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Modeling the Trends and Causal Interaction among Key Selected Microclimatic Elements in Enugu Urban

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Abstract
Backgroung:*The trends of microclimatic elements in urban areas have been monitored over the years by so many researchers. Man, in a bid to modernize his environment, has anthropogenically modified the city microclimate. This study examined the trend and causal interaction among the key microclimatic elements in Enugu Urban from 1971 to 2018.*
Materials and Methods: *The data was obtained from Nigerian Meteorological Agency. Descriptive Time Series Analysis and Pairwise Granger Causality Test Mechanism were employed as analytical techniques.*
Results: *The result shows the skewness and kurtosis of various elements. In the trends, rainfall exhibits a random pattern. The trend of maximum and minimum temperature indicates a smooth distribution. Wind speed pattern shows a random movement and relative humidity also maintains a smooth trend. Also, the trend of sunshine shows a random movement. The study also reveals that there is no directional (or causal) relationship among any pair of the microclimatic elements in Enugu Urban for the period.*
Conclusion: *The evidence of urban heat island is shown in the study, and the study therefore recommends urban forestry and proper urban planning in Enugu Urban. The study also suggests that albedo of surfaces be increased as a good mitigating measure.*
Keywords: *Microclimate; Modeling; Trends; Causal Interaction; Urban Heat Island; Urban Climate.*

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I. Introduction

The trend of urbanization and industrialization has been on the increase since time immemorial. Nigeria cities like the rest of the entire cities in the continent of Africa are rated high on this urbanization process (Enete, 2015). Though urbanization is good in part, but its adverse effects are stupendously large, especially when the urban areas are not well planned. Unfortunately, urban areas, mostly in the developing countries like Nigeria, are planned without weather in mind. This, to a greater extent, has copiously disrupted and modifiedthe microclimate of urban areas, thereby resulting to Urban Heat Island (UHI).The high density of population and economic activity in urban areas leads to intense anthropogenic heat releases within small spatial scales. These include building heating and cooling systems, mass transportation systems and vehicular traffic, and commercial and residential energy use (Blake et al., 2011).

Urban areas are among the most profoundly altered landscapes away from natural ecosystems and processes. It is therefore not surprising that cities have altered microclimates with, among other effects, significantly elevated surface and air temperatures (Blake et al., 2011). The elevation in temperatures is most generally explained in terms of the basic surface energy balance processes of shortwave and longwave radiation exchange, latent, sensible, and conductive heat flows (Oke, 1987). With respect to shortwave, or solar radiation, surface albedo refers to the reflectivity of a surface to visible light and is measured from 0 to 100 percent reflectivity(Blake et al., 2011). The regional albedo of cities is significantly lower than natural surfaces due to the preponderance of dark asphalt roadways, rooftops, and urban canyon light trapping (Blake et al., 2011). These urban features have typical albedo values below 15 percent (Rosenzweig et al., 2006). As a result,this leads to efficient shortwave radiation absorption. The urban skyline, with deep urban canyons, results in a greatly reduced skyview at street level and this impedes longwave radiative cooling processes. This urban vertical geometry further impacts winds, generally reducing ventilation and sensible heat cooling. Also, the replacement of natural soil and vegetation with impervious surfaces leads to greatly reduced evapotranspiration and latent heat cooling (Blake et al., 2011).

Urban Heat Island is the characteristic warmth of urban areas compared to their outskirts (Balogun et al., 2012). It is also often referred to as the increase of air temperature in the near-surface layer of the atmosphere within cities relative to their surrounding countryside (Voogt, 2002). Essence of studies of the UHI are not only predicated on the necessity to gain knowledge of its numerous secondary effects when excessive, but also its practical needs in town planning, prevention of high concentration of air pollution and creation of optimum bioclimatic conditions (Rosenfeld, 1995; Balogun et al., 2010). It was opined that in the urban areas, built-up environment exacerbates heat stress, particularly at night, during heat waves and provides a preferential site for spread of vector borne diseases (Samuels, 2004; Svensson and Tarvainen, 2004).

Balogun et al. in 2012 showedthat the nocturnal heat island was more frequent than the daytime heat island as it exists from less intense to higher intensity categories throughout the study period. Nocturnal heat island intensity was observed to be stronger during the dry season. Although of lower intensity, daytime heat island exists throughout the day except for few hours in the months of November and December that exhibits a reverse thermal contrast. The daytime heat island is observed to be intense in the wet months than the dry months, which may be caused by the evaporative cooling of wet surfaces. On the average, the urban/ rural thermal differences are positive, varying from 4℃ at nocturnal hours during dry months to an approximate of 2℃ around noon during wet months.

Adinna et al. (2009), analyzed the spatial extent of UHI and the applicability of Land SAT/ETM in the study of UHI. It was discovered that land surface temperature positively correlate with concentration of urban structures, population density and human activities. Mostly, UHI trends in urban areas are steeper than in rural areas. The pattern of the obtained UHI intensity values show concentric-like shapes when drawn as isotherms, mostly increase from the suburbs towards the inner urban areas. They also proved the accuracy of the approach, providing insignificant differences between the traditional transect method and satellite techniques. Therefore, the results led to the general conclusion that UHI has a substantial contribution on air temperature parameters in urban areas.

The paper from Enete and Ijioma (2011) provided a new contribution in UHI research in Enugu. They analyzed the temporal and spatial microclimate variations at several sites in Enugu urban using paired measurement programme (PMP). The results indicate that urban climate modifications at day and night were very different. A downtown centred heat island was observed at night in both dry and rainy seasons, while there was a mix of cool and heat islands by day especially during rainy seasons. The daytime variations were strongly correlated to the amount of tree shading. During the night, city climate was highly correlated to sky-view factors and thermal properties in the city.

