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Climate projection and future rainfall trends analysis in the Nouhao sub-basin in Burkina FASO

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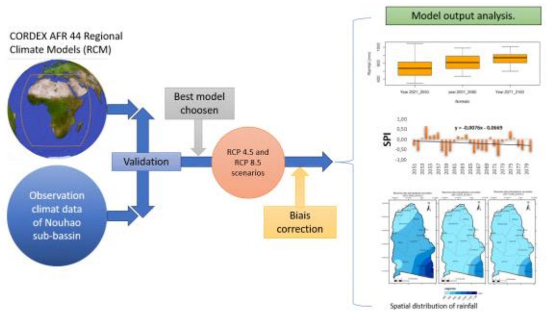
Graphical abstract



Abstract

Climate change is an indicator of changes happening in the biosphere. Monitoring it, will anticipating actions against the resulting disasters. This study, undertaken in Burkina Faso Nouaho sub basin, gives an overview of rainfall in the near, medium and long terms. It is built on regional climates models which are climates projections from global climate models downscaling. These models are generated basis on scenarios like greenhouse gas emissions and radiative forcing called Regional Concentration Pathways (RCP). The two scenarios RCP 4.5 and RCP 8.5 chosen in this study, have enabled to identify a rainfall regional climate model whose output corrected basis on Nouhao sub-basin observation data, highlight changes in sub-basin future precipitation. Over the three defined normal, i.e. normal 1 (2021-2050), normal 2 (2051-2080) and normal 3 (2071-2100), cumulative annual rainfall mean shows a downward trend under the RCP 4.5 scenario, and an upward trend under the RCP 8.5 scenario.

The Standardized Precipitation Index (SPI) for the RCP 4.5 scenario shows very wet years at the start of normal 1, before giving way to alternating years close to normal rainfall, in normal 2 and 3. In the RCP 8.5 scenario, the SPI shows a dominance of dry years in normal 1. In normal 2 and 3, wet and very wet years return to dominate.

The spatial dynamics of future rainfall, meanwhile, show a latitudinal shift in annual rainfall totals towards the south-east of the sub-basin under the RCP 4.5 scenario, and towards the north-west under the RCP 8.5 scenario. The climate projection thus highlights possible future changes in precipitation in the sub-basin. Its consideration could form the basis for the implementation of climate change adaptation strategies in the area.

Keywords: Regional climate model, climate scenario, rainfall distribution, standardized precipitation index , Nouhao sub-basin.

1. Introduction

Climate change is one of the major concerns of the 21st century. Indeed, as climate is the demonstration of weather events, it is a key indicator of changes in the biosphere (Lavorel *et al.* 2017). Since the 20th century, scientists have observed a rapid and unusual change in the Earth's climate, based on indicators such as the global temperature, which has risen by 0.6°C, probably the highest increase recorded in a century over the last millennium (UNESCO 2006). Since then, climate change has become a threat seriously taken considered by individual governments in the world. This has even led to the creation of the Intergovernmental Panel on Climate Change (IPCC), mandated to give scientific expertise on the state of the climate and its trends (Lauret and Barberousse 2015). Various approaches exist to monitor climate change. One of these is climate projection, which depends on the emission, concentration or radiative forcing scenarios used. This approach generally builds on assumptions such as future socio-economic and technological developments (Ouzeau *et al.* 2014). Knowing the climate projection of an area is of great importance to understand the climate changes taking place in this particular area. It is even more important for Sahel countries such as Burkina Faso. For several decades now, the Sahel has been undergoing significant climate change, which has impacted food security, environment and the lives of local communities, making this part of the continent highly vulnerable to climate change effects (Larwanou 2011). In such a context, it is important to understand the trends and future projections of the Sahel climate to better anticipate future challenges and implement effective adaptation policies. The most common means used to explore future climate trend are climate models. At the local level like village, basin, departmental, etc, it's Regional Climate Models (RCMs) from global model downscaling which are used to explore the future climate. In fact, after chosen the best RCM basis on observation data, a bias correction permits to get a output data with reduced uncertainties, very important for vulnerability and impact assessment at local level (Flaounas *et al.* 2011, Bodian *et al.* 2020). In Senegal, Ndiaye have determine the future climate trends and analyze its effect on Senegal river basin through the RCMs (Ndiaye *et al.* 2021). Similarly Okafor has investigated the changes in the climate and the spatiotemporal variations in climate extreme indices of the Dano catchment in Burkina Faso using climate projection from RCMs (Okafor *et al.* 2021).

This study, aims to analyze future rainfall trends in the Nouhao sub-basin on the basis of projection from the climate models downscaling. Specific objectives include i) assess performance of climate models in reproducing rainfall in the sub-basin; ii) calibrating the best performing model in reproducing rainfall in the sub-basin; and iii) analyze the model rainfall outputs.

2. Materials and methods

2.1. Presentation of the study area

The Nouhao sub-basin (Figure 1), where our study was carried out, is an hydrological basin large part of which is in the central-eastern region of Burkina Faso. Its covers 4261 km^2 (IGB-BNDT-BDOT 2002) comprising 16 communes and around 180 villages. Nouhao is the main river which rises in the north-east and flows into the south-west. The rivers in the basin are not permanent, but have an average annual input of 375.28 million m^3. The Nouhao sub-basin has two climate types including, the Sudano-Sahelian climate -with an average annual rainfall less than 900 mm, and the Sudanian climate with an average rainfall beyond 900 mm per year. On average, the rainy season does not exceed 6 months (Edl-Aen 2015). Rainfall in the SBN is monitored by several stations with Dialgaye, Kominyanga, Ouargaye, Zabré, Sangha and Bittou as the main ones. In 2017, this sub-basin was host to 340,000, with water coverage for various uses of 42% (Noba *et al.* 2023). The forest formations found in the Nouhao basin consist mainly of wooded savannah and, to a lesser extent, gallery forests (Fiédi Hakiekou 2011).

2.2. Assessing the performance of regional climate models in reproducing Nouhao rainfall.

2.2.1. Rainfall observation data collecting

For this study, observation data of Nouhao rainfall have been collected through

NASA (National Aeronautics and Space Administration) climate database MERRA-2. These data are from the NASA/POWER/CERES/MERRA2 Native Resolution Monthly and Annual reanalysis. They have been downloaded from 06 specific locations. These locations coordinates are those of the climatologic stations of Bittou, Dialgaye, kominyanga, Ouagaye, Sangha and Zabre which are in and around the subbasin–see Figure 1.

