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Response of soil sustainability indicators to the changing weather patterns in Calabar, Southern Nigeria

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ABSTRACT

The response of soil properties to changing weather variables revealed soil-environment functionality that is used to know whether soil quality is improving, remain constant or declining. This paper investigates the effects of weather variables (temperature, relative humidity, and rainfall) on soil quality and sustainability and its agro-meteorological implications. Soil samples were collected from soils within Calabar Metropolis, Nigeria. Physicochemical properties of the collected soil samples were determined using standard methods, and meteorological data were collected from Nigeria Meteorological Agency at the Airport and University of Calabar Meteorological stations, both at Calabar, Nigeria. Soil sustainability index (SSI), correlation, t-test, coefficient of variation (CV), and trend analysis were computed. From the results, rainfall was found to have a strong negative significant relationship with exchangeable Ca and Na. The results further indicated that temperature and rainfall had negative impact on soil sustainability. Within the period of twelve years under investigation, the sustainability of the soil decreased as the year progressed from 2000 to 2011 by 0.26 % each year. It was concluded that impacts of weather variables such as rainfall and temperature considered in this study, when correlated with exchangeable cations (Ca, K and Na) could be used to assess the effect of climate change on soil health and assist in devising adaptive climate strategies.

1. Introduction

Despite the recent advancements in weather and climatological forecasting and data mining (Akinsanola *et al.,* 2015; Akinsanola & Ogunjobi, 2014), the general weather data observation from meteorological (Met) stations cannot be ruled out. Even with the availability of software's and e-platforms for forecasting and computation which can generate data up to 9 km resolution, the raw data from the observatories are always the reference points to be utilized as take-off base for forecasting and computations.

From common knowledge, when the forecasts and predicted data are at variance with the actual observations, the observed data are always relied upon for correction and determination of the way forward. However, we cannot misinform the populace when climate change realities are on the ground yet what is obtained from forecasts for upwards of 50 – 100 years at 10 – 50 km resolutions are at deviance with the realities. Statistically, it will be possible to get the standard deviations and errors as the margin as argued by climatologists (Akinsanola and Ogunjobi, 2014) for making room for the deviations which at times could be totally at par. When the observed and the predicted data do not pass the goodness of fit (X^2) test, then we must rethink and need to go back to the drawing board.

As agricultural meteorologists, our duty includes community service of advising farmers in southern Nigeria who practice mostly rain-fed farming, on which the effects of changing climate and weather vagaries on crop production (i.e., from the point of sowing till harvesting time) and animal husbandry is inevitable. Rain-fed agriculture depends on weather conditions such as soil temperature, air temperature, relative humidity, and most importantly, rainfall distribution, intensity, and amount. If the rainfall is too much, it might have drastic effects on crop production as this can cause flooding, surface run-off, leaching of essential plant nutrient beyond the root zone of crops and might result to erosion. On the other hand, if it is too little at the critical stages of crops growth such as germination and early growth, the performance of the crop may be thwarted and might lead to permanent wilting. Animals are equally negatively affected when the humidity is too much leading to the prevalence of various diseases. As such, important action in the form of information dissemination needs to be taken. One of the ways in mitigating the challenges of changing weather pattern on the soil is to examine the relationship between soil physiochemical properties and the weather variables.

Soil is a critical resource for meeting the diverse needs of mankind, including serving as a medium for plant growth and reservoir of essential plant nutrients. However, changes in weather variables over a long time could hamper these functions, thus making the soil to function below its optimum level. When this happens, sustainable productivity and net farmer profits and ecosystem services are jeopardized. According to Singh *et al.* (2011), there is a potential linkage between soil quality indicators, land management, and climate variables. Thus, an understanding of how climate variables (rainfall, temperature, and relative humidity) and soil quality interact as reported by Amalu and Isong (2017), and how changes in climate variables will lead to corresponding changes in soil quality and their resultant effect on crop yield and productivity is essential. Andrew *et al.* (2004) pointed out that indicators of soil quality are those measurable soil properties and processes that have the greatest sensitivity to changes in soil function and its ecosystem services. Soil quality can be used to monitor trends in soil properties over time, to determine if soil quality under different land use and management is aggrading, sustaining, or degrading (Karlen *et al.,* 2003).

Having observed the weather data for 12 years on daily basis, from two weather stations in Calabar, Cross River State, Nigeria, and after reviewing what is being forecasted and published in the literature about the study area, this study intends to investigates the effects of weather variables (temperature, relative humidity and rainfall) on soil quality, soil sustainability index and their agro-meteorological implications.

