Contributions of Rainfall and Other Meteorological Factors to Building Collapse in Urban Areas of Anambra State

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Abstract
The high incidence of building collapse in urban areas of Anambra State is a veritable source of worry to both individuals and the State government. In most cases, these collapses are attributed to both construction and engineering error, as well as, the use of inferior building materials, leaving the deleterious effects of meteorological factors. The aim of this paper is, therefore, to analyze the effects of rainfall variables and other meteorological factors to building collapse in urban areas of Anambra State. Data for the paper were collected from Campbell Automated Weather Station at Nnamdi Azikiwe University Awka, Anambra State Physical Planning Board and questionnaire to landlords, government officials and builders. The statistical methods adopted were both Multiple Regression and bivariate correlation analyses. Result indicates that these variables contribute significantly to building collapse in urban areas of Anambra State. Recommendations included building with local materials and ensuring that the isolated meteorological factors responsible for these collapses are taken into consideration when building.

Keywords: Board, building, landlords, rainfall, urban

Introduction

The high incidence of building collapse in urban areas of Anambra State is a veritable source of worry to both individuals and the State government. The building collapse is more of urban than rural problem considering the available statistics from relevant authorities (Okoli, 2016). In 2016 there were many cases of building collapse in Anambra State. In Awka, for instance a three-storey hostel block under construction collapsed at the completion of the first deck. Again a two-storey building collapsed at Agbani-Ifite also in Awka where three persons lost their life. Furthermore, there was the collapse of another three-storey building at Federal Polytechnic Oko (Plate 1).



Plate 1: Building collapse at Federal Polytechnic, Oko, Anambra State.

This is the first of such incident in a higher institution in the State, but in other States, we have many recorded cases of TETfund sponsored building collapse. Some other institutions outside the State where this have happened are: Imo State University Owerri, IBB University Lapai, Niger State and Kano State University of Science and Technology in Wudil (Baffa, 2016). In Onitsha, a four-storey building collapsed in 2016 at 24 Obanye Street near General Post office after a heavy rainfall. This is equally in addition to the collapse of an uncompleted twin three-storey building at Nkwo Eziudu Ogidi also near Onitsha (Ibekanne, 2017). Furthermore, in Ekwulobia, one of the urban areas of Anambra State, Esomnofu (2017) reported the collapse of a two-storey building killing three people and leaving five others seriously injured. Building collapse in Anambra and other States especially Lagos is now a regular occurrence. Fakere, Fadairo and Fakere (2012) noted that incessant building failure has been reported resulting in the loss of lives and property. Most of these collapse were attributed to structural failures especially construction and engineering errors, as well as, the use of inferior materials, other factors that could be read from the literature include inadequate preliminary works, improper walling, lack of approved structural design, poor building material specification, ineffective supervision, climatic factors, adoption of wrong foundation, and poor concrete mix ratio (Seeley, 1987; Whitman 1979; Tomilson 1980; Fakere, Fadairo and Fakere, 2012; Oseghale, Ikpo and Ajayi 2015).

However of all these studies it was only Ogunsemi (2002) and Ayedun, Durodola, and Akinjare (2011) that specifically noted that atmospheric variables contribute substantially to building collapse in Nigeria. They are of the view that a good building is not that which merely fulfills the purpose for which it is designed and erected but a building comely and able to withstand the onslaught of weather conditions. However, Ayedun, Durodola and Akinjare (2011) noted that the reasons adduced for incessant building failure and collapse from building professionals showed that heavy downpour was ranked, 8th out of 12 factors considered, while the landlords ranked factor 7th.The building contractors shared the same view with building professional as they equally ranked it 8th. From these studies it is clear that climatic factors are never regarded by many, including builders and engineers as one serious factor that causes building collapse in Nigeria. Considering our humid environment characterized by incessant heavy rainfall, as well as, destructive winds spells that occasionally destroy buildings mostly at the beginning of the rainy season, the effect of rainfall and other meteorological variables cannot therefore be in doubt. This paper is, therefore, aimed at investigating the contributions of these atmospheric variables to the building collapse in urban areas of Anambra State.

