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Research Article

Merging historical data records with MPI-ESM-LR, CanESM2, AFR MPI and AFR 44 scenarios to assess long-term climate trends for the Massili Basin in central Burkina Faso

Kabore/Bontogho Patricia Emma[†,‡*], Nikiema, Michel[‡], Ibrahim Boubacar[‡], Helmschrot, Jorg[†,ǂ]

[†]University of AbomeyCalavy,
[‡]West African Science Center on Climate and Adapted Land Use
[†]Biodiversity, Evolution and Ecology of Plants (BEE), University of Hamburg, Germany
[ǂ]Southern African Science Service Centre for Climate Change and Adaptive Land Management

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Abstract

*Burkina Faso is facing tremendous challenges for its water and agricultural sector considering temperature and floods which increased during the previous decades and given IPCC climate projections for West Africa. Addressing the lack of knowledge on climate trends at local scale, this paper assesses trends in rainfall as well as means Temperature (Tmean) from 1971 to 2050 in the Massili basin. Hence, a 50 years record (1961-2011) from Gonse station as well as data from four Regional Climate Models (MPI-M-MPI-ESM-LR, CCCma-CanESM2, AFR 44 and AFR MPI) was analyzed. The model data were extracted from the Coordinated Regional Climate Downscaling Experiment (CORDEX) data and included historical runs (1971-2005) and two representative concentration pathways scenarios (RCP4.5 and RCP8.5) for the period 2006-2050, all at 50*50 km^2 spatial resolution. The analysis of the simulation data and their comparison with the observed record indicate that only AFR 44 reproduce well the climate trend sufficiently. However, a bias correction was done for improvement. AFR 44 data predict an increase of Tmean by 1.8 °C (RCP4.5) and 3.0 °C (RCP8.5). With an increase of 7.5 mm (RCP8.5) and an increase of 14.8 mm (RCP4.5) until 2050, both rainfall scenarios from AFR 44 provide increasing estimates.*

Keywords: *Climate trend analysis, MPI-M/MPI-ESM-LR, CCMA/CanESM2, AFR MPI, AFR 44 Regional climate model projection, Massili Basin, Burkina Faso*

1. Introduction

There is an overall acknowledgment from the scientific community that future climate patterns will change depending on regions. Indeed, temperature and rainfall projections show that climate change will impact regions in different ways, with spatiotemporal changes in rainfall pattern, but generally increasing temperatures (*Barrios et al.*, 2008; *Dang et al.*, 2007; *IPCC*, 2001; *Meissner et al.*, 2003; *Snyder et al.*, 2004; *Tarhule*, 2005). Thus impacts of climate change will vary across regions and populations, through space and time, dependent on myriad factors including non climate stressors and the extent of mitigation and adaptation (*IPCC*, 2014). Assessing the future trends of temperature and precipitation at local scale would be a prerequisite to support the development of adaptation and mitigation strategies. Climate change scenarios developed by IPCC constitute a base for future climate change assessment. The first categories of SRESS scenarios were developed in 2000 and differs from the scenarios developed in 2011 (RCPs) and are based on the estimation of Green House Gas emissions. Four family type of Representative Concentration Pathway (RCP) were developed and each one defines a specific emissions trajectory and subsequent radioactive forcing.

A scenario is a storyline or image that describes a potential future, developed to inform decision making under uncertainty(*Parson et al.*, 2007). According to (*Paeth et al.*, 2011) the RCMs differ in how they reproduce the seasonal cycle due mainly to their different dynamical. Indeed, each RCM has it ability to reproduce the historical and future trends of climate patterns. Indeed, the previsions reflect a worrying increase of mean temperatures to 0,8°C by 2025 and up to 1,7°C by 2050 (*NAPA*, 2007) and a decrease of rainfall up to 3.4% by 2025 and up to 7.3% by 2050 (*NAPA*, 2007) over Burkina Faso.

