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Hubert O. Dossou-Yovo * , Abdel Aziz Osseni , Sami Asir Al-Robai , Apollon D. M. T. Hegbe , Brice Sinsin

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Assessing Drought Frequency and Predictive Climate Analysis in two Biosphere Reserves of Benin (West Africa)

Hubert O. Dossou-Yovo [1,*], Abdel Aziz Osseni [2], Sami Asir Al-Robai [3], Apollon D. M. T. Hegbe [4] and Brice Sinsin [1]

[1] Faculty of Agronomic Sciences, Laboratory of Applied Ecology, University of Abomey-Calavi, P.O. Box 1974, Godomey, Benin; dohuoly@yahoo.fr ; bsinsin@gmail.com
[2] Horticultural Research and Management of Green Spaces Unit, Laboratory of Plant, Horticultural and Forest Sciences, School of Horticulture and Management of Green Spaces, National University of Agriculture, P.O. Box 43, Kétou, Bénin.; abdelossen@yahoo.fr
[3] Department of Biology, Faculty of Science, Al-Baha University, Al-Baha 1988, Saudi Arabia; salrobai@bu.edu.sa
[4] Research Unit in Tropical Mycology and Soil-Plants-Fungi Interactions, Laboratory of Ecology, Botany and Plant Biology, University of Parakou. Benin; apollonrossi@gmail.com
* Correspondence: dohuoly@yahoo.fr; Tel.: +22997957040

Abstract: Climate change is affecting the planet, compromising survival and altering forest ecosystems. Investigating climatic variations in all regions is important. The aim of this research was to assess such variations in the W and Pendjari Biosphere Reserves in Benin from 1985 to 2015 and predict climate up to 2045. Drought frequency was assessed by using the Standardized Precipitation and Evapotranspiration Index (SPEI) and correlation was performed between climatic variables. Then a predictive analysis was computed. From 1985 to 2015, there was change in the climate with few severe dry and wet years while no extreme climatic condition was noticed. Most of the years showed nearly normal climatic conditions. The predicted climate indicates an absence of extreme conditions up to 2045 but an increase in the annual humidity is expected. A low decrease in annual mean temperature with high confidence is expected. Decision-makers can better organize adaptation programs and sensitize people in the reserves on their role in environmental conservation and mitigation of climate change using these outputs.

Keywords climate change; drought; mitigation; pendjari; predictive analysis; reserves

1. Introduction

The following facts were reported on Africa regarding the climate change [1]. First, climate change poses a significant threat to African forests and their role in society; agricultural production and overall access to food across the continent may be severely compromised. It was also highlighted that with only basic farming technology and low incomes, many African farmers will have few options to adapt and will inevitably rely more on natural forest resources to survive.

Any strategies addressing climate change in Africa are welcome to enhance the livelihoods of forest-dependent populations. While assessing the vegetation dynamics in the Ouémé delta region on southern Benin, Osseni et al. [2] pointed out that climate change will induce altered ecosystems in many parts of the world. Kingbo et al. [3] has recently assessed climate change in southeast Benin and its influence on the spatio-temporal dynamics of forests and reported that the subequatorial climate of southeast Benin is gradually changing towards a dry climate. In Africa where the majority of the populations depend on natural resources for various purposes, environmental issues are becoming alarming [2]. In other words, climate change is known to interact with threats such as habitat loss and overharvesting to further exacerbate species declines [4]. Climate change is posing

 doi:10.20944/preprints202311.0783.v2

an additional threat that will impact ecosystems currently under protection like National Parks [5], so research aiming to assess their variations and predict trends for the coming are urgently required. In addition, Bougouma et al. [6] reported the influence of climate on the vegetation dynamics.

