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ANALYSING THE RELATIONSHIP BETWEEN DIURNAL ROAD TRAFFIC NOISE AND METEOROLOGICAL VARIABLES IN MAKURDI METROPOLIS, NIGERIA

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ABSTRACT

This paper explores the link between diurnal road traffic noise and meteorological variables based on an experimental study conducted in real traffic conditions in Makurdi metropolis during dry and wet seasons. Measurements of sound pressure level (LP), relative humidity, ambient temperature and wind speed were made at four locations of heavy traffic flow for forty days and the sound pressure level (LP) readings were used to compute the equivalent continuous noise level (Leq). Pearson correlation coefficient and Mann-Kendall trend tests were adopted to determine the relationship between equivalent continuous noise level (Leq) and the meteorological variables. The results revealed inconsistent trends across the different locations and seasons, with relative humidy exhibiting varying insignificant trends across the four locations and seasons with the only significant decreasing trend recorded at High Level Roundabout having a Kendall tau value of -0.6364 and R-value of -0.7315 during the wet season. The ambient temperature showed significant increasing trends at two locations and seasons and insignificant trends in the other locations, while wind speed recorded insignificant increasing trends across all locations except for SRS Junction which recorded a significant increasing trend during the wet season with a Kendall tau value of 0.5273 and R-value of 0.7498 which could be attributed to fluctuation in wind direction at the time of measurement of sound pressure levels. Notably, no consistent relationship was found between road traffic equivalent continuous noise levels and the meteorological variables. The study recommends implementing low-noise pavements and planting of ornamental trees and shrubs to absorb excess traffic noise and mitigate noise pollution.

Keywords: Diurnal, Sound pressure level, Equivalent continuous noise level, Meteorological variables, Traffic flow

INTRODUCTION

Noise can be referred to as sound that is undesired and disturbs human activities (Windaniyati and Radam, 2018). When two sound waves of different frequencies superpose and do not produce a systematic sinusoidal wave but an irregular wave with jerks, a normal sound becomes noise. Traffic noise has become a major and dominating source of noise pollution because of the advancement in technologies and immense growth in automobile industries (Khan *et al*., 2021).

Factors influencing road traffic noise can be categorised into three: infrastructure characteristics, traffic characteristics and environmental factors. Infrastructure characteristics include the type of pavement, the state of conservation and the geometric design which can be controlled during the process of designing, modifying or maintaining roads. Traffic characteristics such as traffic flow, speed, vehicle typology, intrinsic characteristics or tyres are however difficult to control. Meteorological factors also affect both the propagation and the generation of sound (Sánchez-Fernández *et al*., 2021). Meteorological conditions in urban areas affect how sound travels, refracting and scattering sound waves. Outdoor sound propagation is primarily affected by meteorological conditions including temperature, relative humidity and wind, which alter sound waves through refraction, scattering and absorption. Buildings in urban areas can block noise sources, creating quieter spots. However, meteorological conditions can cause noise to travel over and around buildings increasing overall noise levels (Trikootam and Hornikx, 2019).

Relative humidity has a significant influence on sound waves because it affects the density of particles in the air. An increase in relative humidity will increase the speed of sound waves in the air due to a decrease in its dominant density (Mariyo *et al*., 2019). Moist air is less dense than dry air. This causes an increase in the speed of sound. Moisture also causes the specific-heat ratio to decrease, which would cause the speed of sound to decrease. However, the decrease in density dominates, so the speed of sound increases with increasing moisture (Bohn, 1988). Temperature is another parameter that has a substantial effect on the speed of sound. Temperature is known to alter the speed of sound, which is an essential feature of waves propagating through a medium. The speed of sound increases linearly with temperature (Loonkar, 2023). At high temperatures, sound propagation will be faster than low temperatures because air molecules are less dense and more tight at low temperatures (Windaniyati and Radam, 2018). The propagation of sound is also affected by wind speed. According to Trikootam and Hornikx (2019), sound levels increase with increase in wind speed.

A few studies have been carried out on the relationship between road traffic noise and meteorological parameters. A study by Windaniyati and Radam (2018) in Banjarmasin, Indonesia to analyse the relationship between noise and traffic based on the distance, wind speed, and temperature indicated that faster wind speed will result in increase in noise level, and higher temperature will increase the level of noise. Similarly, a research carried out by Trikootam and Hornikx (2019) in Eindhoven, Netherlands revealed that sound levels in the urban residential area increase with increase in mean wind speeds. Amah and Atuboyedia (2020) in a study in Port Harcourt city, Nigeria reported that noise levels increase with increasing ambient temperature and wind speed, whereas the noise levels decrease as the relative humidity increases. The effect of seasonal variation and meteorological parameters on environmental noise pollution was carried out by Khan *et al*. (2021) in selected areas of Rawalpindi and Islamabad, Pakistan. The study reported a trend of increasing noise levels with increasing humidity during summer. According to the researchers, significant variation of noise levels was observed diurnally and seasoned wise between winter and summer months. In another study by Loonkar (2023) in India to analyse the relation between the temperature of a medium and the speed of sound, the researcher reported that the speed of sound increases in a linear connection as temperature rises. The purpose of this study is to analyse the relationship between the diurnal road traffic noise and some meteorological variables (ambient temperature, relative humidity and wind speed). The study was carried out in Makurdi town of Benue State, Nigeria.

Theoretical Background

Mathematical Relationship between Sound Speed and Meteorological Parameters

The speed of sound in air is determined by the air temperature. As the air temperature increases, the speed of sound also increases (Chen, 2004). The relationship between the temperature of air and the sound speed can be expressed as (Chen, 2004; Nowoświat, 2022):

$$V = 331.5\sqrt{1 + \frac{T_C}{273}} \qquad (1)$$

where V is the sound speed at temperature T_C and T_C is the temperature in degree Celsius (°C).

Alternatively, the speed of sound in air may be obtained using the equation (Bello and Garcia, 2010):

$$V = \sqrt{\frac{\gamma R T_K}{M}} = \sqrt{\frac{\gamma R}{M}}\sqrt{T_K} \qquad (2)$$

where γ is the ratio of specific heat which is 1.4 for air, R is the universal gas constant which has the value 8.314 $Jmol^{-1}K^{-1}$, T_K is the temperature in Kelvin (K) and M is the molecular mass of air with the value 0.029 $kgmol^{-1}$.

In equations (1) and (2), the speed of sound is seen to increase as the square root of temperature.

The presence of moisture in air changes its density which in turn affects the speed of sound. Moist air is less dense than dry air and this causes an increase in the speed of sound. Moisture also decreases the specific heat ratio and causes the speed of sound to decrease. However, as moisture increases, the resulting decrease in air density leads to an increase in the speed of sound (Bohn, 1988).

