International Journal of Environmental Trends (IJENT)
http://dergipark.gov.tr/ijent

International Journal of Environmental Trends (IJENT)
2019: 3 (1),60-73
ISSN: 2602-4160
Turkish JournalPark ACADEMIC

Research Article

Evaluating climate variability from rainfall and temperature: insight from Niamey and Maradi in Niger

M. Nisa MENCET YELBOĞA[1]; Hamidou Taffa Abdoul-Azize[1];Cengiz SAYIN

[1] Akdeniz University Faculty of Agriculture Department of Agricultural Economy, Antalya

Received
08 March 2019

Accepted
06 June 2019

Abstract

Niger is one landlocked West African country located between parallels 11° 37 and 23° 33 Northern latitudes, meridians 16 °East longitudes and 0 °10 West longitude and covers 1,267,000 kilometers square. This country has different agro-climatic zonation which are divided into northern Saharan arid with a total annual rainfall average about 20-75 mm, Saharan-tropical; 75-160 mm and Sahelian area with an estimated total annual rainfall average of 250-800 mm. Therefore, the country rainfall pattern varies from one region to another and within one region. Niger as a poor country which agriculture sector employs about 85% of rural population and accounting approximately 45.2% of national economy climate variability may reduce the sustainability of this sector. In addition, Maradi is one of country's important agricultural production regions, but it is recently most exposed to food insecurity while Niamey is a region crossed by the country river. Accordingly, this article aims to evaluate climate variability in these regions during 1979-2013s. Buishand Homogeneity test was being conducted to detect the temporal break of climate variability and regression analysis was being used to estimate its magnitude in these regions. The findings indicate the two regions experienced a variation their total annual rainfall and monthly temperature averages. More, Niamey is more temporal sensitive, but the climate variability is higher in Maradi. Accordingly, during the period 1979-2013 the total annual rainfall of Maradi has fallen by 76% and its monthly temperature has increased by 13,6% whilst total annual rainfall of Niamey has fallen by 46.2% and its monthly temperature mean has increased by 13.6%. Consequently, it urges to implement large mitigation and climate variability reduction strategies to sustain the agriculture sector especially in Maradi as well as to minimize the risk of extinction of the Niger River.

Keywords
Climate variability, mitigation, magnitude, temporal, Maradi, Niamey, Niger

[1] Corresponding Author
Email: nmencet@akdeniz.edu.tr

1. Introduction

During the last decades the climate change and variability become key studied concepts by many authors [1, 2, 3]. The climate change and variability can occur at all locations, but recently most attention has been given to their regional and basin scales to carry out more specifics and key information for implementing more profitable and sustainable local socioeconomic activities [4]. More, for practical environmental management the rainfall and temperature trends have been considered as proxies in investigating climate change and variability [5, 6, 7, 8, 9].

Since the 1950s, numerous anthropogenic activities lead to climate change warming, especially in West Africa which was confronted to several droughts with as outcome important decreases of river flows during the era 1960s-1990s [10, 11, 12, 13].

Also, climate variability is expected to increase the occurrence of droughts, floods and heavy storms in Africa [14, 15]. Similarly, the Sahel is expected to face a rapid increasing of its temperature and more unpredictable rainfall pattern that may lead to uncertain crop production with severe yield drop [16, 13]. In addition, these circumstances represent a risk, especially for the area's small-scale farmer, so that [13] underscore the climate change could a key obstacle for producing sensitive crops such as maize, millet and sorghum in Africa.

Niger is one of West-African countries which economy is strongly dependent agriculture sector which includes about 85% of the country's rural population and accounts approximately at 45.2% of its GDP in 2010 [17]. Therefore, from post-colonial period several agricultural strategies and milestones have been executed in Niger to enhance the country's food security. They are mostly targeting at diversifying a country's agricultural products.

However, Niger agriculture sector depends mainly to total annual rainfall and most of agricultural systems are extensive, so that these agricultural systems are likely to cause environmental degradation and an increasing risk of desertification.

Earlier it has been projected a decline of Millet production by 13% and its yield decline about 42% from increasing temperature and rainfall variability by 2030s, so that in Sahelian countries the desertification questions the long-term viability of agriculture sector [18, 19].