The Pendjari and W Biosphere Reserves are two major fauna and flora reserves subject to the majority of scientific attention and conservation programs in northern Benin [7–9]. However, these ecosystems are facing conservation conflicts and biodiversity decline [10]. Moreover, regarding the climatic variations which have an impact on the evolution of the plant cover and which largely condition animal migration flows and gene transfers in the West African sub-region, it is important to pay particular attention to the climatic variations in this region of northern Benin, home to two of the largest parks in the western region of the African continent. Very few studies have taken stock of climate change in this area, taking the two protected areas as a single element. In the current context of climate change requiring an inventory of climate change and a forecast of future climate conditions, our work comes at the right time to present the evolution of climate variables from 1985 to 2015 in order to identify the periods and those of drought experienced by the region of the two parks and to use existing data for a climate forecast for 2045. It should also be noted that this study follows scientific research by the same researchers on the evolution of plant cover in the study area correlated with climatic variations [9]. In general, this study aims to present the climatic conditions in the study area and specifically, it aims to identify the frequencies of wet and dry periods experienced by the regions of the two largest parks. Benin (W and Pendjari) for the period from 1985 to 2015 and the real novelty of this work, although derived from data supporting the writing of Osseni et al. [9] (under review), is to predict the climatic characteristics in these two areas by 2045 in line with the 30-year time step required in the forecasts climatic. The results of this study will serve as a scientific basis for giving an opinion on climate forecasts in the region of the W and Pendjari National Parks, in northern Benin and better planning conservation programs for mitigating the effects of climate change. Furthermore, these results will motivate many other works on the subject.

Parts of this paper results based on the Standardized Precipitation Evapotranspiration Index (SPEI) used to assess drought magnitude. Instead of the Standardized Precipitation Index (SPI) previously reported by the same research team while assessing the vegetation dynamics in the study area [9], SPEI is here used in order to overcome some limitations of the former. In fact, even when SPI remains widely [11–13], this index is thought to be an incomplete way to apprehend drought due to the fact that it relies only on precipitation but, drought as climatic phenomenon implies temperature and evapotranspiration considerations. Thus, many authors strongly suggested the use of multidimensional approaches to better characterize climatic events [14,15].

In addition, climate models, as undertaken in this study help work through complicated problems and understand complex systems by also allowing us to test theories and solutions [16].

2. Materials and Methods

2.1. Study area

The study covers all the complex of protected areas (Pendjari and W-Benin Biosphere Reserves), their hunting areas as well as their periphery. The peripheries, approximately 25 km wide, made up of village territories, were considered because they benefit from special protection measures within the framework of a vast program of integrated management of transboundary protected areas in northern Benin

This space extends between latitudes 10° 40' N and 12° 30' N and between longitudes 0° 50' E and 3° 22' E (Figure 1). With an area of approximately 22555 km^2, the study area crosses the districts of Tanguiéta, Toucoutouna, Kouandé and Kérou in the department of Atacora and the communes of Banikoara, Kandi and Malanville in the department of Alibori [17]. The climate of the region is Sudanian, characterized by an average annual rainfall between 694 and 1145 mm, with a rainy season and a dry season [7]. The same authors mentioned that the rainy season covers the period from April to October and the dry season covers the period from November to March. As for the temperature, the annual average is 26 ± 4°C (Figure 2). The relief of this region is uneven in places with altitudes varying between 106 and 591 m. The main soils are mineral soils, hydromorphic, vertisol and ferruginous soils [18]. The main plant formations are savannahs and open forests [19]. However, there are also gallery forests, swamp forests and agrosystems, especially outside of the parks. Agriculture is the main income generation activity for the surrounding populations of the W-Pendjari complex in northern Benin. The main crops grown around the complex are food crops such as sorghum, millet, maize, cowpea, yams, cassava yams, cassava, and cash crops (cotton), which occupy a great deal of agricultural land [7]. In recent years, cashew nut agroforestry has increasingly been developed in the southern part of the W Biosphere Reserve. Animal husbandry remains the second most important activity practiced by the local populations. In addition to the traditional agricultural activities, the local people collect numerous non-timber forest products (NTFPs) such as shea, baobab, tamarind and many other products that generate significant income for local populations in the periphery of the reserve [17,20].