Equation (2) is accurate for dry air. To account for the impact of moisture (water vapour) on the speed of sound, two terms, γ and M need to be modified. The terms R and T remain unchanged. The molecular mass of air decreases with added moisture. The ratio of the wet and dry speeds gives the percentage increase in the speed of sound due to relative humidity. Since both wet and dry speed terms involve the same constant terms (R and T), their ratio will cause these to cancel such that (Bohn, 1988):

$$\frac{V_w}{V_d} = \frac{\sqrt{\gamma_w/M_w}}{\sqrt{\gamma_d/M_d}} = \sqrt{\frac{\gamma_w/M_w}{1.4/29}} = 4.5513\sqrt{\frac{\gamma_w}{M_w}} \qquad (3)$$

where γ_w is the ratio of specific heat for wet air, M_w is the molecular mass of wet air, γ_d is the ratio of specific heat for dry air and M_d is the molecular mass of dry air.

Multiplying equation (3) by 100 gives:

$$Increase\ in\ sound\ speed = 455.13\sqrt{\frac{\gamma_w}{M_w}} \qquad (4)$$

Equation (4) shows the relationship between sound speed and relative humidity.

Sound levels are usually higher downwind than upwind from the source (Ovenden *et al.*, 2011; Department of Defense (DOD), 2018). Sound waves travelling in the direction of the wind are bent towards the ground leading to higher sound levels in that direction, while those travelling against the wind are bent towards the sky and lower sound levels are observed (Hannah, 2006). That is:

$$V_{eff} = V + V_{wind} \quad \text{(Downwind propagation)} \qquad (5)$$

$$V_{eff} = V - V_{wind} \quad \text{(Upwind propagation)} \qquad (6)$$

where V_{eff} is the effective speed of sound, V is the speed of sound in still air (approximately 343 ms^{-1} at 20°C) and V_{wind} is the wind speed.

Equations (5) and (6) show that wind speed can either enhance or reduce the speed of sound depending on its direction relative to the path of the sound wave.

Sound Pressure Level

The decibel (dB) scale is generally used to measure sound. The decibel is the logarithmic ratio of one pressure to another (Enda and Eoin, 2014). The sound pressure level (L_P) in decibels is expressed as (Oyedepo, 2014; Akinkuade and Fasae, 2015; Jhanwar, 2016):

$$L_P(dB) = 10log_{10}\left(\frac{P}{P}\right)^2 = 20log_{10}\left(\frac{P}{P_o}\right) \qquad (7)$$

where P is the root-mean-square sound pressure in Newton per square metre and P_o is the standard reference sound pressure with a value of $2 \times 10^{-5}\ Nm^{-2}$ or $20\ \mu Pa$ which corresponds to the human hearing threshold. The sound level meter is designed using the above equation and is used to measure the sound pressure level.

Equivalent Continuous Noise Level

The equivalent continuous noise level (L_{eq}) is the steady sound pressure level which over a specified period of time has the same overall sound energy as the actual fluctuating noise (Akinkuade and Fasae, 2015; Woniewicz and Zagubień, 2015; Egbugha *et al.*, 2016; Thattai *et al.*, 2017). It is computed using (Pachiappan and Govindaraj, 2013; Thattai *et al.*, 2017; Kaushal and Rampal, 2017; Alani *et al*, 2020):

$$L_{eq} = 10log_{10}\frac{1}{n}\left[\sum_{i=1}^{n} 10^{\frac{L_{Pi}}{10}}\right] \qquad (8)$$

where L_{Pi} is i^{th} sound pressure level reading in dB(A) and n is the number of measurements in the assessed time. The A-weighted L_{eq} in decibels is widely recognized as a stable descriptor of traffic noise levels (Nwaogazie and Ofem, 2014; Sukeerth *et al.*, 2017).

Trend Analysis

Due to the irregular nature of the data collected, trend analysis was applied with the following statistical tools:

1. correlation coefficients of the hourly Equivalent continuous noise level and meteorological variables was computed to determine the strength of the linear relationship between these variables.
2. To detect the monotonic increasing or decreasing trends, the non-parametric Mann-Kendall test was applied.

Correlation coefficient

The Pearson product moment correlation coefficient R, measures the strength and the pattern of the linear relationship between two variables. It is expressed as (Tikyaa *et al.*, 2020):

$$R = \frac{n\sum ab - (\sum a)(\sum b)}{\sqrt{n(\sum a^2) - (\sum a)^2}\sqrt{n(\sum b^2) - (\sum b)^2}} \qquad (9)$$

i. The value of R is lie between –1 and +1, with +1 or –1 indicating perfect correlation (i.e. all points would lie along a straight line, having a residual of zero).
ii. An R value close to or approximately equal to zero indicates no relationship between the variables.
iii. An R value greater than 0.8 is described as "strong", whereas a value that is less than 0.5 is generally described as "weak".

iv. A positive R value infers a relationship in which both variables are changing in the same direction (direct proportionality).
v. A negative R value infers a relationship in which both variables are changing in opposite direction i.e. as values for a increase, values for b decreases (inverse proportionality).

Mann-Kendall analysis
The non-parametric Mann-Kendall test is often applied in order to detect trends that are monotonic in nature but not necessarily linear. The null hypothesis H_o in the Mann-Kendall test is that the data are independent and randomly ordered. It does not require the assumption of normality, and only indicates the direction but not the magnitude of significant trends. The Mann-Kendall test statistic S is computed using the formula (Wang *et al*., 2020; Agbo and Ekpo, 2021):

$$S = \sum_{k=1}^{n-1}\sum_{j=k+1}^{n} sign(x_j - x_k) \quad (10)$$

where x_j and x_k are the hourly values of equivalent continuous noise level in the j^{th} and k^{th} hour, where $j > k$. The $sign(x_j - x_k)$ function is defined by (Khambhammettu, 2005; Wang *et al*., 2020; Agbo and Ekpo, 2021):

$$sign(x_j - x_k) = \begin{cases} 1 & if\ x_j - x_k > 0 \\ 0 & if x_j - x_k = 0 \\ -1 & if\ x_j - x_k < 0 \end{cases} \quad (11)$$

A high and positive value of S is an indicator of an increasing trend, while a low and negative value of S indicates a decreasing trend (Khambhammettu, 2005). The Kendall tau (τ) correlation coefficient is computed from the expression (Meals *et al*., 2011; Marsick *et al*., 2024):

$$\tau = 2\frac{S}{n(n-1)} \quad (12)$$

τ has a range of -1 to +1 and is analogous to the Pearson correlation coefficient R. In addition, it is expected that the probability associated with S and the sample size n be computed so as to statistically quantify how significant the trend is. The variance of the statistic S may be computed as (Khambhammettu, 2005; Marsick *et al*., 2024):

$$E(s) = 0,\ var(s) \approx \frac{n(n-1)(2n+5)}{18} \quad (13)$$

The Man-Kendall parameter *S* and variance *VAR(S)* are then used to compute the test statistic *Z* as follows (Wang *et al*., 2020; Hu *et al*., 2020):

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if\ S < 0 \end{cases} \quad (14)$$

The Z statistic follows a normal distribution and is tested at 95% level of significance ($Z_{0.025} = 1.96$). Its value describes the trend as follows (Khambhammettu, 2005):
i. The trend is said to be decreasing if Z is negative and the absolute value is greater than the level of significance,
ii. The trend is said to be increasing if Z is positive and greater than the level of significance.
iii. There is no trend if the absolute value of Z is less than the level of significance.

