Chapter 3
Hazard Events Characterization in Tillaberi Region, Niger: Present and Future Projections

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Abstract Niger is one of the countries most vulnerable to climatic risks. An adaptation to meet these threats is urgent and supported by politicians and decision makers, as stressed in the *Programme d'Action National pour l'Adaptation aux changements climatiques* (PANA) of Niger. The main aim of this paper is to provide an assessment of the current and future scenario of natural hazards in Tillaberi Region (Niger). The mapping of hazard changes in the study area is done comparing the probability of recurrence of severe meteorological conditions for droughts and floods between present and future climate using several projections from the Coupled Model Intercomparison Project Phase 5 (CMIP5). The result is a hazard characterization highlighting the need for urgent interventions. The natural hazard information with exposure and vulnerability assessment indicators can help decision makers in prioritizing interventions in the Tillabéri Region using an objective approach. This methodology has been proposed within the framework of the ANADIA Project that aims to support disaster prevention activities, from national to local scale, helping institutions in the design and implementation of disaster risk management strategies.

Keywords Climate change · Natural hazard · Drought · Extreme rainfall · Niger

3.1 Introduction

Natural disasters, notably floods and drought, are becoming a major concern in West African countries. These are caused mainly by natural hazards such as extremely intense rainfall events or extensive dry periods. With the current rapid

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climate change conditions attention should be paid to natural disasters in all development planning at national, regional and local levels to minimize the risks. The *Programme d'Action National pour l'Adaptation aux changements climatiques* (PANA) of Niger sets adaptation policies as urgent and necessary to cope with future climate risk.

Tillaberi Region, the case study area, is located in the westernmost part of Niger. It consists of 45 municipalities with an estimated 2,722,482 inhabitants in 2012 (INS 2012). Its economy is mainly based on subsistence agricultural and livestock farming. 84.9% of its population live in rural area and 71.7% live below the poverty threshold (INS 2011).

Niger is extremely vulnerable to extreme climate events. The country faced heavy losses due to increased flooding and drought episodes in the last decade. In 2013 alone, the number of victims from floods in the Tillaberi Region was estimated at 39,681 and 2902 hectares of fields were flooded (OCHA 2013).

Numerous factors contribute to increasing local exposure and vulnerability to natural disasters: (i) the changes in river flows and discharges caused by human activities (Mahe et al. 2013), (ii) population growth and related environmental degradation (Leblanc et al. 2008) and (iii) changes in hydrography dynamics (Descroix et al. 2009, 2012). It is clear that some actions are needed to face climate risks. We consider a bottom-up approach in the climate change adaptation process as a key of measures' effectiveness. Adaptation capacity is linked with some local elements such as population food security, education and knowledge of climatic risk. A decrease of vulnerability to climate risk can also be achieved knowing what the future could hold.

Tillaberi Region belongs largely to the Sahelian zone characterized by difficult climatic conditions such as low rainfall and high temperatures that can reach 45 °C. It has a single rainy season from June till September averaging an annual precipitation from 250 mm/year in Abalak, in the north, to 800 mm/year in Gaya, in the south.

The interannual variability is quite significant and it is possible to identify three different phases in the last 30 years: (1) a dry period in the 1980s, (2) a transition decade in the 1990s with a high interannual variability and (3) a wet phase in the first decade of 2000 (Fig. 3.1).

Despite this increasing trend in total rainfall amount, changes in extreme events distribution are slightly different and not immediately related to the seasonal sum. In this case we integrate different climate indexes, such as the Standardized Precipitation Index (SPI) by McKee et al. (1993) at monthly scale, to achieve a more complete climatic characterization.

We analyze changes in rainfall distribution with particular emphasis on extreme events. As described in the Special Report from Intergovernmental Panel on Climate Change (IPCC) *Managing the risks of extreme events and disasters to advance climate change adaptation* (IPCC 2012), the near future will likely see an increasing number of extreme events.

The study analyzes historical climatic trends and future scenarios in Tillaberi Region, identifying hotspots and discusses how observed trends could impact
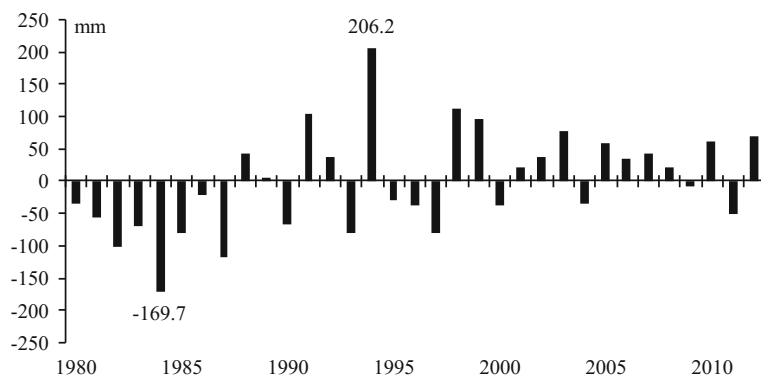
Fig. 3.1 Mean seasonal rainfall in Tillaberi Region (1980–2012). Average over Tillaberi gauge network

human activities. Climate analysis aims to support the quantification of natural risk highlighting the most sensitive zones in the region for drought and floods.