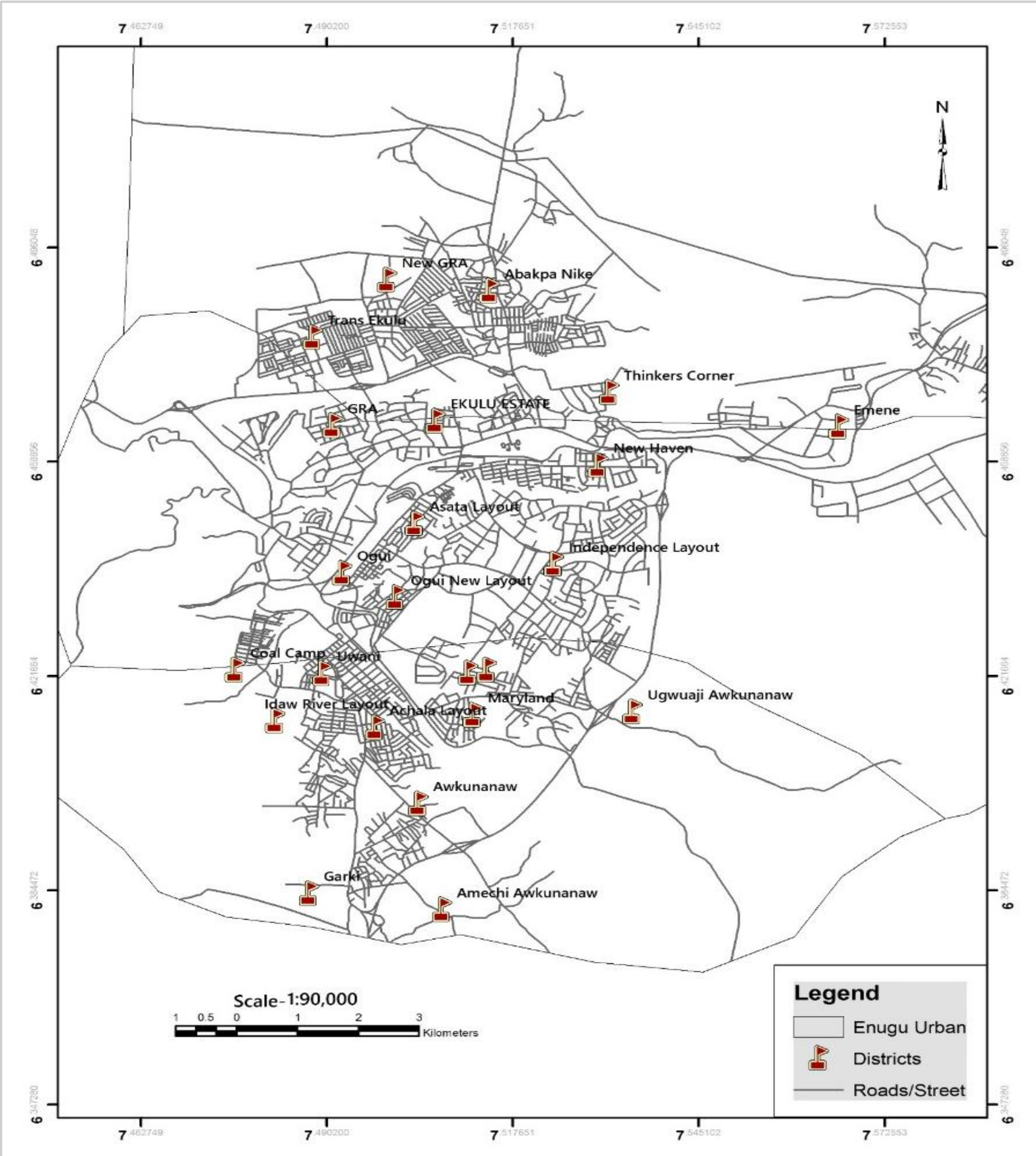
Remote sensing data was applied to map UHI phenomenon in Enugu by Enete and Okwu-Delunzu (2013). The UHI was determined using the land surface temperature (LST) information from thermal infrared band (band6) of landsat image with 120m pixel resolution. A landsat satellite image of October 2008 was used in order to evaluate Normalized Difference Vegetation Index and built-up ratio by cells. Urban impervious areas, highly populated areas, and areas with more anthropogenic activities were recognized to be areas with highest number of UHI-related pixels.

There is a longstanding interest in the question of urban impacts on precipitation both locally and regionally. Early studies by Horton (1921) provided indications that urban centers do play a role in strengthening rainfall activity. Studies by Landsberg (1956) and Stout (1962) discussed the extent to which urbanization may induce and strengthen precipitation. Balling and Brazel (1987),Changnon and Westcott (2002) and Shepherd, Pierce and Negri(2002) have shown evidence that corroborates the earlier findings of enhanced precipitation due to urbanization. However, the hypothesis has been disputed, and even challenged, by other data studies that show no local effect on precipitation (Tayanc and Toros, 1997) or even deficits in precipitation that accompany urbanization (Kaufmann et al., 2007).

The microclimatic studies of tropical regions are still rare and the few works done in Nigeria are mostly on temperature. This paper intends to model the trends and determine the causal interaction among the key selected microclimatic elements in Enugu Urban.

II. Materials and Methods

The Study Area: Enugu urban area is located between latitudes $6^0.21^1$N and $6^0.30^1$N and longitude $7^0.26^1$E and $7^0.37^1$E and covers an area of about 145.8sqkm (Ezenwaji, Awuh and Onwuadiochi, 2018). The map of the study area is shown in (Fig. 1).



Source: Researchers' work

Fig. 1: Map of Enugu Urban

Enugu urban is made up of layouts and these include GRA, Trans-Ekulu, Ogui, Asata, Coal Camp, Uwani, Independence Layout, Achara Layout, New Haven, Emene and Iva Valley. The 2006 National Census recorded the population of Enugu urban as 770,000persons (NPC, 2006). Its 2016 projection, ten years after, was 920,000, while the current population 2018 (end of August) is projected at 1,010,000 ((Ezenwaji, Awuh and Onwuadiochi, 2018).

Under relief, its topography is divided into the escarpment and lowland zones. The geology of the urban area is dominated by two formations namely; the lower coal measure (Mamu formation) and false Bedded sandstone (Ajalli formation) (Ezenwaji et al., 2018; Ezenwaji et al., 2019). The climate is categorized as wet and dry according to the Koppen's climate classification system. This system is characterized by marked wet and dry seasons. Annual Rainfall is usually about 1700mm but can be as high as 2000mm, while daily temperature all through the year is usually high between 28^0C and 33^0C. The high temperature of 33^0C or more are experienced in dry season around the month of March.

The entire urban area is drained by three principal rivers namely Asata which is a tributary of Ekulu, while Ekulu empties unto river Nyaba in the southern areas of the town. All the rivers have their sources in the escarpment east of the town, and flows eastwards in the Cross-River Basin. The vegetation is mainly the Guinea Savanna, which was derived from the original tropical rainforest vegetation of the area that was destroyed as a result of urbanization and other anthropogenic activities, leaving outliers of forest in some localities, especially as deity forest in the traditional home areas of Nike people.