On another hand, since 1992 Niger is a signatory country of United Nations Convention on Climate Change (UNCCC) and recently in 2004 a country signatory of Kyoto. Hence, Niger has implemented several policies such as United Nations Emissions Reductions from Deforestation and Forest Degradation which target at planting trees by providing incentive financial support to Sahelian farmers to reduce the climate pressures [20, 21].

Nevertheless, in the Sahel the climate change leads to inter-annual variability and sensitivity to rainfall, so that the availability of freshwater depends on climate change and variability and represents a key future challenge for sustainable development [5, 22, 23, 24, 25, 26, 27]. Furthermore, the climate approaches based mainly on global and large-scale climate vulnerability are specific timescales (e.g. inter-annual) or regional hydrological datasets [28, 29], so that data scarcity and high variability may be major constraints in apprehending multi-timescale climatic teleconnections driving streamflow variability.

In Niger previous studies investigate mostly the inter-annual climate variability, affected the relationship between rainfall–runoff and the river regimes based on Hydrological and hydro climatic dataset through some complex hydrological methods. However, evaluating climate variability from total annual rainfall and monthly temperature mean could be more practical for agricultural development institution and policy makers to reinforce their ongoing implemented strategies over different timescales. Hence, a good comprehension of temporal climate variability and its magnitude, especially in one of the country vital agricultural region almost permanently exposed to food insecurity as well as in Niamey the only region crossed by the main country water resource may offer a way for implementing short-middle and long-term climate change and variability mitigation strategies in this region.

This study aims to evaluate climate variability from daily rainfall and temperature records, especially to detect a temporal break in total rainfall and monthly temperature as well as to estimate magnitude of this variability during the period 1979-2013. Accordingly, the study attempts to answer the questions: (1) are temporal total annual rainfall and monthly temperature variabilities similar in Maradi and Niamey? (2) Although temporal total annual rainfall and monthly temperature variabilities differ Maradi and Niamey do they have the same magnitude? (3) What is the region more sensitive to total annual variation? (4) What is the region more sensitive to monthly temperature variation?

2. Material and Methods

2.1 Study areas

With about 255 kilometers square Niamey is situated in the South West of Niger between 13°28’- 13°35’ of latitude North and 02°03’ - 02°12’ of longitude while Maradi is situated the southern part of Niger between parallels 13 ° and 15 ° 26' North latitude and parallels 6 ° 16' and 8 ° 36 'East longitude and covers about 41,796 km² as shown in figure 1 below.

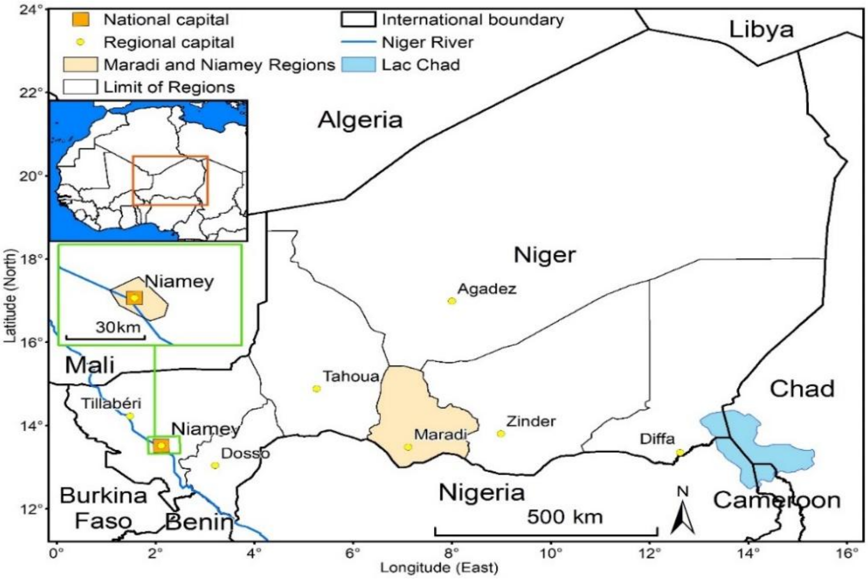


Figure 1. Study areas

2.2 Study data

Data for 1970-2013 have been computed from daily secondary data obtained from the national office of meteorology of Niger and they include daily rainfall and temperature records.