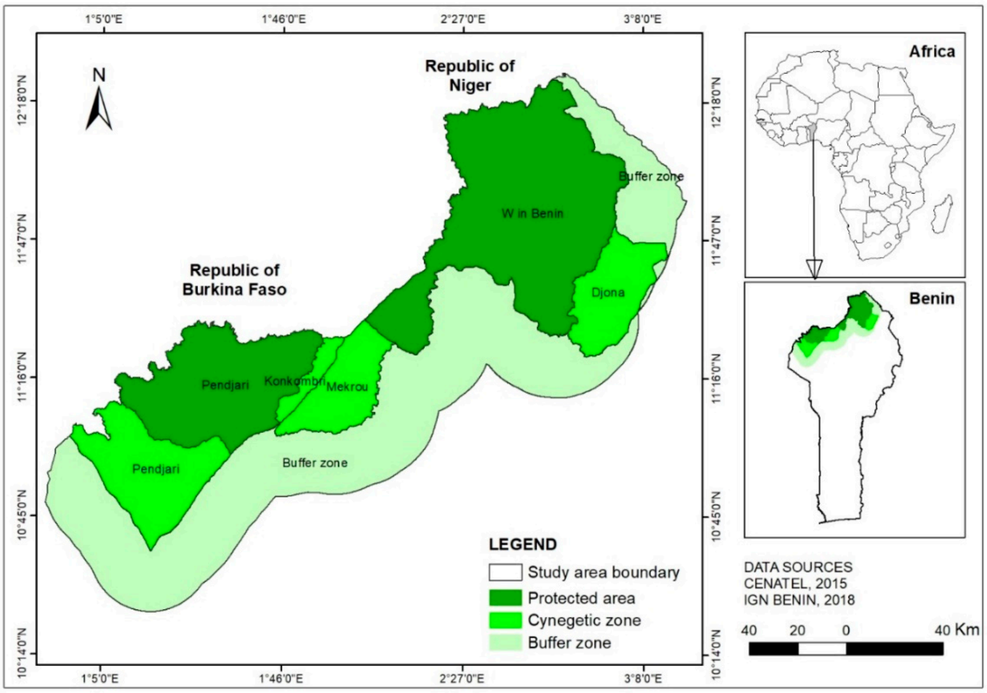

Figure 1. Geographical location of the study area [9].

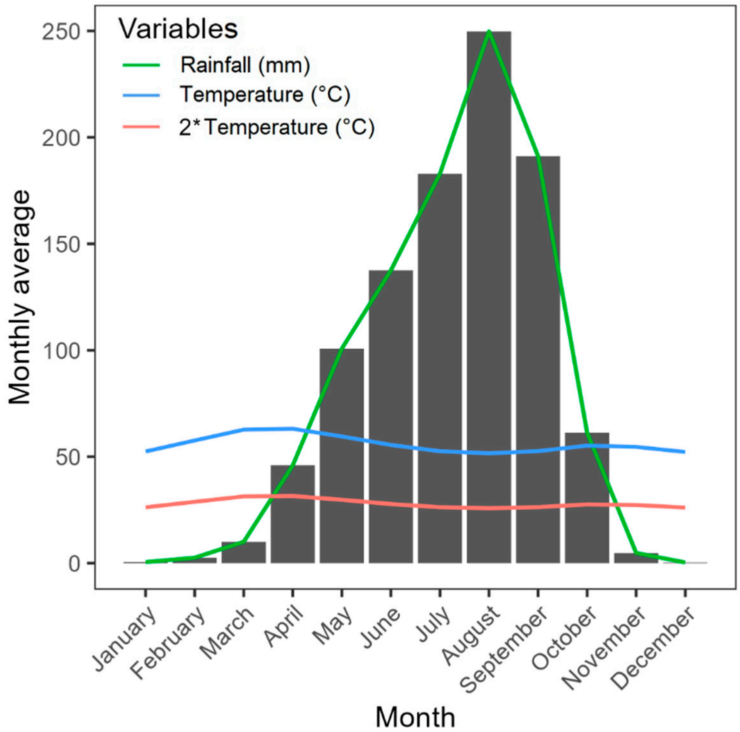

Figure 2. Ombrothermic diagram from 1985 to 2015 for W-Pendjari Biosphere Reserve [9].