2.0 Materials and Methods:

The study area

The study was conducted in Calabar Municipality (Fig. 1). The area is located between Latitudes 04^{o} 50´ and 50^{o} 10´ North of the Equator and Longitudes 08^{o} 18´ and 08^{o} 37´ East of the Greenwich Meridian and on an altitude of 27 m to 36 m above sea level. The area is characterized by two distinct tropical moist climates – the rainy and dry seasons. The dry season occurs from November to February, while rainy season occurs between March and October. The agro-climate of the area is typical of the humid tropical region marked by excess rainfall over evapotranspiration for about eight months in a year. The annual rainfall, temperature, and relative humidity data for the area are presented in Table 1. Geologically, the area has parent material consisting of Coastal Plain Sands (Bulk-trade, 1989). The area is well drained, very porous with soil depth extending up to two meters deep and gentle sloping with a predominance of sheet and rill erosion. The soils of the area had been classified as Typic Paleudults in the Ultisols order using USDA soil taxonomy (Esu, 2005). The flora features consist of shrubs, creepers, evergreen trees, and herbs. The area is used predominantly for horticultural and arable crop cultivation where crops like maize, watermelon, fluted pumpkin, cassava, and yam are grown. The soil of the study area has been used for teaching and research as well as a commercial venture of the faculty of Agriculture and forestry. The farm had been put under similar management practices over the years.

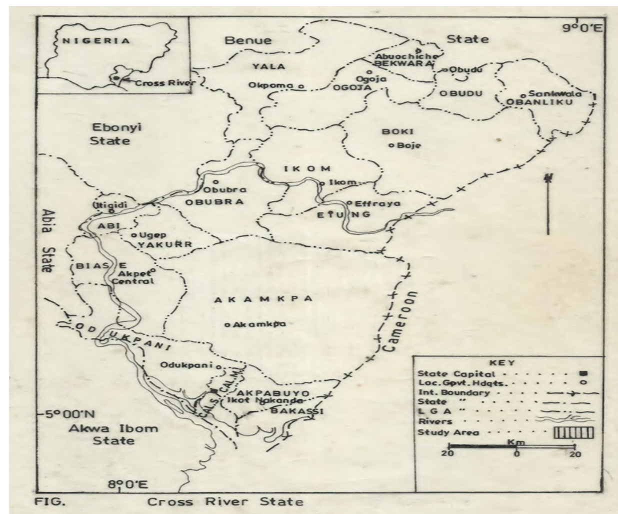

Fig. 1: Map showing the location of the study area (Calabar Metropolis)

Secondary soil properties data

Annual soil data from 2000 to 2010 for the area were obtained from literature on studies within the study location while data of the reference year (2011) data were obtained from the field study and all data were analyzed following standard/routine procedures.

Soil sampling

A total of twenty (20) composite soil samples were collected for the reference year (2011). The samples were collected with the aid of a soil auger at the depths of 0-20 cm. Soil samples collected were labeled in an airtight and clean polythene bags and taken to the laboratory where they were air-dried, then gently grounded, sieved in a < 2 mm sieve and the fine earth fractions were subjected to routine laboratory analysis.

Laboratory Analyses

Particle size distribution was determined by Bouyoucos hydrometer method (Gee and Or, 2002). Bulk density was determined using the core method (Grossman and Reinsch, 2002). Particle density was determined using the pycnometer method as outlined by Blake (1965). Total porosity was calculated from the result of bulk density and particle density. Soil pH (H_2O) was measured electrometrically using glass electrode pH meter in a solid-liquid ratio of 1:2.5 following the procedure outlined by Udo *et al.* (2009). Total organic carbon was analyzed by wet digestion method (Nelson and Sommers, 1996). Total nitrogen content of the soil was determined by wet-digestion, distillation, and titration procedures of the Kjeldahl method as described by Bremner (1996). Phosphorous was determined by Bray 1 method according to the procedure of Udo *et al.* (2009). The exchangeable bases were determined through extraction method with 1*M* ammonium acetate at pH 7 (Thomas, 1982). Amounts of Ca and Mg ions in the leachate were analyzed by atomic absorption spectrophotometer, while K and Na ions were analyzed by flame photometer. Exchangeable acidity (hydrogen and aluminum) were determined by the titrimetric method using 1*N* KCl extract. The percent base saturation of the soil was calculated as the percentage of the sum of the basic exchangeable cations (Ca, Mg, K and Na) to the ECEC of the soil.

Data analysis techniques, models, and procedure

Several techniques have been developed for the analysis of soil and climate data (rainfall and temperature and relative humidity). Soil sustainability index (SSI) was computed following the procedure outline by Lal (1994) for soil data to assess its sustainability, and correlation and t-test were also computed to examine the relationship and differences among studied soil properties. Climate data were subjected to variability and trend analysis. Variability analysis involved the use of standard deviation and coefficient of Variation (CV), while trend analysis involves the use of Mann-Kendall test and Theil Sen's Slope Estimator.

