Effects of Climate Change on Soil Wetness at the Surface and Root Zone of Cocoa Plots in Ondo State Nigeria.

ABSTRACT

Cocoa is a strategic economic crop and a major source of foreign exchange for Nigeria, for which Ondo State is the leading producing area. However, its production has been marked with much fluctuation over the years with a resultant reduction in yield to the tune of 40 to 50% due to climate changes. A study was conducted that covers all the Local Government Areas (LGAs) of Ondo State and data on rainfall, relative humidity, temperature, Surface Soil Wetness (SSW) and Root Zone Soil Wetness (RZSW) were sourced from the database of National Aeronautic Space Agency (NASA). The data were analyzed using the least square regression and correlation coefficient analyses. The result obtained showed that temperatures, relative humidity, the rainfall pattern as well as SSW and RZSW had similar impacts in 38.89% of the LGAs but their effects varied in the remaining 61.11%. For the 41 years of observation, the temperature and relative humidity increased by $0.0033^{o}C$ and 0.019% per annum at R^2 values of 0.0045 and 0.0862 respectively while the rainfall decreased by 17.37mm per annum at R^2 value of 0.1021. The SSW and RZSW decreased by 0.0005 and 0.0006 per annum at R^2 values of 0.0451 and 0.036 respectively. There was a positive correlation of 0.152, 0.758, 0.762and0.995 between temperature and rainfall, rainfall and SSW, rainfall and RZSE as well as SSW and RZSW respectively. The correlations between temperature and relative humidity; SSW, RZSW and years of observations of -0.359, -0.212and -0.190 respectively were inversed. This indicated that climate change had led to high relative humidity, temperatures and rainfall, with a reduction in SSW and RZSW. This trend favours the growth and development of various fungi noted for causing diseases of cocoa. This informs the need for the adoption of good agricultural practices (GAP) to mitigate reductions in cocoa production in the studied LGAs in Ondo state.

Key: *Climate change, Soil moisture, Temperature, Ondo State and Cocoa*.

INTRODUCTION

Soil moisture, Sometimes called soil water or soil wetness is the total amount of water, including water vapour, in an unsaturated soil [1]. It represents the water in land surfaces that is not in rivers, lakes, or groundwater but resides in the pores of the soil. It is a very critical state variable inland–atmosphere interactions due to its pivotal roles in the hydrological cycle, exchange of energy and moisture fluxes, weather and climate systems [2, 3, 4]. It is a vital tool in irrigation planning and water management practices; it plays an important role in agricultural monitoring, drought and flood forecasting, forest fire prediction, water supply management and other natural resources activities. Soil moisture observations can forewarn impending draught or flood conditions before other more standard indicators are triggered [5]. It is dimensionless and varies between 0 and 1, indicating relative saturation between completely dry conditions and completely saturated conditions [6]. The level of soil moisture is however determined by a host of factors beyond weather conditions, which include soil type and associated vegetation. Soil moisture levels affect a range of soil and plant dynamics. The amount of soil moisture can have significantly different implications depending on location, season, soil type, and soil depth.

Surface soil moisture (SSM) is the water that is in the upper 10 cm of soil, whereas root zone soil moisture is the water that is available to plants—generally considered to be in the upper 200 cm of soil [5]. Therefore, root zone soil moisture (RZSM) is a vital variable for agricultural production, water resource management and runoff prediction [7]and there is a strong coupling strength between SSM and RZSM [8].

Cocoa is cultivated as a rain-fed crop, and it is highly sensitive to soil and weather conditions of low rainfall, soil and air moisture deficit, as well as temperature stresses [9, 10]. The changes in the growing environmental conditions with regard to marginal soils and extreme weather events had imposed a lot of constraints on cacao growth and productivity [11]. Shortage of water is the most important factor affecting the physiology and the yielding capacity of cacao in West Africa. As it affects leaf production, leaf expansion, leaf fall, cambial growth, flowering, fruit setting, cherelle wilt and pod growth are all affected by the plant-water potential [12].