These statistical tests were executed using MATLAB software application.

MATERIALS AND METHODS
Study Area
This study was conducted in Makurdi town. Makurdi is the capital city of Benue State situated in central Nigeria. The town is geographically located between Latitudes 7° 38′ and 7° 50′ N, and Longitudes 8° 24′ and 8° 38′ E. The second largest river in Nigeria, the River Benue lies across the town (Abah, 2013). Makurdi has a landmass of about 800 km^2 and an estimated population of 367,588 people according to the National population census data of 2006 (Adeke *et al*., 2018). There are two distinct seasons in Makurdi: dry and wet seasons. The dry season begins in November and usually terminates by March, whereas the wet season starts from April and ends in October, with a mean annual rainfall ranging from 1200 to 2000 mm (Akaahan *et al*., 2016). The average daily temperature in Makurdi varies between 21 and 37°C (Hula, 2010; Odoh and Jidauna, 2013), while the relative humidity varies with seasons, reaching a mean monthly peak of about 92% in the wet season (Onah *et al*., 2020). Wurukum Roundabout, High Level Roundabout, SRS Junction and Ankpa Ward Junction were selected for this study. The selection of these locations was based on the fact that they are areas of heavy and constant traffic flow.

Method of Data Collection
The road traffic sound pressure level (L_P), the ambient temperature, the relative humidity and the wind speed measurements were done at the same time from 7:00 am to 6:00 pm on each day with a time interval of 10 minutes. The measurements were done in two phases. The first phase of data collection was from November to December, 2022, and the second phase was from August to September, 2023, marking the dry and wet seasons respectively. A microprocessor digital sound level meter, model SL-5858 was used to measure the road traffic sound pressure level. The meter was mounted on a stand at a height of 1.5 m above the ground and at a distance of 0.5 m from the operator to minimize the reflection of sound waves off the body. Measurements were taken at a distance of at least 3.5 m away from any reflecting surface to avoid the effect of sound reverberation. Readings from the meter were recorded at each study location and the hourly equivalent continuous noise level (L_{eq}) was calculated for each study location. Similarly, the ambient temperature and relative humidity were measured using a digital thermo-hygrometer, while a digital thermo-anemometer was used to measure the wind speed. The instruments were mounted on a stand at a height of 1.5 m above the ground. Readings from these instruments were recorded at each study location and the hourly average of ambient temperature, relative humidity and wind speed was computed. The measurements were carried out at two busy roundabouts and two busy junctions (cross intersections) in Makurdi town for five days (i.e Mondays, Wednesdays, Fridays, Saturdays and Sundays) at each study location making a total of forty days. The road traffic sound pressure level (L_P) readings obtained from field survey were used to compute the hourly equivalent continuous noise level (L_{eq}) using equation 2. The hourly average of equivalent continuous noise level (L_{eq}), relative humidity, ambient temperature and wind speed in both dry and wet seasons were computed for each study location.

RESULTS AND DISCUSSION
Results
The results of Pearson correlation coefficient and Mann-Kendall trend analysis of the predictability of equivalent continuous noise level (L_{eq}) and meteorological variables for the four study locations during dry and wet seasons are presented in Table 1 to 16. The positive correlation coefficient values recorded imply that the predictability of these meteorological variables has an increasing trend i.e the equivalent continuous noise level (L_{eq}) increases as the

meteorological variables increase, whereas the negative correlation coefficient values imply a decreasing trend i.e the equivalent continuous noise level (L_{eq}) decreases with increasing meteorological variables. The positive values of Kendall tau correlation coefficient and Mann-Kendall coefficient (S) indicate an increasing trend in the predictability of the meteorological variables, while the negative values indicate a decreasing trend. The significance of the results is further confirmed by the Z-statistic values. Similarly, Figure 1 to 12 depicts the predictability trends of the meteorological variables (relative humidity, ambient temperature and wind speed) for the four study locations during dry and wet seasons.

Tables 1: Correlation Coefficient Between the Predictability of Equivalent Continuous Noise Level (L_{eq}) and Meteorological Variables for Wurukum Roundabout During Dry Season

Variable	Correlation coefficient	p-value	Trend	Significance
Relative Humidity	-0.7383	0.0095	Decreasing	Sig.
Ambient Temperature	0.8575	0.0007	Increasing	Sig.
Wind speed	0.4635	0.1510	Increasing	Not Sig.

Table 2: Mann-Kendall Trend Analysis of Equivalent Continuous Noise Level (L_{eq}) and Meteorological Variables For Wurukum Roundabout During Dry Season

Variable	Kendall tau	Mann-Kendall coefficient S	Z statistic	p-value	Trend description (from Z value)	Hypothesis test (h=1: significant, h=0: not significant)	Trend Significance
Relative Humidity	-0.4545	-25	-1.8684	0.0617	Decreasing	h = 0	Not sig.
Ambient Temperature	0.6727	37	2.8026	0.0051	Increasing	h = 1	Sig.
Wind speed	0.2545	14	1.0151	0.3100	Increasing	h = 0	Not sig.

Tables 3: Correlation Coefficient Between the Predictability of Equivalent Continuous Noise Level (L_{eq}) and Meteorological Variables for Wurukum Roundabout During Wet Season

Variable	Correlation coefficient	p-value	Trend	Significance
Relative Humidity	0.1301	0.7030	Increasing	Not sig.
Ambient Temperature	-0.1531	0.6531	Decreasing	Not sig.
Wind speed	-0.2460	0.4659	Decreasing	Not sig.

Table 4: Mann-Kendall Trend Analysis of Equivalent Continuous Noise Level (L_{eq}) And Meteorological Variables for Wurukum Roundabout During Wet Season

Variable	Kendall tau	Mann-Kendall coefficient S	Z statistic	p-value	Trend description (from Z value)	Hypothesis test (h=1: significant, h=0: not significant)	Trend Significance
Relative Humidity	0.2727	15	1.0899	0.2758	Increasing	h = 0	Not sig.
Ambient Temperature	-0.2727	-15	-1.0899	0.2758	Decreasing	h = 0	Not sig.
Wind speed	--0.3455	-19	-1.4013	0.1611	Decreasing	h = 0	Not sig.

Table 5: Correlation Coefficient Between the Predictability of Equivalent Continuous Noise Level (L_{eq}) and Meteorological Variables for High Level Roundabout During Dry Season

Variable	Correlation coefficient	p-value	Trend	Significance
Relative Humidity	-0.2573	0.4450	Decreasing	Not sig.
Ambient Temperature	0.3512	0.2897	Increasing	Not sig
Wind speed	0.2126	0.5303	Increasing	Not sig.