RCP 8.5 was developed using the MESSAGE model and the IIASA Integrated Assessment Framework by theInternational Institute for Applied Systems Analysis (IIASA), Austria. This RCP is characterized by

*Corresponding author: **Bontogho Patricia Emma**

increasing greenhouse gas emissions overtime, representative of scenarios in the literature that lead to high greenhouse gas concentration levels (*Riahi et al.*, 2007) and the radioactive forcing level reaches 8.5 W/m^2. RCP 4.5 was developed by the GCAM (General Circulation Atmospheric Model) modeling team at the Pacific Northwest National Laboratory's Joint Global Change Research Institute (JGCRI) in the United States. It is a stabilization scenario in which total radioactive forcing is stabilized shortly after 2100, without overshooting the long-run radioactive forcing target level (*Clarke et al.*, 2007; *Smith and Wigley*, 2006; *Wise et al.*, 2009). This study is focus on Massili basin temperature and precipitation future trends analysis.

2. Data and Methods

2.1 Study area

The Massili basin (figure 1) is located between the longitudes 1°15'West and 1°55' West and the latitudes 12°17'North and 12°50' North. The basin is a sub-basin of Nakambe watershed at national scale, but is also a tributary to the trans-boundary Volta basin. Covering an area of 2612 km^2 it stretches on a perimeter of 188 km. The natural vegetation is dominated by tree and shrub savannas which represent 27% of the territory while farm land occupied 59%.

According to the agro-ecological zones established through the annual isohyets and duration of longest dry season series provided by the national meteorological network, Massilli Basin belongs to bioclimatic zone within the North type Sudanese where mean annual rainfall varies between 700 and 900 mm/year with a dry season lasting from 6 to 7 months (*Fontès and Guinko*, 1995). The rainy season starts in mid-May and ends in late September. Highest rainfall is recorded between August and September. Temperatures vary from a daily minimum of 16 ° C (December) to a maximum of 40 ° C in March and April.

