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Effects of Changing Climate Variables on Residential Building Fabrics in North Central Nigeria

*Nsofor C., Zubairu S. N. & Abdulrahman M. E.

Architecture Department, Federal University of Technology, Minna
*Correspondence: chukwuebuka.nsofor@gmail.com

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Climate change has become a global concern and its impact has continued to affect human lives, influencing the livelihood of most people across the globe and the concern is based on increasing records, incidents and impacts of climate related disasters on physical infrastructures. This study evaluated the effects of changing climate variables on residential buildings fabrics in North Central, Nigeria. Data on climate pattern for the last thirty years were collected from the Nigerian Meteorological Agency (NIMET), National Space Research and Development Agency (NASRDA) and Data Interim (DIT), and were analysed using trend analysis. The Mohr's test kit was utilised to establish the extent of the climate defects on residential building fabrics within the study area using severity index calculation. The study revealed constant fluctuations in climate variables within the study area with Nasarawa and Kogi States recording peaks in solar intensity and rainfall readings. Also, most of the buildings investigated experienced effects of climate in one way or the other showing defects such as flaking of mortar, biological growths, blistering and peeling of paints. Based on the results obtained from the study, recommendations include provision of moisture barriers, surface water drains around buildings, use of fibre materials, use of bright colours for finishing's and introduction of larger sized windows around residential buildings.

Keywords*:* Built environment, Climate change, Residential buildings, North Central, Variability

INTRODUCTION

Climate is the weather condition of an area over a number of years (Brown, 2011). It is the typical weather conditions experienced at any location or area over series of years. Weather conditions such as rainfall, sun intensity, surface temperature and other meteorological elements recorded on interval for years and the average taken at the end of the targeted period is referred to as the climate of the location where such data were collected. Climate is made up primarily of four elements which are temperature, solar radiation, wind and rainfall. Climate change has also been defined as the variation over time in weather elements, due to factors of human activities or natural vulnerabilities (Odjubo, 2010; IPCC, 2012). Climate change has become a global topic as its effects have continued to threaten human lives and to a large extent, influencing the livelihood of most people across the globe (Onyekure & Marchant; 2012 Akande, 2017). Some of these effects as shown in Figures 1 and 2, are based on increasing records, incidents and impacts of climate related disasters on physical infrastructures that suggest that potential impacts are at a scale that add urgency not only to the efforts to prevent additional disasters, but equally important, to the efforts to adapt the built environment to the impacts of already occurring consequences (Goic, 2012).

Figure 1: Common building defect within the North Central Region

Figure 2: Blistering and flaking of mortar

Source: www.google.co.uk.images.

Over the years, there have been a number of nearly constant variables that determine climate, including latitude, altitude, proportion of land to water, and proximity to oceans and mountains (ECCC, 2018). Many global issues are related to climate, such as the supply of basic needs as food, water, health, and shelter. Unfavorable climate variations may threaten basic needs with increased temperatures, sea level rise, changes in precipitation, and frequent or intense extreme events (Abdulkadir *et al*., 2017).

In the context of environmental policy, the term climatic conditions, has become synonymous with anthropogenic global warming, which is the rise in average surface temperature (Elisha *et al*., 2017). Global warming is the heating of the earth’s surface which results when the atmosphere traps heat radiating towards space (Carter, 2011). Global warming summarizes the term referring to the increase in the surface temperature of the earth. Climate change includes global warming and everything else affected by increasing greenhouse gases (GHG) level (IPCC, 2007). When the average weather of a specific region is altered between two different time periods, then climate change is said to have occurred (Cam, 2012). Climate change usually occurs when there is an alteration in the total amount of the sun's energy absorbed by the earth's atmosphere and surface. It also happens when there is a change in the amount of heat energy from the earth's surface and atmosphere that escapes to space (the area beyond earth’s atmosphere) over an extended period of time. An area's climate is generated by the average weather system, which has five components: atmosphere, hydrosphere, cryosphere, land surface, and biosphere (IPCC, 2011). Over time, scientists have actively worked to understand past and future climate by using observations and theoretical models. Borehole temperature profiles, ice cores, flora land faunal records, glacial and periglacial processes, stable isotope and sea level records (Bulkeley, 2008).