2.2. Acquisition of climatic data from 1985 to 2015

Climatic variables included in this study are annual mean rainfall (mm), annual mean temperature (°C), and annual mean humidity (%). The daily records of these variables from 1985 to 2015 were obtained from the national meteorological agency and meteorological stations of some townships in the study area. Thus, meteorological stations of Kandi, Karimama, Segbana, Malanville, Banikoara covered the eastern part of the study area whereas meteorological stations of Natitingou, Tanguieta, Porga and Materi covered the western areas. Each variable was averaged over all the stations in order to get mean daily values which were used to calculate the annual mean values for the entire study region.

2.3. Drought frequency analysis through the application of the SPEI

To obtain an overview on drought in the study area over the study timescale, we computed the mean, standard deviation and coefficient of variation for annual temperature and rainfall.

In order to appreciate drought severity along the studied period, we used the Standardized Precipitation and Evapotranspiration Index (SPEI). The annual minimal and maximal temperatures were used as inputs to compute first the potential evapotranspiration (PET) using the method of [21]. Then the climatic water balance (D) was calculated by subtracting the PET from the annual precipitation (P). Equation of Thornthwaite [21] was applied in many other studies in the past years to calculate the PET [14,22,23].

D was used as input to calculate the SPEI computed following the method described under SPEI R package by Beguería & Vicente-Serrano [24]. We used the same SPEI thresholds as Danandeh Mehr et al. [25] to categorize drought magnitude (Table 1).

2.4. Correlation between climatic variables

In order to assess the trends between climatic variables over the study period, the correlation between these climatic variables (annual precipitation, annual temperature and annual humidity) was analyzed through spearman rank correlation under stats R package [26]. Indeed, Vrac et al. [15]

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pointed out the need to characterize climate phenomena by multiple variables instead of only single one to ensure better understanding of their processes and effects. These authors argued that, inter-variable correlations are salient statistical information to characterize probabilities of climate events and compound events concurrently. Furthermore, correlation analysis is widely performed [27–29] as preliminary step in ecological niche modelling since it makes it possible to identify variables which would drive similar patterns to avoid overcharging models with predictors. All these statistical analyses were performed using the statistical computing programming language R v4.1.2 [26] through the integrated development environment Rstudio [30].

Table 1. Drought magnitude categorization using SPEI.

SPEI	Category
1.83 and above	Extremely wet
1.43 to 1.82	Very wet
1.0 to 1.42	Moderately wet
−0.99 to 0.99	Near Normal
−1.0 to −1.42	Moderately dry
−1.43 to −1.82	Severely dry
−1.83 and less	Extremely dry

2.5. Predictive analysis of the climatic characteristics of the study for 2035

On purpose to predict variation in climatic variables up to year 2045, we analysis trend and seasonal effects in historical data series (from 1985 to 2015) of each climatic variable. Indeed, we applied the non-parametric statistical test of Mann-Kendal to check for trend in each data series. The Mann-Kendal test is one most widely used statistical test used to detect trend in hydro-climatic times series [31–33]. Preliminary to this test, we assessed dependency structure within the data series in order to decide the exclusion of the serial correlation [31,34]. We applied the trend free pre-whitening (TFPW) method of Yue and Wang [34] to eliminate the serial correlation. The Mann-Kendal test was calculated through Eq. 1:

$$S = \sum_{i=1}^{n} \sum_{j=i+1}^{n} sgn(Kj - Ki)$$

Where,

$$sgn(Kj - Ki) = \begin{Bmatrix} 1\ if\ (Kj - Ki) > 0 \\ 0\ if\ (Kj - Ki) = 0 \\ -1\ if\ (Kj - Ki) < 0 \end{Bmatrix}$$

The statistic S is assumed to be normally distributed with a mean equals to zero in the series Ki, i = 1, 2, 3, ……….n. The discrepancy of S was obtained through Eq. 2:

$$var = \left[\frac{n(n-1)(n-5) - \sum_{y=1}^{x} t_y(t_y - 1)(2t_y + 5)}{18}\right]$$

The test was implemented using the package R trend [35].