The analysis is split in two steps:

- the evaluation of current trends, using data from the rain gauge station network of the National Meteorological Direction of Niger (DMN), the national body in charge of meteorological monitoring;
- the evaluation of some future scenarios using climate model outputs from the Coupled Model Intercomparison Project Phase 5 (CMIP5) at different Representative Concentration Pathways (RCPs). This information is compared with a rainfall estimation dataset, the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS), to quantify future changes compared to present climate.

The hazards are characterized by a selection of climate indexes able to intercept drought and extremely wet conditions. In particular, we have used local experience to choose those most representative of dangerous conditions for the local community aiming to determine the magnitude and location of natural hazards in the region. In fact, the aim of the study is to prepare a minimum set of indexes, simple to calculate, which can intercept local criticalities. This collaborative approach with local institutions has been guided by the need to make the process sustainable by giving local authorities the possibility to reproduce this procedure independently.

Uncertainties are still present in climate modeling. How can this source of uncertainties be managed in the decision making process? The awareness of error must guide the interpretation of the study findings. Uncertainty is frequently seen as a not manageable factor, which limits adaptation process and local communities often consider that the best approach would be to carry on as normal, and respond to climate risks as they occur. Nevertheless, decisions may need to be taken and waiting for a reduction in uncertainty is not the right solution because this approach implies reducing the time available for adaptation measures. If we are uncertain

about what future we need to adapt to, it doesn't mean that we are not confident enough in our knowledge to make decisions to manage climate risks.

In this study we propose the approach of comparing different indicators and evaluating significant trends to achieve the most appropriate ways to tackle climate change in Tillaberi. We are confident that convergence of the evidence could guide strategic choices for the near future.

The study contains an analysis conducted within the framework of the Climate Change Adaptation, Disaster Prevention and Agricultural Development for Food Security (ANADIA) project with the collaboration of the Meteorological National Direction of Niger.

3.2 Materials and Methods

3.2.1 Current Conditions

Daily rainfall data, from the official DMN database, come from the rain gauge station network in the Tillaberi Region. This information is used to assess current climatic conditions. In the analysis we retain stations with at least 30 years of records, considering this period as the minimum requirement to produce a statistical analysis with a common climate reference (1981–2010). The stations fulfill requirements are 29.

Using daily data for each station, we evaluate the total number of dry days (days without rain or with less than 1 mm) and the maximum consecutive dry days recorded in the June–September period identifying drought conditions and assessing their magnitude and distribution. The number of wet days with rain equal to or more than 1 mm and the number of episodes that exceed the threshold of 10 and 20 mm/day are selected identifying wet conditions. Finally, we choose the highest 1-day precipitation, the yearly number of days with rain exceeding the 95th and 99th percentile to describe heavy rains distribution.

Therefore, each station is characterized by the following yearly index (basing on 1981–2010 period):

- R95p, Very wet days (days), Number of days >95th percentile calculated for wet days;
- R99p, Extremely wet days (days), Number of days >99th percentile;
- RR, Precipitation sum (mm);
- RR1, Wet days (days), Number of days ≥ 1 mm;
- R20 mm, Very heavy precipitation days (days) Number of days ≥ 20 mm;
- R10 mm, Heavy precipitation days (days), Number of days ≥ 10 mm;
- RX1 day, Highest 1-day precipitation (mm) Maximum sum for 1 day.

Here, for concision needs, we present only the regional averaged value computed over these 29 stations for each index. This mean value allows the evaluation

of linear regression over time series, intercepting climatic trends and their magnitude at regional scale.