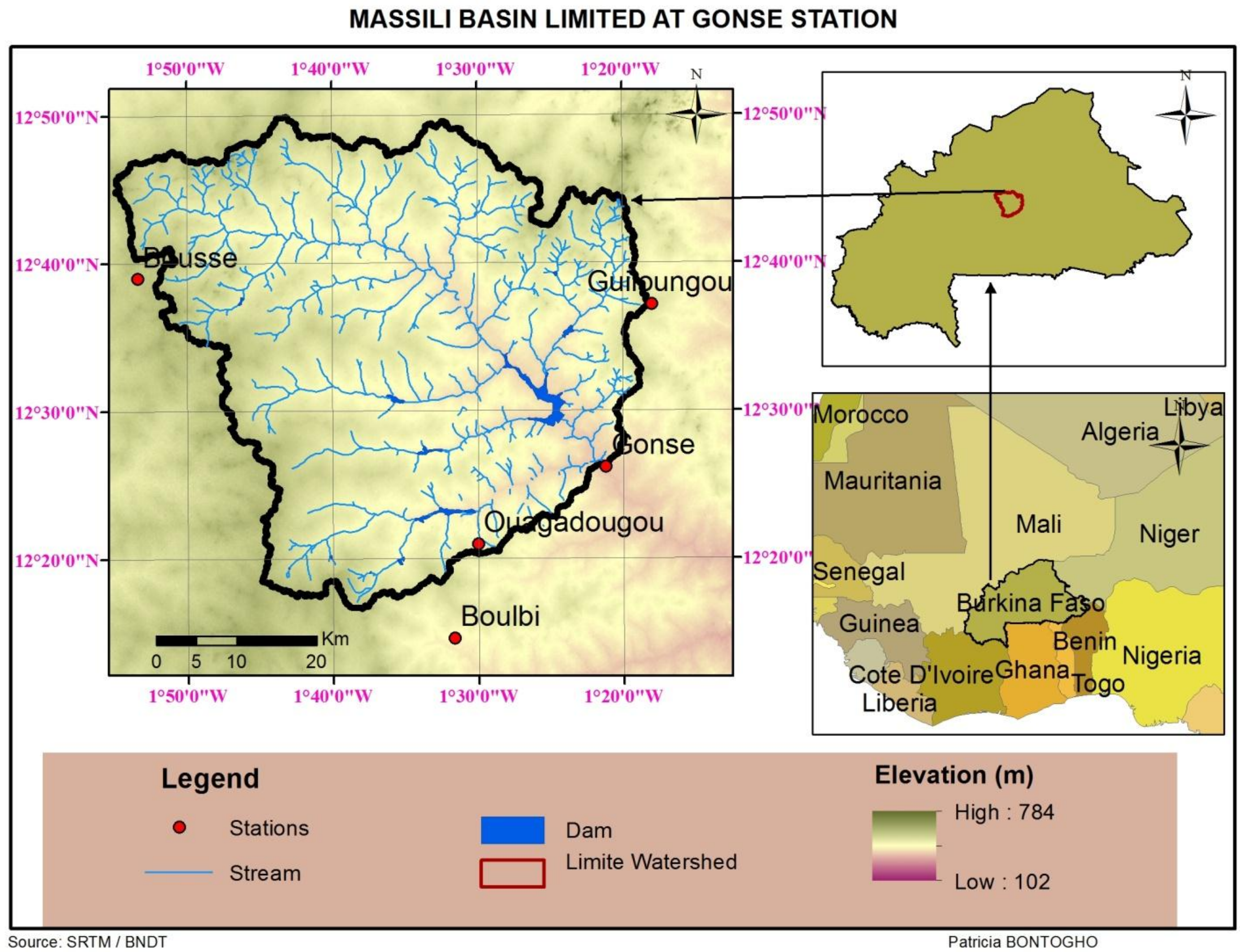


Figure 1: Location of Massili basin limited at Gonse station

2.2 Data

This study makes use of the RCM simulations from the CORDEX database CORDEX-Africa Matrix RCP4.5 and RCP8.5, 2006-2050, about 50km resolution. Projections for the period 2006-2050 in mean temperature and precipitation at monthly time step for Massili basin are used. Therefore the most extreme scenarios RCP8.5 and the steady RCP4.5 from AFR44was developed. Grads were applied to extract Cordex temperature and rainfall dataset at the basin scale.

3 Method

3.1 Choice of RCMs models for projected rainfall and temperature data extraction

Current hydrological impact studies involves application of RCMs output. This requires a selection of appropriate RCM models. Indeed, as mentioned by (*Paeth et al.*, 2011), RCMs differs in how they reproduce the seasonal cycle due mainly to their different dynamical schemes and physical parametizations of the West African monsoon. In order to select the RCM model which will present a better ability to reproduce the past observed rainfall and temperature the method of Taylor diagram was adopted. This method offers a set of RCM data and their performance according to the study area location.

3.2 Bias correction of RCM output data: delta change method

Hydrological climate change impact studies at local scale involve application of regional climate model (RCM) simulations which provides more detailed regional information (*Fowler et al.*, 2007; *Grotch and MacCracken*, 1991; *Salathé*, 2003). However, in many of these climate impact studies, the RCMs output data are applied without a quality control of the RCM data. Thus application of RCMs is still challenging the hydrological community as RCM raw data contains some biases mainly due to model high performance to simulate past and future climate pattern trend. Model bias is defined as a systematic distortion of statistical findings from the expected value. Indeed, climate variables simulated by individual RCMs often do not agree with observed time series. Many authors have highlighted the frequent bias met in RCMs simulations. RCM may misestimate climate variables in general and may simulate incorrect seasonal variations of precipitation (*Christensen et al.*, 2007; *Terink et al.*, 2009; *Teutschbein and Seibert*, 2010). In addition, (*Ines and Hansen*, 2006) noticed that RCM simulate low rain intensity. Consequently, RCMs raw data need to be corrected before application to impact studies. Correction approaches can be classified according to their degree of complexity or simplicity and have low or great ability to reduce errors in climate model output. Whatever the method used for bias correction, the correction simulations cannot reproduce exactly the observed time series as the choice for a correction technique is an additional source of uncertainty (*Chen et al.*, 2013; *Teutschbein and Seibert*, 2012; *Teutschbein et al.*, 2011).