Table 6: Mann-Kendall Trend Analysis of Equivalent Continuous Noise Level (L_{eq}) and Meteorological Variables for High Level Roundabout During Dry Season

Variable	Kendall tau	Mann-Kendall coefficient S	Z statistic	p-value	Trend description (from Z value)	Hypothesis test (h=1: significant, h=0: not significant)	Trend Significance
Relative Humidity	-0.1273	-7	-0.4671	0.6404	Decreasing	h = 0	Not sig.
Ambient Temperature	0.1636	9	0.6228	0.5334	Increasing	h = 0	Not sig.
Wind speed	0.1636	9	0.6228	0.5334	Increasing	h = 0	Not sig.

Tables 7: Correlation Coefficient Between the Predictability of Equivalent Continuous Noise Level (L_{eq}) and Meteorological Variables For High Level Roundabout During Wet Season

Variable	Correlation coefficient	p-value	Trend	Significance
Relative Humidity	-0.7315	0.0105	Decreasing	Sig.
Ambient Temperature	0.8141	0.0027	Increasing	Sig.
Wind speed	0.4455	0.1697	Increasing	Not sig.

Table 8: Mann-Kendall Trend Analysis of Equivalent Continuous Noise Level (L_{eq}) And Meteorological Variables for High Level Roundabout During Wet Season

Variable	Kendall tau	Mann-Kendall coefficient S	Z statistic	p-value	Trend description (from Z value)	Hypothesis test (h=1: significant, h=0: not significant)	Trend Significance
Relative Humidity	-0.6364	-35	-2.6469	0.0081	Decreasing	h = 1	Sig.
Ambient Temperature	0.6364	35	2.6469	0.0081	Increasing	h = 1	Sig.
Wind speed	0.3273	18	1.3275	0.1844	Increasing	h = 0	Not sig.

Table 9: Correlation Coefficient Between the Predictability of Equivalent Continuous Noise Level (L_{eq}) and Meteorological Variables for SRS Junction During Dry Season

Variable	Correlation coefficient	p-value	Trend	Significance
Relative Humidity	-0.6969	0.0172	Decreasing	Sig.
Ambient Temperature	0.6563	0.0283	Increasing	Sig.
Wind speed	-0.3787	0.2507	Decreasing	Not sig.

Table 10: Mann-Kendall Trend Analysis of Equivalent Continuous Noise Level (L_{eq}) and Meteorological Variables for SRS Junction During Dry Season

Variable	Kendall tau	Mann-Kendall coefficient S	Z statistic	p-value	Trend description (from Z value)	Hypothesis test (h=1: significant, h=0: not significant)	Trend Significance
Relative Humidity	-0.3091	-17	-1.2456	0.2129	Decreasing	h = 0	Not sig.
Ambient Temperature	0.3455	10	1.4013	0.1611	Increasing	h = 0	Not sig.
Wind speed	-0.1636	-9	-0.6228	0.5334	Decreasing	h = 0	Not sig.

Table 11: Correlation Coefficient Between the Predictability of Equivalent Continuous Noise Level (L_{eq}) and Meteorological Variables for SRS Junction During Wet Season

Variable	Correlation coefficient	p-value	Trend	Significance
Relative Humidity	0.2042	0.5470	Increasing	Not sig.
Ambient Temperature	-0.1256	0.7129	Decreasing	Not sig.
Wind speed	0.7498	0.0079	Increasing	Sig.

Table 12: Mann-Kendall Trend Analysis of Equivalent Continuous Noise Level (L_{eq}) and Meteorological Variables for SRS Junction During Wet Season

Variable	Kendall tau	Mann-Kendall coefficient S	Z statistic	p-value	Trend description (from Z value)	Hypothesis test (h=1: significant, h=0: not significant)	Trend Significance
Relative Humidity	0.0909	5	0.3114	0.7555	No trend	h = 0	Not sig.
Ambient Temperature	-0.0545	-3	-0.1557	0.8763	No trend	h = 0	Not sig.
Wind speed	0.5273	29	2.1798	0.0293	Increasing	h = 1	Sig.

Table 13: Correlation Coefficient Between the Predictability of Equivalent Continuous Noise Level (L_{eq}) and Meteorological Variables for Ankpa Ward Junction During Dry Season

Variable	Correlation coefficient	p-value	Trend	Significance
Relative Humidity	-0.5163	0.1040	Decreasing	Not sig.
Ambient Temperature	0.4733	0.1415	Increasing	Not sig.
Wind speed	0.2687	0.4244	Increasing	Not sig.

Table 14: Mann-Kendall Trend Analysis of Equivalent Continuous Noise Level (L_{eq}) and Meteorological Variables for Ankpa Ward Junction During Dry Season

Variable	Kendall tau	Mann-Kendall coefficient S	Z statistic	p-value	Trend description (from Z value)	Hypothesis test (h=1: significant, h=0: not significant)	Trend Significance
Relative Humidity	-0.3273	-18	-1.3275	0.1844	Decreasing	h = 0	Not sig.
Ambient Temperature	0.4545	25	1.8797	0.0601	Increasing	h = 0	Not sig.
Wind speed	0.0364	2	0.0781	0.9378	No trend	h = 0	Not sig.

Table 15: Correlation Coefficient Between the Predictability of Equivalent Continuous Noise Level (L_{eq}) and Meteorological Variables for Ankpa Ward Junction During Wet Season

Variable	Correlation coefficient	p-value	Trend	Significance
Relative Humidity	-0.3724	0.2594	Decreasing	Not sig.
Ambient Temperature	0.3787	0.2508	Increasing	Not sig.
Wind speed	0.5313	0.0926	Increasing	Not sig.

Table 16: Mann-Kendall Trend Analysis of Equivalent Continuous Noise Level (L_{eq}) and Meteorological Variables for Ankpa Ward Junction During Wet Season

Variable	Kendall tau	Mann-Kendall coefficient S	Z statistic	p-value	Trend description (from Z value)	Hypothesis test (h=1: significant, h=0: not significant)	Trend Significance
Relative Humidity	-0.2364	-13	-0.9342	0.3502	Decreasing	h = 0	Not sig.
Ambient Temperature	0.2727	15	1.0899	0.2758	Increasing	h = 0	Not sig.
Wind speed	0.3455	19	1.4013	0.1611	Increasing	h = 0	Not sig.