The root system of cacao is concentrated within 80cm of the soil profile, with over 80% of the root biomass housed within the top 40cm [13]. In a mature cocoa tree, most of the fine and secondary roots are found within the first 15-20 cm of the collar [14]. The root distribution of cacao can be characterized as a dense mat of lateral roots with one taproot that anchors the tree and can penetrate the soil up to 2-2.5 m [15]. The density of the lateral roots decreases exponentially with depth. About 20% of the lateral roots can take up water. The taproot is essential for water and nutrient uptake in dry periods [16]. The majority of the roots develop in the upper layer of the soil, close to the litter layer. The soil fertility of most tropical soils is concentrated in this soil-litter interface. [17] described the rooting system of cacao in physiologically shallow soil as being superficial, while that of physiologically deep soil is well dispersed. In most cocoa-producing countries in West Africa, soil water is depleted fast in the top 60 cm of soil depth during extended dry seasons, thus predisposing the plants to drought [18].

The decrease in regional precipitation and the increase in evapotranspiration are driven by global warming and for which draught ranks first among the natural hazards [19, 20, 21]. Projections of climate change have pointed to an increase in mean temperature (about 2 °C by 2080) with a decrease in precipitation [20, 21].This has implicationsfor decreasing crop yield owing to enhanced heat and water stress. Thus, climate change scenarios for the rainforest of Nigeria have indicated variability in rainfall patterns with respect to the amount, distribution, onset and cessation dates along with elevated maximum and minimum temperatures. These projected climatic changes will exacerbate soil moisture and thermal stresses during the dry season with implications for crop performance [20, 21]. Cocoa is cultivated as a rain-fed crop, and it is highly sensitive to soil and weather conditions of low rainfall, soil and air moisture deficit and temperature stresses [9, 22]. The changing growing environmental conditions, with regard to marginal soils and extreme weather events, will impose constraints on cacao growth and productivity.

Light and water limitations have an effect on the availability and uptake of nutrients by cocoa as shortage of water decreases nutrient uptake [23] and low P-availability decreases cocoa plant growth and yield.

This information is of great importance to Ondo State, Nigeria's leading cocoa producing state which in recent years has incurred a decline in cocoa production [24]. According to [25], cocoa production in Ondo state has been marked with fluctuation over the years mainly attributed to climate change. The trend analysis by [25] revealed fluctuations in some of the climatic parameters especially rainfall, temperature and sunshine hours. The Nigeria Meteorological Agency [26] noted rainfall values that were 200-300% higher than normal in some locations in the South Western region which included Ondo State. Thus, awareness of climate change effects becomes imperative to mitigate the adverse effects on agriculture, with a particular preference for cocoa production in Ondo State.

MATERIAL AND METHODS

Study area

The study was carried out in Ondo state located in the South Western Nigeria. The state was created on the 3rd of February, 1976 and it is made up of 18 Local Government Areas the major ones being Akoko, Akure, Okitipupa, Ondo, Ilaje, Idanre and Owo. It is bounded by Ekiti and Kogi State in the north; Edo State in the east; Ogun and Osun States in the west and the Atlantic Ocean in the south. Ondo state covers an area of 14,793 sq km at 120 kilometers North of the Atlantic ocean and it lies between Longitude 4˚30" and 6˚ East, and Latitude 5˚45"N and 8˚15"N of the Equator. Ondo State is characterized by a tropical climate with a rainy season from April to October, while the dry season is from November to March. The state is within a tropical rainforest with a mean rainfall of about 1,634mm per annum.