Prior to bias correct the RCMs output data, it is important to detect the biases through comparison of past, current and projected data. In this study, method of annual average and standard deviation were applied to check the existence of eventual bias on the data. Then the delta change approach is employed to make the output of RCMs respecting the trend of the past climate pattern. The delta-change approach is a transfer method and has been widely used (*Gellens and Roulin*, 1998; *Graham et al.*, 2007; *Lettenmaier and Gan*, 1990; *Middelkoop et al.*, 2001; *Moore et al.*, 2008) because it is straightforward and easy to implement due to its simplicity. The method is based on application of a change factor which is the ratio between mean value in the future and historical run. This factor is then applied to the observed time series to transform this series set into time series that is representative of the future climate.

The monthly temperature deltas and precipitation ratios from the scenarios were applied to the corresponding monthly climate data of the validation period as shown by the following equations:

$$T^{i}_{fut,m\text{-}y} = T_{obs,m\text{-}y} + DeltaT^{i}{}_{,m\text{-}y} \tag{01}$$

$$P^{i}{}_{fut,m\text{-}y} = P_{obs,m\text{-}y} * RatioP^{i}_{m} \tag{02}$$

$$ETP^{i}_{fut,m\text{-}y} = ETP_{obs,m\text{-}y} * RatioETP^{i}_{m} \tag{03}$$

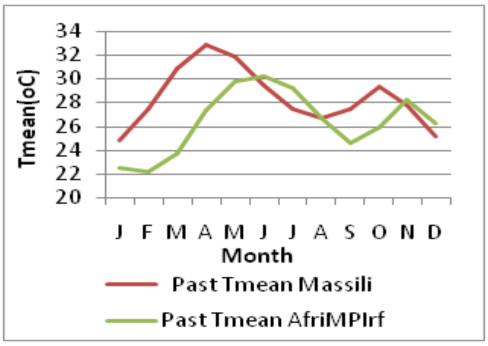
Where i is the scenario index (i=4.5 ,8.5) ;T^{i}fut, m-y is the projected (T°C) for scenario i and month m(m=1,...,12) in year y ; Tobs,m-y is the observed temperature (T°C) for month m in year y under recent past climate; Delta T is the temperature delta (T°C) for scenario i, computed for month m of future year ; P^{i}fut,m-y is the projected precipitation (mm) for scenario i and month m in year y; Pobs, m–y is the observed precipitation (mm) for day d of month m in year y under recent past. climate; and Ratio $P^{i}{}_{m}$ is the precipitation ratio (%) for scenario i, computed for month m of future year; ETP^{i}fut,m-y is the projected evapotranspiration (mm) for scenario i and month m in year y; ETP obs, m–y is the observed Evapotranspiration (mm) for day d of month m in year y under recent past. climate; and Ratio ETP^{i}_{m} is the evapotranspiration ratio (%) for scenario i, computed for month m of future year.

4. Results

4.1 Ability of the detected RCMs to reproduce the past temperature

Figure 2 shows that the monthly mean temperature is underestimated by RCMs output. MPI, CCMA and AFriMPIrf have a lower ability to reproduce the past temperature in Massili basin compared to AFR 44 which offers a better reproduction of the past temperature as shown in figure 2a). Indeed, while MPI gives underestimation of the past Tmean from October to May, and overestimation of Tmean from May to September, CCMA shows an underestimation of temperature over months. AfrMPIrf shows also an underestimation of temperature except in J-J-O. Despite the inability of AFR 44 to reproduce well the past Tmean in A-M and O-N-D, this RCM seems to perform better the past temperature trend the basin. Thus, this model will be selected for the hydrological impact study.