The trend magnitude was appreciated using the Sen's slope (SS) [36] calculated through the equation Eq.3. This statistic is widely used as complement to Mann-Kendall test to deeply analyze trend in time series data [37–39] . Eq.3:

$$SS = \left[\frac{xj - xi}{j - i}\right] \qquad \text{while i < j}$$

In order to forecast each climatic variables up to 2045, we used the traditional the three parameters (p, d, q) model Autoregressive Integrated Moving Average (ARIMA). ARIMA is among one the most widely used to model time series and forecast future [31]. It's recommended for data series which do not exhibit any seasonal patterns. Different values were tested for the parameters of

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each of these model types. We computed the autocorrelation function (ACF) to determine the optimal values of the model parameters.

3. Results

3.1. Trends in climatic variables and drought frequency in the study area

Throughout the study span, the mean annual humidity was 57.09% (± 2.85), while the annual mean rainfall was 987.64 mm (± 114.95) and the annual temperature 27.91°C (± 0.33). A mean Potential Evapotranspiration (PET) of 163.3 mm/year (±10.72) was recorded (Table 2). It was found that the annual mean rainfall, the annual mean humidity and the annual temperature was positively correlated (Figure 3) but the correlation is more stressed between the rainfall and the temperature (Rho=0.5, Supplementary material S1). The Mann-Kendal test (Table 3) indicated an increase trend in these climatic variables ($P<0.005$) except rainfall which did not display any trend over the investigated time period. The Sen's slope suggests respectively a significant ($P<0.01$) increase rate of 0.02°C yr-1 in the annual mean temperature, a highly significant ($P<0.0001$) increase rate 0.22% yr-1 in annual mean humidity. Overall, the SPEI (Figure 4) reveals climatic variations in the study area all over the period with regard to its observation. In fact, there was no extreme dry or wet year from 1985 to 2015 in the study area. Near normal precipitation and evapotranspiration events were observed for 19 years out of 30, representing 63% of the surveyed years (1986, 1988, 1989, 1992, 1993, 1995, 1996, 1997, 1999, 2001, 2002, 2004, 2005, 2006, 2007, 2009, 2013, 2014 and 2015). Nevertheless, four years, 13% of the surveyed years (1991,1994, 1998 and 2003) were very wet whereas only three years, 1% of the study years (1987, 1990, 2000) were severely dry.

Table 2. Descriptive statistics (mean ± standard deviation) on climates parameters during the period 1985 -2015.

Temperature	Humidity	Rain	PET	BAL
27.91±0.33	57.09±2.85	987.64±114.95	163.3±10.72	824.34±115.63

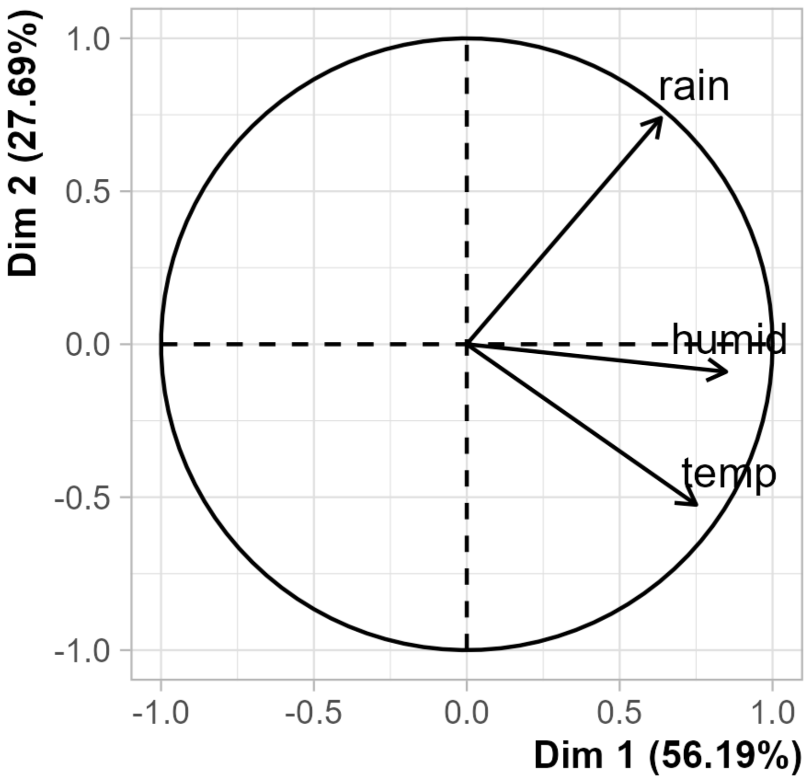

Figure 3. Correlation between climatic variables using the first two components of the PCA.