The evidence of the effects of changing climate is overwhelming globally and several researches provide evidence for the Nigerian context (Obot, 2010; Laryea, 2011; Elum & Momodu, 2017; Onwutuebe, 2019). It is also argued that, Nigeria’s sub-Saharan region has become poorer in the last generation making it quite difficult to cope as well as adapt to the challenges posed by changing climatic variables (Ashelo, 2014; Onwutuebe, 2019). This study attempted to establish the pattern of climate variables within the North Central region of Nigeria. The study was aimed at evaluating the effects of changing climate variables on residential buildings fabrics within North Central, Nigeria.

METHODOLOGY

Three States (Niger, Kogi and Nasarawa) and the Federal Capital Territory were purposively sampled for the study as a result of the availability of meteorological data, increasing records of incidents and impacts of climate related disasters on physical infrastructure. Field observation was employed in collecting the relevant data which were collated, analyzed and used to establish the effects of climate variables on residential buildings within the study area. The population of the study area was collected from the National Population Commission and the national average household size of 3.2 per family as recommended by the Population and Housing Census commission was used to divide the population of the target research area in order to get the number of households within the study area and in turn, the number of residential buildings to be studied using the formula:

$$\mathbf{S} = \frac{N}{1 + N(e)^2}$$

Where: average house hold size = 3.2

S = Sample Size

e = Margin of Error Assumed (0.05)

1 = Theoretical constant

N = Number of Population

$$\mathbf{S} = \frac{10{,}497{,}212}{1 + 10{,}497{,}212\,(0.05)^2}$$

$$\mathbf{S} = \frac{10{,}497{,}212}{1 + 10{,}497{,}212\,(0.025)}$$

$$\mathbf{S} = \frac{10{,}497{,}212}{10{,}497{,}213\,(0.025)}$$

$$\mathbf{S} = \frac{10{,}497{,}212}{16243.03}$$

$$\mathbf{S} = \frac{646.000457264794}{3.2}$$

$$S = 201.93$$

Based on the above, 50 houses were selected from Minna, Lokoja, Lafia and Abuja Municipal Area Council (AMAC) for direct observation using Mohr’s test kit.

Data Sources

The climate data for this research was obtained from both Federal and State Ministries of Lands and Environment, NARSDA, NIMET and Data Interim Analysis Tool. Climate readings for the last thirty (30) years were obtained and analysed to establish the climate pattern within the region. This three decade climate readings were analysed using Trend analysis. The residential building units investigated were accessed using a well-structured checklist to establish most occurring defects resulting from changing climate variables. The Mohr's test kit was used to establish the extent of the defects.

Analysis of Data

Mohr's hardness test kits

Mohr's hardness test kit is a kit used for "scratch testing" substance to determine their abrasion resistance on the Mohr's hardness test range, which ranges from 1 to 10. Diamond on the range is the hardest at 10, while talc is softest at 1. The test kit was employed to determine the extent of the defects on the wall surfaces of the buildings investigated. The data obtained were analysed by means of frequencies and severity index. The severity index analysis uses weighted percentage scores to compare the relative importance of the criteria under study (Kamweru, 2015), while frequency analysis was then conducted to determine the frequency of occurrence and severity indices (Kamweru, 2015):

$$\text{Severity Index (SI)} = \frac{[\sum ai.xi]}{[5\sum xi]} \text{ x } 100$$

Trend analysis

Trend analysis a widely used nonparametric method used to identify statistically significant trends in climate. In this study, the periods 1991–2020 were observed and the formula as shown below was used to examine the trend.

V(S) = [n (n−1) (2n+5) − ∑p=1qtp (tp−1) (2tp+5)]

V(S) = [n (n−1) (2n+5) −∑p=1qtp (tp−1) (2tp+5)]

Where *q* represents total number of tied groups. A set of the same values in a dataset is referred to as a tied group. Each tied group is denoted by t_p. The positive values of *Z* indicate upward (increasing) trends in time series, and the negative values show downward (decreasing) trends. Trends are then tested against some critical values ($Z_{1-\alpha}$) to show that either they are statistically significant or they are not.