The Pearson product-moment correlation coefficient has been computed as a measure of the linear correlation of the index variation over time and the non-parametric Kendall's tau estimation for monotonic trends. Kendall's tau measures the strength of the relationship between the two variables making no assumptions about the data distribution or linearity of any trends. Like other measures of correlation, Kendall's tau assumes a value between −1 and +1. A positive correlation signifies that the values of both variables are increasing. Instead, a negative correlation signifies that as one variable increases, the other one decreases. Confidence intervals can be calculated and hypotheses tested with the help of Kendall's tau. The main advantage of using this measurement is that the index distribution has better statistical properties, and Kendall's tau can be interpreted directly in terms of the probability of observing concordant and discordant pairs. On the contrary, outliers, unequal variances, non-normality and nonlinearity unduly influence the Pearson correlation.

3.2.2   Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) describes the magnitude of dry and wet conditions in a desired location. It allows an analyst to determine the rarity of an episode at a given time scale (e.g. Monthly resolution).

The SPI index is recommended by the World Meteorological Organization (WMO) to be used by all National Meteorological and Hydrological Services around the world to characterize meteorological droughts (WMO 2012). The SPI is simple to calculate because precipitation is the only required input parameter and it is just as effective in intercepting wet periods as dry periods.

The SPI formula is based on the long-term precipitation record. This record is fitted to a probability distribution, which is then transformed into a normal distribution. Positive SPI values indicate greater than median precipitation (wet conditions) and negative values indicate less than median precipitation (drought conditions). Because the SPI is normalized, wetter and drier climates can be represented in the same way.

The classification system shows SPI values to define drought and wet intensities resulting from the SPI as proposed by WMO (Table 3.1).

The SPI was designed to quantify the precipitation deficit for multiple timescales. In fact these timescales reflect the impact of drought on the availability of the different water resources. For instance, soil moisture conditions respond to precipitation anomalies on a relatively short timescale, groundwater, streamflow and reservoir storage reflect the longer-term precipitation anomalies. In this case we are looking for a meteorological characterization and use the 1-month SPI to characterize each single month in the rainy season (June, July, August and

Table 3.1 SPI classification (WMO 2012)

SPI values	Conditions
2.0 and more	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
−0.99 to 0.99	Near normal
−1.0 to −1.49	Moderately dry
−1.5 to −1.99	Severely dry
−2 and less	Extremely dry

September) and a 4-months SPI to characterize the entire rainy season (from June to September).

3.2.3 Future Climate Scenarios

Data for future climate scenarios come from phase five of the Coupled Model Intercomparison Project (CMIP5), which is a set of coordinated climate model experiments. These products are freely available for scientific purposes and there are projections of future climate change on two timescales, near-term (up to about 2035) and long-term (up to 2100 and beyond). So it is possible to download the chosen variable from a list of available models and RCP for the selected period of investigation.

Coordinated Regional climate Downscaling Experiment (CORDEX) is a World Climate Research Programme-sponsored program to organize an international coordinated framework to produce an improved generation of regional climate change projections worldwide for input into impact and adaptation studies within the AR5 timeline and beyond. CORDEX will produce an ensemble of multiple dynamic and statistical downscaling models considering multiple forcing GCMs from the CMIP5 archive.

In this case we evaluate the near-term scenario, until 2035, using daily data on the 2025–2035 period. A subset of these models is evaluated at two RCPs:

– CNRM-CM5 is the CMIP5 version of the ESM developed jointly by CNRM-GAME (Météo-France/CNRS) and CERFACS;
– EC-Earth is an Earth system model that is being developed by a number of European National Weather Services and elaborated by ICHEC (Irish Centre for High End Computing);
– HadGEM2-ES Hadley Global Environment Model 2—Earth System by Met Office Hadley Centre (MOHC);
– MPI-ESM is the Earth System Model running on medium resolution grid of the Max-Planck-Institut für Meteorologie.

The climate change projections depend on greenhouse gas concentrations and emissions and they normally produce different outputs using different RCPs.

The scientific community defines some global anthropogenic Radiative Forcing for the high RCP8.5, the medium-high RCP6, the medium-low RCP4.5 and low RCP2.6 scenarios, namely based on the respectively radiative forcing (+8.5, +6.0, +4.5 and +2.6 W/m^2).

For this study we select the medium-low RCP 45 and high RCP 85 scenarios outputs to perform the analysis with a sufficient number of different simulations to represent future climate variability.

In order to evaluate how realistic the models are in simulating rainfall distribution in the Tillaberi Region, we perform a comparison analysis with the CHIRPS v. 2.0 identifying bias in models outputs. We use the time series overlapping among CHIRPS and General Circulation Models (GCMs) datasets, the 2006–2014 period, performing a simplified bias correction. We evaluate an average correction coefficient for each model output. The CHIRPS dataset has a resolution of 0.05′, so applying this bias correction to the GCM dataset, namely at 0.5′ resolution, we also perform a downscaling of information for future scenarios. This represents an added value in determining different dynamics in the region at very local scale.