2.3 Data analysis

From the daily rainfall and temperature, the monthly temperature means, and total annual rainfall have been calculated. Accordingly, the annual cumulative rainfall of each region has been determined by summing up their daily record with the formula $TAR = \sum_1^n Xi$ (1) where TAR refers to total annual rainfall value and Xi the daily recorded rainfall.

Depending on [30] the direct use of daily temperature mean may underestimate its value which commonly occurs according the non-linear relationship between saturation vapor pressure-temperature.

Hence, the two regions' monthly temperature means have been determined in two steps. According to [30] a monthly temperature mean is determined with the formula $\mathbf{TMean} = \frac{(\mathbf{TMin+TMax})}{\mathbf{2}}$ (2) where, TMean refers to daily mean temperature of air, TMax daily maximum temperature of air and TMin daily minimum temperature of air all in degree Celsius (ºC). Then, monthly temperature mean was being determined with the formula $\boldsymbol{MTA} = \frac{\sum_1^i \boldsymbol{DAT}}{\boldsymbol{N}}$ **(3)** where MTA refers to monthly temperature mean and DTA the represents the daily temperature mean and N refers to the number of the days of a month.

Furthermore, Buishand's Homogeneity Test has being conducted to detect a trend variation of total annual rainfall and monthly temperature amen in the two regions while regression analysis has been conducted to estimate the magnitude of total annual rainfall and monthly temperature means which may be observable on the trend obtained from Buishand's Homogeneity Test.

2.3.1 Buishand Homogeneity Test

To carry out intra and inter regional the trend of total annual rainfall and monthly temperature mean Buishand Homogeneity Test was being conducted. Originated from a formulation given by [31], the Buishand statistic derived from Gardner's statistic which is commonly used for carrying out two-sided break test based on average value for an unsettled period. Gardner's statistic is determined with the formula:

$$G = \sum_{K=1}^{N-1} Pk\left\{{Sk}/{\sigma x}\right\}^2$$

Where $S_k = (X - Xm)$

P_k is the probability that the break occurs just after the K^{th} observation while the variance σ_x is assumed a known value.

On other hand, if σ_x is an unknown value it can be substituted by the variance of the sample D2x and if P_k is homogeneously selected so that the statistic U is determined with the formula:

$$U = \frac{\sum_{K=1}^{N-1}\left({Sk}/{\sigma x}\right)2}{N(N+1)}$$

Where $\mathrm{D2x} = \sum_{i=1}^{n}(Xi - Xm)^2/N$

The critical values of statistic U were being assumed by [32] and then it was being used in Monte Carlo method. Afterward [33] has better estimated U value, so that Buishand Homogeneity Test become the most applied in evaluating the distribution of haphazard variables or parameters according the properties examined in normal case, so that Buishand homogeneity Test is predominantly used in normal event.

2.3.2 Regression model

The regression model is a statistical procedure that allows estimating the linear relationship between two or more variables. It measures the amount of change in one variable that is associated with change in another variable or variables. The regression was used to test the statistical significance whether the observed linear relationship could have emerged by chance or not. Accordingly, the linear regression model has been used to estimate a causal relationship between a break on total rainfall and monthly temperature means. Accordingly, the independent variable (occurrence of break) was labelled X and the dependent variables (variation in total annual rainfall and monthly temperature) was labeled to determine the straight-line relationship that connects X and Y. Hence, the linear relationship between temporal occurrence of break and total annual rainfall and monthly temperature can be stated algebraically as Y = a + bX where a refers to the intercept and b is the slope of the line.

3. Results

3.1 Buishand Homogeneity Test

3.1.1 Temporal trend of total annual rainfall

The figure 1 bellow shows a break representing a reduction in total annual rainfall both in Maradi and Niamey. Mardi total annual rainfall dropped from 807.77 mm to 265 since 1998 while in Niamey it had fallen from 458.87 mm to 141.71mm. Therefore, temporally a reduction in total annual rainfall has earlier occurred in Niamey (1997) and then in Maradi (1998), so that Niamey is temporally more sensitive to total rainfall variability than Maradi.

However, Niamey accounts a reduction of 317. 16mm from 1997 whilst in Maradi this total annual rainfall reduction is about 542.77mm from 1998. Accordingly, although Niamey is temporally more sensitive to total annual rainfall the fall of the annual rainfall in Maradi is more drastic as show on the figure 1.

