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Phenological Responses of Forest Flora to the Changing Climate in Derived Savannas

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ABSTRACT

Background and Objective: Phenological variations in plant species are one of the major indicators of climate change. This study was carried out in three forests of Eha-Alumona, Nsukka, and the changes in phenophases of plant species in the phase of the changing climatic system were ascertained. **Materials and Methods:** Systematic random and survey sampling designs were adopted for the study. Life forms in each quadrat were identified and assessed for phenological variations from 2018-2020. Data on the condition of the forests before the study was collected using an unstructured questionnaire. Climate elements in Nsukka from 2010-2020 were retrieved from the nearest meteorological stations. Changes in plant species phenophases over the years were compared with a t-test, while survey data was analyzed with crosstab. Trends in climatic elements were determined graphically. **Results:** The shift in the leafing periods of *Melia* sp. and *Sterculia tragacantha*, as well as in the reproductive periods of many tree species from September/October to November/December. The mean number of plants that flowered/fructified in the forests decreased in successive years, with *Landolphia owariensis* and *Pachystela brevipes* being unproductive for decades. Rainfall peaks were unimodal and tri-modal, with the onset of rainfall delayed by one month since 2016, while relative humidity decreased by 7%. There was a rise in annual mean temperature by 1°C, with a slight decrease in yearly wind speed. **Conclusion:** These fluctuations in the climatic system of Nsukka have affected the phenophases of plant species in these derived savanna forests.

KEYWORDS

Phenophases, forest flora, derived savanna, climatic system, relative humidity, wind speed

INTRODUCTION

Phenological studies remain the simplest way to checkmate environmental changes, including climate change[1]. The phenological pattern of an individual plant species is often controlled by the intrinsic characteristics and the prevailing environmental conditions[1]. The timing of phenological events can be quite sensitive to environmental conditions. Environmental factors relatively interact with an organism's physiological functions, determining the timing, rate, and extent of its phenological events[2]. The major proximate factor controlling the occurrence of plant phenophases is the local meteorological conditions, such as temporal variations in precipitation and temperature[3]. The flowering of trees in dry tropical forests of Australia generally occurs at the end of the dry season, or the beginning of the wet season, and the

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seasonality changes in rainfall patterns might lead to unusual flowering and fruit dropping[4]. Also, fluctuations in seasonal temperature in temperate regions, usually result in differential responses in leaf unfolding, hardiness, and fall[1]. As a result, the timing of phenophases changes concerning the prevailing patterns of weather, climate, and resource availability[5].

However, the phenological responses in plant species in tropical forests are quite different from those of temperate vegetation because of the lesser degree of seasonal temperature and associated varying day-length insolation[6]. In lowland Atlantic forests, leaf fall and flushes, as well as flowering variations on tree species, correlate strongly with the differences in growing degree days, photoperiod, and precipitation[2]. In tropical deciduous forests, the fruiting and flowering phenology of trees are influenced by the changing climate[7]. Ting *et al.*[8] reported that fruit production is related most strongly to evapotranspiration, while changes in annual mean maximum temperature were responsible for the shifts in the flowering dates of *Rhododendron arboreum*[9]. Ma *et al.*[5] reported that the phenology of *Acacia-dominated* Savannas responded strongly to the variance in annual precipitation across North Australia.

Moreover, indirect effects of climate change on the fruiting pattern of tree species were detected[2], as flowering phenodynamics correlate more strongly to changes in climate than fruiting. Nevertheless, the species-area-relationship model posits the modification of phenological traits with the changing climatic system in the future[1].

Although many studies have suggested a correlation between rainfall and flowering or leaf flushing, external cues have been experimentally demonstrated in only some plant species[10]. Few studies were done on the climate change impacts on tree phenology in all tropical regions[11], with few/no records at present, particularly in derived savannas. Therefore, this work was aimed at assessing the changes in the phenophases of plant species in the three forests of Eha-Alumona with the changing climatic system of the study area.

The objective of this work was to assess the variation in phenological features of plant species in the forests, concerning the changing climate elements in Nsukka (a derived savanna region) from 2010-2020.

MATERIALS AND METHODS

Study location: The study was carried out in three forests of three villages in Eha-Alumona (Osiani, Awofia and Ogbunabo Forests). The Eha-Alumona is one of the towns in the Eastern part of Nsukka Local Government Area of Enugu State. Nsukka is 1 of the 17 local government areas of Enugu State, Nigeria. It lies between Latitudes 6°43'30" and 7°00'30"N, and Longitudes 7°13'00" and 7°35'30"E with a mean elevation of 551.68 m[12]. The three forests got their names based on the village of residence. The first site (Osiani Forest) and the second site (Awofia Forest) shared a boundary with Orba in Udenu Local Government, though the two sites were not in the same village. The third site (Ogbunabo Forest) is situated within the town. All three sites were located in the Northern part of Eha-Alumona.

Sampling design: The study adopted systematic random[13] and survey sampling designs. Plots in the forests were measured at 144 m^2 each while each quadrat, which was laid randomly within each plot was measured at 16 m^2. Quadrat placement in each plot was selected by a pair of random numbers. The sample size of Site 1 (Osiani Forest) was 300 m, and a total of 14 plots with 42 quadrat placements were used in the site. Site 2 (Awofia Forest) had a sample size of 280 m, and 12 plots with 36 quadrat placements were used. The sample size of Site 3 (Ogbunabo Forest) was 290 m, with 10 plots and 30 quadrat placements.

Table 1: Unstructured questionnaire sample used for the study

Forest conditions			A	N	D
1	RaQ	What do you know about this forest?			
	RpQ	This forest has been here before the arrival of your fore fathers			
2	RaQ	Who is in charge of this forest?			
	RpQ	This forest is still under the control of the village head and elders.			
		There are some restrictions on the usage of the forest			
		No human activities is allowed in the forest			
3	RaQ	Is there anything you are no longer seeing in the forest, but had existed before?			
	RpQ	So many plant species are no longer in existence in the forest			
		Resources obtain from the forest remained the same			

RaQ: Raw question, RpQ: Rephrased question; A: Agree, N: Not sure and D: Disagree

All the life forms (plants) in each quadrat laid were collected for identification, and confirmed by Mr. Alfred Ozioko, a plant taxonomist at Bioresource Development and Conservation Programme (BDCP), Nsukka, Enugu State. The timing of seasonal events such as leafing, fruiting, flowering, dying, regeneration, and defoliation occurring in each identified plant sample were monitored and recorded for three years (2018-2020).

Information on the condition of the forests before the commencement of the study was collected using an unstructured questionnaire[14], distributed to twenty persons in each of the villages where each forest is located (Table 1). Twenty elderly people, all above 40 years from each of the villages were interviewed following the consent of the village heads and elders, to authenticate the claim of each respondent. These twenty elders were grouped based on their age range; that is, five persons each at the age range of 41-50, 51-60, 61-70, and 71 years and above.

Climate data: The climatic elements such as temperature, rainfall, pressure, relative humidity, and wind speed over the study area from 2010-2020 were retrieved from the Centre for Atmospheric Research, National Space Research and Development Agency (CAR-NASRDA-2010-2016) and Nigerian Meteorological Agency (NiMet-2017-2020).

Data analysis: Data from plant phenological characteristics and survey samples were analyzed using IBM SPSS Statistics 25. Climate data from the meteorological stations were tested for homogeneity using non-parametric tests (Mann-Whitney U test). Each climate element was analyzed using descriptive statistics[12]. The seasonal index of rainfall per annum was determined by dividing the percentage of the total rainfall of a particular year by the total rainfall of the study period[15]. Variation of each of the climate elements among the years under study was determined using the coefficient of variation, while the pattern for each climate element (trends) among the years (2010-2015 and 2016-2020) was determined graphically.