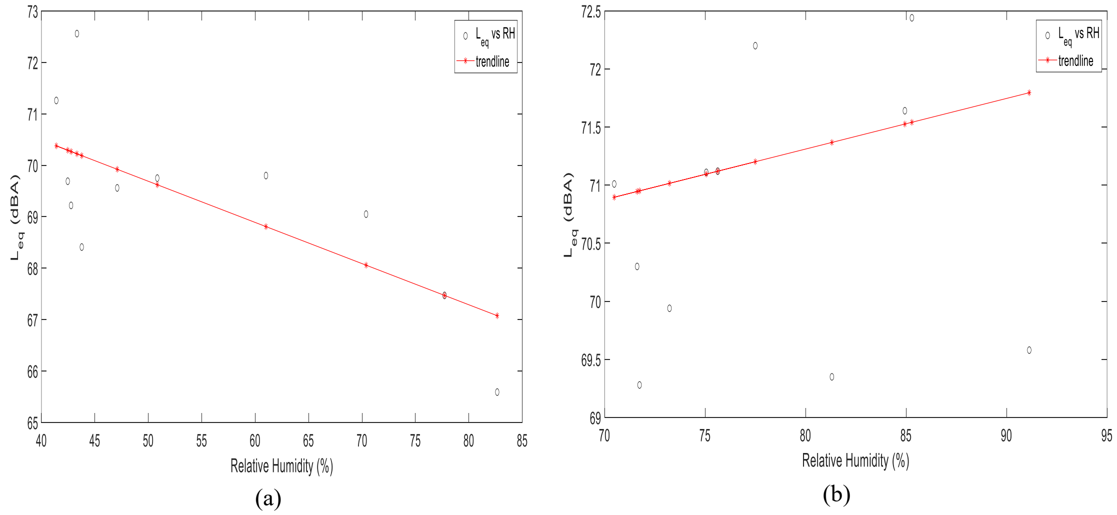
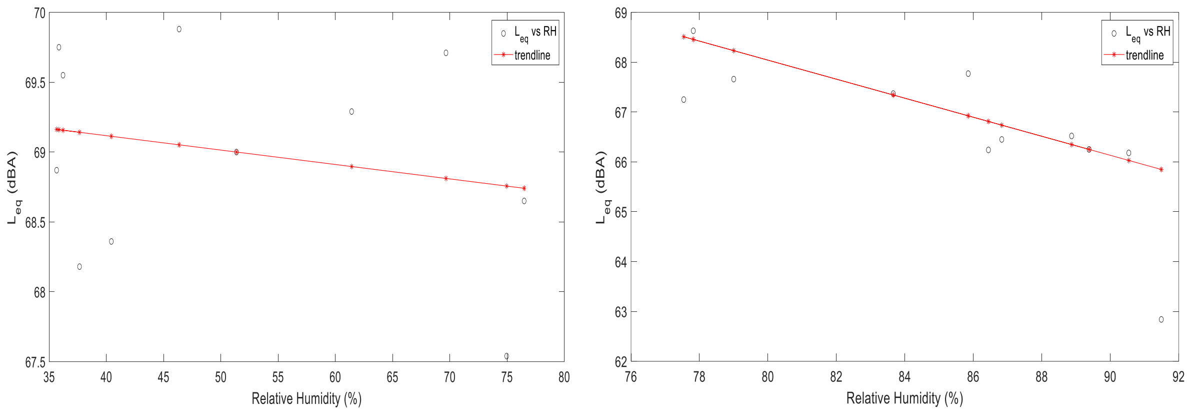
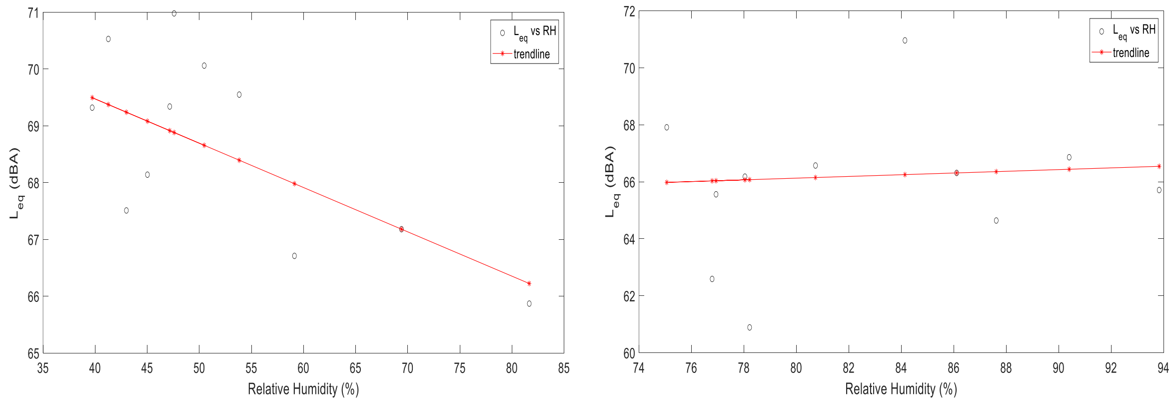


Figure 1: Plot of the Continuous Equivalent Noise Levels Against Relative Humidity at Wurukum Roundabout During (A) Dry Season And (B) Wet Season



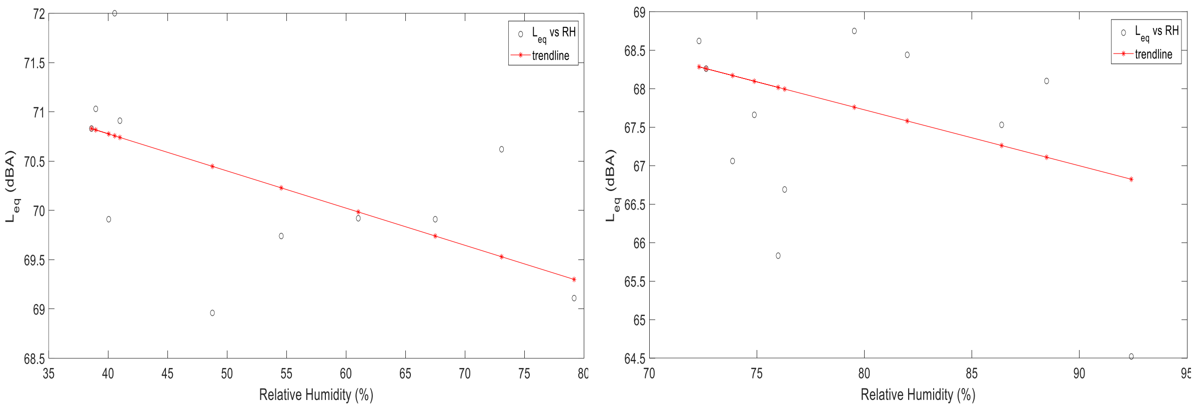
(a) (b)

Figure 2: Plot of The Continuous Equivalent Noise Levels Against Relative Humidity at High Level Roundabout During (A) Dry Season and (B) Wet Season



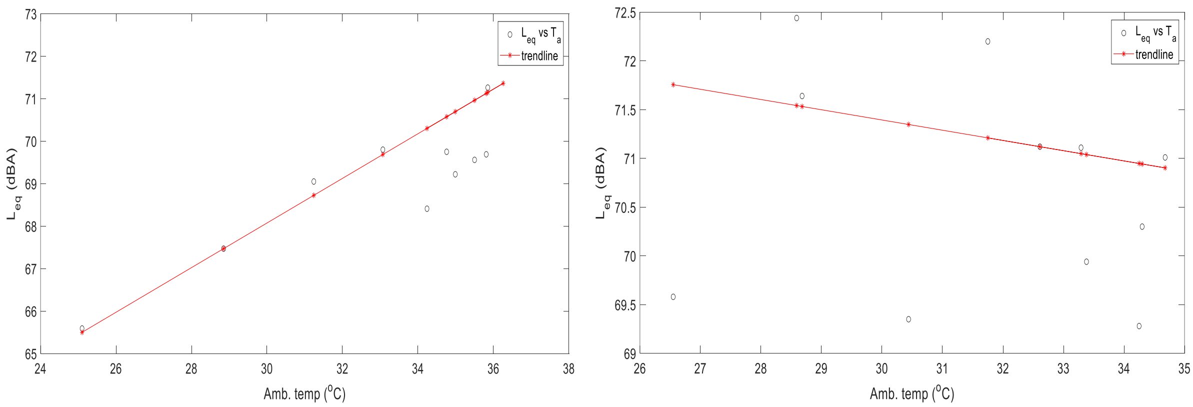
(a) (b)