Materials and Methods

Area of Study

Anambra State is one of the 36 States in Nigeria situated in the South-Eastern part of the country.It is located on latitudes 5°32' and 6°45'N and longitudes 6°43' and 7°22'E respectively (Fig. 1) and has an estimated land area of 4,865sq km. In terms of geology, the area is underlain by various types of sedimentary formations ranging from lower coal measures (Ajalli formation) and the Imo clay shale in north-east part of the State to the south where it neatly underly Awka-Orlu upland. Some parts of the north and central parts are occupied by Bende-Ameki formation, while the southern tip around Ihiala and Nnewi South Local Government Areaare occupied by the Orashi formation. Furthermore, this formation (Bende-Ameki) further dominate the geology of the western parts of the State. The topography of the State shows areas of highlands and lowlands, the highlands area being mainly in the eastern part from Awka to Uga stretches as far south as Umunze in Orumba South Local Government Area.

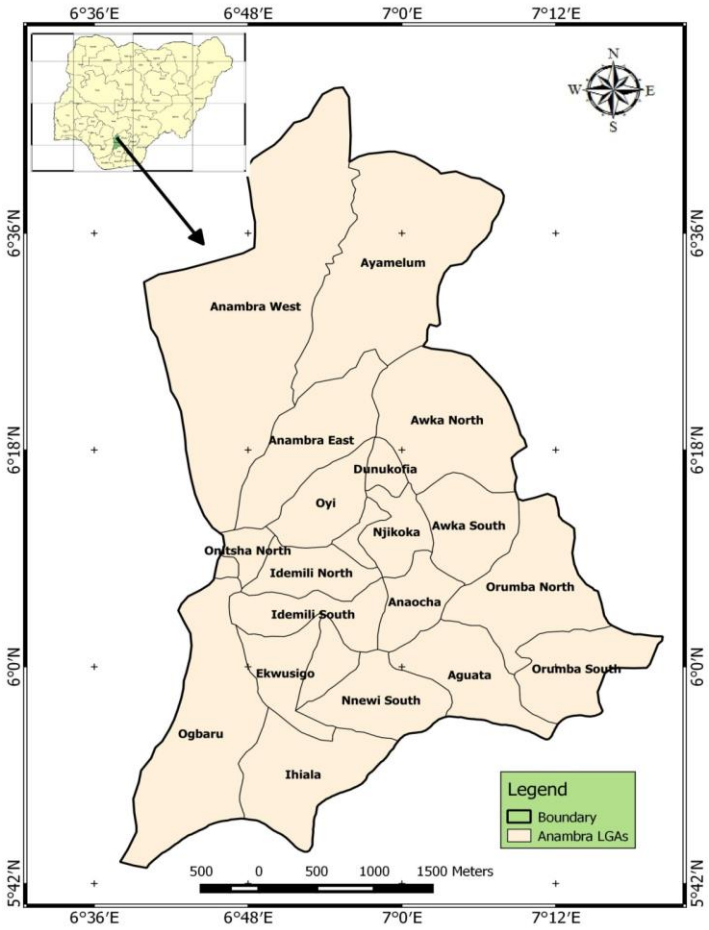


Fig 1: Administrative Map of Anambra State.

It is in this area that the nature of the soil which is friable has given vent to gruesome soil erosion which is the principal environment features of Agulu-Nanka-Oko axis. The soil is of variegated types with the hydromorphic soils of the western half of the State being most dominant while other areas are occupied by ferralitic soils and lithosols. In terms of topography the eastern parts of the town from Awka to Aguata which is in the southern parts of the state, there is an upland which is upto 300m in some areas while there is a slope of the topography from Abagana to the River Niger plains in Onitsha.

The vegetation is mainly the guinea-savanna type, which was not originally in the study area developed as a result of the destruction of the original high forest vegetation through some anthropogenic activities mainly housing construction, urbanisation and farming activities.

Anambra State has so many rivers that drain its landscape, however the most important of these rivers are the Niger, Anambra, Mamu, Idemili and Ulasi.The climate shows that annual mean minimum temperature is about 23^0C, while mean annual maximum is about 32^0C. Annual mean rainfall is about 1750mm, while mean relative humidity is about 68% (NBS, 2009). The State has three major urban centres, namely Awka, Onitsha and Nnewi where the daily construction of houses to address the accommodation needs of the teaming population could be seen (Plate 2) which account for the high rate of building collapse in the urban centers.