RESULTS

Plant species identified in three Eha-Alumona Forests: Seventy-seven plant species belonging to 43 families were discovered in the three forests (Table 2). Osiani forest (Site 1) contained 62 of the total plant species with an average abundance of 2,265 plants; Awofia forest (Site 2) contained 59 species with an average abundance of 1,766 plants, and Ogbunabo forest (Site 3) contained 36 of the identified plants with an average abundance of 827 plant species (Table 2). Out of the 77 plant species identified, 28 plant species (36%) were found in all three forests; 18 plants (23%) were found in both Sites 1 and 2; 3 plants species (4%) in both Sites 1 and 3; 3 plants species (4%) in both Sites 2 and 3 (Table 2). Also, 13 plant species (17%) were found in Site 1 only, 10 plant species (13%) in Site 2, and 2 plant species (3%) in Site 3 (Table 2). Plant species identified in the forests are shown in Table 3.

Table 2: Summary of the numbers of identified plant species in three Eha-Alumona Forests

Forests	Osiani (Site 1)	Awofia (Site 2)	Ogbunabo (Site 3)	All the forests
Total species				77
Total families				43
Species identified	62	59	36	
Average abundance	2,265	1,766	827	
Habitat generalist				36%
Differential species	17%	13%	3%	
Common species between				
Sites 1 and 2-23%				
Sites 1 and 3-4%				
Sites 2 and 3-4%				

Table 3: Checklist of identified plant species in three Eha-Alumona Forests

	Plant species	Family	Osiani	Awofia	Ogbunabo
1	*Abrus precatorius* L.	Fabaceae	✓	×	×
2	*Abutilon* sp. Mill.	Malvaceae	×	✓	×
3	*Acanthus montanus* (Nees) T. Anders.	Acanthaceae	×	✓	✓
4	*Acioa barteri*-Hook. F. ex Oliv.). Engl.	Chrysobalanaceae	✓	✓	×
5	*Alchornea cordifolia* (Schum. and Thonn.) Mull.Arg.	Euphorbiaceae	✓	×	×
6	*Anchomanes difformis* (Blume) Engl	Araceae	✓	✓	✓
7	*Anthocleista djalonensis* A. Chev.	Gentianaceae	✓	×	×
8	*Anthonotha macrophylla* P.Beauv.	Fabaceae	✓	×	×
9	*Antiaris* sp. Lesch.	Moraceae	×	✓	×
10	*Antiaris toxicaria* Lesch.	Moraceae	✓	✓	✓
11	*Aspilia africana* (P.Beauv.) C.D. Adams.	Asteraceae	✓	×	×
12	*Baphia nitida* Lodd.	Fabaceae	✓	✓	✓
13	*Baphia pubescens* Hook.f.	Fabaceae	✓	✓	✓
14	*Blighia* sp. K.D.koenig.	Sapindaceae	×	✓	×
15	*Caesalpinia decapetala* (Roth) Alston.	Fabaceae	✓	✓	✓
16	*Canthium horizontale* (Schumach.) Hiern.	Rubiaceae	✓	×	✓
17	*Carapa procera* DC.	Meliaceae	✓	✓	×
18	*Carica papaya* L.	Caricaceae	×	✓	×
19	*Carpolobia* sp. G.Don.	Polygalaceae	✓	✓	✓
20	*Ceiba pentandra* (L.) Gaerth.	Malvaceae	×	×	✓
21	*Celtis zenkeri* Engl.	Cannabaceae	✓	✓	✓
22	*Chromolaena odorata* (L.) R.M.King and H. Rob.	Asteraceae	✓	✓	✓
23	*Cissus aralioides* (Welw. Ex Baker) Planch.	Vitaceae	✓	✓	✓
24	*Cnestis ferruginea* DC.	Connaraceae	✓	✓	✓
25	*Cola lateritia* K.Schum.	Malvaceae	×	✓	×
26	*Cola millenii* K.Schum.	Malvaceae	✓	✓	✓
27	*Combretum dolichopetalum* Engl. and Diels.	Combretaceae	✓	×	×
28	*Combretum rotundifolium* Rich.	Combretaceae	✓	✓	×
29	*Dacroydes klaineana* (Pierre) H. J. Lam.	Burseraceae	✓	✓	×
30	*Dalbergia armata* E.Mey.	Fabaceae	✓	✓	✓
31	*Dennettia tripetala* Bak. F.	Annonaceae	×	✓	×
32	*Dialium guineense* Willd.	Fabaceae	✓	✓	✓
33	*Dictyandra arborescens* Welw. Ex Hook. F.	Rubiaceae	✓	✓	×
34	*Dioscoreophyllum cumminsii* (Stapf) Diels	Menispermaceae	✓	✓	✓
35	*Dracaena arborea* (Willd.) Link.	Dracaenaceae	×	×	✓
36	*Dracaena mannii* Baker.	Asparagaceae	✓	✓	×
37	*Elaeis guineensis* Jacq.	Arecaceae	×	✓	×
38	*Ficus exasperata* Vahl.	Moraceae	×	✓	✓
39	*Ficus vogelii* Miq.	Moraceae	✓	×	×
40	*Glyphaea brevis* (Spreng) Monach.	Tiliaceae	✓	✓	✓
41	*Hedranthera barteri* (Hook. F.) Pichon.	Apocynaceae	✓	×	×
42	*Hippocratea welwitschii* Oliv.	Celastraceae	×	✓	×
43	*Holarrhena floribunda* (G.Don) T.Durand and Schinz.	Apocynaceae	✓	×	×
44	*Hypoestes rosea* P. Beauv.	Acanthaceae	×	✓	✓

Table 3: Continue

	Plant species	Family	Osiani	Awofia	Ogbunabo
45	*Icacina mannii* Oliv.	Icacinaceae	✓	✓	✓
46	*Justicia insularis* T.Ander.	Acanthaceae	✕	✓	✕
47	*Landolphia dulcis* (Sabine) Pichon.	Apocynaceae	✓	✓	✓
48	*Landolphia owariensis* P.Beauv.	Apocynaceae	✓	✕	✕
49	*Lepidagathis alopecuroides* (Vahl) R Br. Ex Griseb.	Acanthaceae	✓	✕	✓
50	*Melia* sp. L.	Meliaceae	✓	✕	✕
51	*Milicia excelsa* (Welw.) C. C. Berg.	Moraceae	✓	✓	✕
52	*Myrianthus arboreus* P.Beauv.	Urticaceae	✓	✕	✕
53	*Napoleona imperalis* P.Beauv.	Lecythidaceae	✓	✓	✓
54	*Newbouldia laevis* (P.Beauv. ex Bureau.	Bignoniaceae	✓	✓	✕
55	*Ochna serrulata* (Hochst.) Walp.	Ochnaceae	✓	✕	✕
56	*Olax subscorpioidea* Oliv.	Olacaceae	✓	✓	✕
57	*Oplismenus burmannii* (Retz.) P. Beauv.	Poaceae	✓	✓	✕
58	*Osbeckia muralis* Naudin.	Melastomataceae	✓	✕	✓
59	*Pachystela brevipes* (Baker) Baill.	Sapotaceae	✓	✓	✕
60	*Palisota hirsuta* (Thunb.) K. Schum.	Commelinaceae	✓	✓	✓
61	*Pentaclethra macrophylla* Benth.	Fabaceae	✓	✓	✓
62	*Piptadeniastrum africanum* (Hook. F.) Brenan.	Fabaceae	✓	✓	✕
63	*Pleiocarpa mutica* Benth.	Apocynaceae	✓	✓	✓
64	*Pleiocarpa* sp. Benth.	Apocynaceae	✕	✓	✕
65	*Psychotria* sp. L.	Rubiaceae	✓	✓	✕
66	*Psychotria viridis* Ruiz and Pav.	Rubiaceae	✓	✓	✕
67	*Pterocarpus santalinoides* L'her.ex DC.	Fabaceae	✓	✓	✓
68	*Pycnanthus angolensis* (Welw.) Warb.	Myristicaceae	✓	✓	✓
69	*Scleria sumatrensis* Retz.	Cyperaceae	✓	✓	✕
70	*Smilax rotundifolia* Linn.	Smilacaceae	✓	✓	✕
71	*Sphenocentrum jollyanum* Pierre.	Menispermaceae	✓	✓	✓
72	*Spondias mombin* L.	Anacardiaceae	✓	✓	✓
73	*Sterculia tragacantha* Lindl.	Malvaceae	✓	✓	✓
74	*Strychnos pseudoquina* A.St.-Hil.	Loganiaceae	✓	✓	✕
75	*Syzygium guineense* (Willd.) DC.	Myrtaceae	✓	✓	✕
76	*Tabernaemontana pachysiphon* Stapf.	Apocynaceae	✓	✓	✓
77	*Trema orientale* (L.) Blume.	Cannabaceae	✓	✓	✓

