ANALYSTS OF THE VARIATIONS TN SOME HETEOROLOGICAL ELEMENTS PERTINENT TO AIR POLLUTION PREDICTION

BY

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ANALYSIS OP THE VARIATIONS IN SOKE METEOROLOGICAL ELEMENTS PERTINENT TO AIR POLLUTION PREDICTION

By

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A thesis submitted to the postgraduate School, Ahmadu Bello University, zaria in partial fulfilment of the award of Master of Science (M.Sc.) degree in water Resources and Environmental Engineering.

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D E D I C A T I O N

This work is dedicated to my father Mallam Salau Osanaiye, my beloved mother, Mrs. Funmilayo Abibat Salau and my darling 'fiancee', Miss Funmilayo R. Adetutu.

D E C L A R A T I O N

I declare that this thesis was composed by me and that it is a record of my own investigation. It has not been submitted for any previous publication. All sources of information were acknowledged by references.

Salau, O.B. Elias 14/1/92

January, 1992

C E R T I F I C A T I O N

This thesis entitled, "Analysis of the variations in some meteorological elements pertinent to air pollution problems", by Salau, O.B. Elias meets the regulations governing the award of the degree of Master of Science (Water Resources and Environmental Engineering) of Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

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A C K N O W L E D G E M E N T

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ABSTRACT

Variations in the average daily windspeed, temperature and atmospheric pressure records in Ikeja and Kaduna were inverstiqated using time series analytical technique. Results of the harmonic analysis for windspeed showed that the periodic variations accounted for 40% of the total variance while the first, second and third harmonics were found significant. As for the temperature and atmospheric pressure records, the first and second harmonics were found significant accounting for 70% and 90% of the residual variance respectively. Further stochastic analysis on the windspeed residuals showed that the purely random components accounted for 70% of the remaining residuals while the corresponding values for temperature and atmospheric pressure were 50% and 20%.

The good agreement between the observed and predicted values of the elements showed that the predictive models can bo useful in forecasting pollutant concentrations within an industrial area if incorporated into the Gaussian Flume model.

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NOTATION

A, B, C	-	Fourier coefficients
α_o, α_i ; $i = N$	-	regression coefficients for trend analysis
B	-	coefficient which depends on stack.
C(x, y, z)	-	pollutant concentration at point (x,y,z)
E_t	-	Stochastic component of a time series
g*, g	-	Fisher's values for test of significance of harmonics.
γ_k	-	Tukey lag window.
H	-	Effective stack height
h_s	-	stack height
Δh	-	plume rise
λ_i	-	phase angle
m, n	-	coefficients which depends on atmospheric stability.
η_t	-	random variate.
K_x, K_y, K_z	-	eddy diffusivities in x, y, z direction
P_t	-	periodic component
P	-	atmospheric pressure
Q_p	-	source strength.
r_k	-	serial correlation coefficients
s_η^2, σ_η^2	-	sample and population variance of the random variate.
s_t^2, σ_E^2	-	sample and population variance of stochastic part.
ρ_k	-	autocorrelation function
σ_y, σ_z	-	dispersion coefficients in y and z direction
Ta, Ts	-	ambient and stack gas exit temperature.
T	-	fundamental period (365 days)
φ_q, i	-	moving average coefficient.

$\theta_{p,\,i}$	-	autoregressive coefficients of order p
$\bar{V}$, V	-	raw and smoothed normalized variance spectrum.
V_s	-	stack gas exit velocity.
$\bar{u}$, $\bar{v}$, $\bar{w}$	-	windspeed in x, y, z - direction.

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND

The management of air quality is an interdisciplinary field which requires the collaboration of meteorologists, chemists, engineers, health officials, ecologists, land-use planners, sociologists and economists (Munn 1976; Szepesi 1987). The problem could therefore be managed at either the local, regional, continental or global level with the objectives of each differing. At the local level, the objectives will be limited to the protection of human health using emission standards while regional scale may consider problems of land use.

The emission of gaseous wastes by some manufacturing industries into the atmosphere has been assuming a staggering proportion in recent times in Nigeria (Aguiyi, 1988). As an emerging problem, close study and monitoring of its trend is of utmost importance. One way of doing this is by modelling the pollutant transport in the atmosphere which is achieved by a combined action of molecular diffusion and turbulent mixing.