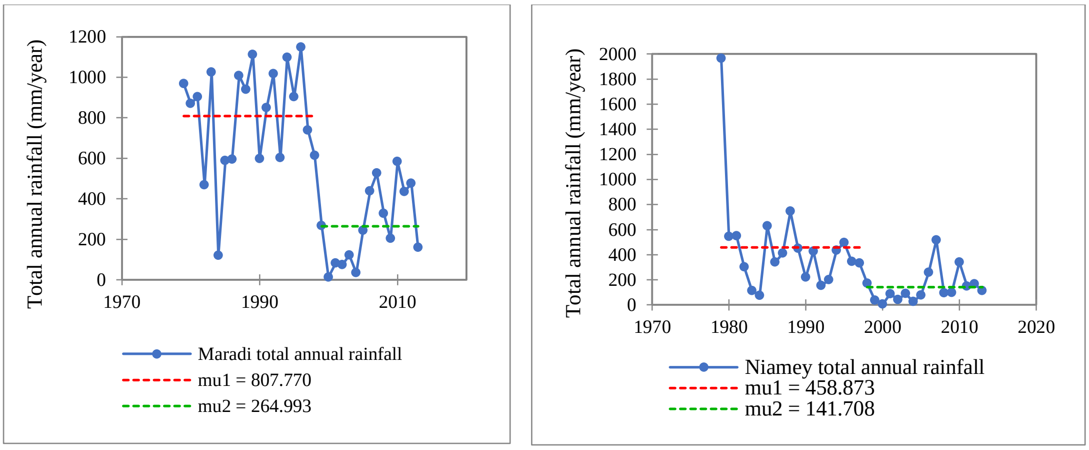


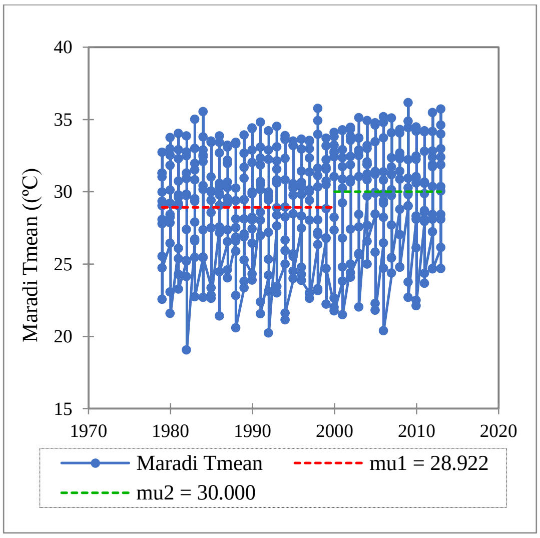
Figure 2. Temporal trend of total annual rainfall

3.1.2 Temporal trend of monthly temperature means

Buishand's tests showed there is a break representing an increase of monthly temperature means both in Maradi and Niamey. In Niamey the monthly temperature mean increases from 30.17 C to 31.284C whereas it passed from 28.92C to 30C in Maradi. Yet, this temporal increase in monthly temperature means occurs in Niamey since 1997 but recently in

2000 in Maradi, so that Niamey is temporally more sensitive to total monthly temperature variability than Maradi. This break in monthly temperature means is shown on the figure 2.

However, Niamey accounts an increase of 1.11C in its monthly temperature since 1997 whilst in Maradi an increase of 1.08C monthly temperature occurs in 2000. Hence, the increase in monthly temperature mean is slightly higher in than in Maradi as well as Niamey is temporally more sensitive to monthly temperature than Maradi as shown on Figure 2.