×: Absent of plant species and ✓: Presence of plant species

Table 4: Summary of the number of plants per phenophase per month in three Eha-Alumona Forests

	Number of plants per month											
Phenophases	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Leafing	4	2	2	3	1	0	0	0	0	0	1	2
Flowering	8	3	4	3	5	3	1	0	13	7	15	5
Fruiting	8	8	4	3	5	6	3	1	2	11	25	13
Defoliation	4	0	0	0	0	0	0	0	0	0	2	7
Dying	3	2	0	0	0	0	0	0	1	1	2	4
Dead	5	0	0	0	0	0	0	0	0	0	0	0
Regeneration	1	2	4	8	0	0	0	0	0	0	0	0

Phenological characteristics of plant species in three Eha-Alumona Forests: The major phenological characteristics exhibited by the identified plants include various periods of leafing, defoliation, flowering, fruiting, dying, and regeneration/germination. These phenophases occur once, twice, or more per year in some plant species observed in the forests (Table 4). Most of the mature deciduous plant species and some perennial herbs and lianas produced new leaves and defoliated at various times of the year from November through May, and these had little or no variation in the three-year study period (Table 4).

Defoliation occurred most in December, followed by January and November, while leafing began at various times of the year from November through May but occurred most in January (Table 4). However, *Melia* sp. and *S. tragacantha* shifted their leafing from February to March, 2020.

Table 5: Comparison of the mean number of reproductive phenophases of plant species in three Eha-Alumona Forests

Year	Osiani Forest (Site 1)	Awofia Forest (Site 2)	Ogbunabo Forest (Site 3)
2018	0.76±0.12^{a}	0.87±0.14^{a}	0.92±0.15^{a}
2019	0.71±0.14^{a}	0.84±0.14^{a}	0.89±0.15^{a}
2020	1.53±0.12^{b}	0.82±0.14^{a}	0.86±0.15^{a}

Values represent Mean±Standard Error. Means with the same letter across the columns were not statistically different at $p<0.05$

Flowering and fruiting of plant species in the forests occurred severally throughout the year (Table 4). Flowering occurred from September through July, but predominantly in November, followed by September and at least in July. Fruit formation occurred throughout the months of the year but predominantly in November followed by December, but least in August (Table 4).

Nevertheless, the forests accommodated several herbaceous annuals, biennials, and perennials in exposed areas or under tall and large trees. These herbs started withering at the onset of the dry season but regenerated from January and ending through April (Table 4).

Moreover, the phenological features of the plant species identified in this work did not vary much among the forests. The mean number of plants that flowered in the forests decreased sequentially from 2018 to 2020, especially in Awofia and Ogbunabo forests, but not significant (Table 5). However, the number of plants that produced flowers in 2020 in Osiani forest (Site 1) was significantly ($p<0.05$) higher compared to other years in the whole sites (Table 5). Other years did not vary with one another but were significantly ($p<0.05$) lower than the number of plants that were fructified in 2020 in Site 1 (Table 5).

Condition of the three Eha-Alumona Forests before the study: Results from the survey analysis showed that in recent years, the forests had encountered gradual and recurrent reduction in size and plant composition through logging for timber purposes, climate change, and other land uses. The major factors responsible for the forest's biodiversity reduction were logging, the quest for virgin land for farming activities, and climate change (Table 6). The assertion for climate change impact was paramount in Awofia Forest, which was devoid of human degradation, with 100% response, due to the control of the forest by the village heads (Table 6). Having observed changes in the reproductive phenophases of many edible plant species such as *Landolphia owariensis* and *Pachystela brevipes* in the forests, with a shift in the month with higher flowering of the forest flora (September/October to November/December), the participants believed that climate change would be the major cause of declining vegetation in Awofia forest. Also, due to nonmonitoring of the forests (Osiani and Ogbunabo Forests), the felling of trees and large lianas for sources of domestic fuel and income coupled with fire and changing climate have reduced major life forms in the forest to the point of extinction. The condition of plant species across the three Eha-Alumona Forests before the study varied by response type. In all the forests, 100% agreed with statement A, while none agreed with statements C, D, or E. Responses to statement B were mixed, with 50% agreement in Osiani and Ogbunabo forests but 100% agreement in Awofia Forest. Disagreement was consistently 100% for statements C, D, and E across all forests. There was uncertainty (50% "Not sure") for statement B in the Osiani and Ogbunabo Forests but no uncertainty in Awofia Forest (Table 6).

Climate elements in Nsukka from 2010 to 2020: The Mann-Whitney U test was applied to examine the distribution of climate elements across categories of each group. The p-values for rainfall, relative humidity, temperature, wind speed, and pressure were all greater than 0.05, indicating no significant differences. Therefore, the null hypothesis is retained for each group shown in Table 7.

Rainfall pattern over Nsukka from 2010 to 2020: Annual rainfall cycles in Nsukka from 2010 to 2020 ranged from 1,305.1 mm to 2,070.3 mm, with an average of 1,652.8 mm per annum (Table 8). Comparatively, annual mean monthly rainfall did not vary much each year from 2010 through 2020, since all the years had a low coefficient of variation (CV), but the seasonality index (SI) was consistently higher from 2017 through 2020 compared to the previous years (Table 8).