The use of satellite data from the MERRA-2 for this study has been motivated by gap accounted in data from surface rainfall observations provided by the Agence Nationale de la Météorologie du Burkina Faso (ANAM). In fact, no rain data were available some months and even years. As a result, the use of these data was difficult. For (Fenta *et al.* 2018) satellite data are generally used to replace of observation data from rainfall stations that are incomplete or inaccessible in certain parts of Africa. Their use depends on their comparison with existing surface observation data.

The MERRA-2 data parameters is based upon the surface observations reported in the NCEI Integrated Surface Database (ISD) of NASA. These data have been validated from 2,606 surface observations stations in the worldwide, including those in Burkina Faso. These validations have used the Slope, Intercept, and R-squared (Rsqrd) associated with linear least squares fit of hourly observations at each surface station to the corresponding MERRA-2 values for the overlapping grid cell for 2001 through 2019. The Mean Bias Error (MBE), Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) represent mean values over the comparison years have been also evaluated as recommended by some authors like Labarere (2012) and Moriasi *et al.* (2007). Many study like those of Ebode *et al.* (2021), Amrouni (2022), Okafor *et al.* (2021) have been implemented in Africa including Burkina Faso through the use of MERRA-2 climate data, proof of its reliability.

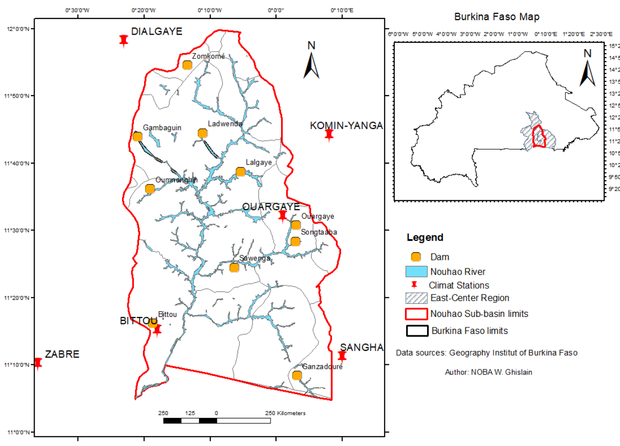


Figure 1. Nouhao sub-basin

2.2.2. Model acquisition and processing

As part of this assessment, downscaling climate models have been acquired firstly. This acquisition is carried out on the (CORDEX) domain.

The selection criteria applied include, the model domain - which is that of Africa, the 50 km resolution, the regionalization of the model, the model parameter, which is precipitation, and the availability of historical data, and those of, RCP 4.5 and RCP 8.5 scenarios. Fifteen model histories that meet these criteria are then downloaded and processed.

The model files, generally produced by cordex, are in network Common Data Form (NetCDF) format. The NetCDF is a file to store multidimensional scientific data (variables) (Rew and Davis 1990). It can only be used with specific tools such as a computer terminal, Climat data operator (CDO), Python, netCDF Operators(NCO), etc. CDO is the one chosen for this research. Processing applied to the models using CDO is as follows: concatenation, conversion, delimitation and variable extraction.

- Concatenation: The files from the cordex database are time series of data compiled in 5-year intervals. To get a single file for a long series of years from the 5-year time series files, they have been concatenated using the syntax: "cdo mergetime infiles outfile".
- Conversion: Data from raw rainfall files acquired from the CORDEX database are generally in Kg m^2 s^{-1}. To change into "mm", which is the commonly used unit to quantify rainfall in Africa, the variable has been so converted by multiplying it by 86.400 using the synthax: "cdo mulc, 86400 infiles outfile".
- Delimitation: The scope of Netcdf file is the African continent. To reduce this coverage to basin level and in line with spread of the various climatological stations, delimitation has been done using the following syntax: "cdo sellonlatbox,lon1,lon2,lat1,lat2 infiles outfiles".
- Variable extraction: It is process to extract data from a geographical point in the model. In this research, 6 climatological stations data have been extracted. The stations are Bittou, Dialgaye, Komin-Yanga, Ouagaye, Sangha and Zabre located in and around the study area through the different models using the "cdo remapnn,lon=...../lat=.......infiles outfiles" synthaxis.

2.2.3. Validation and selection of the best model

To assess the performance of the models and choose the best model, the rainfall history of the models resulting from the processing is compared to the observation at the Nouhao basin level. The comparison period is from 1981 to 2005, i.e. 25 years. This period was adopted due to the fact that the rainfall observation from the climatological stations around and in the Nouhao basin begin in 1981, whereas the historical data from the CORDEX regional models end in 2005. The comparison between the observed data and the models was made by station and on the average of all the stations. The Taylor diagram is a method used to assess model performance. It is a graphical representation of the closeness of one or more series of modelled data compared with a series of observed data. Three (03) statistical indicators are used in this process: the RMSE (root mean square error), the correlation and the standard deviation. A climate model can reproduce monitored data perfectly when the indicators in the diagram, such as RMSE=0 or tending towards 0, correlation =1 and the standard deviation of the modelled data are equal to the standard deviation of the monitored data (Taylor 2001).

2.2.4. Calibration of the chosen climate model

The calibration of the chosen climate model consists in reducing the biases or errors. This is done by correcting the climate bias. Climate bias correction is a means of reducing errors between observed data and climate models when carrying out an impact or vulnerability study on a local scale (Eden *et al.* 2012). The bias correction applied in the research is quantile-quantile correction or quantile mapping. It consists in estimating the correction or bias by transforming the distribution functions of the modelled variables into observed functions using a mathematical function, as follows $X^0 = f(x^m)$ with X^0 = observed variable, X^m = simulated variable, and f() = transformation function. Once estimated, the transformation function is applied to the variables from the future climate simulations (Piani *et al.* 2010). The Qmap package found in the R software and implemented by (Gudmundsson *et al.* 2012) was used to apply this quantile-quantile bias correction. The performance of the correction was then evaluated on the basis of the calculation of the bias of the corrected simulated data compared to the observed data using equation 1 (Taïbi *et al.* 2021)

$$\text{Biais (\%)} = \frac{\text{Simulated\_rain-Observed\_rain}}{\text{Observed\_rain}} * 100 \tag{1}$$

To ensure performance of this correction, the mean annual rainfall of the simulated data was compared with the observed data. This comparison was done after assessing the average rainfall for the sub-basin using the Thiessen polygon method. This method consists in dividing the basin's surface area by the zone of influence of the various climatological stations measuring rainfall and located in or around the sub-basin. The division is carried out geographically using Arcgis 10.8 software, which has a module to determine Thiessen polygons (Brassel, Kurt E. et Reif 1979). E quation 2 gives the formula for assessing the average rainfall after determining the zones of influence and assigning an influence factor to each station (THIESSEN 1911).

$$P_{moy} = \frac{\sum A_i * P_i}{A}$$

Pmoy: average rainfall over the basin, A: total area of the basin (=∑Ai), Pi: rainfall recorded at station i, Ai: area of the polygon associated with station i.