(a)



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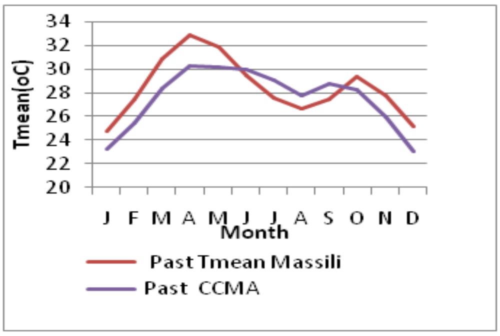

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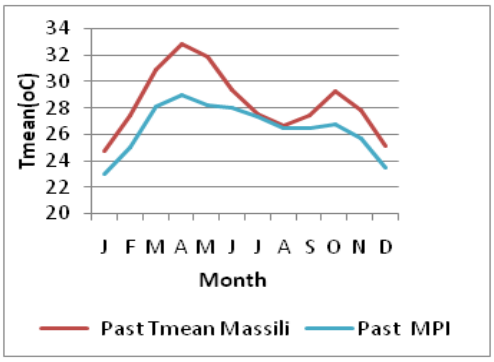
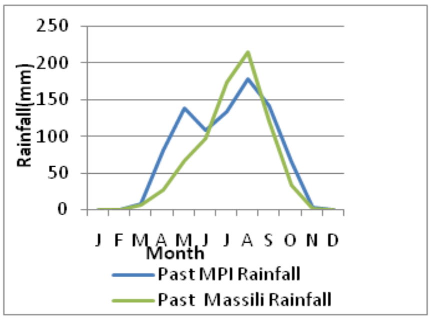


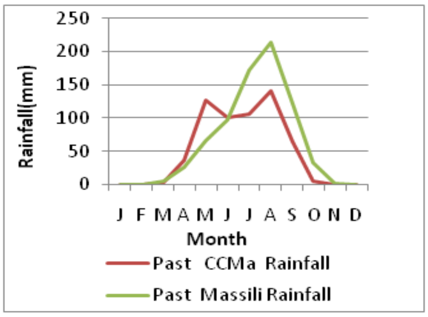
(d)

Figure 2: a) Monthly mean temperature (Tmean) for the period 1971–2000 as observed and simulated by AFR 44for the Massili catchment; b) Monthly mean temperature (Tmean) for the period 1971–2000 as observed and simulated by AFRMPIrf for the Massili catchment; c) Monthly mean temperature (Tmean) for 1971-2000 as observed and simulayed by CCMA; d) Monthly mean temperature (Tmean) for the period 1971-2000 as observed and simulated by MPI

4.2 Ability of the detected RCMs to reproduce the past rainfall



(a)



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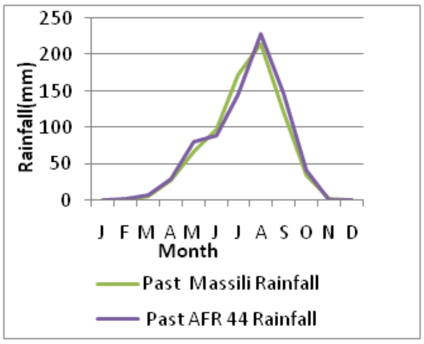

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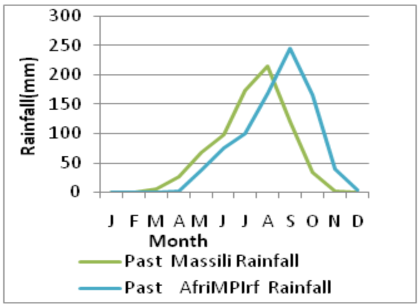


(d)