The scientific literature gives a variety of bias correction methods that are focused on determining the best transfer function to convert model data into realistic ones. In this case, we are evaluating extreme values of rainfall distribution, dry days and the wettest condition. So the Delta change approach is not useful in these ranges, because the method applies the additive coefficient independently of the amount of daily rainfall. The more complex transfer functions such as exponential, logarithmic and quantile mapping methods are more adequate in creating transfer functions applicable over the entire range of rainfall. In this case we adopt a multiplicative correction transfer function determined by averaging yearly accumulation of two datasets.

So for each year we compare the yearly amount of rainfall by CHIRPS and the GCM output:

$$K_m = \frac{\sum_{i=1}^{n} CHIRPS\, daily_i}{\sum_{i=1}^{n} GCM\, daily_i}$$

where m is the year.

We then average the yearly coefficient on the overlapping period among the two datasets, in this case the 2006–2014 period.

$$\overline{K} = \frac{1}{n} \sum_{m=1}^{n} K_m$$

Finally we produce the bias corrected series of the model applying the multiplicative coefficient to each single day.

$$Daily\ CGM_{corr} = K\ daily\ GCM$$

This method has the advantage that GCM corrected series has a yearly amount of rain coherent with the rainfall estimation value. Furthermore it is an easy bias correction method giving local institutions the possibility to perform the analysis on their own contributing to process sustainability.

With the corrected data series the synthetic index has been calculated for drought and extreme rainfall events over 2025–2035 period in order to make a comparison with the current climatic conditions defined by CHIRPS in 1981–2010 climate reference period.

3.3   Results

The spatial distribution of rainfall in Tillaberi is characterized by a clear south-north gradient. Rainfall ranges between 600 and 800 mm in the southern part of the Region, and between 250 and 350 mm in the north. Rainfall distribution averaged over the entire Region demonstrates that some trends are intercepted (Table 3.2). Tillaberi climate is characterized by a slight increase in number of rainy days, above 10 and 20 mm, reflecting changes in rainfall regime recorded in the first decade of 2000. Moreover, regarding extremes, we observe a clear increase in the number of episodes greater than the 95th and 99th percentile.

The regression coefficients for these indexes are quite consistent for all indicators, intercepting significant increases in yearly precipitation, in number of wet days, in number of very heavy precipitation days (RR10 and RR20) and in number of very wet days (R95p). A slightly increase is recorded in number of days >99th percentile and in the highest 1-day precipitation.

Table 3.2 Tillaberi region

|	RR	RR1	RR10	RR20	R95p	R99p	RX1
Average	400.3	29.1	13.6	6.9	1.6	0.3	55.4
Standard deviation	77.2	3.9	2.4	1.5	0.6	0.2	7.5
Max	574.3	37.2	18.1	9.9	3.1	1.1	76.6
Min	238.9	21.9	7.5	2.7	0.6	0.1	39.9
Regression coefficient	4.2	0.2	0.2	0.1	0	0	0.2
correlation	0.48	0.51	0.57	0.48	0.32	0.13	0.2
Tau	0.322	0.241	0.339	0.313	0.258	0.117	0.144
2side_pvalue	0.01	0.05	0.01	0.01	0.03	0.31	0.24
Probability (%)	99	95	99	99	97	69	76

Observed trends in the 1981–2010 period averaging all gauge stations of the Region. RR = Rainfall rate, RR1 = N. rainy days, RR10 = N. rainy days > 10 mm; RR20 = N. rainy days > 20 mm; R95p = N. Rainy days > 95p; R99p = N. Rainy days > 99p; RX1 = highest amount of 1-day rainfall

3.3.1 Standardized Precipitation Index

Using daily rainfall data from the DMN gauge network we calculated the SPI index for each station. We then averaged the SPI values over the entire region giving an overview of the climate in Tillaberi region in 33 years. SPI has been produced at two time scales: (i) 4-months resolution, in order to intercept dry or wet conditions over the entire rainy season, (ii) monthly resolution, describing monthly climatic conditions of the region at higher temporal resolution. Figure 3.2 presents the regional SPI graph. The comparison of these two time scales intercepts criticalities in different stages of the rainy season evolution (onset, central part, end) and gives an idea of the rainfall regime recorded in each year. The graph shows extremely dry conditions recorded in 1984 with a persistent negative SPI in June, July and August. Extremely wet conditions are recorded in 1994 with the highest value of SPI in August. We could associate June SPI to the interannual variability of the rainy season's onset strength. No extreme episodes are recorded in this month even if conditions are moderately dry in 1987. In July, SPI shows a lack of significant fluctuations, especially after 2000 when a sequence of normal conditions is observed. August records the maximum rainfall amount so it is the month most influencing the SPI value of the rainy season. In August there are extreme values over the entire period of monthly SPI: 1984 with a significant episode of drought and 1994 with the wettest conditions.