2.3. Analyzing outputs of the chosen model

Outputs of the selected and corrected model were analyzed over three-time periods: near future (2021-2050), medium future (2051-2080) and long term (2071-2100). The analysis based on the dispersion of cumulative annual rainfall values, the assessment of standardized rainfall indices and the spatial representation of cumulative annual rainfall.

Analysis of the dispersion of the cumulative annual rainfall allows to identify the value of future rainfall fluctuations. Their analyze is so based on graphs, in particular, box plots. Standardized Precipitation Index (SPI) can be used to identify wet and dry periods (IRIE *et al.* 2015). Its assessment is based on Nicholson's method (Nicholson 1985) formulated in equation 3.

$$SPI = \frac{P_i - \bar{P}}{\delta} \quad (3)$$

Pi= Cumulative annual rainfall for year i, P= Interannual mean of the variable over the study period, σ = the standard deviation of the variable over the study period.

Table 1 provides the characteristic of each year by SPI value.

Table 1. SPI classification

SPI	CLASSIFICATION
2 and more	Extremely humid
1.5 à 1.99	Very damp
1.0 à 1.49	Moderately humid
-0.99 à 0.99	Close to normal
-1.0 à-1.49	Moderately dry
-1.5 à -1.99	Severely dry
-2 at least	Extremely dry

Source: (WMO 2012)

Spatial representation of rainfall is appropriate to assessing the spatial distribution of rainfall on the entire Nouhao sub-basin. To this effect, Arcgis 10.8 software which uses the IDW (inverse distance weighted) interpolation method to determine the values of the spatial classes using a linear weighted combination of all the climate stations.

3. Results and discussion

3.1. Performance of climate models in reproducing sub-basin rainfall.

Validation of the various models using the Taylor diagram in all 6 climatological stations produced the findings captured in Figure 2. Analysis of these graphs shows that most of the models roughly reproduce the observed data for the Nouhao sub-basin area from 1985-2005 with one model standing out best. The regional model RC4 forced on the CNRM-CERFACS-CNRM-CM5 global model from the Swedish Meteorological and Hydrological Institute (SMHI), is the best performing model. The model has a very good correlation of over 80% for the 6 stations. Its root mean square error (RMSE) is among the lowest and its standard deviation from observation is also low at most stations. It is therefore the model chosen for the climate projection considering its best performances. The regional model RC4 forced on the CNRM-CERFACS-CNRM-CM5 global model is a model most use in west Africa and particular for Burkina Faso. Okafor *et al.* 2021 and Ogega *et al.* 2020 have used this model in their study respectively in west Africa and Burkina Faso.

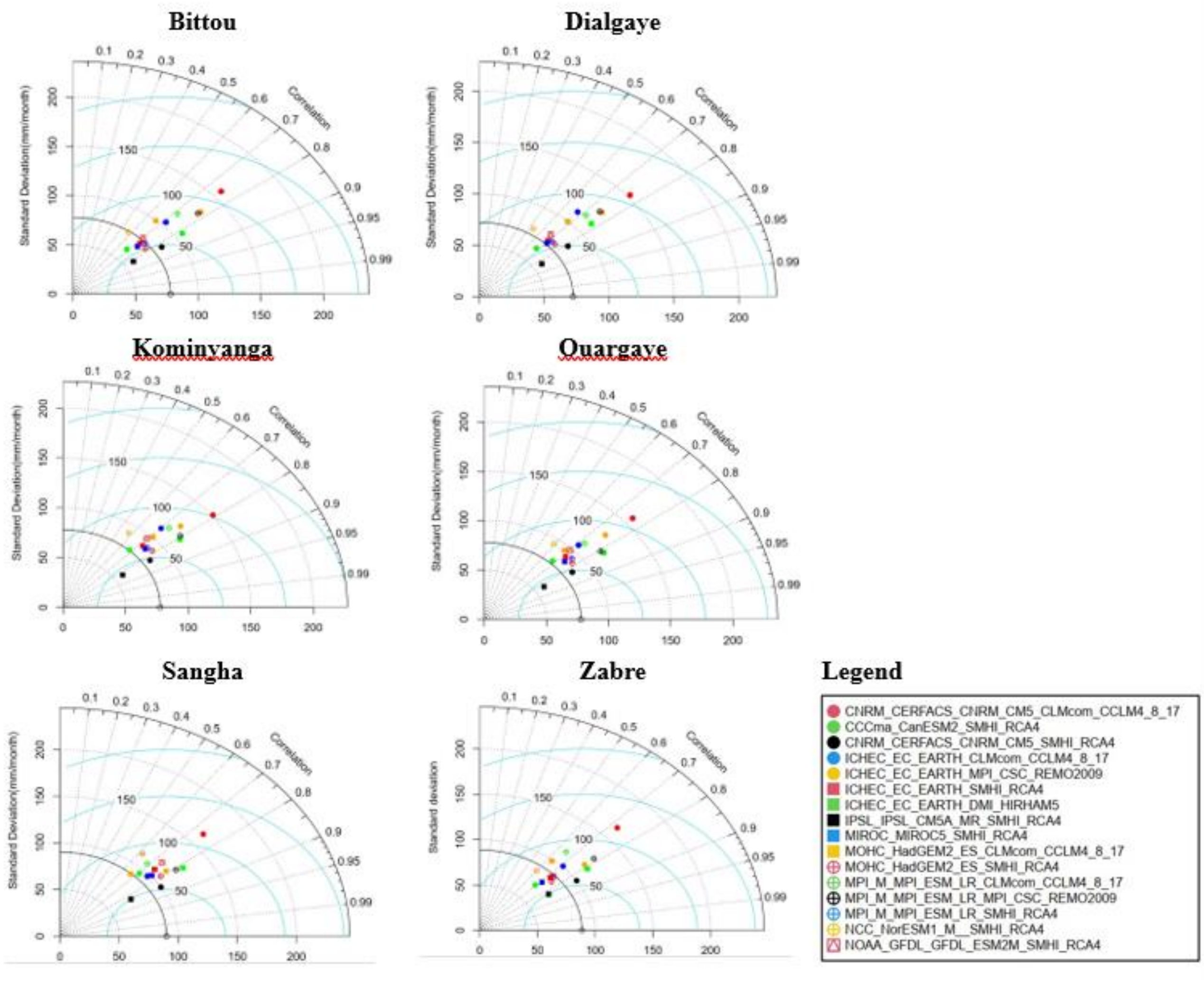


Figure 2. Taylor diagrams comparing models to observation datas of Nouhao sub-basin climate stations.