Data Collection: The data needed for this study were rainfall, maximum temperature, minimum temperature, wind speed, relative humidity and sunshine data recorded at AkanuIbiam International Airport, Enugu, Enugu State, from 1971 to 2018. The study predominantly relied on secondary sources. The data was obtained from the Nigerian Meteorological Agency (NIMET).
Data Analysis: Analytical techniques employed in achieving the research target include Descriptive Time Series Analysis (trends) and Pairwise Granger Causality Test Mechanism. The statistical packages employed include SPSS 25.0,MINITAB 14and Eviews 10 statistical package.

The trend equation is specified thus:

$$y_t = \alpha + b * t \qquad (Eq. 1)$$

Where,

$y_t \text{ is the value of } y \text{ at time } t$

$a \text{ is the intercept/constant}$

$b \text{ is the slope or gradient of the equation}$

$t \text{ is time invariant}$

Meanwhile, the Granger (1969) mechanism for causal or directional relationship between two variables is specified thus:

$$y_t = \sum_{i=1}^{k} \alpha_1 y_{t-1} + \sum_{j=1}^{p} \beta_1 \mu_{t-1} + \varepsilon_t (\text{Eq. 2})$$

y = the variable whose causation is being appraised
y_{t-1} = lagged values of the variable.
Explicitly for this study, we have that:

$$\text{LRAINFALL}_t = \alpha_0 + \beta_{1i} \sum_{i=1}^{k} LTMax_{t-i} + \delta_{1i} \sum_{i=1}^{k} LTMin_{t-i} + \pi_{1i} \sum_{i=1}^{k} LWIND_{t-i} + \theta_{1i} \sum_{i=1}^{k} LRH_{t-i} + \gamma_{1i} \sum_{i=1}^{k} LSUNSHINE_{t-i} + \mu_t (\text{Eq. 3})$$

$$LTMax_t = \varphi_0 + \beta_{2i} \sum_{i=1}^{k} \text{LRAINFALL}_{t-i} + \delta_{2i} \sum_{i=1}^{k} LTMin_{t-i} + \pi_{2i} \sum_{i=1}^{k} LWIND_{t-i} + \theta_{2i} \sum_{i=1}^{k} LRH_{t-i} + \gamma_{2i} \sum_{i=1}^{k} LSUNSHINE_{t-i} + \mu_t (\text{Eq. 4})$$

$$LTMin_t = \varphi_0 + \beta_{3i} \sum_{i=1}^{k} \text{LRAINFALL}_{t-i} + \delta_{3i} \sum_{i=1}^{k} LTMax_{t-i} + \pi_{3i} \sum_{i=1}^{k} LWIND_{t-i} + \theta_{3i} \sum_{i=1}^{k} LRH_{t-i} + \gamma_{3i} \sum_{i=1}^{k} LSUNSHINE_{t-i} + \mu_t (\text{Eq. 5})$$

$$LWIND_t = \varphi_0 + \beta_{4i} \sum_{i=1}^{k} \text{LRAINFALL}_{t-i} + \delta_{14} \sum_{i=1}^{k} LTMax_{t-i} + \pi_{4i} \sum_{i=1}^{k} LMin_{t-i} + \theta_{4i} \sum_{i=1}^{k} LRH_{t-i} + \gamma_{4i} \sum_{i=1}^{k} LSUNSHINE_{t-i} + \mu_t (\text{Eq. 6})$$

$$LTRH_t = \varphi_0 + \beta_{5i}\sum_{i=1}^{k} \text{LRAINFALL}_{t-i} + \delta_{5i}\sum_{i=1}^{k} LTMax_{t-i} + \pi_{5i}\sum_{i=1}^{k} LMin_{t-i} + \theta_{5i}\sum_{i=1}^{k} LWIND_{t-i} + \gamma_{5i}\sum_{i=1}^{k} LSUNSHINE_{t-i} + \mu_t (\text{Eq. } 7)$$

$$LSUNSHINE_t = \varphi_0 + \beta_{6i}\sum_{i=1}^{k} \text{LRAINFALL}_{t-i} + \delta_{6i}\sum_{i=1}^{k} LTMax_{t-i} + \pi_{6i}\sum_{i=1}^{k} LMin_{t-i} + \theta_{6i}\sum_{i=1}^{k} LWIND_{t-i} + \gamma_{6i}\sum_{i=1}^{k} LRH_{t-i} + \mu_t (\text{Eq. } 8)$$

μ_t = Error estimate associated with the model.
L = Log-transformational operator.
$\alpha_i, \varphi_0, \gamma_i, \tau_i, \beta_i, \theta_i$, and δ_i are the model parameters

The lag length is determined automatically by the modified Akaike Information Criterion (AIC).

[

III. Results and Discussion

Table 1: Description of Study Variables

Microclimatic factors	Min	Max	Mean	Std.	Skewness	Kurtosis
Rainfall	760.09	2070.10	1520.0640	270.98443	-.417	.326
Maximum Temperature	290.08	330.87	320.0027	.71717	-1.222	5.678
Minimum Temperature	.00	24O.45	21O.4987	40.55801	-4.641	20.737
Wind Speed	2.70	6.90	5.0875	1.04365	-.799	-.344
Relative Humidity	.00	63.00	56.1250	8.60387	-6.137	40.600
Sunshine	5.10	5.80	5.4083	.15551	.033	-.030

The result in table 1 above describes the data series used in the study. From the result, series of sunshine is skewed to the right while those of rainfall, temperature (maximum and minimum), wind speed, and relative humidity are skewed to the left. There is excess kurtosis in series of maximum temperature, minimum temperature, and relative humidity, indicating significant deviations from the central estimate.