RESULTS

The analysis of climate pattern examining temperature, rainfall, wind and solar intensity within the study area were trend analysed using trend analysis and the man-Kendal seasonal test on the variables of climate within the periods of 1991 – 2020 to establish the rate at which each variable of climate changed within the study period. The building fabrics were then tested using Mohr's test kit to establish the extent of the building defects on building surfaces resulting from effects of changing climate variables. The results are presented below:

Seasonal Trend for Climate Variables within the Study Area

Figure 3 depicts the seasonal trend of rainfall within the four different locations of the study area. The graph shows that Kogi has two peaks which indicate its bimodality. Kogi State is closer to the south west of Nigeria than the other States: in the south west of Nigeria, the mesoscale convective system is not the only driver of precipitation but the monsoonal system. Unlike Kogi State, the other areas: Nasarawa, Niger and FCT have one peak of rainfall each, which indicates the mono-modality of the rainfall system over these regions. The general similar pattern indicates that there are majorly two seasons which include the rainy and the dry season. The dry season, also the period of harmattan is around November and February. This is where we have very little and low amount of precipitation. On the other hand, the rainy season is where we have the maximum amount of rainfall. The season usually lasts for 4-6 months depending on the location or region.

From Figure 3, the monthly rainfall is generally above the monthly average from May to October when converted to percentages for the four stations. The monthly rainfall increases are 17.96%, 26.04%, 28.14% and 33.47% for May; 76.25%, 64.35%, 60.14% and 66.36% for June; 89.38%, 113.15%, 96.16% and 104.30% for July; 137.80%, 148.06%, 99.72%, and 142.88% for August; 99.59%, 132.02%, 125.20% and 116.69% for September and 21.46%, 12.40%, 28.56% and 16.09% for October in Nasarawa, Niger, Kogi and FCT respectively.