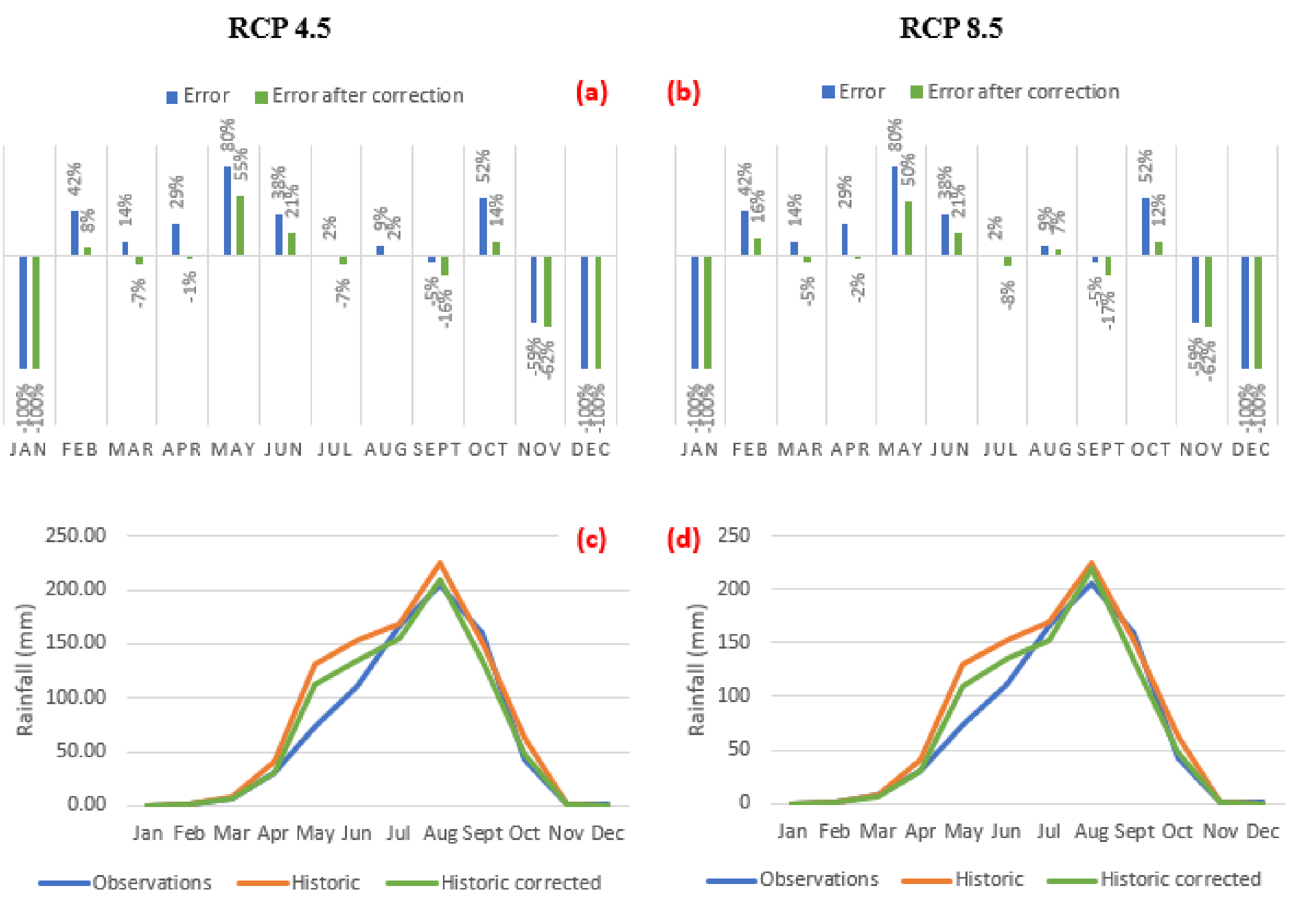


Figure 3. Bias correction performance evaluation for RCP 4.5 and RCP 8.5 of the chosen models.

3.2. Calibration of the chosen climate model

To ensure the quality of the RCP 4.5 and RCP 8.5 outputs of the RC4 model selected, a bias correction was carried out on the 06 climatological stations in the sub-basin. Average rainfall was then calculated using the Thiessen method.

This correction was assessed by calculating the bias before and after correction and by comparing the monthly averages of the historical period (1981-2005) of the corrected simulated data with those of the observed data, as shown in Figure 3. The bias correction performed on the two model outputs shown in Figure 5(a) and 5(b) shows that the months of January, November and December have biases that have almost not been corrected. In fact, January and December still have a corrected bias of 100%, while November, which was 59%, has just fallen to 62%. This can be explained by the fact that the simulated data, as shown in Figure 5(c) and 5(d), reproduce very well the observations at the beginning and end of the year. The major decreases in bias are observed from February to October. These decreases range from plus or minus 5% to 34% for the RCP 4.5 scenario and from plus or minus 2% to 40% for the RCP 8.5 scenario.

According to Deque (2007) it is very difficult to have a bias correction that completely eliminates the errors between the simulations and the observed data because the correction method itself can involve uncertainties. Based on this assertion the correction shown in Figures 5(c) and 5(d) is a good performance because it present that the simulated data corrected by the model are very close to the observed data over the 1981-2005 control period.

3.3. Statistical characteristics of rainfall for the RCP 4.5 and RCP 8.5 scenarios according to the climate model chosen.