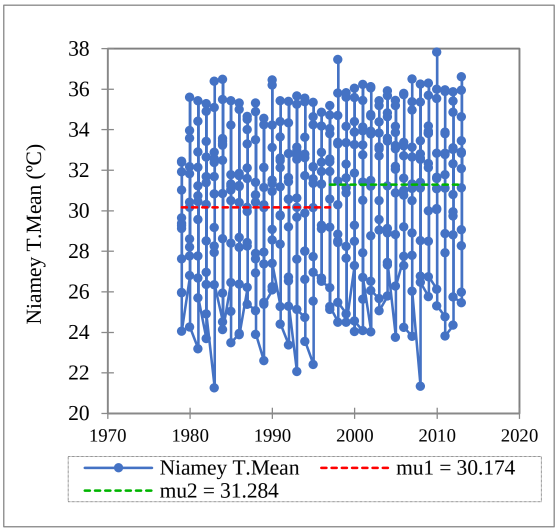


Figure 3. Temporal trend of monthly temperature means

3.2. Regression analysis

3.2.1 Total annual rainfall and monthly temperature

The total annual rainfall mean is greater in Maradi (575.15mm) than in Niamey (313.9 mm). Otherwise the coefficient of variation (ratio of standard deviation to total annual mean) is about 62% for Maradi whilst it accounts about 110.45% in Niamey. Hence, Niamey is temporally more sensitive to total annual rainfall than Maradi. Similarly, the monthly temperature in Niamey (30.70 C) is slightly greater than in Maradi (29.34C) whist the coefficient of variation of monthly temperature is about 11.85% in Niamey and 12.72% in Maradi as shown in table 1.

Table 1. Total rainfall and monthly temperature means, maximum, minimum and coefficient of variation

Variables	Minimum	Mean	Maximum	Std. Deviation	C.V (%)	N
Maradi total annual rainfall	12.64	575.15	1147.85	356.60	62	35

Maradi monthly temperature mean	19.05	29.34	36.15	3,7341	110.45	420
Niamey total annual rainfall	4.13	313.90	1962.96	346.71	11.85	35
Niamey monthly temperature mean	21.5	30.70	37.81	3,639	12.72	420

3.2.2 Magnitude of temporal variation in total annual rainfall

To estimate the variation magnitude of a break obtained with Buishand Homogeneity Test and its impact in booth total annual rainfall and monthly temperature means in the study regions we define a dummy variables. Hence we attribute the value one (1) was for all the year during which there is not any appearance of breaks on trend and a value zero 0) otherwise. The regression analysis results show that the standardized coefficient Beta of total annual rainfall is greater in Maradi (0.7649) than in Niamey (0.462). Accordingly, the occurrence of temporal break in the trend of total annual rainfall mean has significantly impacted the total annual rainfall in Maradi than Niamey so that Maradi is more sensitive to total annual rainfall variability than Niamey.

On another hand, the regression analysis show that the standardized coefficient Beta of monthly temperature means is slight greater in Niamey (1.236) than in Maradi (1.32), so that the occurrence of break in monthly temperature means has significantly impact the monthly temperature in Niamey but not in Maradi. The results are shown on the table 2.

Table 2. Regression results of total rainfall and monthly temperature

Regions	Model	Standardized Coefficients Beta	t	Sig.
Maradi	Constant (total annual rainfall)		4,396	0.000
	Occurrence of break in total annual rainfall	**0.764**	6,807	**0.000****
	Constant (monthly temperature mean)		101,071	0.000
	Occurrence of break in monthly temperature	-0.132	-2,724	0.007
	Constant(total annual rainfall)		1,817	0.078
	Occurrence of break in total annual rainfall	**0.462**	2,996	**0.005***

Niamey	Constant (monthly temperature mean)		119,932	0.000
	Occurrence of break in monthly temperature means	**-0.136**	-2,812	**0.005***

The bold and asterisk the significant level (1%, 5%) in the study regions; Sig. = Significance.

4. Discussion

The results from the figures 2 and 3 both Maradi and Niamey experienced a variability of their total annual rainfall and monthly temperature. Furthermore, these variabilities differ between the two regions, so that Maradi total annual rainfall had fallen from 807.77 mm to 265 mm since 1998 while in Niamey it dropped from 458.87 to 141.70mm since 1997. Accordingly, Maradi with a reduction of 542.7 mm of its total annual rainfall is more sensitive to total annual rainfall than Niamey (317 mm). These results are similar to the findings of [10, 34, 35, and 36] that highlight that West Africa experiences strong spatial and temporal rainfall variability, especially the Sahel areas. Yet, the total annual rainfall's coefficient of variation in Maradi (76%) is greater than in Niamey (46%). This corroborates the previous results found by [35, 36, 37, 38, and 39] that underline Niger experiences a decrease of its annual rainfall by 3.1% per decade during 1950-2014, mainly during the droughts (1970-1980s).