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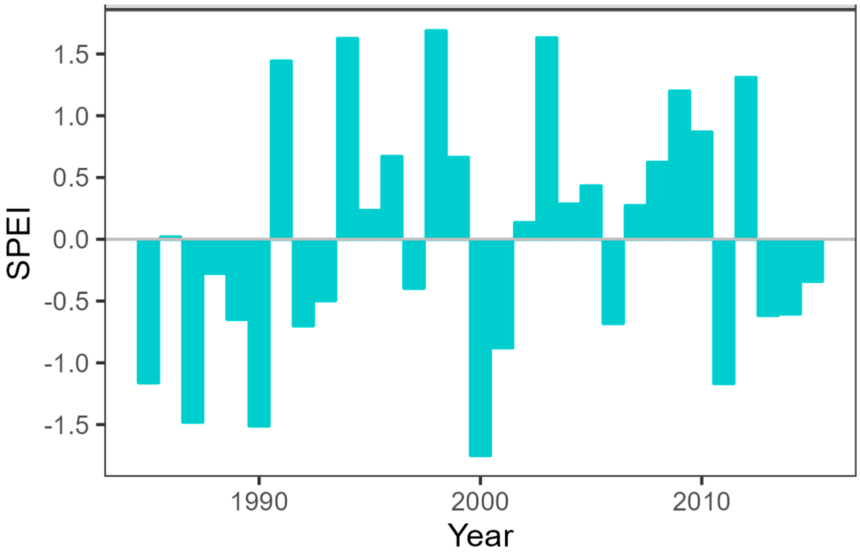

Figure 4. The evolution of Standardized Precipitation and Evapotranspiration Index (SPEI) throughout the study span.

Table 3. Sen's slope with Mann-Kendal test output for trend in the climatic variables during the period 1985-20215.

	Test statistic	n	P value	Alternative hypothesis	S	varS	tau	Sen's slop
Temperature	3.213	31	0.001315	two.sided	190	3,461	0.409	0.02187
Humidity	4.317	31	1.581e-05	two.sided	255	3,462	0.5484	0.2222
Rainfall	1.496	31	0.1347	two.sided	89	3,462	0.1914	3.402

3.2. Predictive climatic characteristics in the study area for 2045

Box-Ljung test indicated that there is no serial correlation (Table 4, P>0.05) in the data series predicted up to 2015 using ARIMA model. This is an evidence of adequacy fit of the model to data of the different climatic variables investigated. The ARIMA (2,1,0) model predicted a very low decrease which can be considered as constancy in annual mean temperature from 2016 to 2045 but a large confidence interval around this mean trend suggested that both increase or decrease trend are plausible (Figure 5a). Forecasted value (up to 2045) of annual mean humidity the optimal parameters (0,1,1) of ARIMA indicated an increase trend (Figure 5b). But the trendless character of rainfall over 1985 and 2015 did make it possible to model the future trend in this variable (Figure 5c).

future trend in this variable (Figure 5c).

Table 4. Serial correlation checking through Box-Ljung test for each climatic variable.

	Test statistic	df	P value
Temperature	0.008006	1	0.9287
Humidity	0.2378	1	0.6258
Rainfall	0.1063	1	0.7444