Mann-Kendall test

As reported in Amalu and Isong (2017), Mann Kendall test is a statistical test widely used for the analysis of the trend in climatologic and in hydrologic time series (Mann, 1945; Kendall, 1955). Assuming the time series data is independent, then the Mann-Kendall statistic *S* for a given sample size can be calculated as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sgn\ (T_j - T_i) \quad \text{...(1)}$$

Where, Tj and Ti are the annual values in years j and i, j > i,

$$\text{sgn}\ (x_j - x_i) = \begin{Bmatrix} +1 & \text{if} & (T_j - T_i) > 0 \\ 0 & \text{if} & (T_j - T_i) = 0 \\ -1 & \text{if} & (T_j - T_i) < 0 \end{Bmatrix} \quad \text{...(2)}$$

The trend is upwards for positive values of, and downwards for negative values of *S*. To test the trend significance, *Z* is computed, and the probability for a standard normal distribution at /*Z*/ is found.

The test statistic τ (Kendall's *tau b*) can be computed as:

$$\tau = \frac{S}{n(n-1)/2} \quad \text{...(3)}$$

The test statistic τ (Kendall's *tau b*) has a range of -1 to +1 and is analogous to the correlation coefficient in regression analysis.

Nevertheless, if n < 10, the absolute value of S is compared directly to the theoretical distribution of S derived by Mann and Kendall, and a two-tailed test is used. Conversely, if $n \geq 10$, the statistical value *S* of the Mann-Kendall test is approximately normally distributed, with zero mean and variance (σ^2) in the absence of ties can be calculated as follows:

$$\sigma^2 = \frac{n(n-1)(2n+5)}{18} \quad \text{...(4)}$$

For the situation where ties occur, σ^2 is extended to the form

$$\sigma^2 = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q}(t_p - 1)(2t_p + 5)\right] \quad \text{...(5)}$$

Where, q is the number of tied groups (a tied group is a set of sample data having the same value), and tp is the number of data points in the pth group.

The value of *S* and $\boldsymbol{\sigma}^2$ are then used to compute the *Z* statistic, which follows a normal standardized distribution thus:

$$Z = \begin{cases} \dfrac{S-1}{\sigma} & \text{if} \quad S>0 \\ 0 & \text{if} \quad S=0 \\ \dfrac{S+1}{\sigma} & \text{if} \quad S<0 \end{cases} \quad \text{...(6)}$$

Distribution pattern and trend of annual climate variables

As shown in Table 1 and Fig. 2, the annual rainfall, temperature, and relative humidity varied both within and between the two Met stations during the years under study. This variation is worthy of close examination.

The results of annual rainfall analysis for NIMET station (red bar) showed that between the years 2000-2011 the minimum rainfall of 2046.2 mm was recorded in 2004 and the maximum amount of 3428.2 mm was recorded in 2007 (Figure 2), and this was the highest peak observed for the study period. This shows that this year was the wettest year

Theil Sen's Slope Estimator*:* Sen's nonparametric method (Sen, 1968) was used to estimate the magnitude of trends in the time series data as presented in the equation below.

$$y(t) = Q(t) + C \quad \text{...(7)}$$

Where y(t) is the climate variable, Q is the slope, and C is a constant.

The slope estimates Qi of N pairs of data is calculated as:

$$Q_i = \frac{x_j - x_k}{j - k} \quad \text{...(8)}$$

In this equation, xj and xk represent data values at time j and k, (j>k) respectively. The median of these *N* values of Q_i is Sen's estimator of the slope which is given as;

$$Q = \begin{cases} \frac{1}{2}\left(Q_{\frac{N}{2}} + Q_{\frac{N+2}{2}}\right) & \text{if N is even} \\ Q_{\frac{N+1}{2}} & \text{if N is odd} \end{cases} \quad \text{.....(9)}$$

The two-sided test is carried out at 100(1 – α) % of the confidence interval to obtain the true slope for the non-parametric test in the series (Mondal *et al.,* 2012). A positive Qi value represents an increasing trend; a negative Qi value represents a decreasing trend over time.

Software used for the Analysis

Data analyses were undertaken using Systat 13 software and Microsoft Excel.

3.0. Results and Discussions:

Preliminary Analysis

Twelve (12) years weather data obtained from the University of Calabar (UNICAL) and Nigerian Meteorological Agency (NIMET) was utilized for the study, and the summary statistic is presented in Table 1. The mean temperature of the study area was 26.9 ^{o} C in UNICAL station and 27.4 °C in NIMET station, while the mean annual rainfall was 2380.7 mm and 2952.4 mm respectively from the UNICAL and NIMET stations in Calabar. The relative humidity stood at 83.3 % and 86.0 % respectively for UNICAL and NIMET (Table 1). According to Afangideh *et al.* (2010), two synoptic meteorological (Met) stations can be sited at a lag of about 100 km apart, which is the distance expected to have reasonable effects in weather variations. In this study, the distance between the two meteorological stations where data were obtained was approximately 5 km apart. Hence the climatic data were adjudged to be valid for the study areas.

