops. A downward trend in extreme rains in July also reassures us that in the coming years we can expect better average conditions for the emergence of rice crop. This doesn't mean that hazardous events are not expected in future. In fact using the return period of extreme events in the June–July period a map was produced showing that amounts of 80 mm/day and more are expected 1 year every 20, so a yearly probability of 5%. This information is also useful for drainage design and management in the Region.

The dynamics of the growing season show that in the Region there is generally a slight trend in the end of season shifting from early to end November. This aspect is very interesting and reassures farmers and decision makers of the opportunity to complete the crop cycle in the case of late starts to the season. But this shift also has negative effects on farming activities; indeed a continuation of favorable conditions for crop development, with delayed maturation and harvesting, can lead to problems of losses due to straying animals and generate conflicts with livestock farmers.

Instead, the intercepted signal on the start of the growing season is weaker and shows an unclear trend in the Region. This could be linked to the current variability in the onset of the West African Monsoon.

Considering natural climate variability, caution will be maintained for agronomic planning in the Region, but a set of quantitative values is now available to support the decision-making process. This information must be constantly updated in order to give end users the very latest available and accurate information of the climate evolution.

4.5 Conclusions

The agro-meteorological characterization provided in this paper aims to support the decision-making process in agriculture through tailored climatic information for the Middle and Upper Casamance Region. The integration of local knowledge with the most recent gridded model outputs intercepts criticalities for rice crop yield.

A set of probability thresholds for the most important climatic threats is given allowing end users to have a clear picture of possible risk scenarios. These values help decision makers in their choices, indeed it is now possible to define the acceptable risk threshold; in other words they can set a level of potential losses that a farmer or politics considers acceptable, given probable climatic conditions. The extreme events' probability could also support new varietal and agronomic choices, guiding farmers in optimizing the production process. Furthermore, these values could support agronomists in the redesign and sizing of the hydraulic system management in the rice valleys of the Region.

The climate variability recorded in the Region suggests caution on the possible recurrence of flood and drought episodes, requiring an improvement in water management systems to reduce the risk of yield losses.

The rainfall estimation gridded dataset describes phenomena through their natural modulation over the territory; it therefore supports local communities in their adaptation by showing a climate change distribution not measurable by the ground meteorological network. This approach allows us to release information at very local level with detailed maps supporting the usability of the analysis results.

Feedback from end users, such as local associations and decentralized agricultural technical services, could guide future fine tuning of the climatic index analysis. Indeed, dialogue between the scientific community and local users is the key element in the innovation process for the improvement of agronomic techniques and strategies to face climate change. Moreover we recommend a synergy among different levels of end users to achieve a coordinated rural development process that considers the most accurate information available on climate.

This approach could be reproduced with General Circulation Models outputs in order to evaluate some possible future scenario giving a picture of what climatic conditions will be like for rice crops in Casamance.

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