Previously [40] highlights that the climate change is seriously impacting the crop production, especially beans production which is a significant source of protein in Maradi region, so that the sensitivity to total annual rainfall may reduce not only the development of agriculture sector in this region but it could also increase its food insecurity level.

Besides, both Maradi and Niamey reveals sensitive to monthly temperature, so that since 1997 Niamey monthly temperature means has increased by 1.1 C whilst Maradi recorded an increase of its monthly temperature of 1.08 C since 2000. Although there is time lag in increasing monthly temperature between the two regions, Niamey is slightly more sensitive to monthly temperature than Maradi. Though the climate variability was assessed at the level of two regions of Niger the findings corroborate those of [41] who highlight that Niger is amongst one of the highest West African countries vulnerable to climate in West Africa.

Conclusion and recommendation

Rainfall and temperature series have been used to evaluate the climate variability and the impact of the occurrence of break in total annual rainfall and monthly temperature in the regions of Maradi and Niamey. Besides, Maradi which reveals more sensitive to total annual rainfall is important agricultural production of the country as highlighted by [42], so this region's sensitivity to total annual rainfall could reduce the development of its agriculture sector. Additionally, the slight sensitivity of Niamey to air temperature could cause an increase of Niger watercourse, so that it may question its long-term sustainability.

This study therefore aimed to evaluate climate variability in these regions. The Buishand Homogeneity Test identified two main breaks in the total annual rainfall and monthly temperature means. Accordingly, Maradi has experienced a decrease of its total annual rainfall in 1998 while Niamey total annual rainfall falls since 1997. The regression analysis shows that the magnitude of total annual rainfall was 76.4% for Maradi and 46.2% for Niamey and this magnitude was 13.2% and 13.6% for monthly temperature means respectively for Maradi and Niamey. More specifically, the regression results show that total annual rainfall is significant by region ($\beta = -0.76$; $p \leq 0.000$ for Maradi and $\beta = 462$; $p \leq 0.005$ for Niamey) as well as for monthly temperature means ($\beta = -132$; $p \leq 0.007$ for Maradi and $\beta = -0.136$; $p \leq 0.005$ for Niamey).

From the research findings, a large implementation of resilient climate change strategies to reduce the regional sensitivity, especially in Maradi could help to improve agriculture sector as well as to the region's food security. Also, the implementation of more climate friendly resource practices may enhance the sustainability of Niger River while reinforcing the practiced agricultural and fishery activities on Niger River bank.

Conflict

None

References

[1] Hoque, M.A., Scheelbeek, P.F.D., Vineis, P., Khan, A.E., 2016. Drinking water vulnerability to climate change and alternatives for adaptation in coastal South and South East Asia. Clim. Chang. 136 (2), 247–263

[2] Li, Z., Huang, G., Wang, X., Han, J., Fan, Y., 2016. Impacts of future climate change on river discharge based on hydrological inference: a case study of the Grand River Watershed in Ontario, Canada. Sci. Total Environ. 548, 198–210.

[3] Wen, X., Wu, X., and Gao, M., 2017. Spatiotemporal variability of temperature and precipitation in Gansu Province (Northwest China) during 1951–2015. Atmos. Res. 197, 132–149

[4] Elsanabary, M.H., Gan, T.Y., 2015. Evaluation of climate anomalies impacts on the Upper Blue Nile Basin in Ethiopia using a distributed and a lumped hydrologic model. J. Hydrol. 530, 225–240.

[5] Mohammed, M.U., Abdulhamid, A., Badamasi, M.M., Ahmed, M., 2015. Rainfall dynamics and climate change in Kano, Nigeria. J. Sci. Res. Rep. 7 (5), 386–395.

[6] Huang, W.-R., Chang, Y.-H., Liu, P.-Y., 2018. Assessment of IMERG precipitation over Taiwan at multiple timescales. Atmos. Res. 214, 239–249.

[7] Karki, R., ul Hasson, S., Gerlitz, L., Talchabhadel, R., Schenk, E., Schickhoff, U., Scholten, T., Bohner, J., 2018. WRF-based simulation of an extreme precipitation event over the Central Himalayas: atmospheric mechanisms and their representation by microphysics parameterization schemes. Atmos. Res. 214, 21–35.