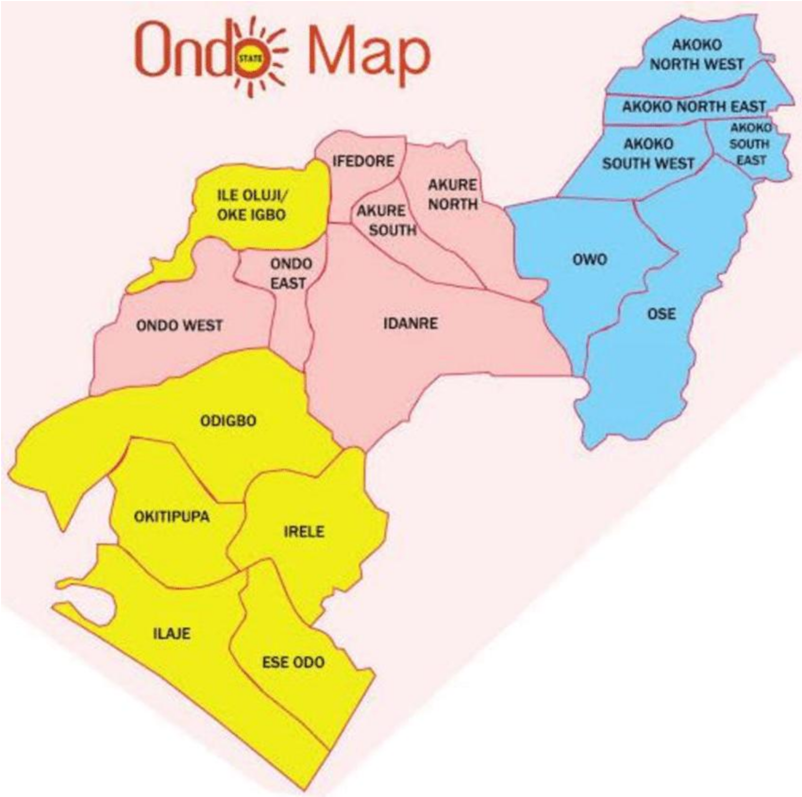

Fig. 1. Map of Ondo State showing the 18 Local Government Areas [27].

Source of Data

The data used were sourced from the National Aeronautic Space Agency (NASA) Prediction of Worldwide Energy Resource (POWER) project data archive. The POWER Project contains over 380 satellite-derived meteorology and solar energy. Analysis Ready Data (ARD) at four temporal levels which are hourly, daily, monthly (by year 12 months + annual averages), and climatology. The POWER Data Archive provides global data via single points (latitude/longitude) at the native resolution of the source data products and a 0.5 x 0.5 degree resolution for regional and global data requests. The data is updated nightly to maintain Near Real Time (NRT) availability (2-3 days for meteorological parameters and 5-7 days for solar). The POWER Project is a Geographic Information System (GIS) enabled interactive web portal that targets three specific user communities: Renewable Energy (RE), Sustainable Buildings (SB), and Agro-climatology (AG). The products are available from daily up to multiple-year averages. The POWER project used the coordinates of the 18 Local Government areas of Ondo state to provide the Surface Soil Wetness (SSW) from the surface to 5cm below and Root Zone Soil Wetness (RZSW) from the surface to 100cm below as well as the rainfall, maximum and minimum temperatures from 1981 to 2022.

Method of Data Analysis

The data were analyzed using an ordinary least squares regression model. The method uses a straight line

$Y = a + bx$

to approximate the given set of data, (x_1,y_1), (x_2,y_2), …, (x_n,y_n), where the number of data points, $n \geq 2$

Implicitly, the model can be represented as follows:

$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + \ldots\ldots\ldots\ldots + b_nX_n + e_i$

Where:

Y = Dependent variable,

Xs = Independent variables,

e = Random error term.
a and b are as defined below.

$$a = \frac{\sum y - m\sum x}{N}$$

$$b = \frac{N\sum(xy) - \sum x \sum y}{N\sum(x^2) - \left(\sum x\right)^2}$$

Where ‘a’ stands for the intercept and ‘b’ stands for the slope; x and y are the coordinates of the data points that represent the variables.
The slope is equivalent to variation in the measured variables per annum.
To quantify the strength of the relationship between the measured variables, the correlation coefficient was computed.
Given two variablesx and y in algebraic form, if the data takes the form of n pairs, (i.e. [x_1, y_1], [x_2, y_2], [x_3, y_3] ... [x_n, y_n]), then the correlation coefficient is given by the equation (PSU, 2023):

$$r = \frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)\left(\left(y_i - \bar{y}\right)\right)}{\sqrt{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2 \sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2}}$$

Where $\bar{x}$ is the mean of the x values, and ȳ is the mean of the y values.
This is the product-moment correlation coefficient (or Pearson correlation coefficient), withthe value of r lying between -1 and +1. A value of the correlation coefficient close to +1 indicates a strong positive linear relationship which shows. One variable increases with the other, while a value close to -1 indicates a strong negative linear relationship indicating that one variable decreases as the other increases. Generally, a value close to 0 indicates that there was no linear relationship.

RESULTS AND DISCUSSION

Meteorological and soil wetness variability of Ondo State.

Table 1 shows the coordinates and meteorological variables of all the Local Government Areas of Ondo State.The maximum and minimum temperatures range from 32.929 to 33.711^{o}c and 14.284 to 16.386^{o}c respectively. Throughout the observation, the mean temperature and rainfall ranged from 23.842 to 24.784^{o}c and 1737.995 to 2675.524mm while the relative humidity ranged from 83.902 to 87.599%. The mean Surface Soil Wetness (SSW) and Root Zone Soil Wetness (RZSW) ranged from 0.771 to 0.864 and 0.776 to 0.874 respectively. The temperatures, relative humidity, rainfall pattern as well as SSW and RZSW are similar in 38.89% of the Local Government Areas of the state but vary across the rest. The statistics of the variables are presented in Table 2.