Table 6: Condition of the plant species in the three Eha-Alumona Forests before the study

	Responses (%)				
Responses	A	B	C	D	E
Osiani Forest					
Agreed	100[a]	50[c]	0	0	0
Disagreed	0	0	100[a]	100[a]	100[a]
Not sure	0	50[b]	0	0	0
Awofia Forest					
Agreed	100[a]	100[a]	0	0	0
Disagreed	0	0	100[a]	100[a]	100[a]
Not sure	0	0	0	0	0
Ogbunabo Forest					
Agreed	100[a]	50[c]	0	0	0
Disagreed	0	0	100[a]	100[a]	100[a]
Not sure	0	50[b]	0	0	0

A: This forest has been here before the arrival of your fore fathers, B: This forest is still under the control of the village head and elders, C: Plants in the forest remained the same just like you met them, D: Resources obtain from the forest remained the same since you knew it, E: Flowering and fruiting pattern of plant species remained the same in the forest, [a]41 years and above, [b]41-60 years, [c]61 years and above

Table 7: Homogeneity test of the climate element's data from National Space Research and Development Agency and Nigerian Meteorological Agency from 2010 to 2020

Climate elements	Null hypothesis	Test	Significant (≤0.05)	Decision
Rainfall (mm)	Distribution of mean rainfall, relative humidity, temperature, wind speed and pressure are the same across categories of each group	Independent-samples Mann-Whitney U test	0.203	Retain the null hypothesis in each group
Relative humidity (%)			0.105	
Temperature (°C)			0.059	
Wind speed (m/sec)			0.686	
Pressure (kpa)			0.958	

Table 8: Total annual, seasonality index and coefficient of variation of rainfall in Nsukka from 2010 to 2020

Year	Total rainfall (mm)	Seasonality index	Coefficient of variation
2010	1576.9	8.67	8.52
2011	1305.1	7.20	6.53
2012	1547.4	8.51	7.52
2013	1402.2	7.68	7.39
2014	1757.8	9.76	6.98
2015	1406.5	7.75	8.08
2016	1377.4	7.53	8.41
2017	2070.3	11.39	7.59
2018	1910.5	10.51	6.55
2019	1934.8	10.60	7.29
2020	1891.6	10.40	7.36

Rainfall peaks from 2011 to 2016 and 2018 were tri-modal (Table 9). In 2011 to 2013, the first peak occurred in May (2011-4.5 mm; 2012-7.1 mm; 2013-7.2 mm), the second in July (2011-5.8 mm; 2012-7.8 mm; 2013-8.3 mm) and the third in September (2011-9.1 mm; 2012-11.2 mm; 2013-8.0 mm), while in 2014, the first peak occurred in February (5.0 mm), the second in June (9.1 mm) and the third in September (14.4 mm). In 2015, the first peak also, occurred in February (1.9 mm), the second in May (8.6 mm) and the third in September (11.7 mm), but in 2016, the first peak occurred in March (4.1 mm), the second in May (6.7 mm) and the third in August (12.3 mm) (Table 9). In 2018, the first peak occurred in April (7.7 mm), the second in July (13.0 mm) and the third in September (8.9 mm). The year 2019 and 2020 had their first peak with the highest rainfall of the year in July (11.9 mm) and June (13.8 mm), respectively (Table 9).

The assessment of the rainfall pattern from January, 2010 to December, 2020 showed that the wet season began properly in April with a value between 1.1 to 9.8 mm, and increased from May (4.5-9.3 mm) through July (3.6-13.0 mm), but declined a little in August (3.0-12.3 mm) reaching its final peak in September

(4.5-14.4 mm) (Table 9). Nevertheless, September remained the most rainy month of the study periods, while December (0.0-0.2 mm) and January (0.0-0.5 mm) remained consistently dry with little or no rainfall (Table 9). The trend in rainfall pattern showed that there was a delay in the onset of rainfall by one month from 2016 to 2020, with the tri-modal pattern tending towards unimodal. The second peak had also been shifted from September to July through the same years above (2016-2020) (Table 9).

Relative humidity over Nsukka from 2010 to 2020: Relative humidity over Nsukka did not vary much from 2010 to 2020 since all the years from 2010 through 2020 had moderate and/or low coefficient of variation (CV) (Table 10). The minimum monthly mean relative humidity was 21.87% recorded in January, 2019 while the maximum was 83.83% recorded in August, 2011 (Table 10). From 2010 through 2012 as well as 2019, there were decreases in mean relative humidity in March after a sharp rise in February. However, from 2013 through 2020 except 2019, mean relative humidity kept increasing from January or February, reached its peak in August but declined from September through December (Table 10).

The month of August had being the most humid month with values between 70.0 to 83.8%, while January remained the least humid month of the study period (21.9-61.7%) (Table 10). The mean relative humidity trend from 2010 to 2020 showed a decrease of at least 2% from January to April, and August to November from 2016 through 2020 (Table 10). Nevertheless, monthly mean relative humidity peaks had shifted from August (from 2010 through 2015) to July (from 2016 through 2020) (Table 10).

Table 9: Monthly mean rainfall in Nsukka from 2010 to 2020

	Mean monthly rainfall (mm)										
Months	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Jan	0.0±0.0	0.0±0.0	0.0±0.0	0.5±0.4	0.0±0.0	0.0±0.0	0.0±0.0	0.1±0.1	0.0±0.0	0.0±0.0	0.0±0.0
Feb	0.0±0.0	2.4±1.3	0.7±0.5	0.2±0.2	5.0±3.2	1.9±1.9	0.0±0.0	0.0±0.0	0.9±0.9	0.5±0.3	0.0±0.0
Mar	0.7±0.3	1.1±0.8	0.0±0.0	0.2±0.1	0.7±0.3	1.1±1.0	4.1±2.3	0.9±0.6	2.1±1.6	2.4±1.6	4.2±2.2
Apr	4.3±2.1	3.1±1.0	3.1±1.5	1.1±0.4	3.6±1.5	1.3±0.8	1.1±0.9	9.8±3.9	7.7±2.6	3.1±1.5	5.4±2.6
May	5.2±2.1	4.5±1.4	7.1±2.2	7.2±2.4	7.8±2.3	8.6±2.0	6.7±2.5	5.5±2.6	7.4±3.2	8.1±2.7	9.3±2.7
Jun	6.9±2.0	3.8±1.3	5.4±1.6	5.1±1.2	9.1±2.5	4.1±1.4	3.7±1.5	11.3±5.2	7.1±2.7	10.8±3.2	13.8±4.4
Jul	4.8±1.5	5.8±2.1	7.8±2.9	8.3±2.6	6.3±2.3	3.6±1.4	4.1±1.3	12.6±3.0	13.0±3.1	11.9±5.0	8.8±2.1
Aug	12.1±5.1	5.4±1.9	6.2±1.5	7.1±2.5	3.0±1.1	5.6±1.8	12.3±3.8	11.1±3.6	7.3±1.9	9.2±2.6	4.7±2.6
Sep	12.2±2.8	9.1±3.3	11.2±2.6	8.0±2.5	14.4±3.7	11.7±2.6	7.0±2.6	10.5±3.4	8.9±2.5	4.5±2.1	8.4±2.2
Oct	4.9±1.2	6.3±1.6	7.6±2.4	5.9±2.4	6.8±2.3	7.0±1.9	5.4±2.2	5.2±1.9	5.5±2.3	10.8±4.1	7.3±2.3
Nov	0.6±0.4	1.3±0.8	1.5±0.8	1.6±1.0	2.6±1.7	1.2±1.2	0.3±0.3	0.8±0.7	2.4±1.4	1.8±1.2	0.0±0.0
Dec	0.0±0.0	0.0±0.0	0.1±0.1	0.7±0.4	0.2±0.2	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0