Plate 2: Daily construction of houses going on at a site.The population of the State in 2006 was 4,182,032 (NPC, 2007) while its 2016 projected figure using the annual urban population growth rate of 5.8% by UN-Habitat (2001) was 4,589,612.

Data Collection

2016 real time data of rainfall and other meteorological variables were collected from Campbell Automated Weather Station at Nnamdi Azikiwe University. Altogether seven atmospheric variables were collected and utilized namely; Electrical Storm, Wind driven rain, Excessive rainfall, Flood depth, Poor drainages, Excessive wind, Total runoff from rainfall. Furthermore,questionnaire were designed and randomly served on the landlords of affected buildings, government officials from the Anambra State Physical Planning Board, Awka Capital TerritoryDevelopment Authority, Anambra State Ministry of Works, Ministry of Housing and Ministry of Lands. Questionnaires were also served randomly on qualified civil engineers and builders in the urban areas of the State between October 2015 and March 2016. From these respondents, we were able to ascertain what they perceive as the reasons for the building collapse in the State and the solution to it.The meteorological variables were labeled, coded and described as shown in Table 1.

Table 1: Meteorological variables and their parametrisation

S/N	Label	Code	Description	Parametrisation
1	E/s	X_1	Electrical storm	Weather observation value
2	w.d.r	X_2	Wind driven rain	Calculated from max rainfall and wind speed
3	Ex.r	X_3	Excessive rainfall	Weather observation value
4	Afd	X_4	Average flood depth	Measured from the flood
5	Poor	X_5	Poor drainage system	Number of areas with poor drainage system
6	ex.w	X_6	Excess wind	Weather observation value
7	Contr.	X_7	Contribution of rainfall to runoff	Calculated from hydrographs

Rainfall and other meteorological data collected from the weather station for each month of 2016 is also presented in Table 2.

Table 2: 2016 Field Data of the Meteorological Variables

Months	E/S (Kv/s)	W.d.r	Ex.r (mm)	Flood depth (m)	No. of Poor Drainages	ex.w m/s	Runoff mm
Jan	1.0	10	78	0.1	10	0.82	0.3
Feb	0.2	25	93	0.4	13	0.74	0.5
March	4.0	84	101	0.8	11	0.80	20
April	3.0	65	820	0.7	20	0.83	900
May	5.0	86	1920	1.5	26	0.82	1220
June	3.0	116	2060	2.2	33	0.89	1420
July	2.0	120	2133	3.2	62	0.84	1580
Aug	1.8	118	2000	2.5	44	0.82	1462
Sept	1.5	133	2107	3.4	43	0.86	1630
Oct.	6.2	124	1930	3.1	28	0.79	1250
Nov.	4.0	73	620	0.6	6	0.76	173
Dec.	1.6	24	52	1.2	1.2	0.81	0.6

Again the statistics of the number of building collapse in Anambra State which was collected from the questionnaire responses of respondents is shown in Table 3.

Table 3: Number of Collapsed Buildings per Month in Anambra State

Month	No of Collapsed Building
January	-
February	-
March	2
April	-
May	1
June	1
July	2
August	-
September	1
October	1
November	-
December	-
Total	8

Source: Fieldwork 2016.

We also gathered from the questionnaire that most respondents identify that rainfall and other meteorological variables are not primary factors but only secondary to the mainline factors because none of them regard them of much importance. These factors are labeled, coded, described and parametised (Table 4).

Table 4: Non Meteorological Factors Resulting to Building Collapse in Anambra State.