Figure 3: Plot of the Continuous Equivalent Noise Levels Against Relative Humidity at SRS Junction During (A) Dry Season And (B) Wet Season



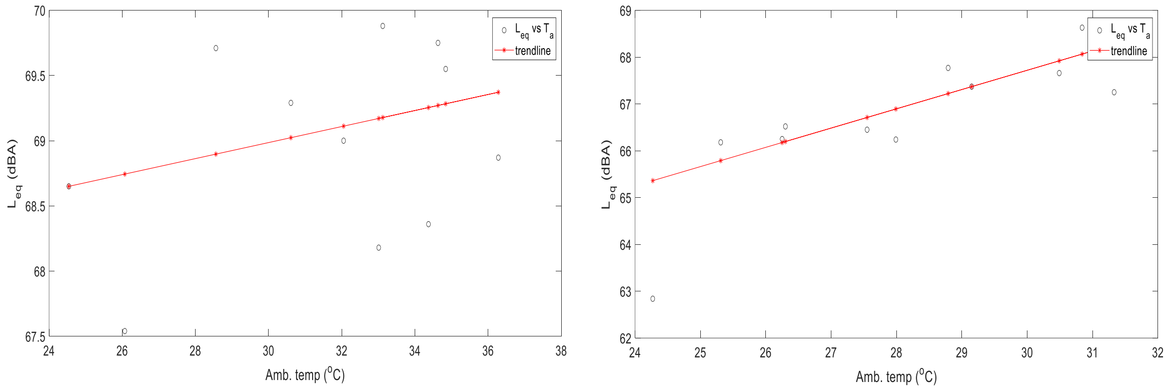
(a) (b)

Figure 4: Plot of the Continuous Equivalent Noise Levels Against Relative Humidity at Ankpa Ward Junction During (A) Dry Season (B) Wet Season



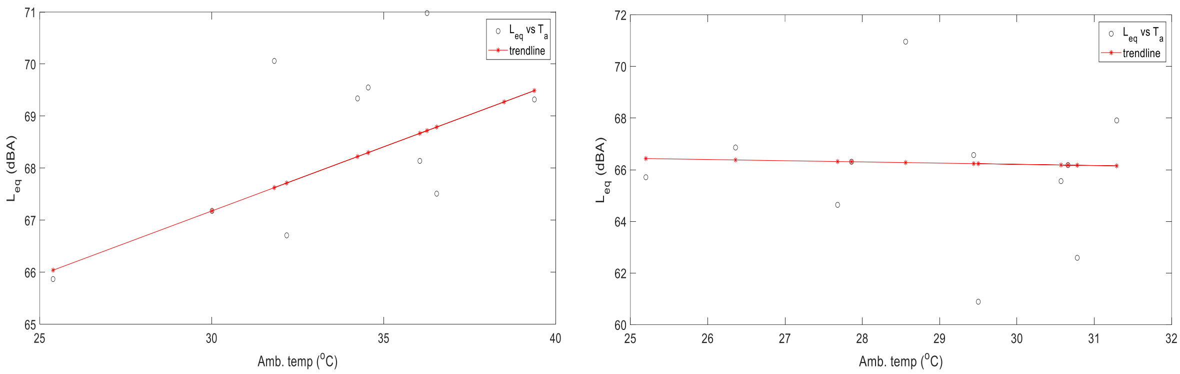
(a) (b)

Figure 5: Plot of the Continuous Equivalent Noise Levels Against Ambient Temperature at Wurukum Roundabout During (A) Dry Season And (B) Wet Season



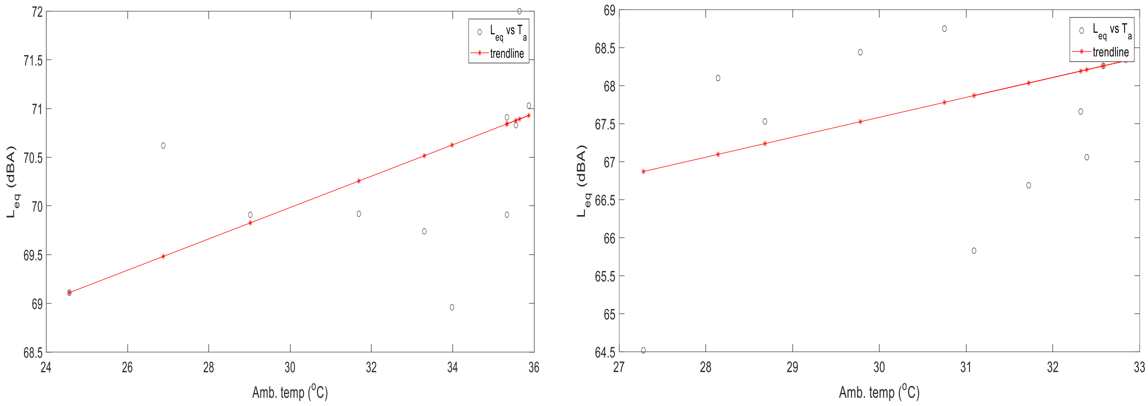
(a) (b)

Figure 6: Plot of the Continuous Equivalent Noise Levels Against Ambient Temperature at High Level Roundabout During (A) Dry Season And (B) Wet Season



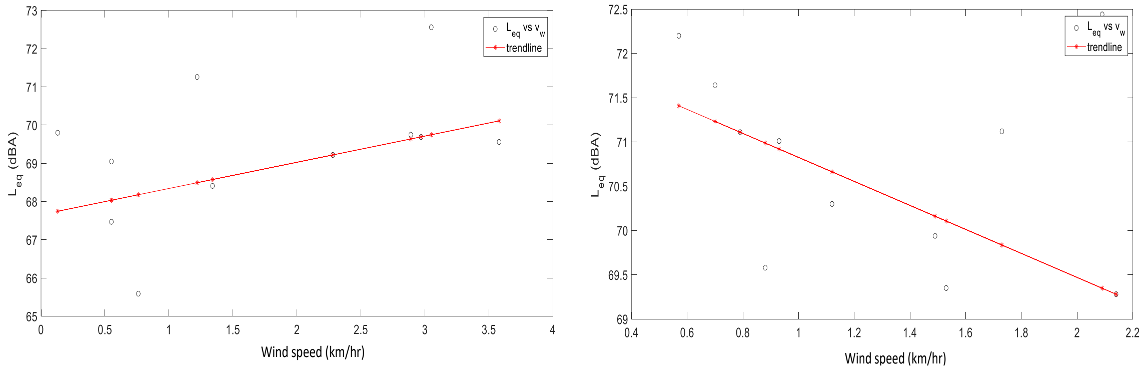
(a) (b)