[8] Iqbal, M.A., Penas, A., Cano-Ortiz, A., Kersebaum, K., Herrero, L., anddel Rio, S., 2016. Analysis of recent changes in maximum and minimum temperatures in Pakistan. Atmos. Res. 168, 234–249.

[9] Salman, S.A., Shahid, S., Ismail, T., Ahmed, K., Wang, X.-J., 2018. Selection of climate models for projection of spatiotemporal changes in temperature of Iraq with uncertainties. Atmos. Res. 213, 509–522

[10] Lebel, T., 2003. Seasonal cycle and interannual variability of the Sahelian rainfall at hydrological scales. J. Geophys. Res. 108, 8389. https://doi.org/10.1029/2001JD001580

[11] Dai, A., Lamb, P.J., Trenberth, K.E., Hulme, M., Jones, P.D., Xie, P., 2004. The recent Sahel drought is real. Int. J. Climatol. 24, 1323–1331. https://doi.org/10.1002/joc.1083.

[12] Dezfuli, A.K., Nicholson, S.E., 2013. The relationship of rainfall variability in western equatorial africa to the tropical oceans and atmospheric circulation. Part II Boreal Autumn. J. Clim. 26, 66–84. https://doi.org/10.1175/JCLI-D-11-00686.1.

[13] IPCC, 2014. Climate Change 2014: Synthesis Report. Intergovernmental Panel on Climate Change, Geneva, Switzerland

[14] Ogungbenro, S.B., Morakinyo, T.E., 2014. Rainfall distribution and change detection across climatic zones in Nigeria. Weather Clim. Extrem. 5, 1–6.

[15] Suleiman, Y., Ifabiyi, L., 2015. The role of rainfall variability in reservoir storage management at Shiroro Hydropower Dam, Nigeria. Momona Ethiopian J. Sci. 7 (1), 55–63

[16] Cervigni, R., Valentini, R., & Santini, M. (Eds.). (2013). Toward climate-resilient development in Nigeria. The World Bank.

[17] Rigourd, C., B. Djariri, P. Dugue, I. Maman, and P. Derache. 2016. Proposition de système national du conseil rural. République du Niger–Haut-Commissariat à l'Initiative 3N" Les nigériens nourrissent les nigériens". Https://agrit rop.cirad .fr/58144 8/1/Rapport%20Str ate%CC%81gie %20con seil%20Rur al%20%20Nig er%20%20201 6%20Ver sion%20Fin ale.pdf.

[18] A. Ben Mohamed, Van Duivenbooden and Abdoussallam, S., 2002. Impact of climate change on agricultural production in the Sahel – part 1. Methodological approach and case study for millet in Niger, Journal of Climatic Change 54(3):327-348 DOI: 10.1023/A:1016189605188, https://core.ac.uk/download/pdf/12108148.pdf

[19] Seidou, A., Berbet, M., Bruneau and Bobee, B., 2006. Parametric Bayesian combination of local and regional information in flood frequency analysis, Water Resources Research, Vol. 42, W11408, doi: 10.1029/2005WR004397. https://doi.org/10.1029/2005WR004397

[20] Epule, T., James D. Ford, Shuaiblwasa, Laurent Lepage (2017). Climate change adaptation in the Sahel. Environmental Science and Policy 75 (2017) 121-137. The journal of peasant Studies, 2018. Vol.45, No 1, 89-107, publishing.
https://doi.org/10.1080/03066150.2017.13112355

[21] UNREDD, UNREDD, 2015. Executive Summary: 2015 Annual Report of the UN-REDD Programme Fund. Available online at: http://www.unredd.net/documents.html?view=browse&customtags=172&startdate=&enddate=&dmlang

[22] Adakayi, P.E., 2012. An Assessment of Rainfall and Temperature Variations in Selected Stations in Parts of Northern Nigeria. University of Jos Institutional Repository Theses and Dissertations Faculty of Environmental Sciences.

[23] GIWA, 2004. Global International Waters Assessment Regional Assessment 43: Lake Chad Basin. Published by the University of Kalmar on behalf of United Nations Environment Programme.

[24] Sobowale, A., Adewumi, J.K., Okuofu, C.A., Otun, J.A., 2010. water resources potentials of hadejia river sub-catchment of Komadugu Yobe River Basin in Nigeria. Agric. Eng. Int. 12 (2), 1–6.