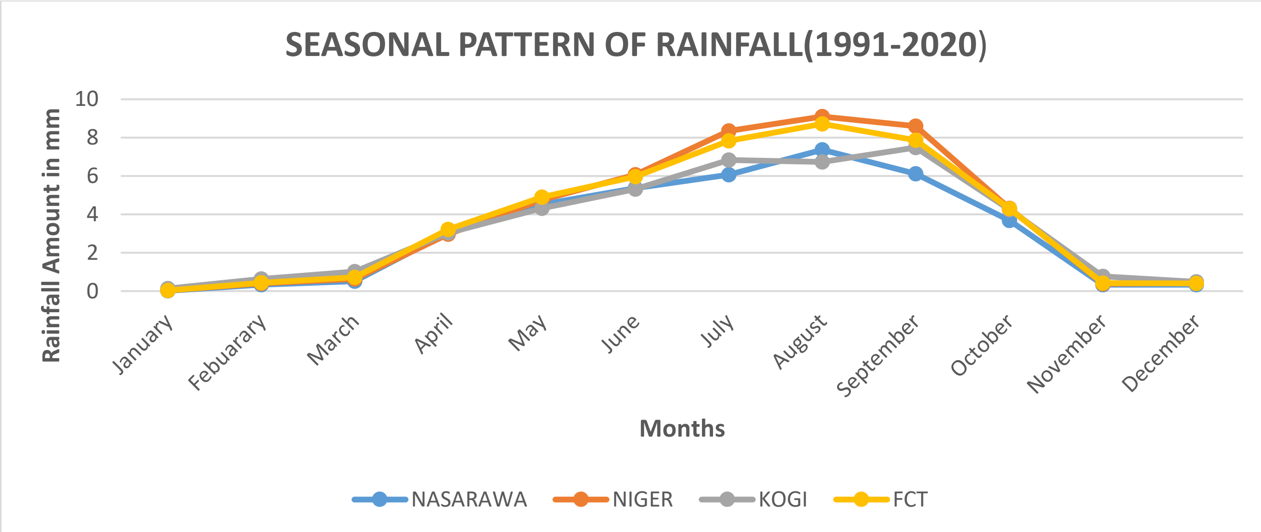

Figure 3: Rainfall Distribution Pattern for the four Locations

Table 1 and Figure 4 depict the seasonal trend of temperature. Nasarawa being the hottest region records the highest value of temperature of about 36°C in the month of March, while FCT has the lowest temperature of about 28°C. Based on the graph, it is apparent that there is a general decrease in temperature between the month of April and October. This is because there is more precipitation between April and October than November and March. Precipitation largely affects the insolation. Clouds, especially low clouds such as cumulus, stratocumulus, etc. are formed more when there is large moisture content in the atmosphere. Clouds generally require aerosols and water vapour to form. Without the existence of water vapour in the lower troposphere, low clouds cannot form. These low clouds and sometimes medium clouds that are more responsible for cloudy days do not allow much insolation and infrared radiation to get to the immediate surface of the earth. Air temperature, however, depends on long wave radiation which is invariably dependent on infrared radiation.

High clouds are usually light and transparent, and are based on the altitude difference from medium and low cloud and do not have much effect on air temperature as the latter. High clouds are usually found during the day during dry season; the highest or maximum temperature is also recorded within this period. So, the diurnal temperature will have much effect on the mean daily temperature during this period.

Table 1: Seasonal Indices of Temperature in North-Central, Nigeria (1991-2020)

SEASONAL PATTERN OF TEMPRATURE (1991-2020)				
MONTH	**NASARAWA**	**NIGER**	**KOGI**	**FCT**
January	1.0808	1.0358	1.0467	1.0582
February	1.1432	1.1032	1.0988	1.1168
March	1.1525	1.1302	1.1032	1.1358
April	1.0782	1.0772	1.0679	1.0714
May	0.9927	0.9995	1.0113	0.9920
June	0.9305	0.9453	0.9578	0.9390
July	0.8932	0.9093	0.9233	0.9012
August	0.8692	0.8925	0.9150	0.8825
September	0.8899	0.9224	0.9198	0.9113
October	0.9257	0.9604	0.9438	0.9489

November	1.0022	1.0114	0.9974	1.0126
December	1.0420	1.0129	1.0149	1.0302

From Table 1, the monthly temperature for all the states are above the monthly average for at least six to seven months which are from January to April, November and December of each year respectively. For every other month, it was observed that the indices are slightly below the monthly averages. However, the month of March recorded the highest temperature values across the states.