Table 1: Comparison of climate data of two meteorological stations in the study area

Year	Temperature (°C)		Rainfall (mm)		Relative humidity (%)	
	UNICAL	NIMET	UNICAL	NIMET	UNICAL	NIMET
2000	26.9	27.1	2666.4	2828.7	85	88.1
2001	26.8	27.2	3073.6	3292.6	84	86.2
2002	26.7	27.3	2691.4	3209.3	83	86.3
2003	26.4	27.4	2113.7	3030.2	86	87.5
2004	27.6	27.7	1728.6	2046.2	85	86.8
2005	27.4	28.1	2533.8	3101.5	83	84.6
2006	26.8	27.0	2951.8	2646.7	84	85.2
2007	26.0	27.0	2417.5	3428.2	84	84.3
2008	26.7	27.1	1931.3	3125.2	82	84.5
2009	26.6	27.4	1401.1	2526.9	82	86.2
2010	26.7	27.5	2003.7	3071.7	82	85.8
2011	27.8	27.8	3055.3	3121.8	86	86.9
Mean	*26.9*	*27.4*	*2380.7*	*2952.4*	*83.8*	*86.0*
SD	*0.51*	*0.34*	*544.77*	*383.78*	*1.47*	*1.21*
CV	*1.89*	*1.24*	*22.88*	*12.90*	*1.75*	*1.41*
Min	*26.0*	*27.1*	*1401.1*	*2046.20*	*82.0*	*84.3*
Max	*27.8*	*28.1*	*3673.60*	*3428.20*	*86.0*	*88.1*

within the period under consideration (2000-2011). In general, the pattern of rainfall distribution fluctuates significantly. The total annual rainfall of the area increased in the period 2000 to 2001 and later decreases from 2002 to 2004, which further increases in 2005 and later drop in 2006 and increase again in 2007. There was a sharp decrease after 2007, which continued till 2009. However, an overwhelming sharp rise was observed in 2001, and this level was also maintained in the subsequent year. The result obtained in this study was similar to what was obtained by Amalu and Isong (2017), and it also supports the findings of Egbinola and Amobichukwu (2013) that equal amount of rainfall is not expected from one year to another. This result implies that the wide variation in rainfall amount over time is significant enough to cause changes in soil properties.