Figure 4 shows the statistical characteristics of the cumulative annual rainfall series for the RCP 4.5 and RCP 8.5 scenarios in the corrected regional RC4 model forced on global model CNRM-CERFACS-CNRM-CM5. These representations are based on 3 times horizons: Normal 1 (2021-2050), Normal 2 (2051-2080) and Normal 3 (2071-2100). The year rainfall cumulative of RCP 4.5 scenario represented in Figure 4 has three major characteristics. The first is the minimum amount of annual rainfall, which is respectively 559 mm, 619 mm and 620 mm for Normal 1, 2 and 3. The second major feature is the median, which shows that 50% of annual rainfall will be below 770 mm, 741 mm and 744 mm for normal 1, 2 and 3 respectively. The mean rainfall for these three periods is 884 mm, 762 mm and 751 mm respectively. The last major piece of information for this RCP 4.5 scenario is the maximum rainfall, which is 1107 mm, 925 mm and 989 mm for Normal 1, 2 and 3 respectively.

For the RCP 8.5 scenario shown in Figure 5**,** the simulated minimum rainfall for the three periods is 546 mm, 634 mm and 698 mm respectively. The median, which divides the output data series into two equal parts, shows values of 735 mm, 809 mm and 870 mm, while the mean is around 738 mm, 811 mm and 850 mm. The maximum rainfall from this RCP 8.5 output for the 3 time periods is 1047 mm, 990 mm and 1011 mm.

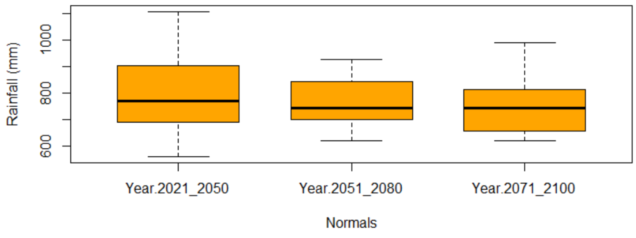


Figure 4. Dispersion of cumulative rainfall according to RCP 4.5

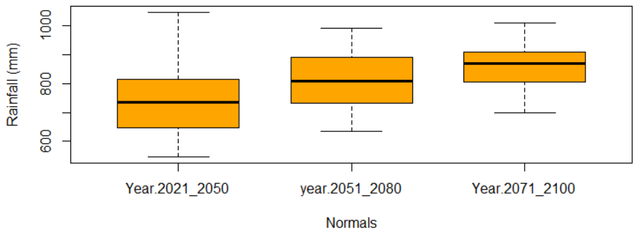


Figure 5. Dispersion of cumulative rainfall according to RCP 8.5

In summary, for the RCP 4.5 scenario, the mean values of the rainfall decrease as time move towards the end of the century, highlighting rainfall decrease over the time, whereas in the case of the RCP 8.5 scenario, the trend is the opposite, i.e., the mean values of cumulative rainfall increase over time.

The rainfall decline in the African zone revealed by the RCP 4.5 scenario in our study is also observed in other studies. The strategy Cote d'Ivoire national climate change program refers to a decrease of rainfall around 8% by 2100 under RCP 4.5. (Bernard 2014). The same was observed in Benin (Kwawuvi 2023) in the Oti River basin, where a fall in rainfall of around 103.6 mm/year between 2021 and 2050 is expected under RCP 4.5. As for the RCP 8.5 scenario, where an increase in rainfall is observed, Yonaba (2020) made the same observation in the Tougou basin in Burkina Faso.

3.4. Characteristics of future climate variability in the Nouhao basin According to RCP 4.5 and RCP 8.5 scenarios

The Standardized Precipitation Index (SPI) assessed based on the rainfall data from the RCP 4.5 and RCP 8.5 scenarios of RC4 chosen presented in Figures 6 and 7 is a means to predict rainfall trends in the Nouhao sub-basin. SPI was developed by American scientists McKee, Doesken and Kleist since 1993 to quantify the rainfall deficit on multiple time scales (OMS & OMM 2012), (Bedoum *et al.* 2014). It is also used to characterize rainfall variability and meteorological drought (EL Hawari & EL Ghachi 2023).

Figure 6 shows the SPI calculated based on data from the RCP 4.5 scenario for normal 1, 2 and 3. Normal 1 begins with very wet and extremely wet years, before giving way to alternating slightly dry and slightly wet years, with a tendency for slightly dry years to dominate from 2040 onwards. Normal 2 is marked by a dominance of so-called near-normal years. This dominance continues in Normal 3 until the last decade, when moderately dry years appear. The SPI of Normal 1 and 3 present some long series of dry periods which are often indicative of drought, it's the case of the periods 2032-2037 and 2093-2094 which appear as drought years of drought, as is the case in normal 1 and 3, where the SPI indicates that the periods 2032-2037 and 2093-2094 are drought years.

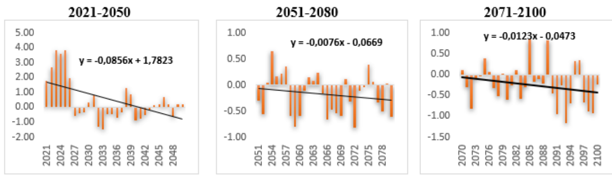


Figure 6. SPI of RCP 4.5

Figure 7 shows the SPI of rainfall data from RCP 8.5 of the selected model spread over the three normal. Normal 1 show alternating dry and wet years, with very dry years predominating.

Normal 2 is characterized by alternating very dry and wet periods, with wet periods dominating. This trend continues in normal 3, with very wet years appearing from time to time. The SPI of RCP 8.5 of the chosen model reveals a long series of dry years in normal 1, a sign of drought. In fact, the ranges of years in the dry periods of normal 1 from 2022-2024; 2030-2038 and 2048-2050 are drought periods in terms of the value of their SPI.