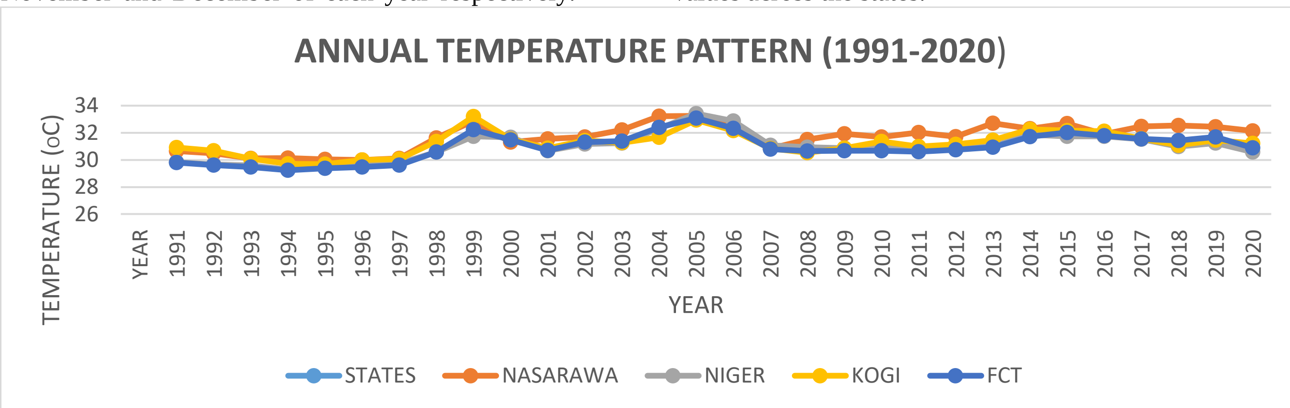

Figure 4: Temperature Distribution Pattern for the four Locations

Table 2 and Figure 5 show the seasonal trend in wind speed within the study area. The wind seasonal patterns over the four states are somewhat similar based on the fact that the wind is dependent on temperature difference. The wind pattern shows that the speeds during the dry seasons are faster than during the rainy season. During the rainy season the predominant wind is the southwesterly wind, which is associated with wetness and coolness; however, during the dry season the northeasterly wind is the predominant wind which is associated with dryness and hotness. During the dry season, more radiation enters the earth atmosphere and can trigger more temperature difference. Kogi has the highest wind speed from April to October. Altitude also plays a major role on wind speed.

Table 2: Seasonal Indices of Wind Speed in North-Central, Nigeria (1991-2020)

SEASONAL PATTERN OF WIND (1991-2020)				
MONTH	NASARAWA	NIGER	KOGI	FCT
January	1.4319	1.4937	0.9400	1.3153
February	1.2987	1.3152	0.9980	1.2037
March	1.0907	0.9962	1.1713	1.0315
April	1.0261	0.9364	1.2414	1.0058
May	0.8732	0.8430	1.0696	0.8942
June	0.8343	0.8316	1.0588	0.8995
July	0.9018	0.8915	1.1425	0.9872
August	0.8829	0.8958	1.1346	0.9991
September	0.6991	0.7115	0.9015	0.8032
October	0.6647	0.6619	0.7829	0.7238
November	0.9570	1.0188	0.7288	0.9192
December	1.3395	1.4043	0.8307	1.2175

From Table 3, the patterns of the seasonal indices of wind speed are similar across the states considered except Kogi. For Nasarawa, Niger and FCT, the wind speeds were higher in the months of January to April and December. For Kogi, the speed is higher above the monthly average from the month of March to August each year.

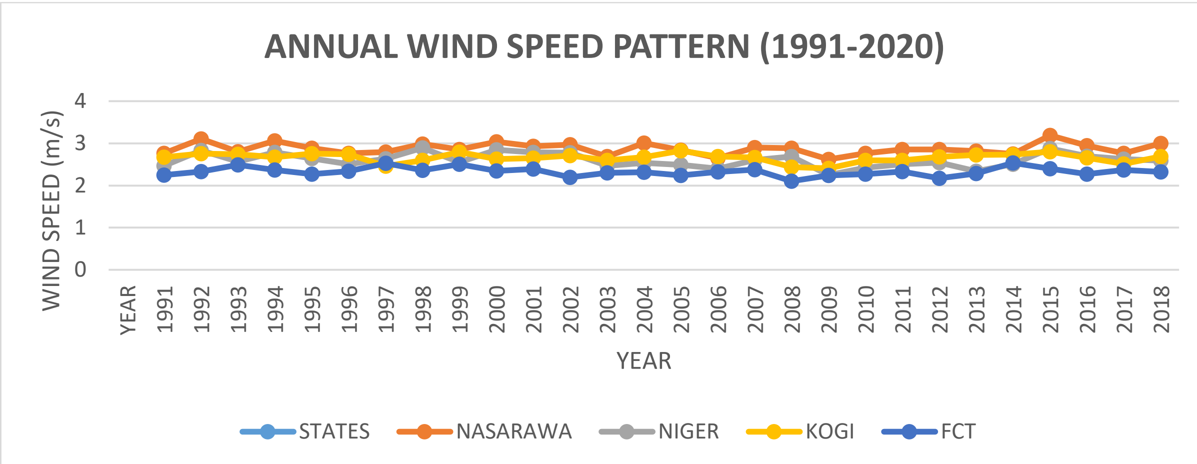

Figure 5: Wind Distribution Pattern **for the four Locations**

Table 3 and Figure 6 results show the seasonal trend in solar intensity pattern over the study area. Solar irradiance is dependent on the amount of solar radiation that is able to transmit through the atmosphere. The clearness of the sky which can be measured by an index called clearness index is affected by particles like aerosols. The seasonal pattern depicts that solar intensity is dependent on seasons where it is high during the dry season. Clearer skies appear more during hot season. Clouds, especially low clouds such as cumulus, stratocumulus, etc. are formed more when there is large moisture content in the atmosphere. Clouds generally require aerosols and water vapor to form.