Values represent mean and ±: Standard error

Table 10: Mean relative humidity in Nsukka from 2010 to 2020

	Mean relative humidity (%)										
Month	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Jan	54.1±3.1	35.2±2.5	42.7±3.9	49.1±3.6	61.7±0.9	60.7±1.3	59.6±0.3	50.2±2.9	60.3±3.0	21.9±0.8	46.4±3.0
Feb	59.8±2.8	67.1±0.8	66.6±0.9	56.7±3.3	61.0±1.7	67.2±0.6	62.2±0.5	57.8±3.0	55.1±3.9	52.5±3.2	57.5±2.5
Mar	58.3±2.5	65.5±0.6	57.7±1.5	66.8±0.6	69.1±0.5	70.4±0.1	65.5±0.1	67.7±0.8	66.0±2.6	51.0±2.6	66.5±0.9
Apr	69.9±1.4	72.0±0.9	70.0±0.7	72.7±0.9	71.8±0.4	69.4±0.4	66.2±0.1	71.8±1.0	73.2±0.8	63.3±0.8	73.4±1.1
May	76.7±0.7	76.1±0.7	75.1±0.9	75.5±0.8	72.3±0.1	71.6±0.2	66.2±0.1	79.0±0.8	79.7±0.8	76.6±0.8	76.8±0.7
Jun	80.8±0.6	79.4±0.5	78.7±0.6	78.1±0.7	72.0±0.0	76.0±0.0	67.0±0.0	82.4±0.8	81.1±0.7	80.5±0.7	80.5±0.8
Jul	82.0±0.6	81.1±0.5	81.9±0.6	82.0±0.5	72.2±0.1	76.0±0.0	67.8±0.3	83.9±1.1	82.1±0.7	82.1±0.6	82.4±1.0
Aug	83.3±0.6	83.8±0.6	83.0±0.6	83.1±0.4	73.0±0.0	76.0±0.0	70.0±0.0	83.4±0.7	79.6±0.6	82.5±0.9	82.4±0.9
Sep	82.7±0.5	82.1±0.6	82.0±06	81.0±0.6	73.0±0.0	76.6±0.1	57.3±1.4	83.5±0.8	82.7±0.8	82.7±1.0	82.1±0.9
Oct	79.9±0.6	79.1±0.6	79.2±0.5	78.5±0.5	72.9±0.1	77.0±0.0	53.0±1.1	81.3±0.7	80.7±0.7	77.6±0.8	79.7±0.7
Nov	75.2±0.7	66.1±2.2	74.0±0.8	73.5±0.8	72.4±0.5	70.4±1.2	44.3±0.7	60.1±2.8	65.9±2.4	71.5±0.7	78.8±1.1
Dec	49.7±2.6	37.4±2.4	49.8±3.5	59.7±3.3	70.3±1.0	56.8±0.6	34.2±1.7	66.6±1.4	64.4±2.4	66.6±2.2	53.4±3.2
CV	17.3	23.9	19.1	15.4	6.1	9.2	18.2	16.2	13.4	27.0	17.6

Values represent mean, ±: Standard error and CV: Coefficient of variation

Table 11: Maximum, minimum and total annual mean temperature in Nsukka from 2010 to 2020

	Annual mean temperature (°C)		
Year	Maximum	Minimum	Total
2010	29.0±0.5	24.6±0.4	27.4±0.5
2011	28.8±0.4	24.5±0.5	27.0±0.4
2012	28.9±0.5	24.3±0.5	27.0±0.4
2013	29.2±0.5	24.9±0.4	27.4±0.5
2014	29.3±0.4	24.5±0.5	27.0±0.4
2015	30.3±0.5	25.6±0.4	28.4±0.4
2016	29.5±0.5	24.3±0.5	27.2±0.4
2017	30.3±0.5	25.6±0.4	28.3±0.4
2018	30.1±0.4	25.1±0.4	27.7±0.4
2019	30.1±0.4	25.0±0.3	28.1±0.3
2020	30.5±0.5	24.1±1.7	28.2±0.4

Values represent mean and ±: Standard error

Table 12: Monthly mean temperature in Nsukka from 2010 to 2020

	Temperature (°C)										
Years	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Jan	28.3±0.2	27.2±0.2	27.5±0.2	28.3±0.2	27.2±0.2	28.9±0.3	27.5±0.2	28.9±0.3	26.9±0.3	28.2±0.3	27.5±0.3
Feb	29.6±0.2	28.4±0.2	28.3±0.2	29.6±0.2	28.4±0.2	29.9±0.3	28.3±0.2	29.9±0.3	30.1±0.3	29.0±0.3	29.6±0.3
Mar	29.9±0.3	29.7±0.2	30.2±0.2	30.1±0.2	29.8±0.1	31.3±0.2	30.3±0.2	31.4±0.2	30.1±0.2	30.0±0.2	31.1±0.2
Apr	28.9±0.3	28.1±0.3	28.0±0.4	28.9±0.3	28.2±0.3	29.4±0.3	28.2±0.3	29.4±0.3	28.5±0.2	29.7±0.4	29.1±0.3
May	27.6±0.2	27.3±0.2	26.9±0.2	27.6±0.2	27.5±0.2	28.7±0.2	27.5±0.3	28.6±0.2	27.8±0.3	28.5±0.2	28.5±0.2
Jun	26.3±0.2	26.3±0.2	25.9±0.2	26.5±0.2	26.3±0.2	28.1±0.2	26.4±0.3	27.8±0.2	27.3±0.2	27.3±0.2	26.7±0.7
Jul	25.3±0.2	25.6±0.2	25.3±0.2	25.3±0.2	25.8±0.2	26.8±0.2	25.5±0.3	26.8±0.2	26.8±0.2	26.8±0.2	26.8±0.2
Aug	25.3±0.1	24.6±0.2	24.7±0.2	25.3±0.1	24.6±0.2	26.3±0.2	24.7±0.2	26.3±0.2	26.4±0.2	26.6±0.2	26.9±0.1
Sep	25.4±0.2	25.7±0.2	25.6±0.2	25.4±0.2	25.7±0.2	26.9±0.1	25.6±0.2	26.9±0.1	26.5±0.2	27.7±0.2	26.6±0.1
Oct	26.4±0.2	26.2±0.1	26.2±0.2	26.4±0.2	26.2±0.1	27.8±0.2	26.2±0.2	27.8±0.2	27.5±0.2	27.3±0.2	27.5±0.2
Nov	27.7±0.1	27.8±0.1	28.0±0.2	27.7±0.1	27.8±0.1	28.0±0.2	28.0±0.2	28.0±0.2	28.2±0.2	28.6±0.2	29.0±0.1
Dec	27.5±0.2	26.9±0.2	27.7±0.2	27.5±0.2	26.9±0.2	28.2±0.3	27.7±0.2	28.2±0.3	26.5±0.2	27.1±0.2	29.1±0.2

Values represent mean and ±: Standard error

Temperature distribution over Nsukka from 2010 to 2020: Air temperature distribution in Nsukka from 2010 to 2020 showed a slight maximum and minimum increase in recent years (Table 11). The lowest maximum annual mean temperature of 28.8°C was recorded in 2011 while the highest maximum annual mean temperature of 30.5°C was recorded in 2020 (Table 11). Also, the lowest minimum annual mean temperature of 24.1°C was recorded in 2020 while the highest minimum annual mean temperature of 25.6°C was recorded in 2015 and 2017 (Table 11). A comparison of the total annual mean temperature revealed that yearly records fluctuated from 2010 through 2017 with a steady increase from 2018 through 2020 (Table 11). Two thousand and fifteen was the hottest year (28.4°C) while 2011, 2012, and 2014 were the coldest years recording 27.0°C each (Table 11).

However, the maximum monthly mean temperature of 31.4°C was recorded in March, 2017 while the minimum monthly mean temperature of 24.6°C was recorded in August, 2014 (Table 12). However, March remained the hottest month of the study period with the lowest monthly mean temperature of 29.7°C recorded in 2011, but the month of August remained the coldest, with the lowest monthly mean temperature of 24.6°C recorded in 2014 (Table 12). Consideration of the annual mean temperature trends within the study periods showed a rise in mean temperature from 2016 to 2020 by 1°C (Table 12).

