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Full Length Research Article

THE TRENDS IN TEMPERATURE AND SOLAR IRRADIANCE FOR ZARIA, NORTH WESTERN, NIGERIA, BETWEEN 1986 AND 2015

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ABSTRACT
This work presents a statistical analysis of the trends in temperature and solar irradiance for Zaria between 1986 and 2015, using average temperature and solar irradiance data. Analysis showed that the average monthly temperature of the first decade was hotter than that of the second decade by 1.20.% and the third decade was hotter than that of the second by 3.22%, and an increase of 2.05% in the average monthly temperature was observed between first and the third decade. The average minimum temperature of the second decade was observed to be higher than that of the first decade by 0.80% and the third decade had an increase of 1.07% over the second decade; hence, a difference of 1.87% was observed between the first decade and the third decade. Furthermore, the solar irradiance of the second decade was observed to increase by 25.69% over the first decade, while that of the third decade was observed to reduce by 17.81% over the second decade. A difference of the solar irradiance of 12.45% was observed between the first and the third decade. It was also observed that the years; 2003, 2009, 2010 and 2013 had the highest maximum annual temperature; while the years: 1993, 2006, 2009, 2010 and 2015 had highest minimum temperature. The result of the analysis shows that Zaria is gradually getting warm and the temperature rise is connected to the solar irradiance in line with the general global trend thereby leading to the global warming concept.

Keywords: Trend, Temperature, Solar Irradiance, Zaria

INTRODUCTION
The study of the rates of climatic change and their impact on the environment and society is important and essential to predicting global and regional climatic variations and to determining the extent of human influence on the climate (Oguntunde *et al*. 2006). The increase in the global mean temperature by 0.7^{o}C within the last century, is a clear evidence of a rapid global climatic change, and a cause of concern especially, for climate scientists. Karl *et al*. (1993) analysed temperature data from 37% of global land mass and found high increment in the minimum compared to the maximum temperature. This is significant, as it explains the increase in rainfall intensities and the flood increase around the globe (Oriola *et al*, 1994).

The climate of a location can be understood most easily in terms of annual or seasonal averages of temperature and precipitation (Salami and Okeola, 2012). This paper seeks to analyse the temperature trends and solar irradiance in Zaria between 1986 to 2015, using the average monthly temperature data of Zaria, sourced from the Nigerian Meteorological Agency (NIMET) Zaria; to observe whether or not there exists any significant rate of change (or change pattern) between these years, enough to predict future climate variations; and to alert any cause for alarm.

The Study Area
Zaria is a local government in Kaduna State, situated in the center of Northern Nigeria about 900km from the Atlantic, and about 660m above sea level (Figure 1). It lies within the tropical wet/dry climatic zone and is characterized by a strong seasonality in rainfall and temperature distribution (Umar, 2012). This seasonality in rainfall distribution is caused by the oscillation of two air masses: the tropical maritime air mass (mTs) and the tropical continental air mass (cTs). When the mTs is prevailing over the study area, the area experiences the rainy season, while the cTs ushers in the dry season with its cool and dusty nature which occasionally limits visibility and reduces radiation from the sun (Umar, 2012)

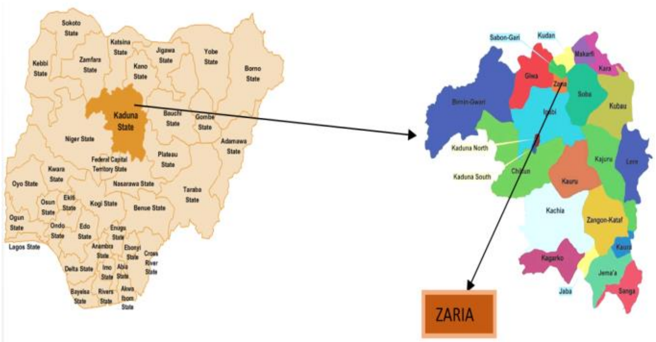


Figure 1: Maps Showing the Location of Kaduna State in Nigeria and the Location of Zaria in Kaduna State.