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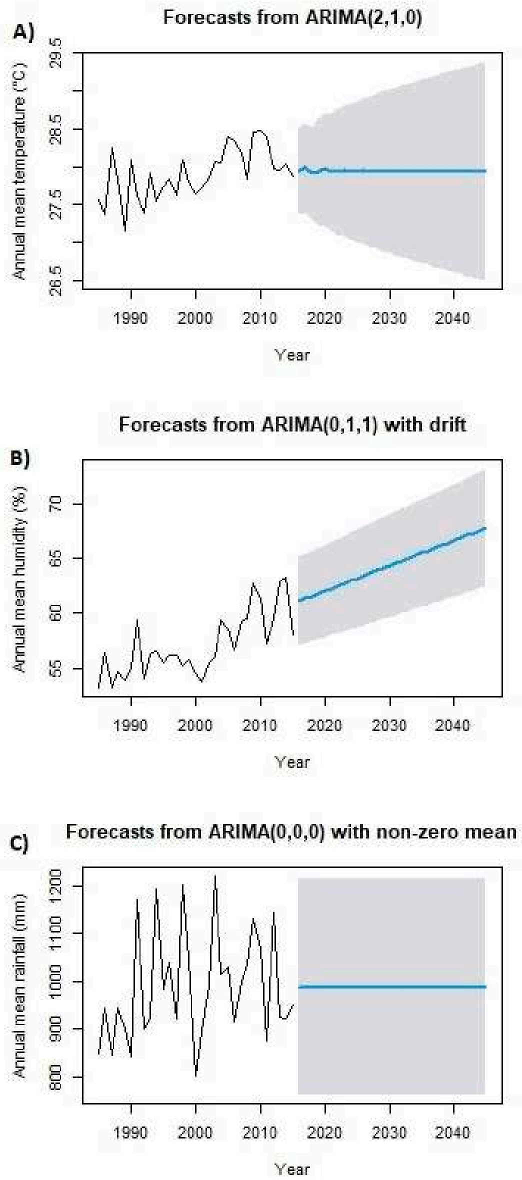

Figure 5. Forecast up to year 2045 for a) the annual mean temperature, b) annual mean humidity an c) annual mean rainfall.

4. Discussion and implications for the conservation of the W and Pendjari Biosphere Reserves

This study revealed no extreme drought or wet times while we recorded few severe dry and wet years all over the study period. Yet, the majority of the surveyed years from 1985 to 2015 exhibited nearly normal and moderate climatic conditions. Such findings confirm that the region is somehow facing climate change and they allow us to say that for a period of 30 years, the region of the W and Pendjari Biosphere Reserves experienced few severe dry and wet times. This change in the climate corroborates findings of the Benin National Climate Adaptation Policy reporting climate change in Benin from the southern to its northern parts from 1979 to 2019 [2,40].

As a result, the nearly normal climatic conditions recorded mean that overall both humans and wildlife in this region met their required living climatic conditions. In fact, it has been stated that climate change is having a profound effect on people, wildlife and ecosystems worldwide (https://www.caryinstitute.org/climate-change-ecology). However, although there were very few severe dry and wet times in the two Biosphere Reserves for a period of 30 years, the impacts of this on wildlife might have been significant since such conditions altered ecosystems [2]. Other studies

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can investigate the trends in animal populations in the two national parks W and Pendjari for the reported severe wet and dry years in order to assess the impacts on wildlife. Morever, assessing the trends in food crops as well as cash crop production in this region for such periods will lead to assessing the relationship between such variations in the climate and the agricultural production in the region. According to the United Nations Environmental Protection Agency, there is evidence that this drought and severe wet times, although very few, would have negatively affected crops, livestock and food security in the region [41] (https://www.epa.gov/climateimpacts/climate-change-impacts-agriculture-and-food-supply).

As the national parks of Pendajri and W are among the last refuges of wild animals in the West African region, the overvall normal climatic trend recorded from 1985 to 2015 lets assume that animal like the Northwest African cheetah, the West African lions are still meeting the ecological preferendum in these ecosystems (https://www.africanparks.org/the-parks/w). However, according to the Food and Agriculture Organization of the United States (FAO), the overexploitation of this wildlife like illegal hunting may be threatening its survival (https://www.fao.org/3/s2850e/s2850e05.htm). Regarding climatic variations in West Africa in addition to human effects on wildlife, there is a need to consider divergent regional perspectives to enhance conservation programs [42].