The 2000s are almost characterized by normal conditions. September marks the end of the rainy season and in the time series the SPI values for this month show a slight trend toward wet conditions. In summary SPI shows a quasi-normal situation in the last decade that means a globally favorable condition in rainfall distribution
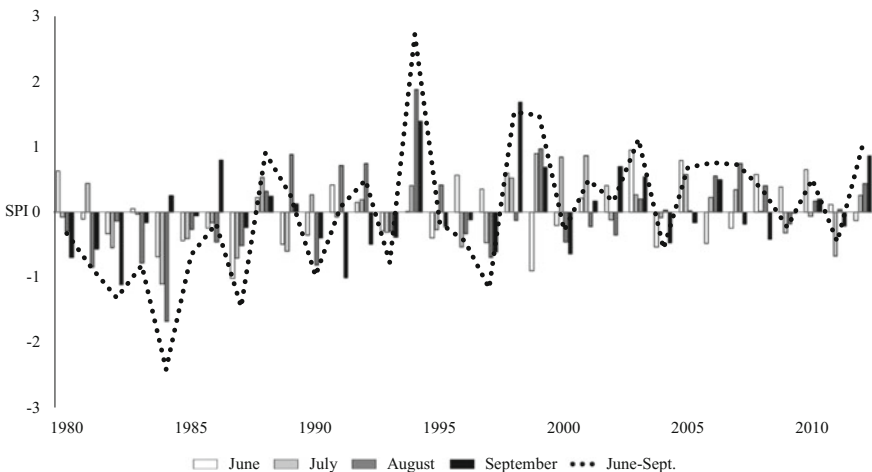
Fig. 3.2 June, July, August and September monthly SPI distribution and 4-months SPI in 1981–2012 period

comparing the driest period of the 1980s and wettest period of the 1990s. SPI is not conceived to intercept changes in daily extremes distributions, in fact in the last decade several floods are recorded in the region, but it could intercept dry and wet periods in rainfall distribution. SPI must be considered as complementary information of the daily extreme events distribution in classifying target period rainfall distribution with respect to time series. The increase of extreme rainfall events in a SPI wet period is normal, but as in the case of Tillaberi, the increase of extreme rainfall events in SPI normal period indicates an increase of extremes in rainfall distribution.

3.3.2   Future Scenarios

The last IPCC AR5 affirms: *The frequency and intensity of heavy precipitation events over land will likely increase on average in the near term.* (Kirtman et al. 2013). This statement is valid at global scale, so this study focuses on the Tillaberi Region analyzing the near-future conditions and extreme events likelihood.

We computed a very large set of indicators and here we present the most representative ones. We found that rainfall distribution is predicted to very likely increase drought and flood risk in Tillaberi Region. In fact several climate trends and climate model simulations from CORDEX-CMIP5 show: likely increase in maximum consecutive dry days; likely increase in number of dry periods of more than 5 days; likely increase in number of very heavy precipitation days; and likely increase in highest 1-day precipitation (mm)—Absolute value in the period.

The projections of future climate, describing drought conditions, have been produced and we show here the result of the comparison between the maximum number of consecutive dry days (RR < 1 mm) in June-September period between CHIRPS dataset and different GCMs (Fig. 3.3).

The 2025–2035 period presents an average increase of 1–3 days in the maximum number of consecutive dry days in the rainy season with a slight east to west gradient. The increase in intense dry conditions must alert end users in the region, especially farmers and food security actors. Prolonged dry periods could cause stress in rainfed crops and consequently reduce final yield. In a region with mainly subsistence agriculture this means an urgent need for adaptation.