MATERIALS AND METHODS
Maximum and minimum air temperature data and the solar radiation data were obtained from the Nigerian Meteorological Agency (NIMET) Zaria, for the period (1986-2015). These air temperatures were measured using the maximum and the minimum CASELLA LONDON model thermometers which has a minima range of – 50^{o}C to + 30^{o}C and a maxima range from -30^{o}C to +50^{o}C (Figure 2). The thermometer for measuring the

maximum temperature, uses mercury as its thermometric substance, which has a convex surface or meniscus that pushes along a small piece of steel called an index, when the temperature rises, the mercury expands and when the temperature falls, the index stays in position (Amit, 1966). Therefore, the maximum temperature is observed to correspond to the lower or left side of the index at the end of the day. This index can be reset by tilting the thermometer or by using a small magnet. The thermometer for measuring the minimum temperature on the other hand, uses alcohol as its thermometric substance, which has a concave meniscus and an index below the meniscus (John, 1989). When the temperature falls, the index is pulled down the meniscus; when the temperature rises, the alcohol expands past the index, which stays in position; so that at the end of the day, the minimum temperature corresponds to the upper or right side of the index (Landis, 2009).

Figure 2: A Typical Outdoor Minima-Maxima Thermometer

Principle of Operation

The ideal gas law states that

$$PV = NK_BT \qquad (1)$$

Where
P is the pressure, V is the volume, N is the number of molecules, K_B is the Boltzmann's constant, and T is the temperature.

Hence,

$$\left(\frac{F}{A}\right)V = NK_BT \qquad (2)$$

$$\left(\frac{F}{A}\right)A.S = NK_BT \qquad (3)$$

$$F.S = NK_BT \qquad (4)$$

$$(m.a).S = NK_BT \qquad (5)$$

$$\left(m.\frac{v}{t}\right).S = NK_BT \qquad (6)$$

$$(m.v).\frac{s}{t} = NK_BT \qquad (7)$$

$$(m.v).v = NK_BT \qquad (8)$$

$$\frac{1}{2}mv^2 = \frac{1}{2}NK_BT \qquad (9)$$

$$\boldsymbol{K.E} \propto \boldsymbol{T} \qquad (10)$$

Where, *F* is the force, *A* is the area, *m* is the mass, *s* is the distance, *v* is the velocity and *K.E* is the kinetic energy.
Hence, when the temperature increases the thermometric substance gains Kinetic energy and expands. In a similar way it loses kinetic energy and contracts when there is a fall in temperature.
The Solar Irradiance which is the measure of the solar energy or the amount of work done by the sun's rays, on the other hand, was measured using the Gunn Bellani Solarimeter, which uses the principles of radiation, evaporation and condensation. The instrument is usually kept in an air tight glass case which contains water which when exposed to the rays of the sun via the glass, the rays causes the water to evaporate, and the vapour is collected at the upper chamber and condensed back to water (distilled water). The amount or quantity of the condensed water measures the energy of the sun in millilitres (ml) or Watts per meter square (W/m^2). Hence, the solar irradiance of the day (Akinyosoye *et al*, 2006)
Furthermore, the annual temperature values were computed from the monthly rainfall amount using equation (11)

$$A_T = \frac{1}{12}\sum_{i=1}^{12} T_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Where A_T is the amount of annual temperature at the station, and T_i is the amount of monthly temperature for the months of the year.
The mean monthly temperature amount for the thirty-one period (1986-2015) was computed using equation (12)

$$\overline{TT_j} = \frac{\sum_{j=1}^{30} T_j}{30} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (12)$$

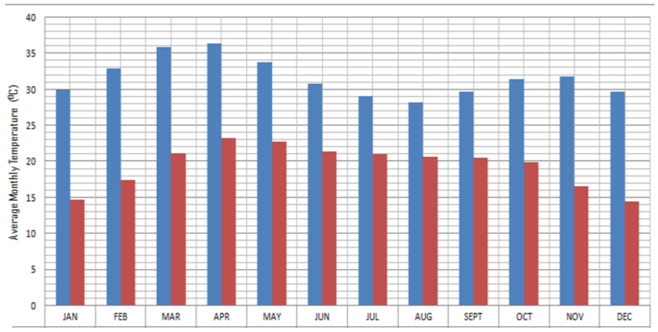
Where $\overline{TT_j}$ is the mean monthly temperature amount for the period (1986-2015)
The standardized values were calculated for all the years from the use of the long-term mean, the year mean, and the standard deviation using equation (13)

$$\boldsymbol{\varphi} = \frac{x-\bar{x}}{\sigma} \ldots\ldots\ldots\ldots . \ldots\ldots\ldots\ldots\ldots\ldots (13)$$

Where $\boldsymbol{\varphi}$ represents the standardized departure, x is the actual value of air temperature, $\bar{x}$ is the long term mean value of the air temperature, and σ is standard deviation.
Confidence test was performed on the data set used and it was verified using 95% confidence interval. Coefficients of skewness, kurtosis and variation were also investigated.