[25] Umar, A.S., Ankidawa, B.A., 2016. Climate variability and basin management: a threat to and from wetlands of Komadugu Yobe Basin, North Eastern Nigeria. Asian J. Eng.Technol. 4 (2), 25–36.

[26] Olagunju, T.E., 2015. Drought, desertification and the Nigerian environment: a review. J. Ecol. Nat. Environ. 7 (7), 196–209.

[27] Sawa, B. A.1, Ati, O. F., Jaiyeoba, I. A., Oladipo, E. O. (2015) Trends in aridity of the arid and semi-arid regions of Northern Nigeria; J. Environ. Earth Sci. 5 (10): 61–68

[28] McGregor, G., 2017. Hydroclimatology, modes of climatic variability and stream flow, lake and groundwater level variability: a progress report. Prog. Phys. Geogr. 41, 496–512. https://doi.org/10.1177/0309133317726537.

[29] Sidibe, M., Dieppois, B., Mahé, G., Paturel, J.E., Amoussou, E., Anifowose, B., Lawler, D.M., 2018. Trend and variability in a new, reconstructed streamflow dataset for West and Central Africa, and climatic interactions, 1950–2005. J. Hydrol. https:// doi.org/10.1016/j.jhydrol.2018.04.024.

[30] Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. 1998. Crop Evapotranpiration: Guildlines for computing crop water requirements, FAO Irrigation and Drainage Paper No 56. Food and Agriculture Organisation, Land and Water. Rome, Italy

[31] Gardner, L. A. 1969). On detecting changes in the mean of normal variates. The Annals of Mathematical Statistics, 40(1), 116-126.

[32] Buishand, T. A., 1982. Some methods for testing the homogeneity of rainfall records. Journal of hydrology, 58(1-2), 11-27.

[33] Buishand, T. A., 1984. Bivariate extreme-value data and the station-year method. Journal of Hydrology, 69(1-4), 77-95.

[34] Lebel, T., Ali, A., 2009. Recent trends in the Central and Western Sahel rainfall regime (1990-2007). J. Hydrol. 375, 52–64. https://doi.org/10.1016/j.jhydrol.2008.11.030

[35] Hountondji, Y. C., Sokpon, N., Nicolas, J., & Ozer, P. (2009). Ongoing desertification processes in the sahelian belt of West Africa: an evidence from the rain-use efficiency. Recent Advances in Remote Sensing and Geoinformation Processing for Land Degradation Assessment. ISPRS Series, Taylor and Francis, 173-186.

[36] De Longueville, F., Hountondji, Y.C., Kindo, I., Gemenne, F., Ozer, P., 2016. Long-term analysis of rainfall and temperature data in Burkina Faso (1950–2013). Int. J. Climatol. 36 (13), 4393–4405.

[37] Chamard, P. C., & Courel, M. F. (1999). La forêt sahélienne menacée. Science et changements planétaires/Sécheresse, 10(1), 11-18.

[38] Hountondji, Yvon, Pierre Ozer, and Bernard Tychon. "Etude des modifications environnementales à partir des données pluviométriques et NDVI de NOAA-AVHRR en Afrique de l'Ouest." Les Journées des Géographes Belges : Evaluer la capacité du milieu (2003) : 19-24.

[30] Gemenne, F., Blocher, J. M. D., De Longueville, F., Vigil Diaz Telenti, S., Zickgraf, C., Gharbaoui, D., & Ozer, P. (2017). Changement climatique, catastrophes naturelles et déplacements de populations en Afrique de l'Ouest. Geo-Eco-Trop: Revue Internationale de Géologie, de Géographie et d'Écologie Tropicales, 41(3).

[40] Mamadou, A., & Salaou, A. (2013). Women's land rights in a changing climate: A case study from Maradi, Niger. A New dialogue: Putting people at the heart of global development.

[41] Ayodotun, B., Bamba, S., & Adio, A. (2019). Vulnerability Assessment of West African Countries to Climate Change and Variability. Journal of Geoscience and Environment Protection, 7, 13-25. https://doi.org/10.4236/gep.2019.76002

[42] INS (2017). Maradi en Chiffres http://www.stat niger.org/statistique/file/Regions/Maradi/Maradi_Chiffres_2017.pdf