High clouds are usually light and transparent, and in fact based on the altitude difference from medium and low cloud and do not have much effect on air temperature as the latter. High clouds are usually found during the day during dry season.

Table 3: Seasonal Pattern of Solar Intensity in North-Central, Nigeria (1991-2020)

SEASONAL PATTERN OF SOLAR INTENSITY (1991-2020)				
MONTH	**NASARAWA**	**NIGER**	**KOGI**	**FCT**
January	1.0921	1.0432	1.1113	1.0820
February	1.1279	1.0924	1.1186	1.1148
March	1.1344	1.1361	1.1101	1.1484
April	1.0759	1.1278	1.0627	1.1154
May	1.0089	1.0314	1.0131	1.0159
June	0.9006	0.9333	0.9254	0.9204
July	0.8410	0.8431	0.8051	0.8067
August	0.7827	0.7749	0.8034	0.7480
September	0.8587	0.8966	0.8613	0.8710
October	0.9828	0.9967	0.9630	0.9862
November	1.0993	1.0776	1.0839	1.1033
December	1.0958	1.0468	1.0971	1.0878

From Table 3, the monthly solar intensity for all the states show above monthly average for at least six to seven months which are from January to April, November and December of each year respectively. For every other month, it was observed that the indices are slightly below the monthly averages. It was observed that the pattern of solar intensity and temperature are the same for the whole area.

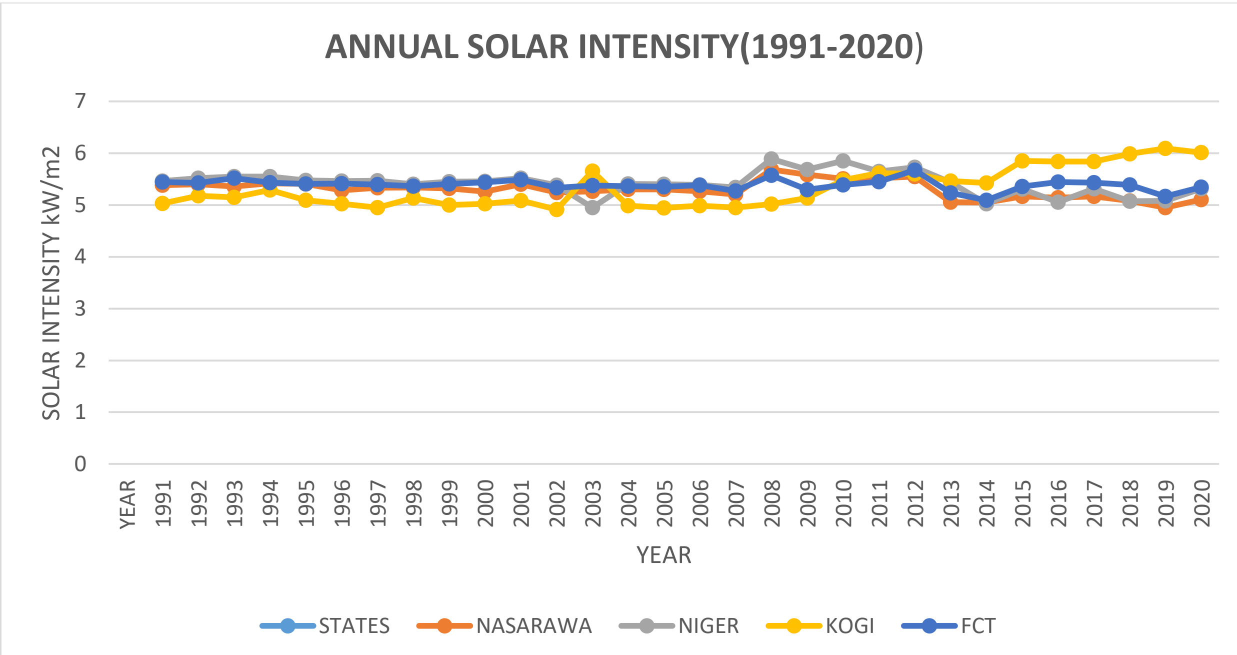

Figure 6: Seasonal Pattern of Solar Intensity Distribution Pattern for the four Locations