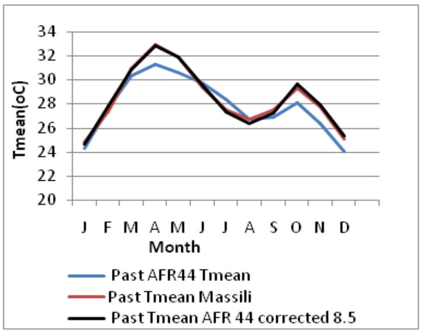
Figure 3: a) Monthly rainfall for the period 1971–2000 as observed and simulated by MPI and for the Massili catchment; b) Monthly rainfall for the period 1971–2000 as observed and simulated by CCMA for the Massili catchment; c) Monthly rainfall for the period 1971–2000 as observed and simulated by Afri 44 for the Massilicatchment;d) Monthly rainfall for the period 1971–2000 as observed and simulated by AfriMPIrf for the Massili catchment

MPI, CCMA and AFriMPIrf have a lower ability to reproduce the past rainfall in Massili basin compared to AFR 44 which offers a better reproduction of the past rainfall as shown in figure 3. Indeed, both MPI and CCMA gives two picks during the rainy season while in Massili basin the rainy season occurred only between June-September with high rainfall amount recorded in August.

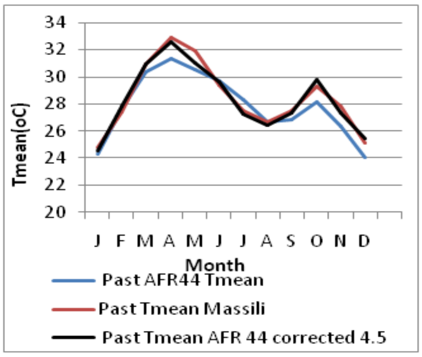
In addition, AfriMPIrf reproduces slightly the rainfall cycle in the basin but with September as the month of high rainfall occurrence. AFR44 however has a satisfactory reproduction of the rainfall trend. In summary, compared to MPI, CCMA and AfriMPIrf, AFR 44 tends to perform better the past rainfall cycle in Massili basin. Thus, output data of this model will be selected to force the hydrological model for the climate change impact study.

4.3 RCM output bias corrected

Using the delta change method, the future rainfall and temperature were corrected.



(a)



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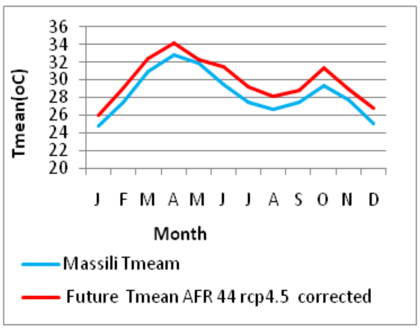

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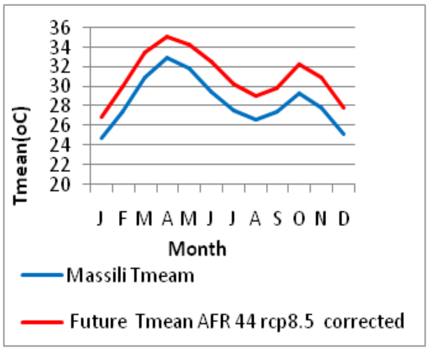
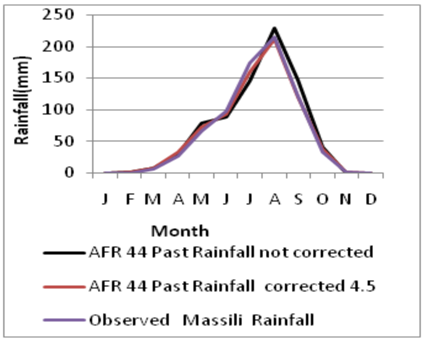