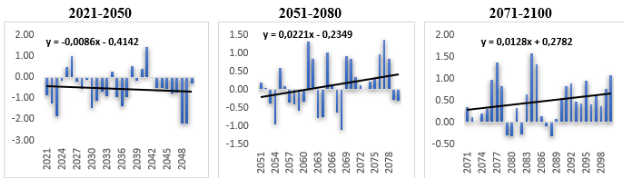


Figure 7. SPI of RCP 8.5

Based on the analyses induced by the SPI of RCP 4.5 and RCP 8.5 of chosen model, it's expected rainfall variability in the Nouhao basin in the short, medium and distant future. The variability induced by this rainfall will carry consequences. For (David & Noël 2014) Rainfall-induced variability in West Africa is a major risk for agriculture, which heavily relies on rainfall. In particular, the consecutive wet years observed in RCP 4.5 and RCP 8.5 is an indicator of increased rainfall. Increased rainfall can lead to major flooding, which can cause deaths and significant material damage (Nouaceur 2020). From a hydrological point of view, increased rainfall increases river flow, groundwater levels and fills surface reservoirs (Koné *et al.* 2019, Qadem *et al.* 2022). It can also help rebuild the plant cover in some arid zones (Cornet 1992). Consecutive years of light humidity or drought leads either to more water or to latent droughts (Ghenim and Megnounif 2013). More specifically, normal conditions with alternating slightly wet and slightly dry years can disrupt cropping calendars and reduce crop yields (Souberou *et al.* 2018, Djohy *et al.* 2015). Successive dry years negatively impact runoff. Rainfall deficits can cause a reduction in groundwater reserves, resulting in a drop in level of monitoring wells (Goula *et al.* 2006). In Burkina Faso, another observation made in relation to consecutive dry years is the reduction in surface water areas in wetlands (Yameogo *et al.* 2023). In agricultural terms, succession of dry years causes water stress, leading to poor crop yields (Rodrigue *et al.* 2023).

3.5. Spatial characteristics of future rainfall in the Nouhao basin

Figure 8 shows a spatial representation of the data from RCP 4.5 and RCP 8.5 of the model chosen for the three normal periods -the near, medium and distant futures. This spatial representation shows that in RCP 4.5 normal 1, the northern part of the sub-basin is covered by rainfall averaging less than 850 mm per year. The majority of the central part is covered by an average rainfall of between 850 mm and 900 mm per year. The south-eastern of the sub-basin has an average rainfall of between 900 and 1100 mm per year. In the normal 2 and 3 of RCP 4.5, the majority of the sub-basin is covered by an average annual rainfall of less than 850 mm, with only a small portion in the south-eastern part having an average of around 850 to 900 mm.

The rainfall from RCP 8.5, shows in normal 1 and 2 a spatial zone mostly covered by mean annual rainfall of less than 850 mm, while revealing a small portion in its south-eastern part which shows rainfall ranging from 950 mm in normal 1 and 1000 mm in normal 2. In RCP 8.5 normal 3, the spatial distribution of mean annual rainfall shows rainfall of less than 850 mm in the northern part of the sub-basin. In most of the central part of the sub-basin, mean annual rainfall is between 850 and 900 mm. In the south-eastern part, mean annual rainfall is up to 1100 mm. The summary that can be made of this spatial characteristic is that the spatial variability of rainfall induced by the RCP 4.5 scenario is characterized by a decrease in rainfall from north to south-east in the sub-basin over time. In the RCP 8.5 scenario, the opposite effect occurs, with an increase in rainfall from south-east to north over time.

The spatial dynamics of rainfall induced by the RCP 4.5 scenario for the future confirms the decline in rainfall observed in Burkina Faso since 1951, resulting in a latitudinal shift of the mean isohyets towards the south (Kabore *et al.* 2017, Robert 2010).

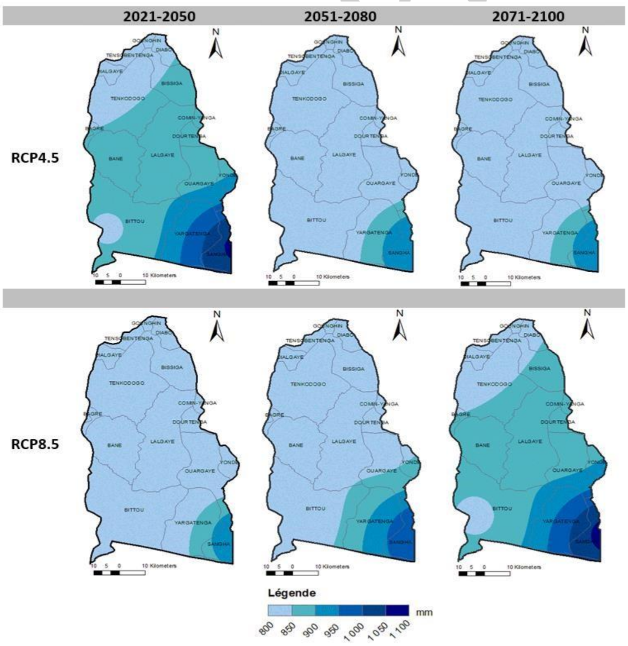


Figure 8. Spatial distribution of future rainfall according to RCP 4.5 and RCP 8.5.

4. Conclusion

The climate projection in the Nouhao sub-basin in Burkina Faso has helped to identify a climate model that best reproduces rainfall behaviour in the basin. Using this model, an overview of the spatio-temporal behaviour of future rainfall in the sub-basin has been realized. The projection shows that future mean annual cumulative rainfall decreases from normal 1 to normal 3 in the RCP 4.5 scenario. In fact, the yearly mean rainfall waiting for the Normal 1, 2 and 3 are respectively 884 mm, 762 mm and 751. In Scenario RCP 8.5 the climate projection shows an opposite behavior of cumulative rainfall average i.e. an increase. The mean rainfall for the three normal is 738 mm, 811 mm and 850 mm respectively.

Variability analysis shows a predominance of slightly dry periods in RCP 4.5 with some extreme events as very damp and extremely humid years, recorded at the first's years of Normal 1.

In the RCP 8.5 scenario, the variability analysis shows that, dry periods prevail in normal 1 but over time balance out with wet periods in normal 2 before being dominated by wet periods in normal 3. This scenario shows a comeback of wet period from Normal 1 to normal 3.

The spatial dynamics of future rainfall show a latitudinal shift in cumulative annual rainfall towards the south-east of the sub-basin under the RCP 4.5 scenario, showing that the annual quantity of rain register in northern-west part of sub-basin will move to southern-east part as time goes on. In the RCP 8.5 scenario it's a moving of latitudinal shifts in cumulative annual rainfall from southern-east towards the northen-west which is noticed, meaning that the rainfall quantities receive will increase with time by moving toward the northen-east.

The behavior of Nouhao sub-basin future climate revealed in this study could be a basis of its impact assessing, and the people vulnerability in the sub basin in order to set up adaptation strategies.