While the maximum number of consecutive dry days intercepts the most acute stress, a proxy indicator for chronic drought stress is the number of periods of more than 5 consecutive dry days recorded in Tillaberi Region. We present here, similarly to the previous index, the average difference between each GCMs output compared to present climatic conditions defined by CHIRPS.
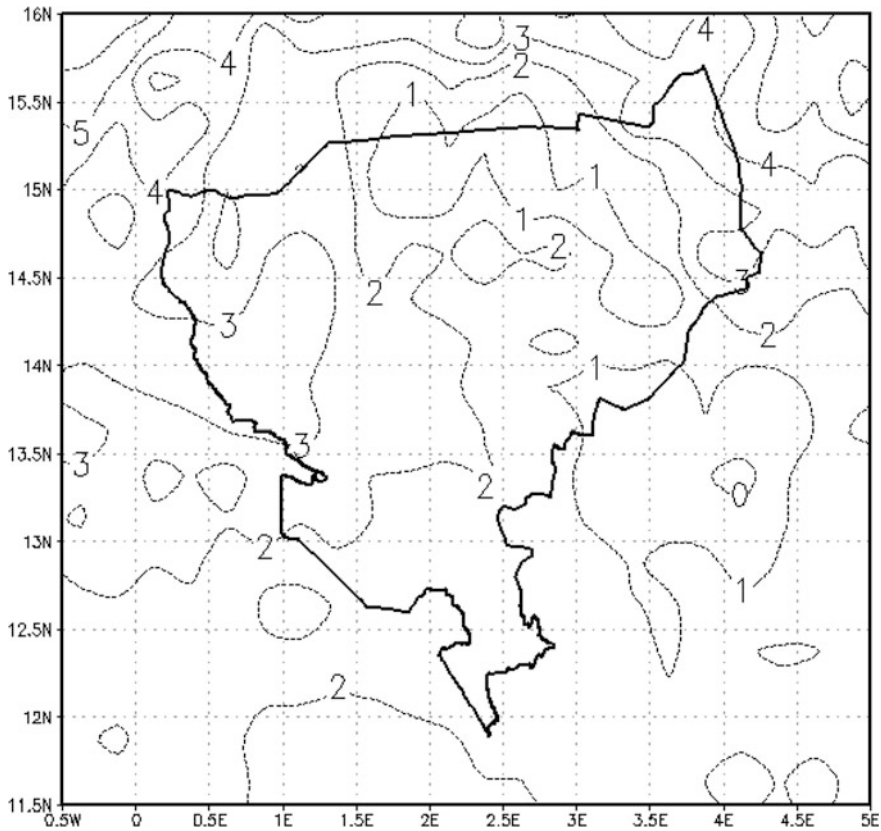
Fig. 3.3 Maximum number of consecutive dry days (RR < 1 mm)—June–September (rainy season)—Difference 2025–2035 (GCMs) versus 1981–2010 (CHIRPS)

The map (Fig. 3.4) shows that in Tillaberi Region we could expect an increase in the number of periods of more than 5 dry days that ranges between 0.5 and 1.5.

Coupling this information with the previous, the increase in the maximum length of dry period, we can affirm that more acute and chronic drought conditions are likely in the near future. We also produced some heavy rains scenarios using GCMs. We focused attention on the very heavy precipitation days, the ones with rainfall of more than 20 mm, making a comparison between GCMs and CHIRPS dataset. The averaged result is presented in Fig. 3.5.
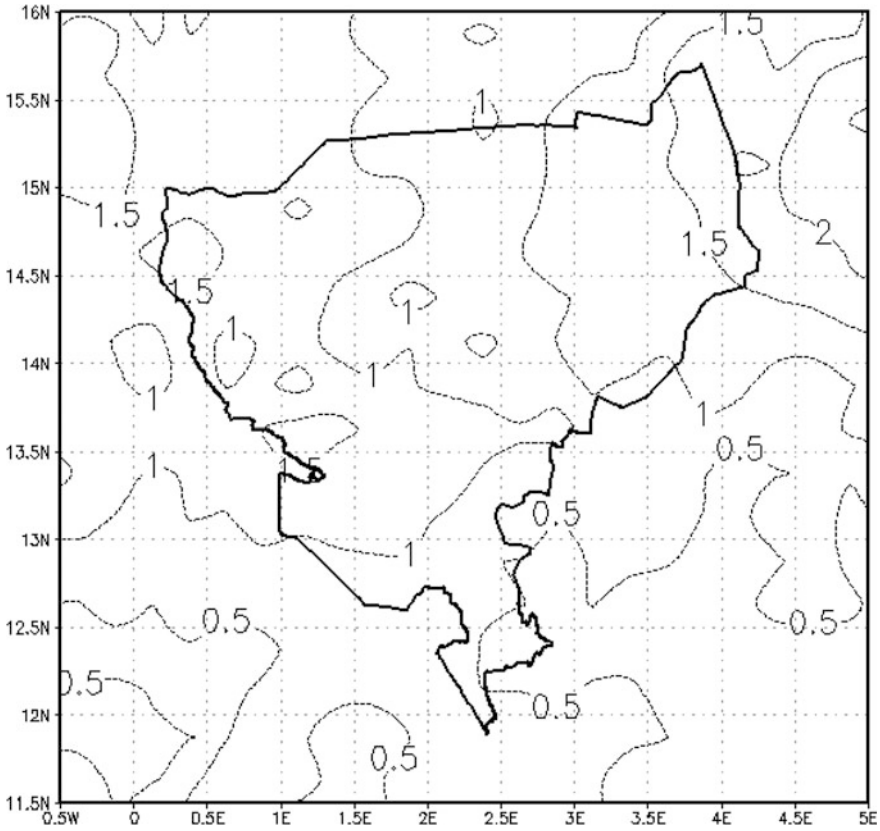
Fig. 3.4 Number of dry periods of more than 5 consecutive dry days (RR < 1 mm) per year Difference 2025–2035 (GCMs) versus 1981–2010 (CHIRPS)