S/N	Label	Code	Description/Parametisation
1	Mat	X_1	Inferior maternal (number of sites with inferior materials)
2	Lack	X_2	Lack of approved building plans (No of unapproved building plans)
3	Wet	X_3	Building on wet lands (No of buildings on wetlands)
4	Draw	X_4	Submitted but unchecked structural drawing (No of submitted but unchecked drawings)
5	Poor	X_5	Poor building material specification (No of times builders specify wrong materials)
6	Sup	X_6	Poor supervision (No of sites with poor supervision)
7	Wrong	X_7	Adoption of wrong foundation (No of buildings with wrong foundation)
8	Mix	X_8	Poor concrete mix ratio (No of sites with this problem)
9	Quarks	X_9	Patronizing quacks (No of houses being built by quarks)
10	Chan	X_{10}	Building on flood channel (No of buildings on flood channel)

Field data of the above factors were compiled and presented in Table 5.

Table 5: Field Data of Non Meteorological Factors Resulting in Building Collapse in Anambra State.

Month	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
January	5	3	4	8	3	5	3	2	5	2
February	1	2	4	3	1	1	2	2	4	6
March	2	0	1	2	1	4	0	6	2	4
April	0	1	0	0	3	0	2	1	4	3
May	3	0	2	3	4	1	1	0	2	2
June	1	3	6	1	0	5	2	2	3	8
July	0	2	5	2	2	4	3	2	3	6
August	4	3	4	1	3	2	1	4	5	8
September	3	2	1	4	3	3	3	2	1	6
October	2	3	2	6	2	3	2	4	2	10
November	2	0	1	0	0	3	1	4	3	2
December	3	2	1	2	2	4	1	3	2	0

Data Analysis

The data of both meteorological and non-meteorological factors were subjected to statistical analysis using multiple regressions and bivariate correlation analyses. Our choice of these two techniques were to build a statistical relationship of the independent variables and the dependent variable (number of building collapse in 2016) and to determine the relationship existing between the most important meteorological variable and the number of building collapse in the State in 2016. StatisticalPackage for the Social Sciences (SPSS) version 20 was employed in the calculations. The multiple regression equation is of the form indicated in equation 1 with the number of building collapse as dependent variable Y.

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 \ \ldots b_nx_n + e \qquad (1)$$

The combined strength of the relationship between the independent and dependent variables of the meteorological variables was assessed by their resultant Multiple Regression Coefficient (R) and Coefficient of Multiple Determination (R^2). The contribution of individual variable to the explanation of the variation is given by R^2change which

indicates the number of building collapse that can be explained by linear dependence on 7 meteorological variables operating together. This level of variation has been computed to be 0.184 meaning that 18.4% of the variation in number of building collapse is explained by these meteorological factors leaving 81.6% unexplained which is attributed to other factors. The equation that yielded the result is in equation 2 while the summary of the result of the regression analysis is presented in Table 6.

$$Y = 15.2 + 1.60x_1 + 1.24x_2 + 0.89x_3 + 0.44x_4 + 1.72x_5 + 0.62x_6 + 1.66x_7 + e \qquad (2)$$

Table 6: Result of the Multiple Regression Analysis of Meteorological Variables

Statistics	**Result**
Multiple Correlation (R)	0.429
Co-efficient of Multiple Determination (R^2)	0.184
Standard Error of Estimate (SEE)	0.083

From Table 5, the SEE of our result means that any value estimated from the regression model will have a 95% chance of falling within +/-0.83 of actual value, which reflects that the lower the value of SEE, the more accurate a predictor is the regression equation.Considering this, we can attribute our formulated regression model to be adequate for the explanation of building collapse in Anambra State. To further reveal the contributions of these variables to the explained variation we computed successive values of multiple correlation coefficient obtained by introducing independent variables at each computation $Ry.x_1x_2$, $Ry.x_1x_2x_3$, $Ry.\ x_1x_2x_3\ x_4\ \ldots x_n$. The difference in the square of R^2 may be regarded as the contribution of each variable. The result of the computation of relative contributions of these variables is presented in Table 7.

Table 7: Relative Contributions of the Variables

Variable	Multiple R	R^2 Change	% Explained
X_1	0.233	0.054	5.4
X_2	0.402	0.104	10.4
X_3	0.412	0.010	1.00
X_4	0.420	0.008	0.8
X_5	0.424	0.004	0.4
X_6	0.429	0.005	0.4
	Total	**-**	**18.4**

From Table 6, it could be seen that variable X_2 (wind driven rain) occupies a primate position among other variables with 10.4% or 56.4% in absolute term which is more than half of the contributions of other variables put together. This factor is followed by X_1 (Electrical storm) with 5.4% or 29.0%, as well as, X_3 (Excess Rainfall) with a contribution of 1% or 5.4% in the same absolute scale. Taking together,these three variables contributed 90.8% leaving 9.2% for the rest of the other three variables.