Table 1. Meteorological and Soil Wetness Variables of Ondo State Local Government Areas

Local Government Areas	Longitude (°N)	Latitude (°E)	Maximum Temp (°C)	Minimum Temp (°C)	Mean Temp (°C)	Mean Rainfall (mm)	Relative Humidity (%)	Mean surface Soil Wetness	Mean Root Zone Soil Wetness

Akoko South West	7.381	5.667	32.996	14.965	23.981	1890.680	85.859	0.771	0.776
Akoko North East	7.55	5.878	33.399	14.284	23.842	1737.995	83.902	0.797	0.794
Akoko North West	7.617	5.772	33.399	14.284	23.842	1738	83.902	0.797	0.794
Akure North	7.278	5.268	32.996	14.965	23.981	1890.68	85.859	0.771	0.776
Akure South	7.215	5.161	33.711	15.856	24.784	2423.66	86.883	0.82	0.835
Ese Ondo	6.257	4.935	32.929	16.386	24.658	2675.52	87.599	0.864	0.874
Idanre	7.109	5.116	33.492	15.74	24.616	2609.35	87.401	0.846	0.859
Ifedore	7.388	5.081	33.711	15.856	24.784	2423.66	86.883	0.82	0.835
Ilaje	6.259	4.769	32.929	16.386	24.658	2675.52	87.599	0.864	0.874
IleOluji/ Okeigbo	7.202	4.868	33.711	15.856	24.784	2423.66	86.883	0.82	0.835
Irele	6.488	4.87	32.929	16.386	24.658	2675.52	87.599	0.864	0.874
Odeigbo	6.795	4.868	33.492	15.74	24.616	2609.35	87.401	0.846	0.859
Okitipupa	6.503	4.78	32.929	16.386	24.658	2675.52	87.599	0.864	0.874
Ondo East	7.088	4.956	33.492	15.74	24.616	2609.35	87.401	0.846	0.859
Ondo West	7.026	4.769	33.492	15.74	24.616	2609.35	87.401	0.846	0.859
Ose	7.016	5.688	33.288	15.163	24.226	2031.63	85.935	0.788	0.79
Owo	7.199	5.593	32.996	14.965	23.981	1890.68	85.859	0.771	0.776

As observed in Table 2, the standard deviation shows a close relationship between the temperatures, and relative humidity on one hand and between the SSW and RZSW values on the other hand. However, there was a wide variation in the rainfall values across the various years of observation. The average rainfall range was greater than the recommendation for cocoa production which is between the ranges of 1500mm-2000m [28]. The maximum annual temperature average was also higher than the ICCO recommendation of 30 – 32^{o}C.

Table 2: Statistics of the climatic variables

ClimaticVariables	No.of observation	Mean	Standard Deviation	Minimum	Maximum
Avg. Rainfall	41	2296.008	666.993	1198.535	4492.673
Avg. Max. Temp	41	33.294	0.605	32.334	34.915
Avg. Relative Hum.	41	86.437	0.794	84.843	88.195

SSW	41	0.822	0.029	0.747	0.888
RZSW	41	0.830	0.036	0.737	0.906

Determination of Temperature, Rainfall and Relative Humidity Variations.

The rainfall, relative humidity and maximum temperature variation across the state within the 41 years of observation are shown in Fig. 2, 3 and 4 below. Fig. 2 shows that the average maximum temperature was highest (34.915^{o}C) in 1998 and least (32.241^{o}C) in 1987. The mean rainfall (Fig 3) was highest (4492.673mm) in 1982 and least (1198.535mm) in 2014 while the average relative humidity (Fig 4) variation was highest (88.195%) in 2013 and least (84.843%) in 1983. Throughout the observation period (41 years), the average maximum temperature increased by 0.1353^{o}C (0.0033^{o}C per annum) at a regression coefficient (R^2) of 0.0045, the average rainfall decreased by 712.17mm (17.37mm per annum) at R^2 value of 0.1021 while the relative humidity increased by 0.779% (0.019% per annum) at R2 of 0.0862.