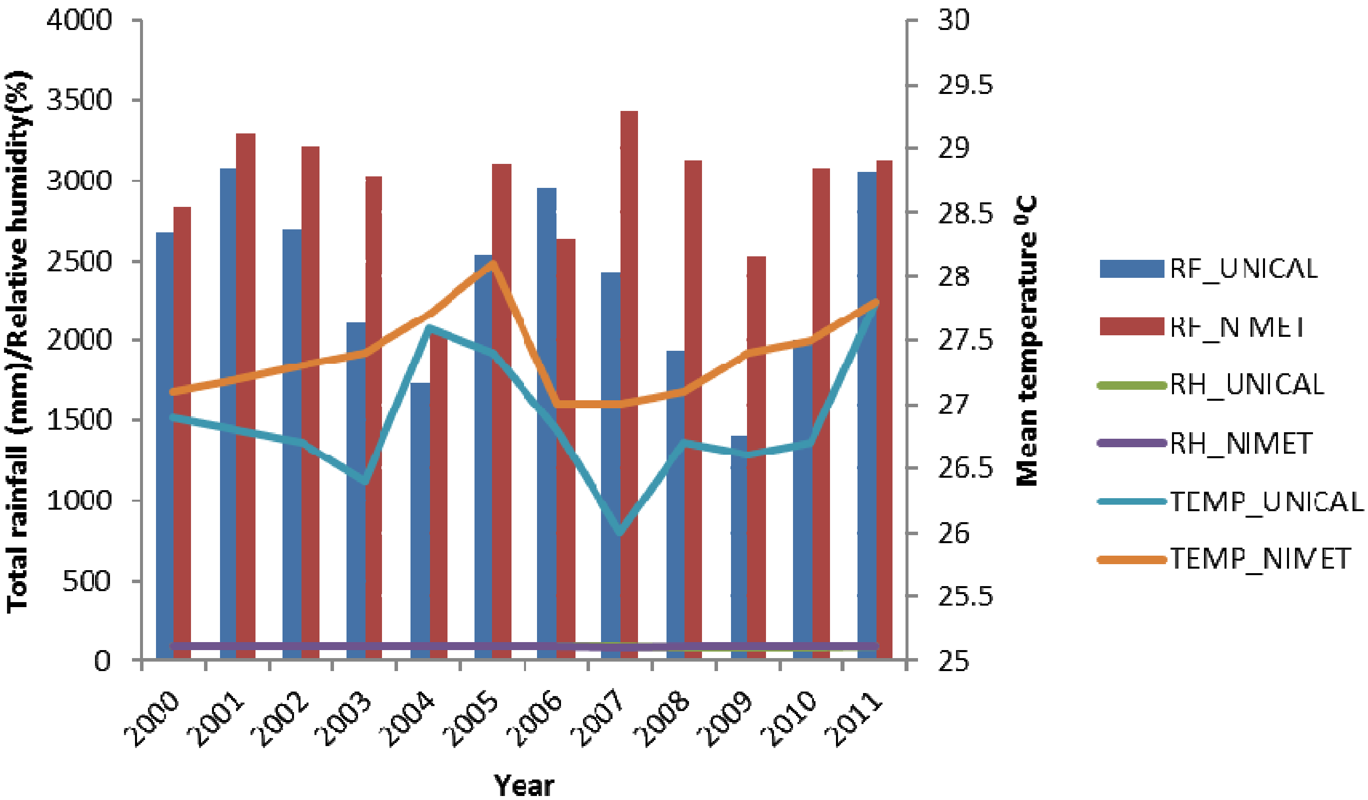

Fig 2: Rainfall, temperature and relative humidity distribution in Unical and NIMET stations

The analysis of mean annual temperature data indicates a clear presence of variation in temperature pattern in the study area. There were increases and decreases in mean annual temperature from 2000 to 2011. Firstly, the area experienced an increase in temperature from 2000 to 2005, after which the mean annual temperature dropped and rose again after 2006 and continue to increase till 2011. However, between the years 2000-2011, the lowest temperature of 27.2 ^{0}C was recorded in 2001, and the highest temperature of 28.1 ^{0}C was observed in 2005 (Figure 2). The results of annual relative humidity values were found to be reasonably stable across the study area over the study period (Fig. 2). Also, a similar distribution pattern was observed in UNICAL station (blue bar), but the figures obtained from NIMET station were consistently higher than data obtained from UNICAL Met station. The disparity in data sets was investigated in this study by subjecting the data to T-test analysis to validate if there is any significant difference between the two data sets. This will counter or confirm reliability in using any of the two data sets independently. The results of the validation via T-test showed that the two data sets from the two Met stations were significantly different from each other (Table 2). Therefore, it would not be advisable to use any of the observed data. The reliability of the data is at stake. However, having studied the result carefully, in addition to the effect of climate in the tropics which is expected to push climate variables upward, it will be wise to use more reliable and specifically data that were obtained from NIMET bearing in mind the state-of-the-art equipment at NIMET. Hence, NIMET data was used to access the impact of weather variables on soil quality and sustainability in the study area.

The results of Mann–Kendall trend statistics highlighted negative (decreasing) trends in annual climate variables except for NIMET temperature (Table 3). Total rainfall for both UNICAL and NIMET stations exhibited a non-significant decreasing trend at the rate of -56.47 and -3.55 mm year^{-1} for UNICAL and NIMET stations respectively. Similarly, relative humidity exhibited a non-significant decreasing trend at the rate of -0.183 and -0.158 percent year^{-1} for UNICAL and NIMET stations. However, UNICAL exhibited a non-significant decreasing trend (Z = -0.35) for annual temperature with a magnitude of -0.013 °C year^{-1} while NIMET exhibited a non-significant increasing trend (Z = 1.24) for annual temperature with a magnitude of 0.045

Table 2: Degree of homogeneity of different climate variables between UNICAL and NIMET Stations

Climate variables	Mean±SD. UNICAL station	NIMET station	Mean difference	t- test	df	Sig.(2-tail)
Temperature	26.86±0.51	27.38±0.34	-0.51	-5.13	11	0.000***
Rainfall	2380.68±544.77	2952.41±383.78	-571.73	-4.05	11	0.002***
Relative humidity	83.83±1.46	86.03±1.21	-2.20	-6.32	11	0.000***

=significant at 5%; SD = **Standard Deviation; df = degree of freedom

Table 3: Annual trend of climate variables in Calabar

Climate variables	S	Tau b UNICAL	Z	Q	Trend	S	Tau b NIMET	Z	Q	Trend
Total rainfall	-16	-0.242	-1.029	-56.465	decreasing	-2	-0.030	-0.069	-3.547	decreasing
Temperature	-6	-0.091	-0.35	-0.013	decreasing	19	0.288	1.24	0.045	increasing
RH	-19	-0.288	-1.265	-0.183	decreasing	-17	-0.258	-1.10	-0.158	decreasing