Wind speed variation in Nsukka from 2010 to 2020: Wind speed over Nsukka from 2010 to 2020 followed similar a pattern and did not vary much from year to year (Table 13). Wind speed was mainly high in January, August, and December, but very low in June and October throughout the study period (Table 13). However, in 2011, 2014, and 2018, the low mean wind speed was shifted from October to November while that of the June trough was shifted to July in 2015 and 2016, and to May in 2019. Also, in 2010 and 2013, the January peak of monthly mean wind speed was shifted to March (Table 13).

Table 13: Monthly mean wind speed in Nsukka from 2010 to 2020

	Wind speed (m/sec)											
Years	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Jan	3.2±0.7	4.6±1.0	3.9±1.0	2.9±0.9	4.7±0.9	4.6±1.0	3.8±0.9	4.6±1.3	4.5±0.8	2.8±0.7	4.0±0.5	7.8±0.4
Feb	3.1±0.5	3.3±0.7	3.2±0.7	2.8±0.6	3.2±0.6	3.3±0.7	3.0±0.7	3.4±0.7	2.7±0.7	3.1±0.7	3.3±0.4	6.1±0.1
Mar	3.4±0.6	3.1±0.6	3.3±0.6	3.9±0.6	2.9±0.6	3.5±0.7	3.5±0.5	4.0±0.7	3.5±0.5	2.5±0.5	3.3±0.4	6.6±0.2
Apr	3.3±0.6	3.3±0.6	3.6±0.5	3.0±0.6	3.4±0.5	3.6±0.6	3.3±0.5	4.1±0.6	3.2±0.6	2.8±0.6	3.4±0.4	6.6±0.2
May	3.0±0.6	3.1±0.6	2.9±0.7	2.8±0.7	3.2±0.6	2.5±0.6	3.1±0.6	3.8±0.6	2.9±0.7	1.8±0.5	2.8±0.4	5.7±0.3
Jun	2.2±0.5	2.9±0.3	2.3±0.6	2.3±0.5	2.7±0.4	2.7±0.5	2.4±0.4	3.2±0.6	2.3±0.6	2.3±0.4	2.6±0.3	5.0±0.2
Jul	2.9±0.6	3.2±0.6	2.5±0.7	2.8±0.6	3.1±0.6	2.4±0.6	2.3±0.6	3.5±0.6	2.4±0.8	2.2±0.4	2.8±0.6	5.4±0.3
Aug	3.9±0.7	3.5±0.7	3.1±0.6	3.1±0.7	3.9±0.6	2.9±0.7	2.5±0.6	4.2±0.7	3.1±0.6	2.3±0.5	3.5±0.5	6.4±0.4
Sep	2.2±0.5	2.1±0.4	1.9±0.6	2.4±0.5	2.3±0.5	2.2±0.5	2.2±0.6	2.7±0.5	1.8±0.6	1.9±0.4	2.4±0.6	4.3±0.2
Oct	1.6±0.4	1.8±0.4	1.7±0.4	1.3±0.4	2.0±0.4	1.6±0.4	1.5±0.4	1.8±0.4	2.1±0.6	1.3±0.4	1.5±0.3	3.2±0.1
Nov	2.0±0.4	1.6±0.3	1.8±0.4	2.0±0.5	1.9±0.4	1.7±0.4	1.6±0.5	2.6±0.5	1.4±0.4	1.4±0.3	1.4±0.3	3.5±0.2
Dec	3.8±1.1	3.1±1.2	3.0±0.9	4.3±1.2	3.6±1.1	4.0±1.3	4.5±1.2	6.2±1.5	3.8±1.0	2.6±0.6	1.9±0.4	7.3±0.7
CV	2.11	2.27	2.19	2.35	2.16	2.64	2.65	2.54	2.60	2.09	2.43	

Values represent mean, ±: Standard error and CV: Coefficient of variation

Table 14: Monthly mean pressure in Nsukka from 2010 to 2020

	Mean monthly air pressure (kpa)										
Years	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Jan	93.7±0.9	93.5±0.2	93.8±0.2	93.8±0.1	93.5±0.2	93.7±0.1	93.8±0.2	93.7±0.1	93.5±0.2	93.8±0.1	93.8±0.2
Feb	92.5±0.1	91.4±0.2	93.1±0.1	93.0±0.2	91.4±0.2	92.5±0.1	93.1±0.2	92.5±0.1	91.4±0.2	93.0±0.2	93.1±0.2
Mar	92.4±0.2	92.6±0.2	92.3±0.1	92.0±0.2	92.6±0.2	92.4±0.2	92.3±0.1	92.4±0.2	92.6±0.2	92.0±0.2	92.3±0.1
Apr	92.6±0.3	92.2±0.2	92.6±0.2	92.9±0.2	92.2±0.2	92.6±0.3	92.6±0.2	92.6±0.2	92.2±0.2	92.9±0.2	92.6±0.2
May	93.5±0.1	93.1±0.2	93.6±0.1	94.3±0.2	93.1±0.2	93.5±0.2	93.6±0.1	93.5±0.2	93.1±0.2	94.3±0.2	93.6±0.1
Jun	95.3±0.2	95.7±0.1	95.3±0.1	94.9±0.2	95.7±0.1	95.3±0.2	95.3±0.1	95.3±0.2	95.7±0.1	94.9±0.2	95.3±0.1
Jul	96.0±0.2	95.6±0.2	95.4±0.1	94.7±0.1	95.6±0.2	96.0±0.2	95.4±0.1	96.0±0.2	95.6±0.2	94.7±0.1	95.4±0.1
Aug	96.1±0.2	96.5±0.2	96.0±0.2	95.3±0.3	96.5±0.2	96.1±0.2	95.8±0.2	96.1±0.2	96.5±0.2	95.0±0.3	95.8±0.2
Sep	94.8±0.1	95.0±0.1	94.8±0.1	94.6±0.2	95.3±0.1	94.8±0.1	95.0±0.2	94.8±0.1	95.0±0.1	94.6±0.2	94.8±0.1
Oct	93.7±0.2	93.7±0.1	93.7±0.1	94.0±0.2	93.7±0.1	93.7±0.2	93.7±0.1	93.7±0.1	93.7±0.1	93.9±0.2	93.7±0.1
Nov	92.7±0.2	92.5±0.2	92.8±0.1	93.2±0.2	92.5±0.2	92.7±0.2	92.8±0.1	92.7±0.1	92.5±0.2	93.2±0.2	92.8±0.1
Dec	94.1±0.2	93.0±0.2	93.3±0.1	92.8±0.1	93.0±0.2	94.1±0.2	93.3±0.1	94.1±0.2	93.0±0.2	92.8±0.1	93.3±0.1
CV	1.44	1.71	1.29	1.07	1.72	1.44	1.28	1.43	1.69	1.02	1.26

Values represent mean, ±: Standard error and CV: Coefficient of variation

The maximum mean wind speed was 6.2 m/sec recorded in December, 2017 while the minimum was 1.3 m/sec recorded in October, 2013 (Table 13). A comparison of the yearly trend in wind speed showed a slight decrease in yearly wind speed from 2016 through 2020 especially in July, August, and November. From 2010 through 2015, wind speed was higher in January and August compared to the wind speed from 2016 through 2020, while December peak mean wind speed was higher from 2016 through 2020 compared to the previous years (Table 13).