Of the several models currently available for the prediction of air pollutant concentration in ambient air, the Gaussian plume model is the most widely used (Ermak 1977, Szepesi 1987). Its widespread use is due to the availability of dispersion data and ease of application. The model, which is a simplified solution of the lagrangian description of the atmospheric transport, describes the pollutant concentration at any point downward of a source as a function of the windspeed, dispersion coefficients, source emission

strength and effective stack height. The effective stack height itself is the sum of the stack height and the plume rise. The plume rise can be determined by a number of equations as proposed by different researchers (e.g. Holland (1953); Moses (1968); Brigg (1971); Lalas and Karas (1977).

Holland (1953) showed by energy balance of the emitting pollutants and the environment that the plume rise depends on the windspeed, exit velocity, stack gas temperature, atmospheric pressure and the ambient temperature. However, Moses (1968) proposed a simple equation in terms of the windspeed and a coefficient which depends on stack parameter. Furthermore, Lalas and Karas in their discussion on the maximum ground level concentration presented by Ragland (1976) expressed the rise in terms of windspeed, down wind distance and a coefficient in a power law form in which the indices depend on atmospheric stability.

In addition, the dispersion coefficients are also directly dependent on the windspeed and the downwind distance. The dependence of plume rise, and the dispersion coefficients on the windspeed underscore the importance of windspeed ata on the accurancy of Gaussian plume model.

Szepesi (1987) pointed out that inaccuracies in model values could be attributed to uncertainties in meteorological input data, emission inventories and from the monitoring network set up for model confirmation. Of the three uncertainties, the meteorological input data seemed to be the gravest, for when other uncertainties are taken care of, Gaussian plume model has an accuracy of about 70% in stable atmospheric condition and may be in error by a factor of two in very unstable conditions. This condition

calls for review of the parameters on which the model depends; of which windspeed data is most prominent (Dobbins, 1979).

One of the techniques for extracting the most information from some data series is by time series analysis which was recognised as important task in air pollution meteorology (Szepesi 1987). The technique is useful when it is necessary to forcast some of the parameters that can enable the forcast of pollutant concentration at a future date. A compact form of the meteorological input data can hence be obtained by this method.

1.2 OBJECTIVES OF THE STUDY

The need to obtain a compact model describing the daily windspeed, temperature and atmospheric pressure data is paramount. This will not only remove the uncertainties in the meteorological input data, it will also enable the forcast of the most likely pollutant levels in the environment. Toward this goal, this research is designed with the following objectives:

(a) To investigate the nature of the daily variations in windspeed, temperature and atmospheric pressure in an area.

(b) To investigate the nature of the non-seasonal residuals with a view to developing a model explaining their variations.

(c) To develop models for predicting the daily average for windspeed, temperature and atmospheric pressure.

1.3 SCOPE OF THE STUDY

The analysis is limited to those of average daily records of windspeed, temperature and atmospheric pressure in Ikeja and Kaduna between 1970 and 1988.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 P R E A M B L E

There are two approaches to the description of the behaviour of pollutants in the atmosphere: Euler and Lagrange. In the Eulerian approach, the positions of the pollutants are described with respect to fixed co-ordinate system while the moving fluid is the basis of the Lagrangian approach. Each has its inherent difficulties which make exact solution of the pollutant concentration impossible (Seinfeld 1975). While the Eulerian method is mathematical in nature, the Lagrangian technique looks at the pollutants in terms of the probability of finding a specie at a particular position vector at any point in time.

2.2 EULERIAN APPROACH

In describing the pollutant behaviour in a turbulent fluid, a fixed co-ordinate system is designated with respect to the source and with the x-axis parallel to the wind direction, y-axis horizontal and normal to wind direction and the z-axis vertical and normal to wind direction. The general advection-diffusion equation governing atmospheric dispersion is of the form: (Seinfeld, 1975).

$$\frac{\partial c}{\partial t} + \bar{u}\frac{\partial c}{\partial x} + \bar{v}\frac{\partial c}{\partial y} + \bar{w}\frac{\partial c}{\partial z}$$

$$= \frac{\partial}{\partial x}\left(K_x \frac{\partial c}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial c}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial c}{\partial z}\right) + RI \quad \text{------(}$$

where $c(x,y,z)$ is the pollutant concentrate at point x,y,z with respect to the point source, $\bar{u},\bar{v},\bar{w}$, the average wind speed, K_x, K_y, K_z eddy diffusivities, RI, the reacting pollutant term

and SI, sink. The subscripts, x,y,z refer to x, y, z directions respectively (Seinfeld 1975). Ranca and Cuppett (1977), [illegible] the advection terms in y, and z direction because they are small compered to that in the x-direction, obtained the equation:

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} = \frac{\partial}{\partial y}\left(K_y \frac{\partial c}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial c}{\partial z}\right) \qquad (2)$$

Equation (2) does not include the effect of gravitational settling and deposition on the down-wind concentration of pollutants. These effects were first incorporated by Calder (1961) when he took the gravitational settling flux and the ground deposition flux to be proportional to the local air concentration. These effect would change atmospheric diffusion equation to:

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} = \frac{\partial}{\partial y}\left(K_y \frac{\partial c}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial c}{\partial z}\right) + W_z \frac{\partial c}{\partial z} \qquad (3)$$

where W_z is the particulate settling velocity.