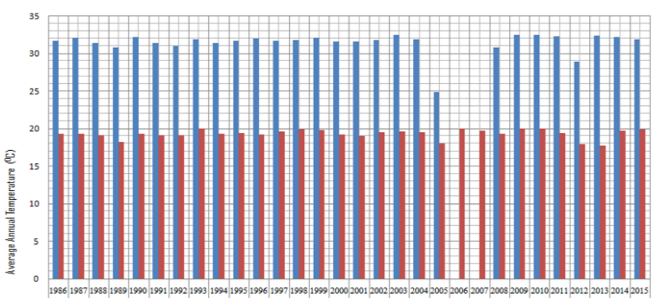
RESULTS AND DISCUSSION

Analysis of the monthly mean air temperature over Zaria from 1986-2015, shows an increase during the months of January to April, a drop in temperature from May down to September, and increase in temperature in October to November and a drop in temperature in December (Figure 3). Figure 4, clearly shows the average annual maximum and minimum air temperature over Zaria for the three decades with the last decade showing a slight increase on the average. The highest maximum temperature obtained in the three decade period was 36.34°C and the lowest minimum temperature obtained was 14.45°C. Also, an increase in air temperature values in Zaria were observed to be higher during the dry season as compared to the wet season. This variation in temperature could be attributed to the equator ward incursion of mid-latitude systems, with alternating cool and warm air masses (Adefolalu and Amici, 2006).



Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
MAX	29.93	32.93	35.86	36.34	33.84	30.86	29.01	28.26	29.73	31.41	31.79	29.67
MIN	14.64	17.37	21.07	23.28	22.72	21.39	20.99	20.64	20.50	19.90	16.57	14.45

Figure 3: Average Monthly Maximum and Minimum Air Temperature over Zaria from 1986-2015

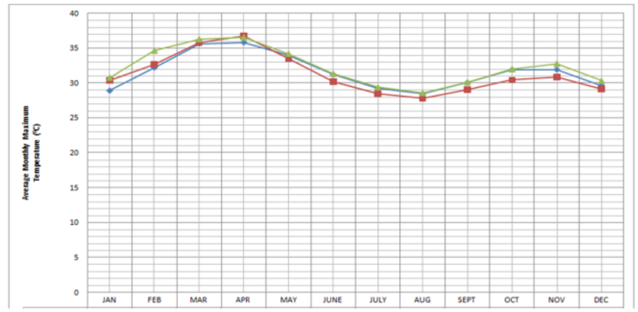


	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
MAX	31.	32.	31.	30.	32.	31.	31.	32	31.	31.	32.	31.	31.	32.	31.
MIN	19.	19.	19.	18.	19.	19.	19.	20	19.	19.	19.	19.	19.	19.	19.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
MAX	31.	31.	32.	32	24.	[illegible]	[illegible]	30.	32.	32.	32.	29	32.	32.	32
MIN	19	19.	19.	19.	18	20	19.	19.	20	20.	19.	17.	17.	19.	20

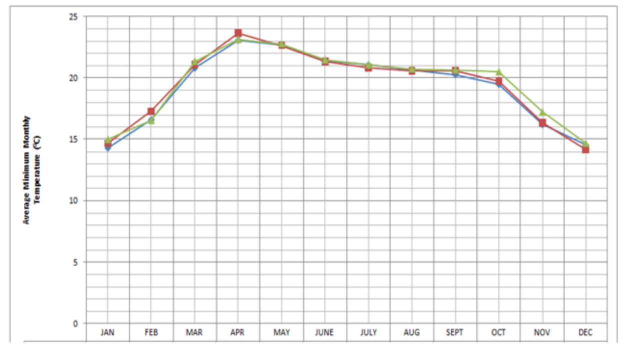
Figure 4: Average Annual Maximum and Minimum Air Temperature over Zaria from 1986-2015, note that Average Maximum temperatures for 2006 and 2007 were not provided because they were not recorded

Furthermore, analysis of standardized decadal anomalies of air temperature over Zaria showed an average increase in the average minimum temperature but a decrease in the average maximum temperature (Figures 5 and 6). The average monthly temperature of the first decade was hotter than that of the second decade by 1.20% and that of the third decade was hotter than that of the second by 3.22%, and an increase of 2.05% in the average monthly temperature was observed between first and the third decade (Table 1).