Furthermore another multiple regression analysis was performed on ten non-meteorological factors already parametised (Table 4). The result of the computation show that these 10 variables when regressed with the number of collapsed buildings contributed 79.6% to the number of collapsed buildingsshowing that the number of the buildings that collapsed in the State can beexplained by the 10 variables operating together thus leaving 20.4% unexplained and from which the contributions of

meteorological factors (18.4%) when added to it gives 98.0% leaving 2.0% to be attributed to other factors not included in this analysis.

The equation that yielded these results is written as:

$$Y = 10.2 + 2.1x_1 + 3.2x_2 + 1.4x_3 + 0.8x_4 + 1.5x_5 + 0.9x_6 + 0.7x_7 + 0.1x_8 + 1.8x_9 + 0.22x_6 \quad (3)$$

The summary of the multiple regression analysis of non-meteorological factors was calculated (Table 8).

Table 8: Result of the Multiple Regression Analysis

Statistics	**Result**
Multiple Correlation (R)	0.892
Co-efficient of Multiple Determination (R^2)	0.796
Standard Error of Estimate (SEE)	0.029

The SEE of 0.029 from the equation is an indication of high predictive power of the regression model empolyed in the analyses. The monthly data of the most important meteorological variable X_2(wind driven rain) was correlated with number of collapsed buildings with the aid of Pearson's Product Moment Correlation (PPMC) analytical technique and the calculation gave strong correlation result of 0.710 with the co-efficient of Multiple Determination of 50.4%. To test the significance of this correlation co-efficient we employed a version of student't' test given as

$$r = \frac{\sqrt{n-2}}{\sqrt{1-r^2}} \quad (4)$$

The calculation, gave the value of 3.10 which at 0.05 level of significance with 10 degrees of freedom, is more than the critical value of 't',1.81. Since, the calculated t of 3.10 > 1.81, it means that there is a significant relationship indicating that the association did not in any way occur by chance.

Discussion

The result of various analysis show that meteorological factors which are not regarded as contributing much to the incidence of collapsed buildings by many respondents and authors of the subject contributed 18.4% to the observed variation in Awka. This means that according to Ayoade (2012) we now have buildings that have been erected that are not adapted to the local climates either in terms of their architecture or the building materials used. Although such buildings may look elegant or modern, they were not built to withstand the vagaries of weather elements. Their indoor micro climates are artificially created by the use of fans, air conditioners and air humidifiers at great cost which further weakens the building. There are indeed four aspects of building for which knowledge of climate is invaluable. These are:

i. The planning and design of a building
ii. The actual construction of the building
iii. The maintenance of a building after its construction.
iv. The maintenance of satisfactory and confortable indoor microclimate in a building.

When a building is erected it alters the microclimate of the environment of its location and thus subjected to the climate influences of that environmentwhich they must withstand. Two variables that contribute highly are X_1 (Electrical storm) and X_2 (Wind driving rain) and these impact so negatively on houses built in the tropics. For example electrical storm tear houses into pieces where lightening conductors are not installed as these conductors are desirable to control

electrical problems that emanate from thunderstorms that frequently occur in the tropics. Again the driving rain can be a problem on the building through its splashing activities as a result of wind action. The rain water that rests on the walls as it splashes on it,gets soaked and repeated action weakens the blocks especially if the blocks were not molded with the desired mix. The extent of rain penetration in the buildings especially those under construction in Anambra State can be calculated by taking the maximum rainfall in mm in 5minutes and the wind speed in meters per second at the time of the occurrence of the rain. A water penetration in excess of the desirable penetration limit of 100 had been calculated for some areas in Nigeria (Enedi, 2014, Akiyemi, 2014 and Uzoigwe, 2016).