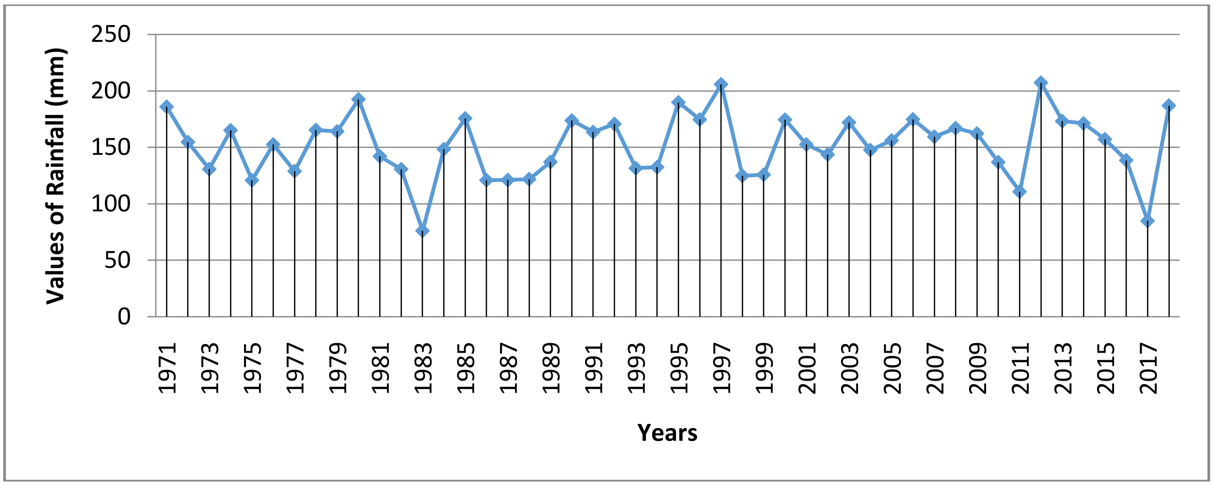


Fig. 1: Pattern of Rainfall for the Study Period

From the descriptive presentation of pattern of annual rainfall distribution within the period, it is observed that rainfall in Enugu urban exhibits a random pattern. Particularly, between 2012 and 2017, there was a steady drop in rainfall (from 2070.103mm to 840.834mm). This rises to 1860.844mm. The 95 percent confidence interval lies between 1430.521mm – 1600.099mm.

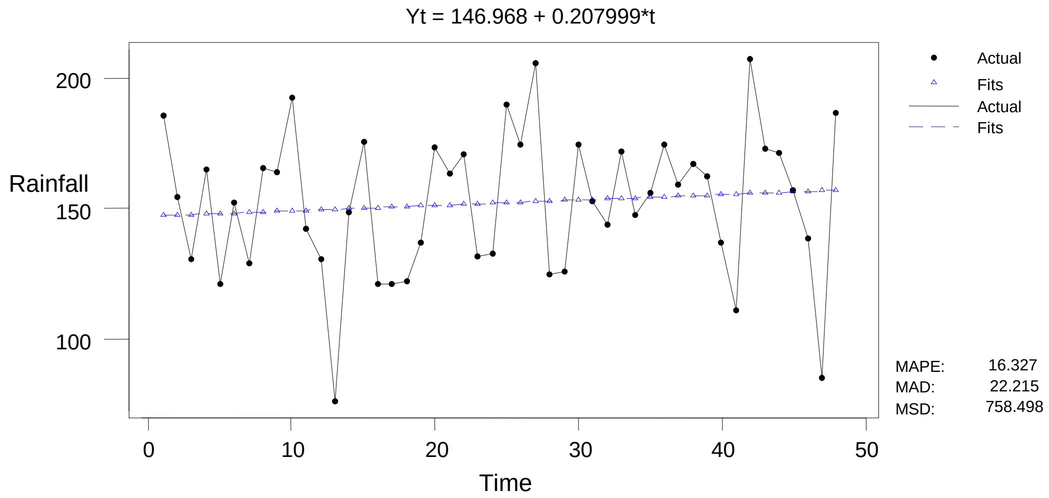


Fig. 2: Trend Analysis for Rainfall

The trend graph indicates a random movement in pattern of rainfall in the area. From the trend equation, the constant volume of rainfall for the study period is 145.998mm with a varying coefficient of 0.242mm. This indicates that at a particular time period, the volume of rainfall either increases or decreases by 0.242mm. The efficiency of the estimate was measured using the MAPE, MAD, and MSD. The mean absolute percentage error (MAPE) is 16mm; mean absolute deviation was 22mm, while the mean standard deviation was 769mm. This indicates uncertainty in prediction of rainfall in the area.

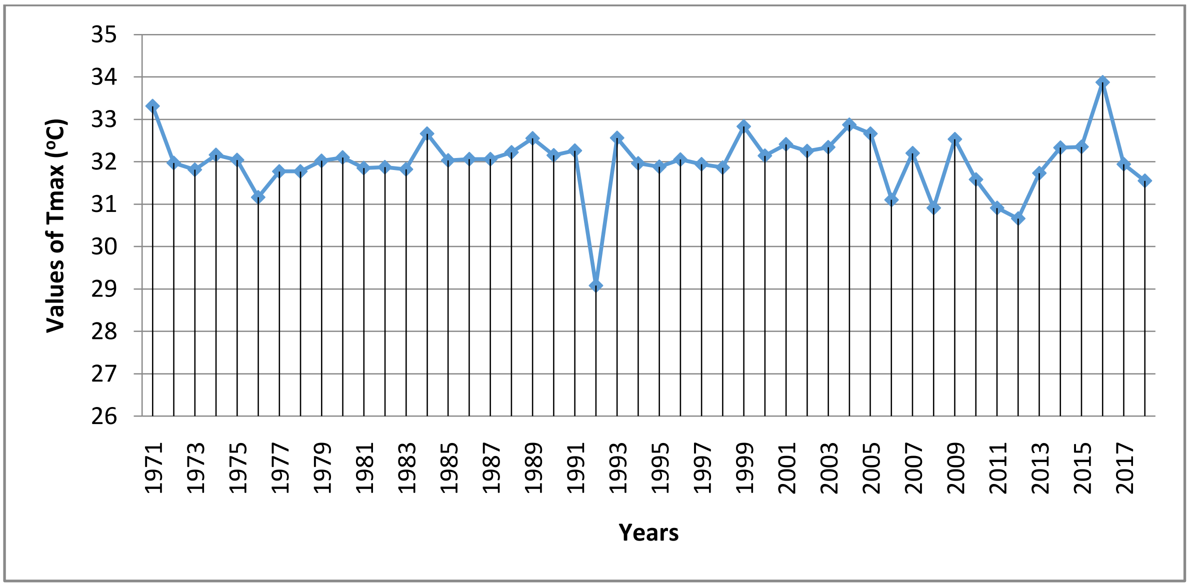


Fig. 3: Pattern of TMax (^{o}C) for the Study Period

The trend (pattern) of maximum temperature as shown in figure 3 indicates a smooth distribution in the area. From the result, the maximum temperature of the area oscillates between 29.08^{o}C and 33.87^{o}C. The minimum value was observed in the year 1992, while the maximum value was seen in the year 2015.