Table 4: Selected physical properties under the influence of climate variability in the cultivated tropical rainforest study

Year	Climate variability Temp. (°C)	Rainfall (mm)	RH (%)	Soil physical properties Sand (%)	Silt (%)	Clay (%)	Textural class	Bulk density (g/ cm^3)	Particle Density (g/cm^3)	Total Porosity (%)	Source
2001	27.2	3292.6	86.2	81.0	5.0	14.0	Sandy loam	1.47	2.40	39.26	Okoh (2001)
2002	27.3	3209.3	86.3	66.9	5.0	16.6	Sandy loam	1.52	2.40	43.33	Etukakpan (2002)
2004	27.7	2046.2	86.8	84.0	8.0	08.0	Sandy loam	1.35	2.45	44.90	Chijoke (2004)
2005	28.1	3101.5	84.6	84.0	3.3	09.4	Sandy loam	1.40	2.43	42.39	Edemumoh (2005)
2007	27.0	3428.2	84.3	67.0	2.0	30.0	Sandy CL	1.42	2.45	42.04	Peters (2007)
2008	27.1	3125.2	84.5	84.6	8.9	10.7	Sandy loam	1.48	2.44	43.44	Iyabo (2008)
2010	27.5	3071.7	85.8	76.7	6.0	17.3	Sandy loam	1.43	2.39	40.17	Udo (2010)
2011	27.8	3121.8	86.9	82.3	4.0	13.7	Sandy loam	1.48	2.44	39.34	Field work (2011)

Note: RH = relative humidity, CL = clay loam. Sources: (last column)

Relationship between Soil Properties

The soil properties obtained in the study area for twelve years is presented in Table 4 and 5. Correlation analysis was performed to show the inter-dependence between and among the various soil properties which are hardly observed when interpretations are made directly from raw laboratory analytical data. Thus, in the results of the correlation shown (Table 6), properties that indicated strong positive or negative correlation was selected. Within the period of twelve years there was a strong negative significant correlation between clay and sand ($r = -0.828$, $p < 0.05$), C/N ratio and total nitrogen (TN) ($r = -0.877$, $p < 0.01$) and year and total nitrogen (TN) ($r = -0.716$, $p < 0.05$). The negative relationship between clay and sand was by the theory that puts sand to be negatively related to clay. This result is in line with the findings of Seyoum (2016) and Tsozue (2016). Also, the negative correlations of TN with the C/N ratio demonstrated that as the C/N ratio increases, TN decreases. The higher C/N ratio in the studied soil will enhance nitrogen loss because soil organic carbon could act as an electron donor in the denitrification of NO_3^--N^3. Wang *et al.* (2016) also reported a negative correlation between the C/N ratio and TN (− 0.624, p< 0.01). Similarly, there was a strong positive significant correlation between exchangeable potassium (K) and exchangeable calcium (Ca) ($r = 0.763$, $p < 0.05$), exchangeable sodium (Na) and exchangeable calcium (Ca) ($r = 0.732$, $p < 0.05$), exchangeable acidity (EA) and organic carbon (OC) ($r = 0.739$, $p < 0.05$), exchangeable acidity (EA) and available phosphorus (AP) ($r = 0.714$, $p < 0.05$), exchangeable acidity (EA) and effective cation exchange capacity (ECEC) ($r = 0.859$, $p < 0.01$). The result implies that as exchangeable Ca increases, exchangeable K and Na increases correspondingly, and as exchangeable acidity increases, organic carbon, available phosphorus, and effective cation exchange capacity increases.