	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1986-1995	28.93	32.23	35.66	35.81	33.96	31.22	29.28	28.49	30.08	31.94	31.94	29.66
1996-2005	30.32	32.6	35.77	36.72	33.48	30.14	28.47	27.77	29.04	30.4	30.84	29.12
2006-2015	30.81	34.65	36.27	36.54	34.19	31.37	29.41	28.6	30.14	32.01	32.79	30.36

Figure 5: Average Decadal Monthly Maximum Temperature Over Zaria from 1986-2015



Month	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1986-1995	14.28	16.57	20.78	23.05	22.69	21.39	21.04	20.64	20.25	19.45	16.18	14.51
1996-2005	14.64	17.27	21.05	23.63	22.63	21.3	20.83	20.55	20.58	19.73	16.33	14.16
2006-2015	14.99	16.54	21.38	23.15	22.79	21.49	21.09	20.74	20.66	20.51	17.21	14.67

Figure 6: Average Decadal Monthly Minimum Temperature over Zaria from 1986-2015

Table 1: Average Decadal Monthly Maximum Temperature for 30 Years

S/N	Month	Temp (°C) (1986 – 1995
1	JAN	28.93
2	FEB	32.23
3	MAR	35.66
4	APR	35.81
5	MAY	33.96
6	JUNE	31.22
7	JULY	29.28
8	AUG	28.49
9	SEPT	30.08
10	OCT	31.94
11	NOV	31.94
12	DEC	29.66
	Total	379.2

S/N	Month	Temp (°C) (1996 - 2005)
1	JAN	30.32
2	FEB	32.6
3	MAR	35.77
4	APR	36.72
5	MAY	33.48
6	JUNE	30.14
7	JUL	28.47
8	AUG	27.77
9	SEPT	29.04
10	OCT	30.4
11	NOV	30.84
12	DEC	29.12
	Total	374.67

S/N	Month	Temp (°C) (2006 - 2015)
1	JAN	30.81
2	FEB	34.65
3	MAR	36.27
4	APR	36.54
5	MAY	34.19
6	JUNE	31.37
7	JULY	29.41
8	AUG	28.60
9	SEPT	30.14
10	OCT	32.01
11	NOV	32.79
12	DEC	30.36
	Total	387.14

% change btw 1st & 2nd decade	% change btw 3rd & 2nd decade	% change btw 3rd & 1st decade
1.19	**3.22**	**2.05**

The average minimum temperature of the second decade was observed to be higher than that of the first decade by 0.80% and the third decade had an increase of 1.07% over the second decade; hence, a difference of 1.87% was observed between the first decade and the third decade (Table 2).

Table 2: Average Decadal Monthly Minimum Temperature for 30 Years

S/N	Month	Temp (°C) (1986 - 1995)	S/N	Month	Temp (°C) (1996 - 2005)	S/N	Month	Temp (°C) (2006 - 2015)
1	JAN	14.28	1	JAN	14.64	1	JAN	14.99
2	FEB	16.57	2	FEB	17.27	2	FEB	16.54
3	MAR	20.78	3	MAR	21.05	3	MAR	21.38
4	APRIL	23.05	4	APRIL	23.63	4	APRIL	23.15
5	MAY	22.69	5	MAY	22.63	5	MAY	22.79
6	JUNE	21.39	6	JUNE	21.30	6	JUNE	21.49
7	JULY	21.04	7	JULY	20.83	7	JULY	21.09
8	AUG	20.64	8	AUG	20.55	8	AUG	20.74
9	SEPT	20.25	9	SEPT	20.58	9	SEP	20.66
10	OCT	19.45	10	OCT	19.73	10	OCT	20.51
11	NOV	16.18	11	NOV	16.33	11	NOV	17.21
12	DEC	14.51	12	DEC	14.16	12	DEC	14.67
	Total	230.83		Total	232.70		Total	235.22
% change btw 2nd & 1st decade		0.80	%change btw 3rd & 2nd decade		1.07	% change btw 3rd & 1st decade		1.87

Worthy of note however is that, the solar irradiance of the second decade was observed to have increased by 25.69% over the first decade, while that of the third decade was observed to reduce by 17.81% over the second decade (Figures 7, 8 and 9). A difference of the radiation of 12.45% was observed between the first and the third decade (Table 3).