Figure 7: Plot of the Continuous Equivalent Noise Levels Against Ambient Temperature at SRS Junction During (A) Dry Season And (B) Wet Season



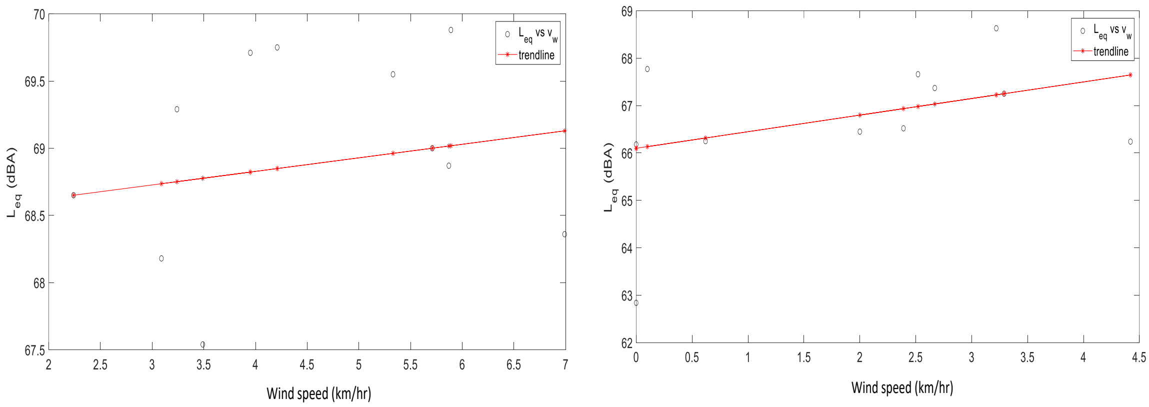
(a) (b)

Figure 8: Plot of the Continuous Equivalent Noise Levels Against Ambient Temperature at Ankpa Ward Junction During (A) Dry Season And (B) Wet Season



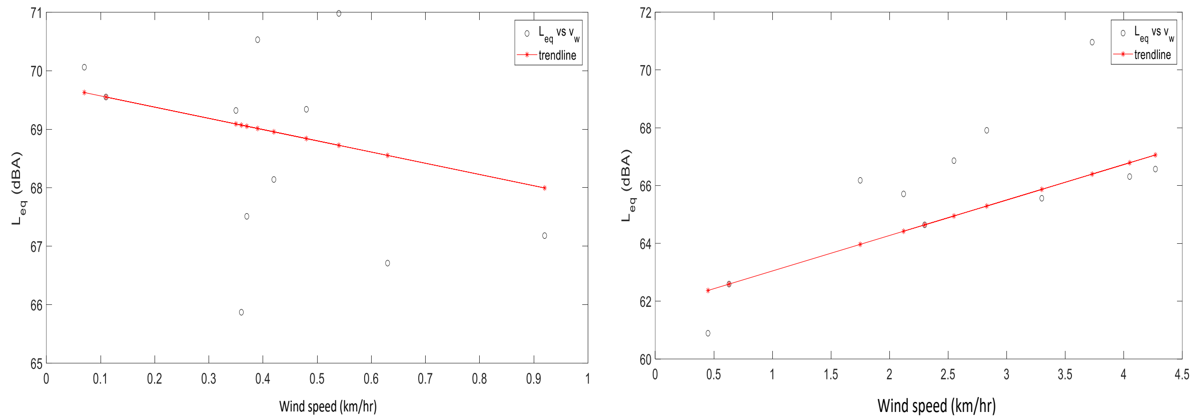
(a) (b)

Figure 9: Plot of The Continuous Equivalent Noise Levels Against Wind Speed at Wurukum Roundabout During (A) Dry Season and (B) Wet Season



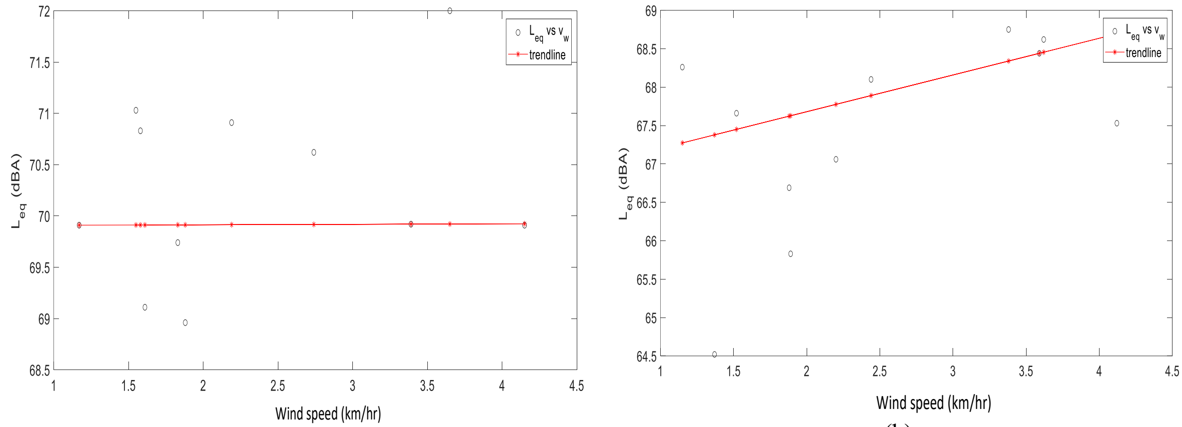
(a) (b)

Figure 10: Plot of the Continuous Equivalent Noise Levels Against Wind Speed at High Level Roundabout During (A) Dry Season and (B) Wet Season



(a) (b)

Figure 11: Plot of the Continuous Equivalent Noise Levels Against Wind Speed at SRS Junction During (A) Dry Season and (B) Wet Season



(a) (b)

Figure 12: Plot of the Continuous Equivalent Noise Levels Against Wind Speed at Ankpa Ward Junction During (A) Dry Season and (B) Wet Season

Discussion

From the nonlinear analysis carried out on relative humidity, ambient temperature and wind speed in Makurdi metropolis, it was observed that all the parameters showed strong signatures of chaos. The trend of predictabilities was not linear and well defined as most of the parameters showed random fluctuations over the forty days period observed. From the results of Pearson correlation, relative humidity showed significant decreasing trends at Wurukum Roundabout and SRS Junction (Tables 1 & 9), but insignificant decreasing trends at High Level Roundabout and Ankpa Ward Junction (Tables 5 & 13) during dry season. The wet season results indicated that the relative humidity at Wurukum Roundabout and SRS Junction (Tables 3 & 11) displayed insignificant increasing trends, whereas that at High Level Roundabout and Ankpa Ward Junction (Tables 7 & 15) showed significant and insignificant decreasing trends respectively. The Kendall tau (τ) and Mann-Kendall Statistic (S) for relative humidity during dry season indicated insignificant decreasing trends in all the study locations as presented in Tables 2, 6, 10 & 14. On the other hand, the Kendall tau and Mann-Kendall Statistic for relative humidity during wet season showed insignificant increasing and decreasing trends at Wurukum Roundabout and Ankpa Ward Junction respectively as illustrated in Tables 4 & 16, whereas that at High Level Roundabout and SRS Junction displayed significant decreasing trend and no trend respectively as shown in Tables 8 & 12. This is further illustrated in Figure 1(a & b) to 4(a & b).