In Anambra State our calculation on some of the buildings under construction reveal that most of them have a penetration index above the 100 limit. For houses that are completed with occupants, to prevent this, the walls should be painted with good quality paints or they can be fitted with overhangs especially around openings such as windows and doors (Chandler, 1976, Ayoade, 1993, 2004, 2012). Excessive rainfall especially the one with intense characteristics apart from the fact that it is likely to generate wind driven rain, results in high amount of runoff that may erode the foundations of buildings. In Anambra State, all the north-west, west central and south west (Fig. 2) areas of the State indicate they are heavily prone to flood. In this wise, builders in Onitsha and Nnewi urban areas which are located in flood vulnerability areas should take this into serious consideration when building.

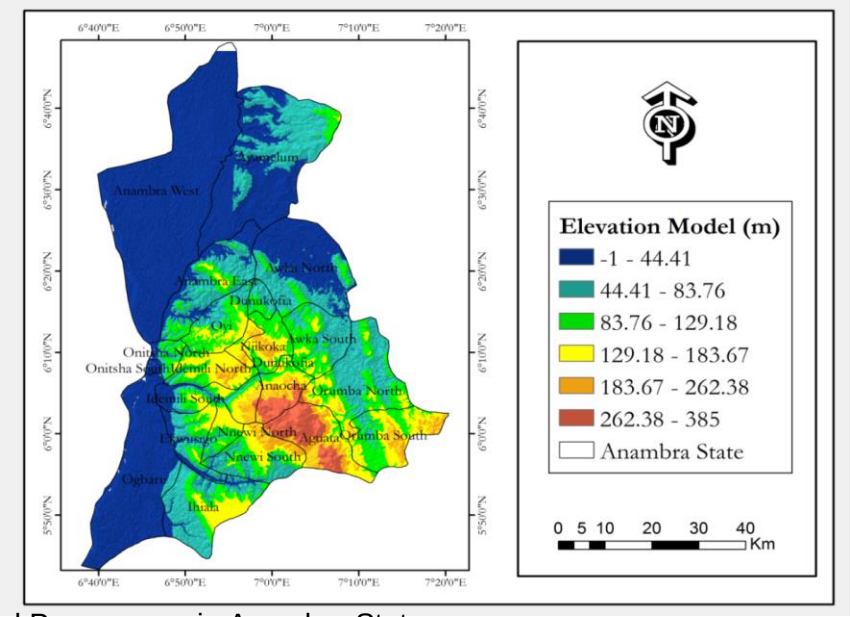


Fig 2: Flood Prone areas in Anambra State

Again excess wind can pull down a building although it contributes a low value in our study, but it could be understood that the pressure exerted by the wind on a building because of the obstruction to it is usually enormous. This pressure is usually proportional primarily to the square of the wind velocity. Onyeodili (2015) in his study of the influence of wind on buildings indicate that some studies show the enormous contribution to the collapse of buildings in Lagos.

Overall, we havefrom the study seen that these meteorological factors indeed contribute to the building collapse in Anambra State contrary to the prevalent belief.

Conclusion

Rainfall and meteorological factors should have important consideration during the design and building of a house. Although we have seen that non meteorological factors contribute much in our study area, but at the same time meteorological factors which have not received any consideration was found to contribute as high as 18.4%. It can be say that some of the buildingsthat collapse might not have had anything to do with some of the often touted reasons such as lack of approved building plan, poor supervision, use of poor building materials but to some of these meteorological factors operating together. This study should be taken as a baseline for more involving and penetrating research in the area.

Recommendations

1. The architects should henceforth design buildings that conform to the meteorology of the tropical environment.
2. Rainfall especially the wind driven rain should specifically be singled out for proper consideration during the design and building in any urban area in Anambra State.
3. Landlords and house owners should install overhangs over openings like windows and doors in their houses, as at time wind driven rain operate without the notice of anybody.
4. The State government should enact a law prohibiting people from building in runoff and flood paths, and to ensure that meteorological factors are considered before approval is given.
5. We need to modify our new architecture to conform to prevalent standards. In this way we should start to erect buildings that will be in tune with the local climates either in terms of architecture or the materials used.

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