Air pressure over Nsukka from 2010 to 2020: Air pressure over Nsukka from 2010 through 2020 did not vary much among the years with low CV each year (Table 14). However, the monthly mean pressure decreased from January through March and started increasing till August, when it declined, reaching its second-lowest value in November or December (Table 14). The year 2011, 2014, and 2018 had their lowest air pressure in February instead of March (Table 14).

Nevertheless, the month of August had the highest air pressure with values between 95.0 to 96.5 kpa while March remained the least in monthly mean pressure (92.0-92.6 kpa) (Table 14). The monthly trends in mean air pressure varied slightly among the years from 2010 through 2020. There was an increase in monthly mean pressure from February, 2016 to 2020 with an equivalent decrease from August, 2016 to 2020 (Table 14).

DISCUSSION

The seventy-seven plant species belonging to 43 different families that were identified in the forests are comparable to the 76 plant species reported by Onyekwelu *et al.*[16] in Queen's, Oluwa, and Elephant forests of South-Western Nigeria. However, the 36% record of forest generalists in this study was a little bit lower than the 50% habitat generalist plant species discovered by Adekunle[17] in the three forest reserves of Southwestern Nigeria. The similarity in the phenological features of the plant species among the Eha-Alumona forests could be due to their proximity. Park *et al.*[18] stated that native species' flowering times were similar to other natives in the same region. However, the reproductive phenophase of the plant species in the forests decreased sequentially from 2018-2020, especially in Awofia and Ogbunabo Forests, with a little delay in leafing of *Melia* sp. and *Sterculia tragacantha* in 2020. All these phenomena could only be linked to changes in climate as, respectively stated by Zhao *et al.*[1] and Asmamaw *et al.*[19] on the sensitivity of biodiversity to environmental conditions and the need for ecosystem resilient against environmental disturbances, which invariably affects the phenological features of living organisms[5].

Flowering and fruiting of plant species in the forests, which deviated from the September/October flowering/fruiting pattern (as obtained from the survey sampling) to November/December was a clear indication of the impact of changing climate in derived savanna forests. There was a higher significant mean number of reproductive phenophases of the forests' flora in 2020 in Osiani forest compared to other years in the sites. This could be attributed to the effect of fire suppression in the forest. Alvarado *et al.*[20] stated that fires can reduce flowering and fruiting by destroying buds, flowers, and fruits, affecting species that reproduce during the fire season as well as reducing the availability of large-seeded fruits[21]. However, fire incidences on plant communities have been discovered to stimulate, as well as shift the starting dates of germination, flowering, and fruiting and also, elevate fruit production[22-24].

Survey results showed that many plant and animal species were no longer in the forests, as a result of disturbances such as deforestation, fire, and/or climate change. Kacki and Hegedüšová[25] stated that human impact on the environment such as land use and improved farming systems, exhibited primarily in the extinction of key native dominant species in vegetation, especially on a local scale. Asmamaw *et al.*[19] reported that unless ecosystems become resilient enough against environmental disturbances, no life could exist on this planet as a result of changing climates by extreme weather events. Moreover, some plant species, especially *Pachystela brevipes* and *Landolphia owariensis* have not been productive in the forests for over two decades, which might be connected to the delay in the commencement of rainfall in recent decades as obtained from the survey results. This is agreed with the report of Numata *et al.*[4] that changes in rainfall seasonality can lead to unusual flowering events and fruit drop. Borchert *et al.*[3] also stated that temporal variations in precipitation and temperature are the major proximate factors controlling the occurrence of plant phenophases.

Homogeneity test of the climate elements showed that the data from the two meteorological stations were similar. This observation was in line with Basheer and AL-Rijabo[26], who reported a high correlation of some climatic elements among meteorological stations in Iraq.

The annual rainfall cycles in Nsukka from 2010-2020 ranged from 1,305.1-2,070.3 mm, with an average of 1,652.8 mm per annum. This record was relatively higher than the report of Ndubuaku *et al.*[27], that the mean annual rainfall in Nsukka ranged between 1,450-1,850 mm from 2007 to 2009. However, Uguru *et al.*[28] reported that annual rainfall records for Nsukka beyond 2003 were consistently higher than the overall mean value (≈1555 mm) recorded over the forty years (1970-2010).

Furthermore, the overall cumulative monthly mean rainfall from 2010 through 2020 showed that September remained the wettest month, while December and January remained consistently dry with little or no rainfall. This agreed with the report of Onyenucheya and Nnamchi[12] that, the peak of rainfall occurs in September and the least, in January and December for which no rainfall occurred. Rainfall peaks deviated from being bi-modal (in May and September) as stated by Uguru *et al.*[28], to tri-modal pattern in 2011, 2012, 2013, 2014, 2015, 2016, and 2018 in this study. This contrasted with the report of Uguru *et al.*[28] that, the bimodal rainfall pattern prevalent in the tropics, is evident in Nsukka, with the first peak occurring in June, and the second peak, in September.

However, the trends in rainfall pattern showed that there was a delay in the onset of rainfall by one month from 2016-2020, with the tri-modal pattern tending towards an unimodal pattern. The highest peak of monthly mean rainfall also, shifted from September to July, with a reduction in rainfall amount of 15.18 mm through the same years. This agreed with the report of Uguru *et al.*[28] that, the rainfall amount received in February dropped, depicting a delay in commencement of rains in the last three decades. The reduction in the highest rainfall peak of 2016 through 2020 relative to 2010-2015 might have been caused by the decrease in relative humidity and air pressure with the concurrent increase in air temperature.

The unimodal trend in rainfall in this study showed that the rainfall pattern in Nsukka has changed tremendously within the decade, exhibiting heavy downpours at the middle of the year with little spread among the months each year. Moreover, the years 2019 and 2020 had an unimodal rainfall pattern with their peak rainfall in July and June, respectively. This is in line with the report of Uguru *et al.*[28] that, a discernable shift of the second peak of rainfall from September to October from 2001-2010 occurred within the decade. However, the second peak of rainfall in the present study was different from the report of Uguru *et al.*[28]. These deviations from the normal highest rainfall in September showed that the rainfall pattern in Nsukka for the past two decades has been fluctuating, and changed considerably.

The observed minimum monthly mean relative humidity was 21.87% recorded in January, 2019 while the maximum was 83.83% recorded in August, 2011. This agreed with the report of Onyenucheya and Nnamchi[12], that relative humidity was lowest in January, and highest in the rainy month of August. The observed values in this study showed a drastic decrease compared to the report of Onyenucheya and Nnamchi[12] findings, that the relative humidity in January was 45.53% and that of August was 85.01%. However, Uguru *et al.*[28] reported a progressive drop in relative humidity after 2005 in contrast to the amounts of rainfall recorded in the same period. The mean relative humidity trend from 2010-2020 showed a decrease of about 7% in February, and November from 2016 through 2020. The reduction in relative humidity from 2016 through 2020 might be facilitated by the increase in air temperatures and wind speed in the same years due to a negative correlation. Uguru *et al.*[28] reported a progressive drop in relative humidity after 2005. Nevertheless, monthly mean relative humidity peaks shifted from August, 2010 through 2015 to July, 2016 through 2020. This showed a gradual but consistent change in the climate pattern of the study area for the past ten years.