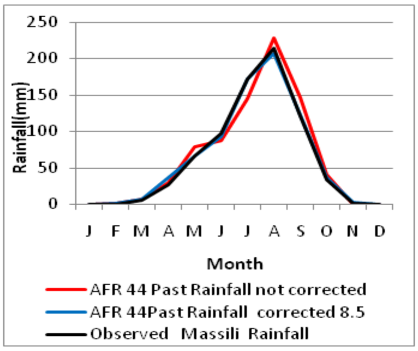
(d)

Figure 4: a) Past monthly mean temperature as simulated by AFR 44 8.5; b) Past and monthly mean temperature as simulated by AFR 44 4.5; c) Future monthly mean temperature as simulated by AFR 44 4.5; d) Future monthly mean temperature as simulated by AFR 44 8.5

The monthly rainfall tendency of the RCMs is almost univocal for the Massili basin. Figure 4 shows the monthly past (corrected and not corrected) and future (past and not corrected) temperature over the past period by 2050. The AFR 44 data predict an increase of Tmean by 1.8 ° C (RCP4.5) and 3.0 °C (RCP8.5) from 1971 to 2050. AFR 44 under RCP4.5 and RCP8.5 scenarios is showing an increase in future rainfall patterns.



(a)



(b)

Figure 5:a) Past corrected and not corrected monthly rainfall as simulated by AFR 44 rcp 8.5 over 1975-2000 in Massili catchment ; b) Past corrected and not corrected monthly rainfall as simulated by AFR 44 rcp 4.5 over 1975-2000 in Massili catchment

Figure above shows the monthly past (corrected and not corrected) rainfall over the past period by 2050. With an increase of 7.5 mm (RCP8.5) and an increase of 14.8 mm (RCP4.5) until 2050, both rainfall scenarios from AFR 44 provide increasing estimates.The increasing trend of rainfall indicated corroborates and may attest the finding of (*Salack et al.*, 2011) on the Sahel growing green again.

5. Discussion

The findings of this study show that RCM simulations raw data are a source of huge uncertainties which may hamper subsequent impact simulations. Consequently, correcting bias seems to be primordial for climate-change impact studies despite the problematic aspects related to bias correction methods (*Ehret et al.*, 2012) . To obtain realistic rainfall and temperature in the past and future climate, delta change method was used. Application of delta change method showed a satisfactory performance and transferability to potentially changed climate conditions, as it was able to correct the past and future climate conditions however limit of delta change method are not neglected. Indeed, according to (*Teutschbein and Seibert*, 2012) , physical causes of model errors are not taken into account and, thus, a proper physical foundation is missing .In addition, spatiotemporal field consistency and relations between climate variables are modified. They also highlighted that conservation principles are not met, variability ranges might be reduced without physical justification and feedback mechanisms are neglected (*Ehret et al.*, 2012). Thus the worst impact of climate change on Massili basin is unavoidable.

The increasing trend of temperature and rainfall are in line with (*IPCC*, 2014) findings which state that global surface temperature change for the end of the 21st century is likely to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP2.6. It is likely to exceed 2°C for RCP6.0 and RCP8.5, and more likely than not to exceed 2°C for RCP4.5. Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. Warming will continue and will lead to high evaporation with great consequences in open reservoirs water availability. In addition, increase in precipitation may lead to extreme event occurrence (flood) such as the flood experienced within the basin on 1srt September 2009.

Conclusion and outlook

Climate change is ongoing and it is important to understand the future trend of its patterns at local scale which will serve as precursor for accurate adaptations strategies. The purpose of this paper was thus to analyse future climate change in Massili basin The work is realized using monthly data of rainfall and temperature from RCMs. The results show that Massili basin would experience worst impact of climate change. Temperature and precipitation are assumed to increase in the future.This study is part of a broader research that will assess future climate impact on the basin hydrological processes. The study showed that linking historic climate data with RCM projections are suitable assessing long-term climatic trends and, therewith, providing the required knowledge to develop climate adaptation strategies in Burkina Faso.

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