References

Amrouni Y. (2022). Dynamique de l'occupation du sol par télédétection de la zone de transition des deux Atlas tellien et saharien dans la wilaya de Tiaret (Algérie). [Thèse de doctorat. Université Ibn Khaldoun-Tiaret-]. http://dspace.univ-tiaret.dz/bitstream/123456789/9450/1/TH.D.SNV.FR.2022.48.pdf

Bedoum A., Bouka C., Alladoum B., Mbanghoguinan. and Al. E. (2014). Impact de la variabilité pluviométrique et de la sécheresse au Sud du Tchad: Effet du changement climatique. Revue Ivoirienne des Sciences et Technologies, 23, 13–30.

Bernard D. K. (2014). Document De Strategie Du Programme National Changement Climatique (2015–2020). https://cdn.climatepolicyradar.org/navigator/CIV/2014/national-climate-change-program-pncc_c0e96b9a213964be73bc26da9646be46.pdf

Bodian A., Diop L., Panthou G., Dacosta H., Deme A., Dezetter A., Ndiaye P. M., Diouf I. and Vischel T. (2020). Recent Trend in Hydroclimatic Conditions in the Senegal River Basin. Water, 12(2), 436. https://doi.org/10.3390/w12020436

Brassel, Kurt E. et Reif D. (1979). A procedure to generate Thiessen polygons. Geographical Analysis, 11(3), 289–303.

CORDEX-AFR 44. (n.d.). ESGF@LiU/CORDEX. [Online]. Available: Retrieved May 10, 2023, from https://esg-dn1.nsc.liu.se/search/cordex/

Cornet A. (1992). Relation entre la structure spatiale des peuplements végétaux et le bilan hydrique des sols de quelques phytocénoses en zone aride. L'aridité une contrainte au développement. 245-263.

David S. P. and Noël D.A.G.O. (2014). Dynamique du plan d'eau du barrage de Natiokobadara et production rizicole dans le nord de la Côte d'Ivoire. Journal Africain de Communication Scientifique et Technologique, 27, 3571-3580.

Deque M. (2007). Frequency of precipitation and temperature extremes over France in an anthropogenic scenario: Model results and statistical correction according to observed values. Global and Planetary Change, 57(1–2), 16–26. https://doi.org/10.1016/j.gloplacha.2006.11.030

Djohy G.L., Edja A.H. and Nouatin G.S. (2015). Variation climatique et production vivrière: la culture du maïs dans le système agricole péri-urbain de la commune de Parakou au Nord-Benin, Afrique Science, **11(6)**, 183–194.

Ebode V.B., Dzana J.G., Amougou J.A. and Al. E. (2021). Modélisation hydrologique et son apport en situation de non-stationnarité et de données hydropluviométriques lacunaires, application au bassin versant du Nyong à Mbalmayo. Afrique SCI, 18(3), 36–47. https://www.researchgate.net/profile/Valentin-Ebode/publication/357307497_Modelisation_hydrologique_et_son_apport_en_situation_de_non-stationnarite_et_de_donnees_hydropluviometriques_lacunaires_application_au_bassin_versant_du_Nyong_a_Mbalmayo/links/61c5b

Eden J.M., Widmann M., Grawe D. and Al. E. (2012). Skill, correction, and downscaling of GCM-simulated precipitation. Journal of Climate, 25(11), 3970-3984.

Edl-aen. (2015). Schema directeur d'amenagement et de gestion des eaux de l'espace de competance de l'agence de l'eau du nakanbe. tome i. etat des lieux.

El Hawari J. and El Ghachi M. (2023). La variabilité pluviométrique et le risque de la sécheresse dans le bassin de Souss-Massa-Maroc à travers l'Indice Standardisé des précipitations (ISP). Revue Internationale de La Recherche Scientifique (Revue-IRS), 1(2), 61-69.

Fenta A.A., Yasuda H., Shimizu K. and Al. E. (2018). Evaluation of satellite rainfall estimates over the Lake Tana basin at the source region of the Blue Nile River. Atmospheric Research, 212, 43-53.

Fiédi Hakiekou. (2011). Etude de l'impact des activités agro-sylvo-pastorales sur le sous-bassin versant de Nouaho nord au Burkina Faso : proposition de modèle de gestion durable des ressources hydriques, pédologiques et végétales au profit des communautés locales dans le contex. http://documentation.2ie-edu.org/cdi2ie/opac_css/doc_num.php?explnum_id=388

Flaounas E., Bastin S. and Janicot S. (2011). Regional climate modelling of the 2006 West African monsoon: sensitivity to convection and planetary boundary layer parameterisation using WRF. Climate Dynamics, 36(5–6), 1083–1105. https://doi.org/10.1007/s00382-010-0785-3

Ghenim A.N. and Megnounif A. (2013). Ampleur de la sécheresse dans le bassin d'alimentation du barrage Meffrouche (Nord-Ouest de l'Algérie). Physio-Géo, Volume 7, 35–49. https://doi.org/10.4000/physio-geo.3173

Goula B.T.A., Savane I., Konan B., Fadika V. and Kouadio G.B. (2006). Impact de la variabilité climatique sur les ressources hydriques des bassins de N'Zo et N'Zi en Côte d'Ivoire (Afrique tropicale humide). VertigO, Volume 7 Numéro 1. https://doi.org/10.4000/vertigo.2038

IGB-BNDT-BDOT. (2002). Base nationale de données topographiques et d'occupation de terrain.

IRIE G.R., Soro G.E. and Bi T.A.G. (2015). Changements d'états de surface et évolutions spatio-temporelles des précipitations sur le bassin versant de la Marahoué (Côte d'Ivoire)[Performance analysis of few statistical indices to characterize drought conditions in Côte d'Ivoire]. International Journal of Innovation and Applied Studies, 13(2), 386.

Kabore P.N., Ouedraogo A, Sanon M. and Al. E. (2017). Caractérisation de la variabilité climatique dans la région du Centre-Nord du Burkina Faso entre 1961 et 2015. Climatologie, 14, 82–95.

Koné B., Dao A., Fadika V., Noufé D. and Kamagaté B. (2019). Effet de la Variabilité Pluviométrique sur les Écoulements de Surface dans le Bassin Versant de l'Agnéby au Sud-Est de la Côte d'Ivoire. European Scientific Journal ESJ, 15(27). https://doi.org/10.19044/esj.2019.v15n27p383

Kwawuvi D. (2023). Intra-Seasonal Rainfall Variability and Its Implications on Streamflow In The Oti Basin, West Africa. https://wascal-uac.org/wp-content/uploads/2023/07/Thesis_Kwawuvi_2023.pdf

Labarere J. (2012). Corrélation et régression linéaire simple. UE4 Biostatistique. Université Joseph Fourier Grenoble.