The maximum monthly mean temperature of 31.4°C was recorded in March, 2017 while the minimum monthly mean temperature of 24.6°C was recorded in August, 2014. These values were higher compared to the 22.43°C diurnal minimum temperature, and 29.47°C maximum diurnal temperature recorded by Onyenucheya and Nnamchi[12]. Moreover, March remained the hottest month of the study period with a mean temperature range of 29.7-31.43°C while August remained the coldest with a mean temperature range of 24.6-26.92°C. This agreed with the report of Onyenucheya and Nnamchi[12] that March is the warmest month of the year with a temperature averaging 27°C while August is the coldest month with an average temperature of 22.9°C. Consideration of the mean temperature trends within the study periods showed a rise in mean temperature from 2016 to 2020 by 1°C. The increase in air temperatures in Nsukka from 2016 through 2020 might be facilitated by a decrease in air pressures and relative humidity from 2016 to 2020 especially in the rainy months of August. Uguru *et al.*[28] reported a 10°C increase in temperature in 1987, 2005, 2006, and 2007, with an obvious rise in annual temperature in 2010.

Wind speed was mainly high in January, August, and December but very low in June and October throughout the study period. Onyenucheya and Nnamchi[12] reported that maximum wind speed occurred in December with a speed of 1.79 m/sec, and a minimum of 0.89 m/sec in October. However, in 2011, 2014, and 2018, the low mean wind speed was shifted from October to November while that of the June trough was shifted to July in 2015 and 2016, and to May in 2019. This depicted a clear change in the climatic condition of Nsukka for the past few decades. Also, in 2010, 2013, and 2019, the January peak of monthly mean wind speed was shifted to February and March. This showed inconsistency in wind speed patterns in Nsukka for over a decade.

The maximum mean wind speed was 6.2 m/sec recorded in December, 2017 while the minimum was 1.3 m/sec recorded in October, 2013. These values were higher than the values recorded by Onyenucheya and Nnamchi[12] (1.79 m/sec) maximum and (0.89 m/sec) minimum. However, January remained the most windy month of the study period followed by December, while October was the least. This deviated slightly from the report of Onyenucheya and Nnamchi[12] that maximum wind speed occurs in December and the minimum, in October. Comparison of the yearly trend in wind speed from 2010 through 2020, showed a slight decrease in yearly wind speed of 0.2-0.3 m/sec from 2016 through 2020, especially in July, August, and November. From 2010 through 2015, wind speed was higher in January but higher in December from 2016 through 2020. This showed inconsistency in wind speed patterns in Nsukka for over a decade. The month of August had the highest air pressure while March was the least in monthly mean pressure. This deviated from the report of Onyenucheya and Nnamchi[12] that the maximum atmospheric pressure in Nsukka occurred in July and the minimum, in April. However, there was an increase in monthly mean pressure by 0.3 kpa from February 2016-2020 with an equivalent decrease from August, 2016-2020. This showed inconsistency in air pressure pattern in Nsukka for over a decade.

In this study, the number of plant species (77) identified in the three forests studied was similar to 76 plant species reported by Onyekwelu *et al.*[16] in three forests of Southwestern Nigeria despite being in different ecological zones. The phenological features of the plant species among the Eha-Alumona forests were similar, which could be the effect of their proximity as suggested by Park *et al.*[18] that native species' flowering times were similar to other natives in the same region. Moreover, some plant species, especially *Pachystela brevipes* and *Landolphia owariensis* have not been productive in the forests for over two decades, which might be connected to the delay in the commencement of rainfall in recent decades as obtained from the survey results. This is in line with the report of Numata *et al.*[4] that changes in rainfall seasonality can lead to unusual flowering events and fruit drop. Borchert *et al.*[3] also stated that temporal variations in precipitation and temperature are the major proximate factors controlling the occurrence of plant phenophases.

The annual rainfall cycles in Nsukka from 2010-2020 ranged from 1,305.1-2,070.3 mm, with an average of 1,652.8 mm per annum. This record was relatively higher than the report of Ndubuaku *et al.*[27], that the mean annual rainfall in Nsukka ranged between 1,450-1,850 mm from 2007-2009. However, Uguru *et al.*[28] reported that annual rainfall records for Nsukka beyond 2003 were consistently higher than the overall mean value (≈1555 mm) recorded over the forty years (1970-2010). Rainfall peaks deviated from being bi-modal (in May and September) as stated by Uguru *et al.*[28], to tri-modal pattern in 2011, 2012, 2013, 2014, 2015, 2016, and 2018 in this study. This contrasted with the report of Uguru *et al.*[28] that, the bimodal rainfall pattern prevalent in the tropics, is evident in Nsukka, with the first peak occurring in June, and the second peak, in September. Also, the unimodal trend in rainfall in this study showed that the rainfall pattern in Nsukka has changed tremendously within the decade, exhibiting heavy downpours at the middle of the year with little spread among the months each year.

The observed minimum monthly mean relative humidity was 21.87% recorded in January, 2019 while the maximum was 83.83% recorded in August, 2011. The observed values in this study showed a drastic decrease compared to the report of Onyenucheya and Nnamchi[12] findings, that the relative humidity in January was 45.53% and that of August was 85.01%. However, Uguru *et al.*[28] reported a progressive drop in relative humidity after 2005 in contrast to the amounts of rainfall recorded in the same period.

The maximum monthly mean temperature of 31.4°C was recorded in March, 2017 while the minimum monthly mean temperature of 24.6°C was recorded in August, 2014. These values were higher compared to the 22.43°C diurnal minimum temperature, and 29.47°C maximum diurnal temperature recorded by Onyenucheya and Nnamchi[12]. Also, the maximum mean wind speed in this study was 6.2 m/sec recorded in December, 2017 while the minimum was 1.3 m/sec recorded in October, 2013. These values were higher than the values recorded by Onyenucheya and Nnamchi[12] (1.79 m/sec) maximum and (0.89 m/sec) minimum. However, January remained the most windy month of the study period followed by December, while October was the least. This deviated slightly from the report of Onyenucheya and Nnamchi[12] that maximum wind speed occurs in December and the minimum, in October. The month of August had the highest air pressure while March was the least in monthly mean pressure. This deviated from the report of Onyenucheya and Nnamchi[12] that the maximum atmospheric pressure in Nsukka occurred in July and the minimum, in April.

From the study, it was clear that the climatic system of derived savanna regions is changing with observable effects on the forest flora of the region. More work is needed to obtain comprehensive data on the extent, and rate of changes in climate in derived savanna regions. This may not be readily feasible without government assistance, since research on the effects of climate on biodiversity is capital intensive. With the use of remote sensing technology, more data would be procured with reduced labor, cost, and time of inventory.

CONCLUSION

This study has shown changes in phenological characteristics of forests' flora in Derived Savanna regions in recent years due to changing climate. The phenological changes include plant species extinction, delay in leafing, shifting, suppression, and reduction in reproductive phenophases. If this trend continues without being checked, it might result in food insecurity and other unprecedented effects on biodiversity shortly. Planted forest programs should be embarked upon in derived savanna regions to mitigate the debilitating effects of climate change on biodiversity.

SIGNIFICANCE STATEMENT

Climate change remains the major threat to the sustenance of biodiversity globally. However, the dynamic nature of the human body system invariably hinders rapid and accurate detection of the extent, to which the climatic system of a particular region has changed. Phenological studies remain a vital indicator of changing climate. In this study, a shift in the leafing periods of *Melia* sp. and *Sterculia tragacantha*, as well as in the reproductive periods of many tree species was detected. Rainfall peaks were unimodal/tri-modal, coupled with a decrease in relative humidity by 7%. There was a rise in annual mean temperature by 1°C. The unimodal nature of rainfall, decreased relative humidity and a rise in monthly temperature contributed to the variation detected in plant species studied. It is recommended that planted forest programs should be embarked upon in derived savanna regions to mitigate the debilitating effects of climate change on biodiversity.

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