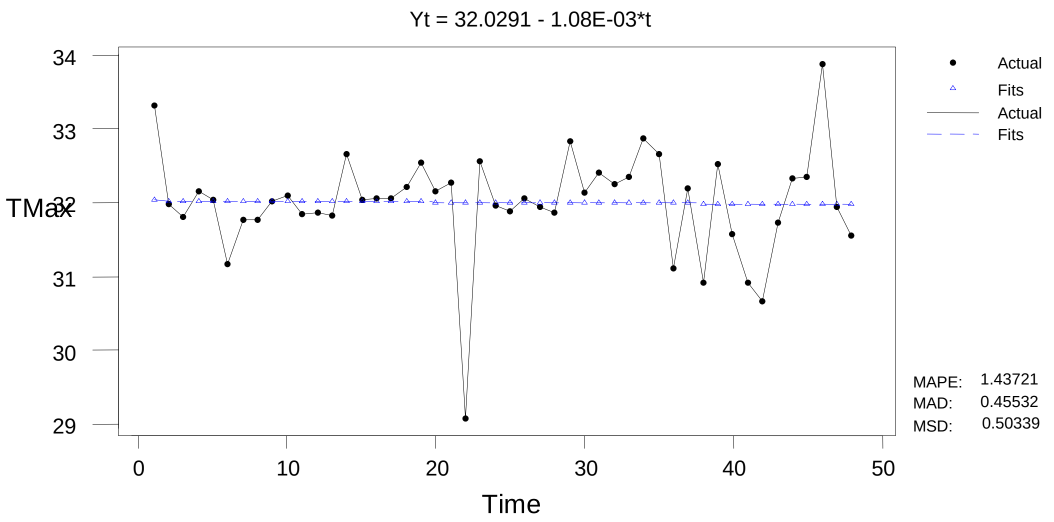


Fig. 4: Trend Analysis for TMax

The trend result shows that the maximum temperature is more or less detrending. This is evidenced by the negative slope of the trend equation. Particularly, the maximum temperature lies within 32^{o}C for the period under review.

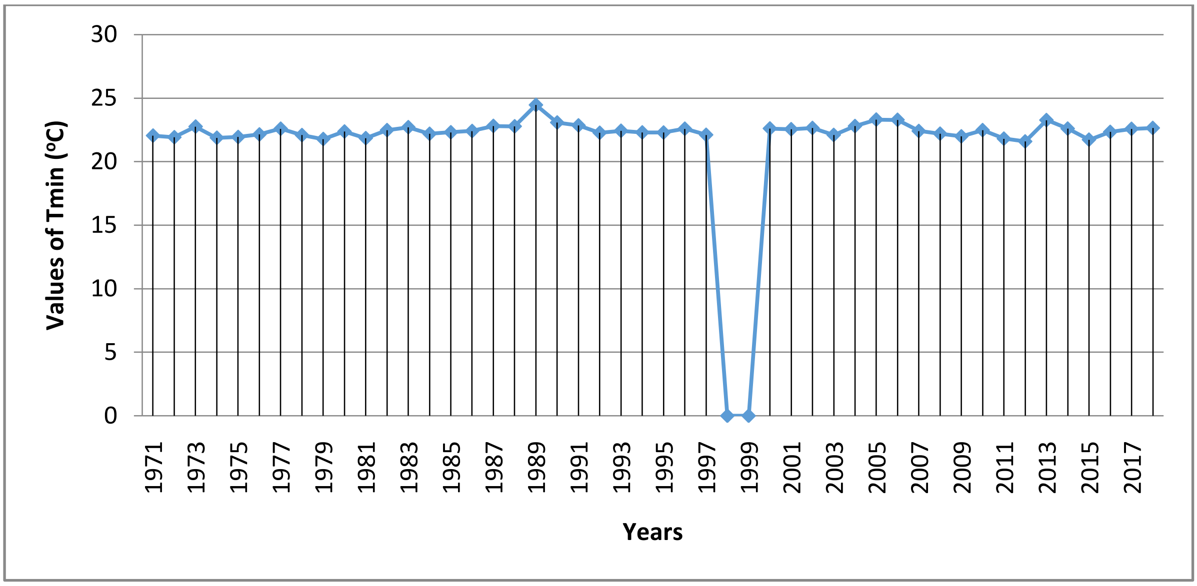


Fig. 5: Pattern of TMin (^{o}C) for the Study Period

The trend (pattern) of minimum temperature in Enugu Urban for the study period is as shown in figure 5. The result indicates a smooth distribution of minimum temperature in the area. From the result, the value of minimum temperature in the year 1998 and 1999 was zero as no record was traced by the agency. The least (or minimum) value was observed in the year 1992, while the maximum value was observed in the year 2015.

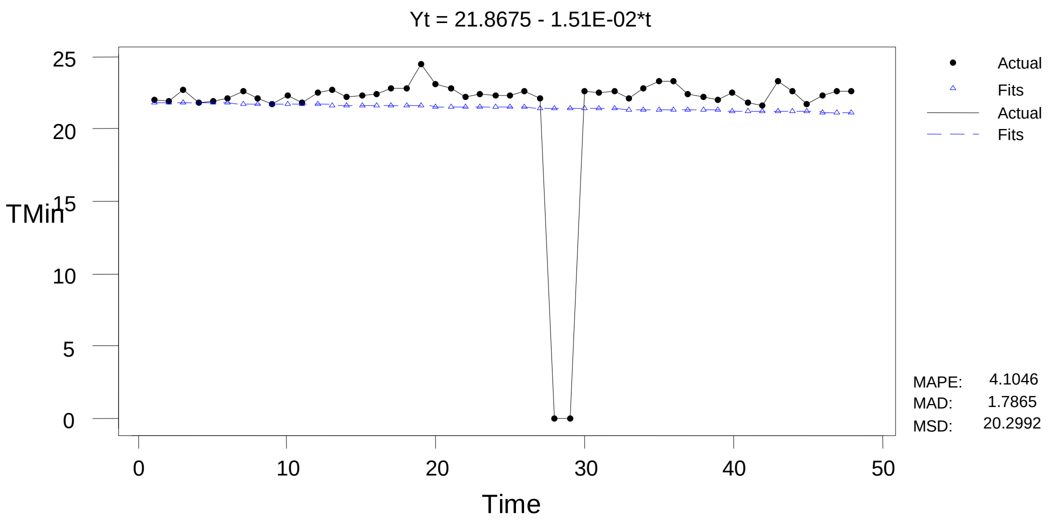


Fig. 6: Trend Analysis using for TMin

The trend equation in figure 6 shows that the constant minimum temperature is 22^{o}C with a constant of variation of 0.0151^{o}C. This indicates a close variation in the series of minimum temperature within the period in the study area. However, at every increase in time period, the minimum temperature increases by 0.0151^{o}C.