The number of very heavy precipitation days is likely to increase in the 2025–2035 period. The variation is estimated at between 1 and 3 days more with a clear south-north gradient. We did the same analysis with the highest 1 day precipitation amount evaluating changes in the most intense phenomena (Fig. 3.6).

The map confirms a clear increase in the maximum of rainfall in the highest 1-day precipitation with a rise ranging between +30 and +70 mm. We want to underline the fact that an absolute value in changes could be affected by unbiased
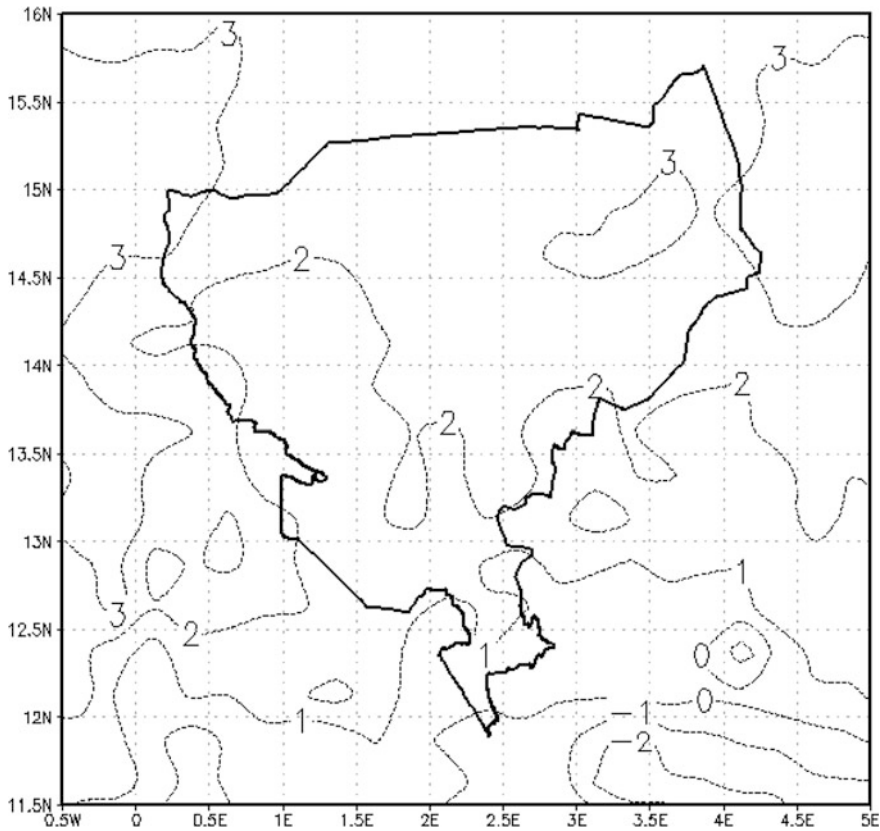
Fig. 3.5 Very heavy precipitation days (days)—Number of days RR $\geq$ 20 mm per year—June–September—Difference 2025–2035 versus 1981–2010 (CHIRPS)