Mohr's Building Fabric Defect Test

Using Mohr's building fabric defect test to assess the extent of the defect, it was found that some of the most occurring defects are the flaking of mortar, Biological growths, Blistering and Peeling of Paints which could be caused by changing climate, inappropriate building material use and poor construction methods. The prevalent occurrence and frequencies of these defects on buildings within the study area were investigated. Table 4 indicates the wall defect using scales of Very high, High, Average, Low and very low, reveals that all the defects highlighted are frequently experienced on buildings within the study area, however, the indicators of peeling of paints, flaking of mortar and blistering are more rampant.

Table 4: Wall defects and frequency of occurrence in buildings within the study area

S/N	Defect	VH 5	H 4	AVG 3	L 2	VL 1	Total	Mean	Mean2	Std D	(SI)
1	Flaking of mortar	30	120	40	6	4	200	3.83	15.29	3.385262	76.6
2	Biological growths	20	30	116	24	10	200	3.13	10.65	2.742262	62.6
3	Blistering	66	84	30	12	8	200	3.94	16.6	3.558089	78.8
4	Peeling of paints	120	50	20	6	4	200	4.38	20.04	3.957272	87.6

Table 5 shows the relative severity indices of defects associated with concrete. The result shows that flaking of mortar, 'blistering and peeling of paint all occurred at the horizontal band up to 0.9m above ground level and are the three most severe symptoms which are associated with wall defects in buildings. The study also identified biological growth to also be a factor associated with building defects.

Table 5: Wall defects and frequency of occurrence in buildings within the study area

DEFECT	MEAN	STD Deviation	Ranking
Biological growths	3.13	2.7	4th
Flaking of mortar	3.83	3.39	3rd
Blistering	3.94	3.56	2nd
Peeling of paints	4.38	3.96	1st

NB: 1.0-2.49=indicators not visible, 2.50-3.49= indicators moderate and 3.50 -5.00= indicators severe.

Table 6: Severity indices of symptoms associated with wall defects.

DEFECT	Severity Index (SI)%	Ranking
Biological growths	62.6	4th
Flaking of mortar	76.6	3rd
Blistering	78.8	2nd
Peeling of paints	87.6	1st

The severity indices of the symptoms associated with wall defects is expressed using the formula below:

$$\text{Severity Index (SI)} = \frac{[\sum ai.xi]}{[5\sum xi]} \times 100$$

From Table 7, the hardness of the two hundred (200) buildings investigated measured from 0.00m to 0.90m was 2.0, the hardness from 0.91m to 2.0m was 2.50 and from 2.1m to each building's head room on the hardness scale was 3.00.

Table 7: Measurement on the hardness scale

No.	Height above the ground level	Hardness
1.	0.00m - 0.90m	2.0
2.	0.91m - 2.0m	2.5
3.	2.1m-3.0m	3.0

The wall composition above ground level indicated severe effect of saturation by moisture. Thus the hardness showed plaster weakness and the saturation of the mortar reduced as the height of the walling material increased (indicating damp-rising measurably reducing as the height of the walling material increased).

CONCLUSION AND RECOMMENDATIONS

The study indicated constant fluctuation in climate variables, solar intensity and temperature continued to increase and rainfall pattern records both sequential increase and decrease all through the study period. Also, most of the Buildings investigated experienced effects of climate in one way or the other showing defects such as rusting, cracks, blistering, flaking and biological growth.

The investigation indicated that the selected residential buildings studied were not sufficiently designed or developed to suit the changing climate of the environment. There were visible signs of poor construction methods and inappropriate construction technology which in general contributed to some of the above listed problems.

Based on the results, it is recommended that there should be the provision of moisture barriers (for example, external wall tiles), surface water drainage, the use of aerated clay blocks, the use of more and larger windows for lighting, the use of fibre materials, the use of bright coloured materials, and the use of glasses that should be incorporated during design considerations that are climate timely necessary.

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