Larwanou M. (2011). Chapitre 7 Changements Climatiques Dans Le Sahel Et Les Savanes Ouest-Africaines: Impacts Sur Les Formations Boisees Et Les Ressources En Arbres. Forets, Faune Sauvage Et Changement Climatique En Afrique. https://afforum.org/oldaff/sites/default/files/French/French_2.pdf#page=146

Lauret P. and Barberousse A. (2015). Le GIEC, une communauté d'expertise originale. Cahiers Philosophiques, n° 142(3), 121. https://doi.org/10.3917/caph.142.0121

Lavorel S., Lebreton J.-D. and et Le Maho Y. (2017). Les mécanismes d'adaptation de la biodiversité aux changements climatiques et leurs limites. In Institut de France, Académie des sciences, Paris.

MERRA-2. (n.d.). POWER Data Access Viewer. [Online]. Available: Retrieved July 26, 2023, from https://power.larc.nasa.gov/data-access-viewer/

Moriasi D.N., Arnold J.G., Van Liew M.W. and Al. E. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE, , 50(3), 885–900.

Ndiaye P.M., Bodian A., Diop L., Dezetter A., Guilpart E., Deme A. and Ogilvie A. (2021). Future trend and sensitivity analysis of evapotranspiration in the Senegal River Basin. Journal of Hydrology: Regional Studies, 35, 100820. https://doi.org/10.1016/j.ejrh.2021.100820

Nicholson S.E. (1985). Sub-saharan rainfall 1981–84. Journal of Climate and Applied Meteorology, 24(12), 1388–1391.

Noba W.G., Damiba L., Doumounia A., Zongo I. and Zougmore F. (2023). Assessing Water Resources Access of Nouhao Sub-Basin, Burkina Faso. Journal of Water Resource and

Protection, 15(04), 149–164. https://doi.org/10.4236/jwarp.2023.154009

Nouaceur Z. (2020). La reprise des pluies et la recrudescence des inondations en Afrique de l'Ouest sahélienne. Physio-Géo, Volume 15, 89–109. https://doi.org/10.4000/physio-geo.10966

Ogega O.M., Gyampoh B.A. and Mistry M.N. (2020). Intraseasonal Precipitation Variability over West Africa under 1.5 °C and 2.0 °C Global Warming Scenarios: Results from CORDEX RCMs. Climate, 8(12), 143. https://doi.org/10.3390/cli8120143

Okafor G.C., Larbi I., Chukwuma E.C., Nyamekye C., Limantol A. M., & Dotse S.-Q. (2021). Local climate change signals and changes in climate extremes in a typical Sahel catchment: The case of Dano catchment, Burkina Faso. Environmental Challenges, 5, 100285. https://doi.org/10.1016/j.envc.2021.100285

OMS, & OMM. (2012). ATLAS DE LA SANTÉ ET DU CLIMAT. Rapport, 7. https://www.uncclearn.org/wp-content/uploads/library/who203fre_0.pdf

Ouzeau G., Déqué M., Jouini M., Planton S., Vautard R. and Jouzel J. (2014). Scénarios régionalisés: édition 2014 pour la métropole et les régions d'outre-mer. Le Climat de La France Au XXIe Siècle, 4.

Qadem Z., Khalid O.B.D.A., Qadem A. and Al L. (2022). impact de La Sècheresse sur les Réservoirs Souterrains dans le plateau de Saïs, Maroc. Geomaghreb, 16.

Rew R. and Davis G. (1990). NetCDF: an interface for scientific data access. IEEE Computer Graphics and Applications, 10(4), 76–82. https://doi.org/10.1109/38.56302

Robert É. (2010). Les zones pastorales comme solution aux conflits agriculteurs / pasteurs au Burkina Faso : l'exemple de la zone pastorale de la Doubégué. Cahiers d'Outre-Mer, 63(249), 47–71. https://doi.org/10.4000/com.5861

Rodrigue A., Guy W.C. and Yabi I. (2023). Risques agro-climatiques et production agricole dans la commune de zogbodomey au sud-benin. African Scientific Journal, 03(16), 050 – 082.

Souberou K.T., Barre I.O., Yabi I. and Ogouwale E. (2018). Fondements Géographiques De La Valorisation Agricole des Bas-Fonds Au Sud Du Bassin Versant De l'Oti (Bénin). European Scientific Journal, ESJ, 14(21), 136. https://doi.org/10.19044/esj.2018.v14n21p136

Taïbi S., Zeroual A. and Melhani N. (2021). Evaluation de deux méthodes de correction de biais des sorties de modèles climatiques régionaux Cordex-Africa pour la prévision des pluies : cas du bassin côtier oranais. Proceedings of the International Association of Hydrological Sciences, 384, 213–218. https://doi.org/10.5194/piahs-384-213-2021

Taylor K E. (2001). Summarizing multiple aspects of model performance in a single diagram. Journal of Geophysical Research: Atmospheres, 106(D7), 7183–7192. https://doi.org/10.1029/2000JD900719

Thiessen A.H. (1911). Precipitation averages for large areas. Monthly Weather Review, 39(7), 1082–1089.

UNESCO. (2006). Prévision Et Gestion des Effets Du Changement Climatique Sur Le Patrimoine Mondial Rapport commun du Centre du patrimoine mondial, des Organisations consultatives et d'un large groupe d'experts à la 30e session du Comité du patrimoine mondial. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjp1fC3ytb-AhWVi1wKHd4_D_UQFnoECCoQAQ&url=https%3A%2F%2Fwhc.unesco.org%2Fdocument%2F6672&usg=AOvVaw1tBdtyW1CGam-hJYvD33Ay

Yameogo W.V.M., Kabore O., Sanon Z., Akpa Y.L., Traore F., Tankoano B. and Hien M. (2023). Dynamique spatio-temporelle des surfaces en eau du bassin du Nakanbé-Mané au Burkina Faso. International Journal of Biological and Chemical Sciences, 17(1), 233–246. https://doi.org/10.4314/ijbcs.v17i1.17

Yonaba R.O. (2020). Dynamique spatio-temporelle des états de surface et influence sur le ruissellement sur un bassin de type sahélien: cas du bassin de Tougou (Nord Burkina Faso). Thèse de doctorat. Institut International d'Ingénierie de l'Eau et de l'Environnement. https://theses.hal.science/tel-03119095/