Effects of weather variables on soil properties and sustainability

The results of inter-relationship between temperature, rainfall and relative humidity (Table 6) showed that there was a negative relationship between temperature and rainfall ($r = -0.419$, $p > 0.05$) and positive relationship between temperature and relative humidity ($r = 0.290$, $p > 0.05$). Although the relationships obtained in the present study is not significant but shows how the various weather variables are related in the study area. However, the assessment of the impact of this weather variable on the various soil properties investigated only showed a strong negative significant relationship between rainfall and exchangeable Ca ($r = -0.721$, $p < 0.05$) and rainfall and exchangeable Na ($r = -0.957$, $p < 0.01$). This means that as rainfall increases, the soil exchangeable cations notably Ca, and Na will decrease correspondingly over the years under study. This coupled with low inherent fertility, and high levels of acidity that characterized acid sand soil in the study area could be responsible for low fertility status of the soil. During the mid-rainy season, there is always a problem of heavy leaching, erosion and generally poor performance in terms of arable crops' growth in the study area as earlier observed by Okon *et al.* (2010). Amalu and Isong (2015) had reported that excessive rainfall amounts that characterize the area could leach out virtually all nutrient elements from the rhizosphere zones. Conversely, the results also showed a strong positive significant relationship between rainfall and exchangeable Ca ($r = 0.778$, $p < 0.05$) and rainfall and exchangeable K ($r = 0.794$, $p < 0.05$). Nevertheless, in order to assess the over-arching influence of weather variables on soil properties, soil sustainability index (SSI) as proposed by Lal (1994) was estimated (Table 7) and correlation computed to determine its impact. The results as presented in Table 8 showed a negative relationship between temperature and SSI ($r = -0.040$, $p > 0.05$) and rainfall and SSI ($r = -0.344$, $p > 0.05$) whereas a positive relationship between relative humidity and SSI ($r = 0.164$, $p > 0.05$) was obtained. Furthermore, within twelve years under investigation, there was a negative relationship between SSI and year ($r = -0.197$, $p < 0.05$). This implies that the sustainability of the soil decreases as the year progressed from 2001 to 2011. That is, soil quality declined by 0.26 % each year over the period under study (Fig. 2). This was glaring as the soil quality sustainability did not reduce significantly as the year progressed from 2001 to 2011, since the relationship obtained was very weak ($R^2 = 0.0258$) and not statistically significant. As such, it could be vehemently said that within ten years, there was no direct impact of rainfall, temperature, and relative humidity on the soil quality sustainability of the *acid sand* soil of Calabar. Hence, soil quality sustainability varied independently of the climatic variability.

Table 5: Selected soil chemical properties under the influence of climate variability at the tropical rainforest study area at Calabar

Year	Climate variability			Soil chemical properties											Source
	Temp. (°C)	Rain-fall (mm)	RH (%)	pH	Org. C (%)	T.N (%)	Av.P (mg kg^{-1})	Ca^{++}	Mg^+	K^+	Na^+	E.A.	ECEC	B.S. (%)	
								(Cmol kg^{-1})							
2001	27.2	3292.6	86.2	5.7	0.52	1.2	12.7	1.40	0.32	0.12	0.07	0.91	2.8	67.7	Okoh (2001)
2002	27.3	3209.3	86.3	4.9	0.16	0.76	46.5	3.5	2.6	0.09	0.07	3.40	9.6	63.8	Etukakpan (2002)
2004	27.7	2046.2	86.8	5.1	1.22	0.10	9.0	7.2	0.11	0.2	3.4	2.75	13.66	79.9	Chijoke (2004)
2005	28.1	3101.5	84.6	4.8	1.10	0.20	N.R.	N.R.	N.R.	N.R.	N.R	N.R	N.R	N.R	Edemumoh (2005)
2007	27.0	3428.2	84.3	5.0	1.44	0.12	45.8	1.4	1.0	0.07	0.08	2.16	4.71	54.1	Peters (2007)
2008	27.1	3125.2	84.5	4.7	0.90	0.06	66.0	1.7	0.6	N.R	0.06	4.80	3.62	87	Iyabo (2008)
2010	27.5	3071.7	85.8	4.8	2.31	0.33	73.0	1.6	2.8	0.09	0.07	21.0	25.56	17.8	Udo (2010)
2011	27.8	3121.8	86.9	5.1	0.90	0.08	11.7	5.6	2.6	0.10	0.07	0.96	9.33	89.7	Field work (2011)

Table 7: Soil sustainability index of rainforest over ten years under study

Year	Climatic parameters / variables: Relative Humid-ity (%)	Annual Rainfall (mm)	Temp (°C)	Soil sustain-ability Index (SSI)
2001	27.2	3292.6	86.2	32
2002	27.3	3209.3	86.3	32
2004	27.7	2046.2	86.8	34
2005	28.1	3101.5	84.6	30
2007	27.0	3428.2	84.3	26
2008	27.1	3125.2	84.5	38
2010	27.5	3071.7	85.8	26
2011	27.8	3121.8	86.9	32

Table 8: Impact of weather variables on SSI

	Temp	RF	RH	SSI	Year
Temp	1				
RF	-.419	1			
RH	.290	-.470	1		
SSI	-.040	-.344	.164	1	
Year	.155	.101	-.126	-.197	1