error in the models, but it is important to observe that both extremely dry and wet conditions likely increase in future. This means that Tillaberi is probably moving toward a climate characterized by an intensification of extreme events. This negative scenario means more favorable condition for floods and droughts and the expected exacerbation of intrannual variability could lead to a reduction in crop yields, soil erosion phenomena and an increased population exposure to climate risks.
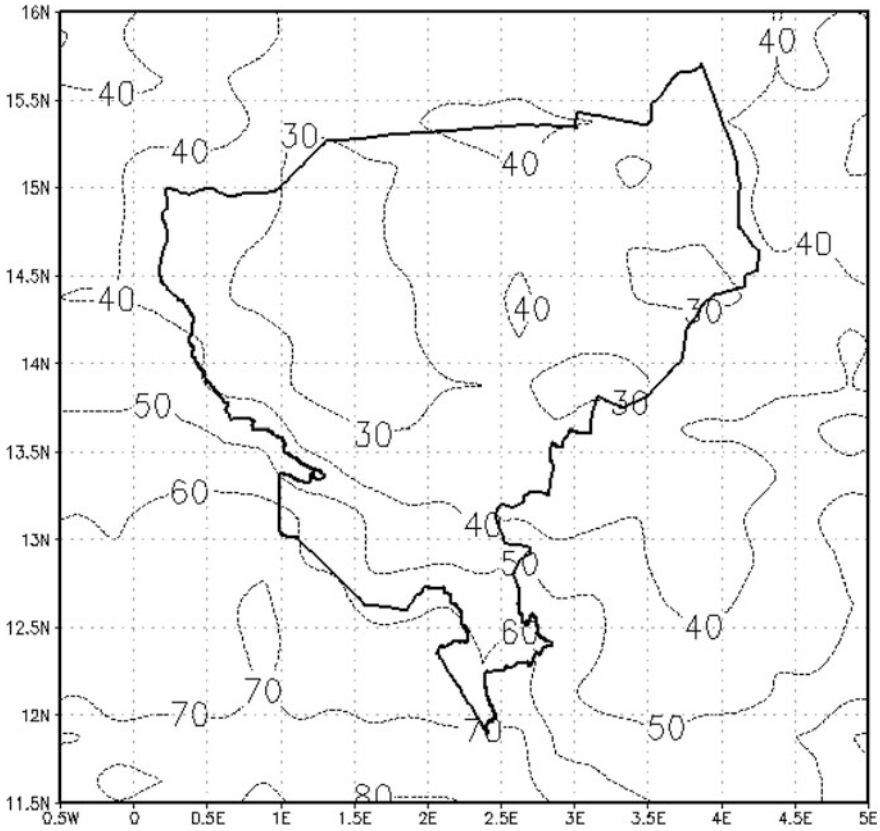
Fig. 3.6 Highest 1-day precipitation (mm)—Maximum RR sum for 1 day interval—(June–September)—Difference 2025–2035 versus 1981–2010 (CHIRPS)

3.4 Conclusions

While in the past drought was the main threat for Niger, in the last decade, yearly records for Tillaberi show the loss of many lives and production due to floods. Hazardous events frequency and intensity seem likely to increase in the future.

In this paper we characterize the distribution of extreme events evaluating current trends and future scenarios. Attention is placed on time and space distribution performing a daily resolution analysis because the pattern of intense rains can be detected only at high temporal resolution.

The findings of this study show that a serious menace is the extreme rainfall events exacerbation as confirmed by future scenarios from several bias corrected GCMs. We applied a simplified bias correction method mostly dedicated to intercept changes in rainfall distribution extremes using the overlapping period (2006–2014) of GCMs and CHIRPS rainfall estimate.

The most significant current trend intercepted in Tillaberi Region is the increase in intense rainfall phenomena. SPI analysis shows an absence of significant dry and wet periods in the recent past. The combination of these two pieces of information implies an increase of extreme events in a normal rainfall regime. Near-future projections for rainfall distribution confirm the intensification of rainfall extremes. GCMs outputs show a consistent increase in very intense rainfall phenomena and an increase in the highest 1-day rainfall amount. At the same time for drought characterization, GCMs outputs show an increase in dry spells intensity. Both maximum number of consecutive dry days and the number of periods of more than 5 consecutive dry days are predicted to increase. The combination of this information gives a not favorable picture of what we could expect for near-future climate conditions in Tillaberi and it must alert decision makers to urgently take some action.

The findings of the study demonstrate the importance of tailored climate analysis when we move toward local scale (from sub-national to municipalities). Criticalities could be intercepted only by the study of most intense phenomena at a daily resolution because these changes in extremes distribution are not detectable by typical seasonal climatic trends analysis, distributed within IPCC reports or other studies at national level.

Mapping climate changes highlights criticalities at very local scale and it could contribute to selecting priorities for the Tillaberi climatic risk adaptation process. In addition, maps support the risk assessment process giving the possibility of superposing the quantification of natural hazard likelihood with other vulnerability and exposure indicators.

Considering Tillaberi's current population growth and environmental degradation combined with the higher probability of negative climatic extreme conditions must alert decision makers to apply opportune and urgent measures in order to reduce climate risk.

As a last statement, we suggest that whenever new GCMs and rainfall estimation datasets are distributed, to perform an up-to-date analysis giving decision makers the most accurate information on future climate conditions.

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