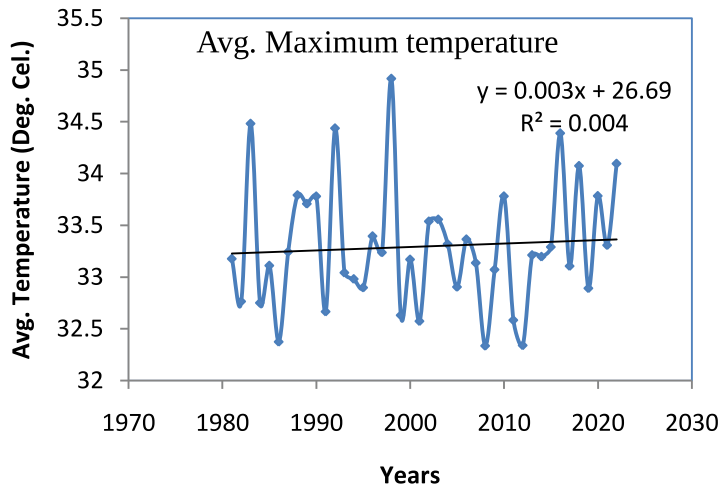

Fig. 2: Average maximum temperature variations.

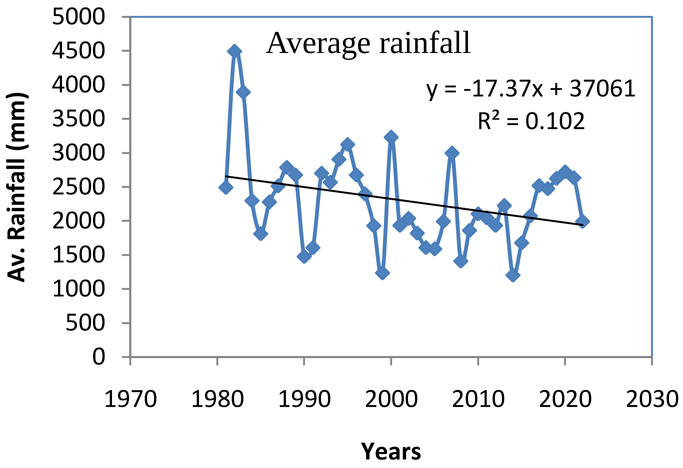

Fig. 3: Average Rainfall Variations

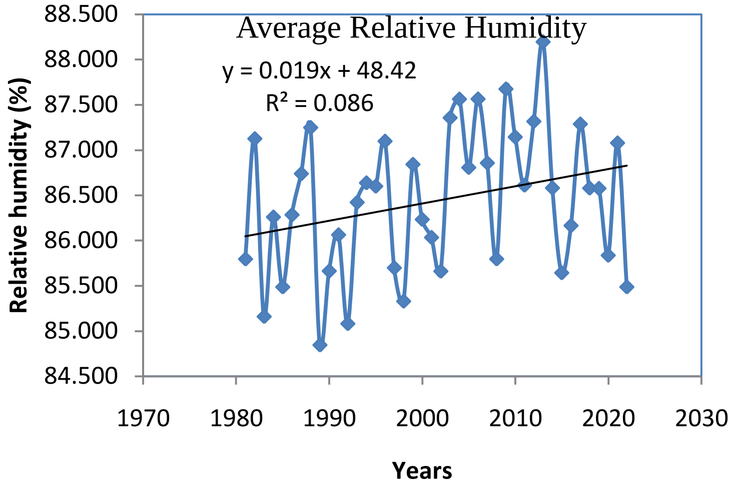

Fig. 4: Average relative humidity variations

Mean surface and root zone soil wetness evaluation

The mean surface and root zone soil wetness in the state from 1982 to 2022 are shown in Fig. 5 and 6.The evaluation of SSW (Fig 5) revealed that 1982 recorded the highest value (0.888) while in 1990 it was 0.747 as as the lowest value. The SSW decreased by 0.205 (0.0005 per annum) in 41 years at R^2 value of 0.0451. The RZSW (Fig. 6) was highest (0.906) in 1982 and lowest (0.737) in 1999. The RZSW decreased by 0.246 (0.0006 per annum) at R^2 value of 0.036.