RH = relative humidity; Temp = air temperature

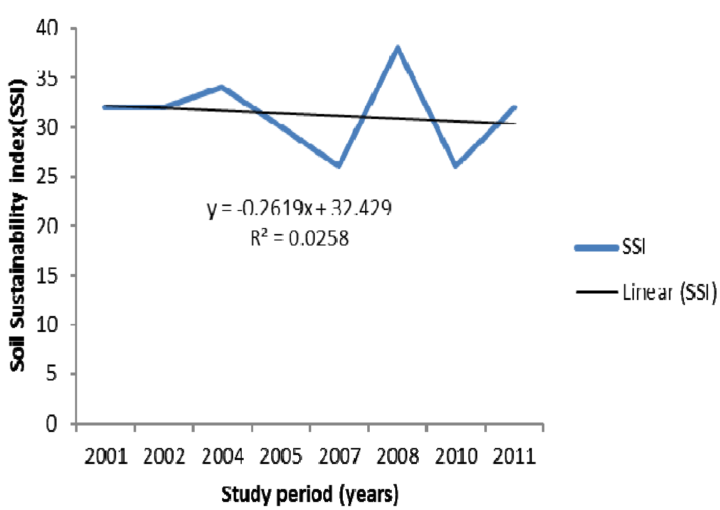

Fig. 3: Influence of time on soil sustainability index in Calabar

Table 6: Matrix of Pearson correlation coefficients between means of selected soil properties and some weather variables

	Tem	RF	RH	sand	clay	pH	OC	TN	CN	AP	Ca	Mg	K	Na	EA	ECEC	BS	Year
Tem	1	-.419	.290	.521	-.594	-.163	.132	-.296	-.045	-.626	.223	-.055	.035	.236	-.097	.072	-.399	.155
RF		1	-.470	-.460	.590	.025	-.150	.317	-.313	.315	**-.721***	.295	-.634*	**-.957****	-.014	-.341	-.203	.101
RH			1	.134	-.356	.465	-.227	.297	-.272	-.340	**.778***	.375	**.794***	.436	.017	.443	.416	-.126
sand				1	**-.828***	.079	.060	-.230	.315	-.422	.152	-.473	-.031	.298	-.126	-.139	.101	.158
clay					1	.017	.233	.025	.011	.414	-.297	.323	-.071	-.396	.137	.054	-.092	.156
pH						1	-.354	.689	-.421	-.507	.149	-.237	.553	.119	-.361*	-.211	.315	-.502
OC							1	-.485	.410	.368	-.144	.144	.012	.095	**.739***	.632	-.482	.626
TN								1	**-.877****	-.102	-.237	.025	.213	-.247	-.067	-.115	-.015	**-.716***
CN									1	.184	.288	-.166	-.087	.310	.016	.044	.352	.659
AP										1	-.283	.478	-.290	-.335	**.714***	.463	-.016	.364
Ca											1	.179	**.763***	**.732***	-.150	.342	.643	.061
Mg												1	.066	-.371	.529	.627	.032	.462
K													1	**.735***	.029	.459	.384	-.262
Na														1	-.098	.257	.290	-.220
EA															1	**.859****	-.369	.443
ECEC																1	-.123	.393
BS																	1	-.007
Year																		1

Agro-meteorological Implications

The present study has indicated that changing weather pattern decreased soil quality by 0.26 % each year over the period under study, and this means that the functions that soil performs are likely to be affected in unexpected directions, and this on long term would have a negative impact on the future use of soils. Agronomically, these changes are likely to affect crop production as changes in air temperature, and rainfall will affect the ability of crops to germinate, grow, and reach their potential harvest. This corroborates the findings of Amalu and Isong (2017) that extreme temperature and rainfall may perturb seed germination and the emergence and alter soil biological activities and soil quality. The life cycles of many soil-borne pests and diseases are controlled by soil moisture regimes (SMR) and soil temperature regimes (STR). Hence, increasing or decreasing rainfall amount and temperature will affect the amount of soil-borne pests and diseases. Also, Eswaran *et al.* (1997) noted that soil temperatures above or below critical limits severely inhibits seed germination even if there is adequate soil moisture. Brevik (2013) has also reported elsewhere that changing weather pattern and climate change has caused tremendous changes in the physicochemical properties of agricultural soils resulting in low productivity. This, in addition to another factor, could be responsible for low crop productivity and food insecurity in the study area.

Conclusion

We investigated the temporal changes in soil quality as influenced by weather variables on the coastal plain sand within Calabar agro-ecological zone from years 2000 to 2011. The results clearly illustrated that temperature and rainfall had a negative impacts on soil sustainability. Within the period of twelve years under investigation, the sustainability of the soil decreased as the year progressed from 2001 to 2011 by 0.26 % each year. Rainfall was found to have a strong negative significant relationship with exchangeable Ca and Na. The findings of this study will provide decision and management tools for farm consultants and supervisors, soil conservationists and researchers to guide against declining sustainability of soils and provide basic data regarding changes in soil properties as a result of climate change. Further studies involving the dynamic monitoring of soil physical and chemicals properties controlling crop growth and development are still needed to determine their long-term changing patterns of weather on soil quality on soils of different parent materials.

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