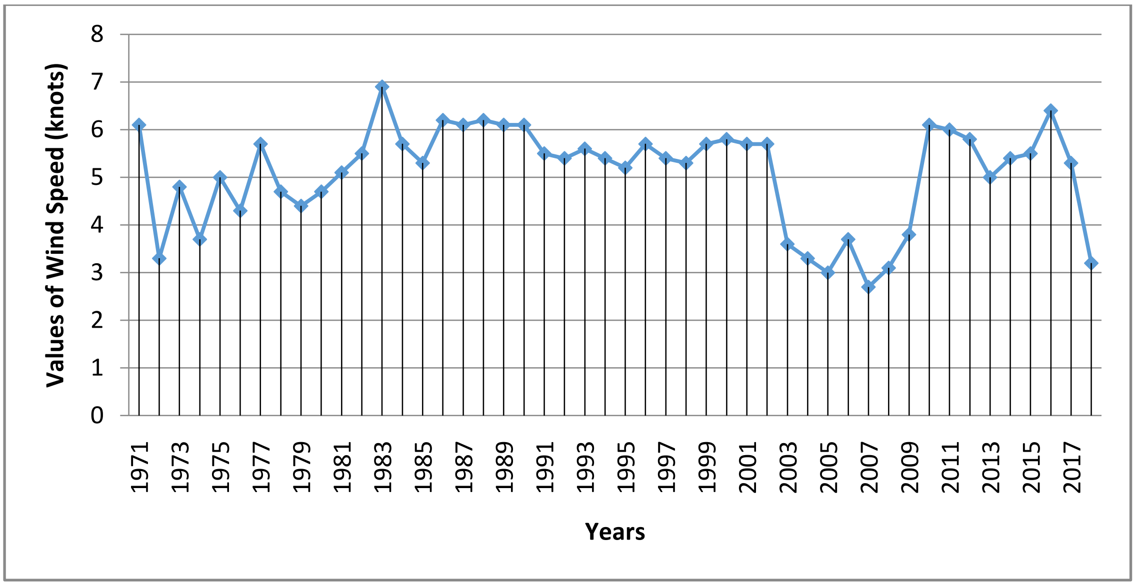


Fig. 7: Pattern of Wind Speed (knots) for the Study Period

The graphical representation shows a random movement in pattern of wind speed for the period. Particularly, there was a serious drop between 2003 and 2007. This rises in 2008 to 2010 and falls steadily from 2011 to 2013. It goes up again in 2014, 2015, 2016, and 2017; then dropped in 2017 and 2018. This shows that the pattern of wind speed in Enugu Urban cannot be predicted with certainty.

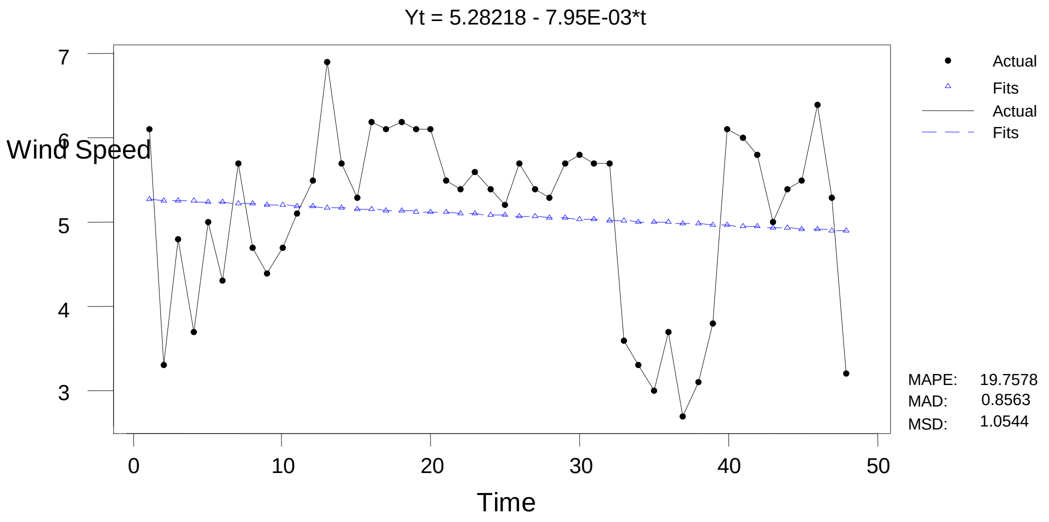


Fig. 8: Trend Analysis for Wind Speed

The trend result shows that the series of wind speed in Enugu Urban exhibit a detrending random movement (or trend) over the period. The result shows that at every unit increase in time, the wind speed decreases by about 0.00795knots.