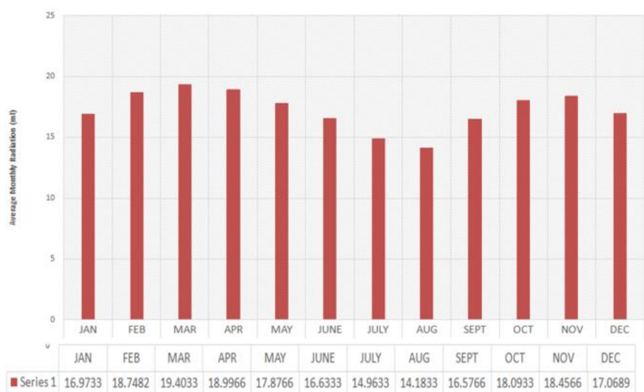


Figure 7: Average Monthly Radiation over Zaria from 1986-2015

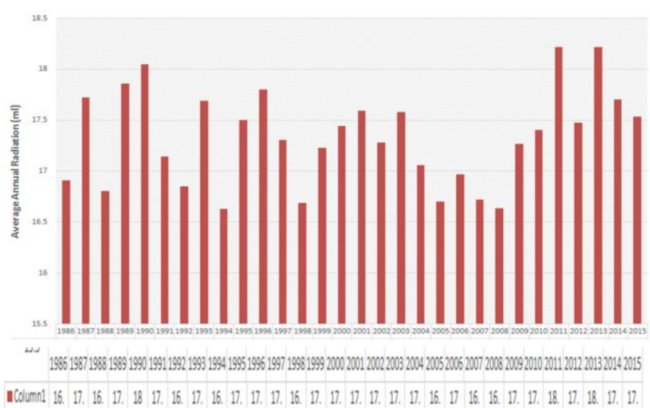


Figure 8: Average Annual Radiation over Zaria from 1986-2015

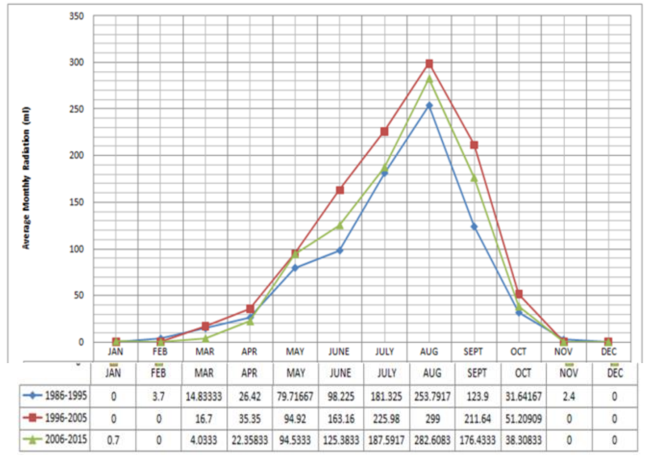


Figure 9: Average Decadal Monthly Radiation over Zaria from 1986-2015.

It was also observed that the years: 2003, 2009, 2010 and 2013 had the highest maximum annual temperatures, while the years: 1993, 2006, 2009, 2010 and 2015 had highest minimum temperature values

Table 3: Average Decadal Monthly Radiation for 30 Years

S/N	Month	Irradiance(W/m^2) (1886 -1995)	S/N	Month	Irradiance(W/m^2) (1996 -2005)	S/N	Month	Irradiance(W/m^2) (2006 - 2015)
1	JAN	0.00	1	JAN	0.00	1	JAN	0.70
2	FEB	3.70	2	FEB	0.00	2	FEB	0.00
3	MAR	14.83	3	MAR	16.70	3	MAR	4.03
4	APRIL	26.42	4	APRIL	35.35	4	APRIL	22.36
5	MAY	79.72	5	MAY	94.92	5	MAY	94.53
6	JUNE	98.23	6	JUNE	163.16	6	JUNE	125.38
7	JULY	181.33	7	JULY	225.98	7	JULY	187.59
8	AUG	253.79	8	AUG	299.00	8	AUG	282.61
9	SEPT	123.90	9	SEPT	211.64	9	SEPT	176.43
10	OCT	31.64	10	OCT	51.21	10	OCT	38.31
11	NOV	2.40	11	NOV	0.00	11	NOV	0.00
12	DEC	0.00	12	DEC	0.00	12	DEC	0.00
	Total	815.95		Total	1097.96		Total	931.95
% change btw 2nd & 1st decade		25.68	%change btw 2nd & 3rd decade		17.81	% change btw 3rd & 1st decade		12.45

Conclusion

There is an average increase in temperature in Zaria and also an increase in the average solar radiation over Zaria. Hence, the rise in temperature over Zaria could be attributed to the rise in solar radiation over Zaria. It is also clear from analysis that there is a 1.87% decadal changes in minimum temperature around Zaria area, Kaduna State, Nigeria in line with the general knowledge of global warming and climate change.

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