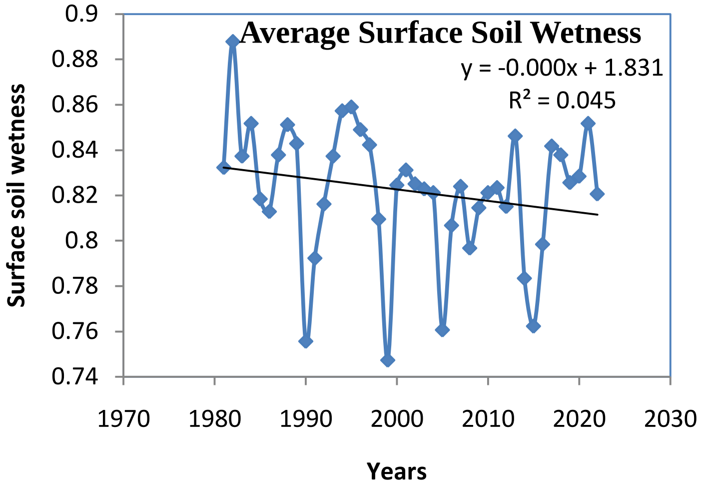

Fig. 5: Mean surface soil wetness (SSW)

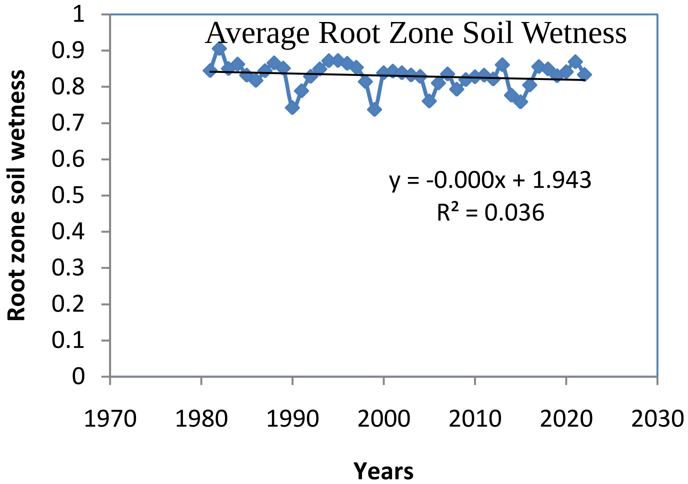

Fig 6: Mean Root Zone Soil Wetness (RZSW)

Correlation analysis of the variables

The variables were correlated to deduce the relationship. The values obtained are shown in Table 3. It was observed that there was a positive but weak correlation between temperature and rainfall. Rainfall had a strong positive correlation with SSW and RZSW while the correlation between SSW and RZSW was equally strong and positive. The correlation between temperature and relative humidity was inversely proportional, also, SSW, RZSW and the years of observations correlation were inverse. In general, as averred [29] high relative humidity and temperatures favour fungal growth and contribute to the diffusion of cocoa diseases. Where soil moisture is adequate, very high humidity as obtained in Ondo State is considered undesirable since it favours the development of various diseases of cocoa. Adequate cocoa farm sanitation through routine pruning is recommended to mitigate pests and diseases in cocoa farming in Ondo State.

Table 3: Correlation analysis of the climatic variables

Climatic variable 1	Variable 2	Outcome
Temperature	Rainfall	0.152
Temperature	Relative Humidity	-0.359
Rainfall	Surface Soil Wetness (SSW)	0.758
Rainfall	Root Zone Soil Wetness (RZSW)	0.762
Surface Soil Wetness	Root Zone Soil Wetness (RZSW)	0.995
Surface Soil Wetness	Years of observation	-0.212
Root Zone Soil Wetness	Years of observation	-0.190

CONCLUSION AND RECOMMENDATION

The study revealed that the mean maximum temperature and rainfall in Ondo State are higher than the range recommended by ICCO (1500 – 2000mm, 30 – 32^{o}C respectively). The average maximum temperature and relative humidity increase was 0.0033^{o}C and 0.019% respectively per annum while the rainfall decreased by 17.37mm per annum. The Surface Soil Wetness (SSW) and Root Zone Soil Wetness (RZSW) decreased by 0.0005 and 0.0006 respectively. There was a positive correlation (0.152, 0.758, 0.762, 0.995) between temperature and rainfall, rainfall and SSW, rainfall and RZSE as well as SSW and RZSW respectively. The correlation between temperature and relative humidity; SSW, RZSW and years of observation (-0.359, -0.212, -0.190) respectively was inversely proportional. However, the soil moisture across the Local Government Areas of Ondo State was adequate.

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