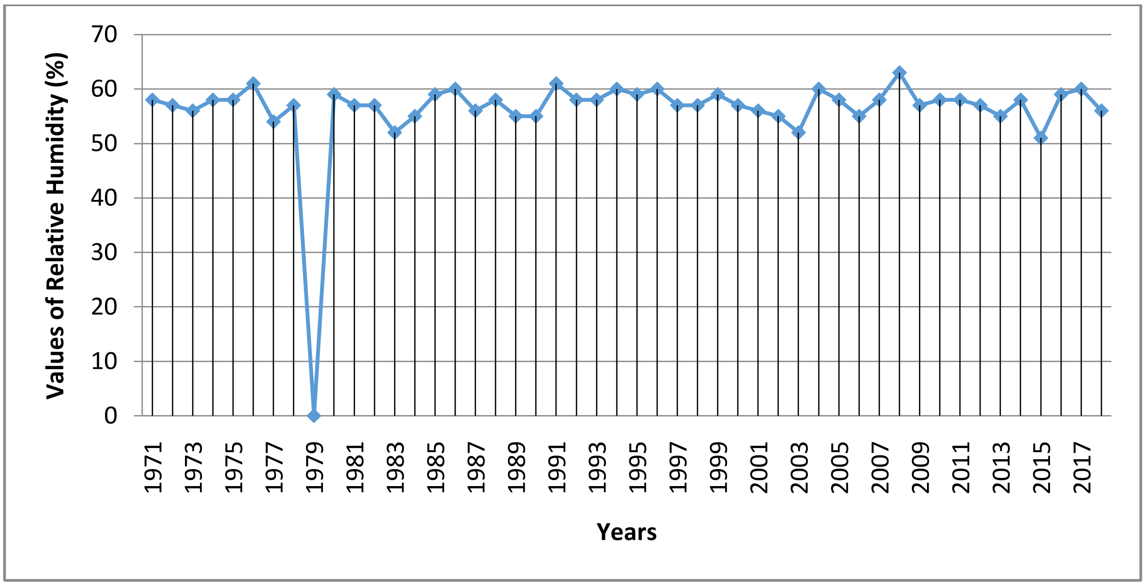


Fig. 9: Pattern of Relative Humidity (%) for the study period

The graphical representation of relative humidity in Enugu Urban for the period of 1971 to 2018 maintained a smooth trend except in 1979 where there was no record of the relative humidity by the agency. However, the relative humidity lies between 50 to 60 percent for the period under review.

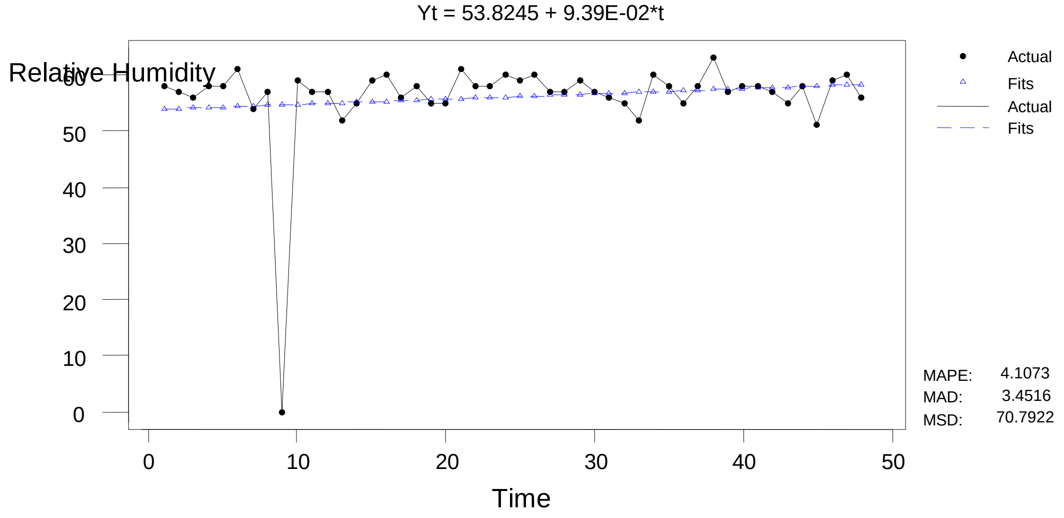


Fig. 10: Trend Analysis for Relative Humidity

The trend graph shows accelerating pattern in series of relative humidity for the period of review. From the result, a unit increase in time will lead to about 9.39 percent increases (or decrease) in relative humidity with a constant value of 53.8%. This indicates that relative humidity in Enugu Urban is more or less stable within the study period.

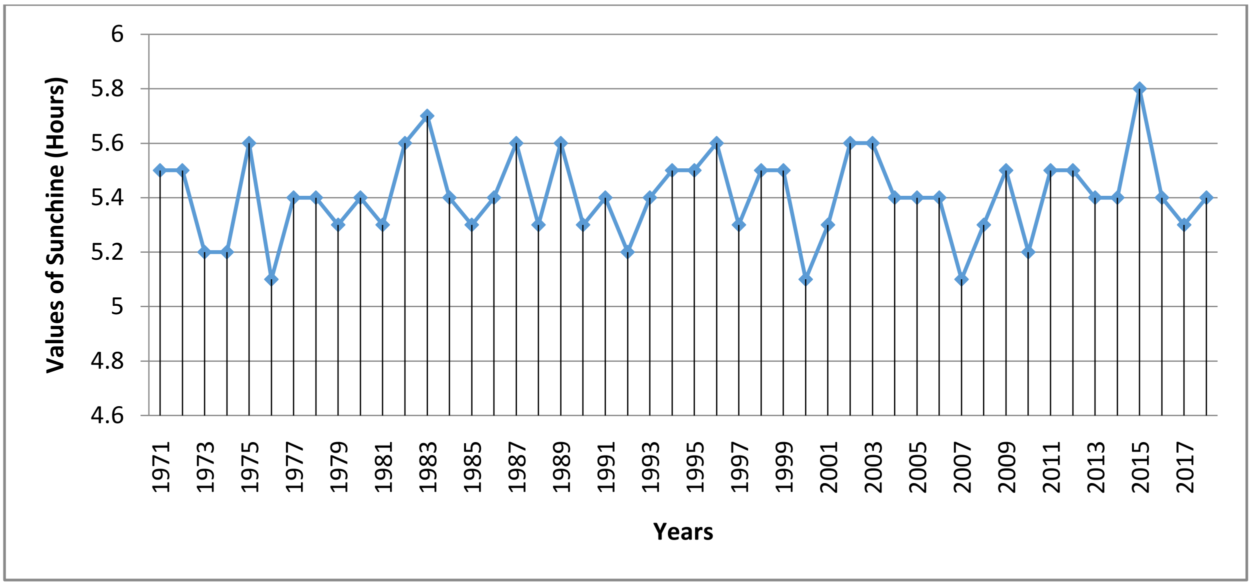


Fig. 11: Pattern of Sunshine (Hours) for the study period

The descriptive trend result of sunshine in Enugu Urban from 1971 to 2018 shows a random (rise and fall) movement. This movement indicates a wide variation within the period. However, there is high level of unpredictability of the series in the area.