Similarly, the ambient temperature in the dry season showed significant increasing trends at Wurukum Roundabout and SRS Junction (Tables 1 & 9), while that at High Level Roundabout and Ankpa Ward Junction indicated insignificant increasing trends (Tables 5 & 13) based on Pearson correlation analysis. The results of wet season revealed insignificant decreasing trends at Wurukum Roundabout and SRS Junction (Tables 3 & 11), while that at High Level Roundabout and Ankpa Ward Junction showed significant and insignificant increasing trends respectively as presented in Tables 7 & 15. The Kendall tau and Mann-Kendall Statistic for ambient temperature during dry season displayed insignificant increasing trends in all the study locations except at Wurukum Roundabout (Table 2) where the trend increased significantly. Conversely, during wet season, the Kendall tau and Mann-Kendall Statistic showed significant increasing and insignificant increasing trends at High Level Roundabout and Ankpa Ward Junction respectively (Tables 8 & 16), whereas that at Wurukum Roundabout and SRS Junction indicated insignificant decreasing trend and no trend respectively as shown in Tables 4 & 12. This is further depicted in Figure 5(a & b) to 8(a & b).

The results of the Pearson correlation coefficient trend analysis for wind speed during dry season revealed insignificant increasing trends in all the study locations except at SRS Junction where there is insignificant decreasing trend

(Table 9). In the wet season, the results showed insignificant increasing trends at High Level Roundabout and Ankpa Ward Junction (Tables 7 & 15), while that at Wurukum Roundabout and SRS Junction indicated an insignificant decreasing trend and a significant increasing trend respectively as presented in Tables 3 & 11. The Kendall tau and Mann-Kendall Statistic for wind speed during dry season showed insignificant increasing trends at Wurukum and High Level Roundabouts (Tables 2 & 6), whereas that at SRS and Ankpa Ward Junctions indicated insignificant decreasing trend and no trend respectively as displayed in Tables 10 & 14. The Kendall tau and Mann-Kendall Statistic during wet season revealed insignificant increasing trends at High Level Roundabout and Ankpa Ward Junction as presented in Tables 8 & 16, while an insignificant decreasing trend and a significant increasing trend were observed at Wurukum Roundabout and SRS Junction respectively as shown in Tables 4 & 12. This is further displayed in Figure 9(a & b) to 12(a & b). In the Mann-Kendall trend analysis, a significant trend implies that the absolute value of Z-statistic is greater than $Z_{\alpha/2} = 1.96$ with the level of significance (p-value) less than 0.05, while an insignificant trend implies that the absolute value of Z-statistic is less than $Z_{\alpha/2} = 1.96$ with the level of significance (p-value) greater than 0.05. Similarly, no trend indicates that the absolute value of Z-statistic is less than the level of significance.

The results of the Pearson correlation coefficient and Mann-Kendall trend analysis of the predictability of equivalent continuous noise level (L_{eq}) and ambient temperature showed an increasing trend in all the study locations during dry season. This is in agreement with the existing literature that sound levels increase with increasing temperature (Loonkar, 2023). These results also agree with the findings of Amah and Atuboyedia (2020). The wet season results indicated an increasing trend for ambient temperature in all the study locations except at Wurukum Roundabout and SRS Junction where the ambient temperature showed a decreasing trend according to Pearson correlation, while the Mann-Kendall trend analysis indicated a decreasing trend for ambient temperature at Wurukum Roundabout and no trend at SRS Junction. The negative trends at Wurukun Roundabout and SRS Junction align with the findings of Sánchez-Fernández *et al*. (2021), Pachiappan and Govindaraj (2013) and Subramani *et al*. (2012) but disagree with the existing literature. The negative trends could be attributed to wind flow variation. Sound levels are higher downwind than upwind (Ovenden *et al*., 2011; DOD, 2018). Also, the relative humidity indicated a dcreasing trend in all the study locations during dry season. These results disagree with the existing literature that sound levels increase with increase in relative humidity (Mariyo *et al*., 2019). However, the results agree with the findings of Amah and Atuboyedia (2020) and Pachiappan and Govindaraj (2013). Similarly, during wet season, the relative humidity showed a decreasing trend in all the study locations except at Wurukum Roundabout and SRS Junction where the relative humidity showed an increasing trend according to Pearson correlation, while the Mann-Kendall trend analysis indicated an increasing trend for relative humidity at Wurukum Roundabout and no trend at SRS Junction. The observed decreasing trends could be attributed to wind flow variation. In the same light, the correlation of equivalent continuous noise level (L_{eq}) and wind speed showed an increasing trend in all the study locations during dry season except at SRS Junction where the wind speed showed a decreasing trend according to Pearson correlation, while the Mann-Kendall trend analysis indicated no trend for wind speed at Ankpa Ward Junction. The results at SRS and Ankpa Ward Junctions are in variance with the existing literature that sound levels increases with increasing wind speed (Trikootam and Hornikx, 2019). This could be due to the fact that the direction of noise measurement was against the wind direction. Conversely, the wet season results showed an increasing trend for wind speed in all the study locations except at Wurukum Roundabout where the wind speed showed a decreasing trend. The positive trend results also agree with the findings of Amah and Atuboyedia (2020).

The main limitation of this work is the inavailability of automated equipment with data logging for the continuous monitoring of sound pressure levels and atmospheric conditions at the study locations due to paucity of funds. These equipment when installed at the study locations could take readings over several months or years and even at night in order to establish more reliable results on the relationship between traffic noise and meteorological variables.

CONCLUSION

In this study,the parametric Pearson correlation coefficient and the non-parametric Mann-Kendall trend tests were used to analyse the relationship between road traffic equivalent continuous noise level and meteorological variables in Makurdi Metropolis. The results showed inconsistent trends across the different locations and seasons, with relative humidy exhibiting varying insignificant trends across the four locations and seasons with the only significant decreasing trend recorded at High Level Roundabout during the wet season. The ambient temperature showed significant increasing trends at two locations and seasons and insignificant trends in the other locations, while wind speed recorded insignificant increasing trends across all locations except for SRS Junction which recorded a significant increasing trend during the wet season which could be attributed to fluctuation in wind direction at the time of measurement of sound pressure levels. No consistent relationship was found between road traffic equivalent continuous noise levels and the meteorological variables. The study recommends implementing low-noise pavements and planting of ornamental trees and shrubs to absorb excess traffic noise and mitigate noise pollution.

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