The predictive assessment of the climatic conditions up to 2045 showed a low decrease in annual temperature with likely increase or decrease due to a large confidence. Such a likely increase trend in the temperature is in line with Sylla et al. [43] who reported an increase in the temperature in Westmost Sahel. Whereas the annual mean humidity is expected to face an increase up to this year. These trends mean that the region is still expected to face climate change in the coming years even if severe variations are not announced based on our predictive method. Our findings are in line with those reported by Benin Ministry in charge of environmental protection, stressing that Benin will continue facing climate change whether sustainable adaptation strategies are not implemented and adopted [40]. Taking into account the human population growth and the fact that human activities have potential impacts on the climate, there is a need to better define and implement sustainable climate change mitigation and adaptation pathways made available to decision-makers [42,44]. Local people should be trained and informed on the impacts of their actions as well as part they have to take in the environmental protection. Any drastic change in the climate has potential effects on plants, animals, people and the ecosystem sustainability, meaning threats to the two natural reserves. In fact, a predictive study on the climate of West Africa reported that future changes can produce significant stresses on agricultural activities, water resources management, ecosystem services and urban areas planning [43].

Reviewing future climatic forecasts, Sylla et al. [43], reported an increase trend in temperature and a decrease trend in rainfall and humidity. This contrasts with findings of the present study. However, Sylla et al. [43] considered findings of different assessment reports of the Intergovernmental Panel on Climate Change (IPCC) which modeled and forecasted future climate considering different scenarios of radiative forcing up to the year 2100 under some specific assumptions on greenhouse gas concentration. But in this study, the analytic process (ARIMA model) used to forecast future values in the targeted climatic variables, considers just the variability in the past values without any deterministic assumption. Thus, it's possible to reach contrasting findings with deterministic models.

This study revealed that the Biosphere Reserves of Pendjari and W in north Benin had faced climate change from 1985 to 2015 and will continue facing it with various trends. Almost normal precipitations and evapotranspiration were noted in the past with few severe dry and wet years. The absence of extreme wet and dry years is a positive point in favour of people, crops and wildlife in the study area. The predictive analysis did not show neither extreme nor severe periods up to 2045 although noticeable variations in the mean annual temperature and humidity are announced. However, adaptation and mitigation policies are useful to avoid severe changes in the future in this region. Regarding the ongoing context of global warming, extreme or severe climatic conditions will not only affect the biological diversity of the reserves ecosystems but also induce food scarcity and food insecurity due to low crop yield. People in a situation of hunger will exert high pressure on the natural resources in their surroundings.

Similar to our research, Liu et al. [45] applied the standardized Precipitation and Evapotranspiration Index to analyze the spatiotemporal drought in a province of China. Likewise reported in the present paper, these authors also used the mulitivariable linear regression method to assess the significance of drought characteristics in their study region. Moreover, Khadka et al. [46] stated drought characteristics in the northeast of Thailand by using the SPEI and reported that understanding such climatic parameters can help in planning and implementing drought mitigation and management strategies. Such findings add value to our study and confirm the importance of basing management policies on outputs of this research in the two Biosphere Reserves. The predictive models ARIMA used in this research corroborate methods applied by Amjad et al. [47] to predict the variations in temperature in the Karachi region of Pakistan. It shows the relevance of the predictive approach applied in this research.

One of the limitations of this research is the lack of combing satellite data track for better comparison of climatic variations [48]. The increasing intensity and frequency of droughts under climate change requires relevant ways to monitor droughts [48]. The ecological risks associated with the climatic variations in these two Biosphere Reserves are necessary as perspective studies to better state how far the change in the climate is affecting the ecological patterns in such protected areas. Furthermore, migrations of animals along the two reserves for the study period should be stated as well as undertaking a global climatic study on Pendjari and W Biosphere Reserves in Benin, Burkina Faso and Niger. This will help find out which parts of these transboundary parks are receiving more animal populations due to the climatic variations. To better monitor such variations in the two reserves, the application of the artificial intelligence methods is suggested. Overall, the present article should motivate many other investigations on the two reserves in the field of climatic variations in relation with plant and animal species dynamics.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org.

Author Contributions: H.O.D.Y., A.A.O., S.A.A.R., A.D.M.T.H. did the conceptualization. H.O.D.Y., A.A.O. and A.D.M.T.H.; did the data collection. H.O.D.Y., A.A.O., S.A.A.R., A.D.M.T.H.; analyzed all data, wrote the manuscript and edited it. B.S. supervised the research, edited and validated the last version before submission.

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Conflicts of Interest: The author declares no conflict of interest.

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