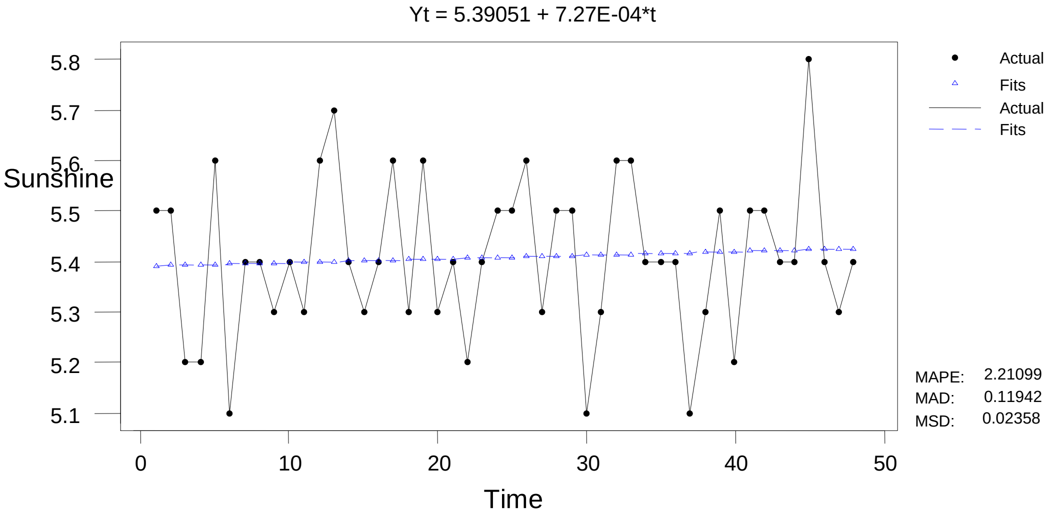


Fig. 12: Trend Analysis for Sunshine

The trend representation above shows that the series of sunshine maintained appreciative random movement over the period. From the trend equation, the constant value of sunshine is 5.4hours with a slope of 0.000727hours, indicating insignificant variation between years.

Table 2: Granger Causality Test Result

Pairwise Granger Causality Tests
Sample: 1971-2018
Lags: 2

Null Hypothesis:	Obs	F-Statistic	Prob.
LTMAX does not Granger Cause LRAINFALL	46	0.26430	0.7690
LRAINFALL does not Granger Cause LTMAX		0.04858	0.9526
LTMIN does not Granger Cause LRAINFALL	42	1.32933	0.2770
LRAINFALL does not Granger Cause LTMIN		0.93575	0.4014
LRH does not Granger Cause LRAINFALL	43	0.51208	0.6033
LRAINFALL does not Granger Cause LRH		0.63933	0.5332
LWIND does not Granger Cause LRAINFALL	46	0.47122	0.6276
LRAINFALL does not Granger Cause LWIND		1.30409	0.2824
LSUNSHINE does not Granger Cause LRAINFALL	46	0.64167	0.5316
LRAINFALL does not Granger Cause LSUNSHINE		0.04986	0.9514
LTMIN does not Granger Cause LTMAX	42	0.00976	0.9903
LTMAX does not Granger Cause LTMIN		0.54000	0.5873
LRH does not Granger Cause LTMAX	43	5.00778	0.0117
LTMAX does not Granger Cause LRH		0.48061	0.6221
LWIND does not Granger Cause LTMAX	46	0.13951	0.8702
LTMAX does not Granger Cause LWIND		1.15741	0.3244
LSUNSHINE does not Granger Cause LTMAX	46	2.23889	0.1194
LTMAX does not Granger Cause LSUNSHINE		0.11335	0.8931

LRH does not Granger Cause LTMIN	39	0.02694	0.9734
LTMIN does not Granger Cause LRH		0.97420	0.3878
LWIND does not Granger Cause LTMIN	42	2.31853	0.1126
LTMIN does not Granger Cause LWIND		1.12869	0.3343
LSUNSHINE does not Granger Cause LTMIN	42	2.74518	0.0773
LTMIN does not Granger Cause LSUNSHINE		0.36768	0.6948
LWIND does not Granger Cause LRH	43	0.84496	0.4375
LRH does not Granger Cause LWIND		2.20103	0.1246
LSUNSHINE does not Granger Cause LRH	43	0.28737	0.7518
LRH does not Granger Cause LSUNSHINE		0.26749	0.7667
LSUNSHINE does not Granger Cause LWIND	46	0.43915	0.6476
LWIND does not Granger Cause LSUNSHINE		2.23855	0.1195

Source: Authors' Eviews 10 output

As shown in the pairwise granger causality test result, there is no directional (or causal) relationship among any pair of the microclimatic elements in Enugu Urban for the period. The implication is that, changes in one of the microclimatic elements are independent of changes in another.

IV. Conclusion/Recommendation

This study has modeled the trends and causal interaction of the key selected microclimatic elements in Enugu Urban. The microclimatic parameters showed some random movements in trends.This mean annual maximum temperature 32.0^0C has explained why Enugu Urban is warmer and hotter than its surrounding rural counterparts such as Nkanu, Awgu, Aninri, Udi, Ezeagu and Neke. This explanation is simply a characteristic of urban heat island.The gradual and random changes in the city microclimate are as a result of rapid changes in the city morphology, limited trees as well as chlorofluorocarbons and other gasses and pollutants emanating from the industries, car exhausts and abattoirs. The study also reveals that there is no directional (or causal) relationship among any pair of the microclimatic elements in Enugu Urban for the period.The study therefore, recommends tree planting and proper urban planning in the study area. It also suggests increasing the albedo of surfaces as a good mitigating measure.

Increasing the albedo of surfaces such as roofs and pavements and urban forestry will drastically reduce the cooling energy use in buildings and lower the ambient air temperature through evapotranspiration. Vegetation covers reduce cooling energy demand by blocking the sun's radiation. In the work ofEnete and Ogbonna (2018), it was opined that another adaptation and mitigation strategy is building institutional capacity. This entails;

- Improve capacity of institutions to develop, regulate, enable and sustain strategies and policies targeted at

(a) Improving building design and performance
(b) Improving energy efficiency of appliance and equipment
(c) Reducing Green House Gas (GHG) emissions and
(d) Encourage energy saving and green behavior among city residents. Providing appropriate services and infrastructure.

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