Under steady state condition and sufficiently large windspeed, coupled with the fact that K_y, K_z are functions of the downwind distance, equation (3) reduces to a manageable form:

$$u\frac{\partial c}{\partial x} = K_y \frac{\partial^2 c}{\partial y^2} + K_z \frac{\partial^2 c}{\partial z^2} + W_z \frac{\partial c}{\partial z} \qquad (4)$$

This was the basis of the analytic solution proferred by Ermak, (1977). Although Rounds (1955), Smith (1962) and Heines and Peters (1974) as reported in Ermak (1977) and Seinfeld (1975) have obtained analytic solutions to this atmospheric transport equations for a number of cases, the solutions have not been extensively used. This is due to their complicated nature and the difficulty in applying them under a variety of atmospheric stability conditions. Other researchers such as Sulton (1952) Smith (1957), Pasquill (1974) have found exact solutions to equation (4) for some boundary conditions and different expli[illegible]

for u, K_y, K_z as functions of the independent variables, x,y,z.

The complex nature of the equations has also led to the use of numerical methods of which there have been many propositions (e.g. Randerson,(1970) Skarew(1970) Shir(1972) Egan and Mahonney(1972) Shir and Sheih(1973). All these techniques have their limitations and cannot be applied in areas different from where they have been developed (Szepezi 1987).

2.3 LAGRANGIAN APPROACH

This approach is concerned with the behaviour of fluid particle with the mathematical equation governing the motion based on the probability of finding a fluid particle at location x,y,z, at time t. A general expression for the concentration c(x,y,z,t) which takes account of the initial particle distribution and the spatial - temporal distribution of particles sources S(x,y,z,t) was given by Seinfeld (1975) and Dobbins (1979) as:

$$C(x,y,z,t) = \iiint Q(X,t/X_o,t_o)\,\bar{C}(X_o t_o)\,dx\,dy\,dz + \int_{t_o}^{t}\iiint Q(X,t/X',t')S(X,t) \qquad (5)$$

The first term of equation (5) represents the particles present at time t_o while the second accounts for particles added from sources between t' and t. The evaluation of the equation also depends on the correct evaluation of the transition probability distribution function Q. Equation (5) becomes more complex if a reaction term is added. However, its solution has been obtained

after some simplifications and assumptions. One of such models is the Gaussian plume model which Seinfeld (1975) showed, was a special solution of the Lagrangian description of pollutant transport when the emission of the point source is considered as puffs with infinitesimal emission time lapse.

2.3.1 GAUSSIAN PLUME MODEL

This is the most widely used model for stack design and environmental impact analysis. It has achieved widespread use for computation of the spatial distribution of pollutant concentration for a point source because it is easy to use, plume dispersion data are available and that most measured data fit reasonably well into the model, (Whaley 1974, Shun et al. 1975; Szepezi, 1987; Ermak 1977). The model is based on the following assumption (Mahoney 1974; Dobbins 1979);

(a) Constant wind speed and direction in the vicinity of the point source. However Herman (1979) has incorporated the windshear to increase accuracy.

(b) Effluent centre remains constant downstream after equilibrium plume height is reached.

(c) The maximum concentration at any downwind distance occurs at the centre line.

(d) The concentration profiles are average over some time, typically one hour.

(e) None of the effluent is lost implying that there is reflection of material into the atmosphere.

(f) The emission rate is constant and the pollutants are chemically inert.

The inability of this model to account for unsteady emission rate, varying meteorological conditions and uncertainties in plume trajectories notwithstanding, it is still one of the best models for environmental impact assessment.

For a point source discharging at an effective emission height H(m), under a constant windspeed u(m/s), and a source strength ($g/m^3 s$), the concentration at point (x,y,z) downstream of the source is given as:

$$C(x,y,z) = \frac{Q_p}{2\pi \sigma_y \sigma_z u} \exp\left[-\tfrac{1}{2}\frac{y^2}{\sigma_y^2}\right]\left\{\exp -\tfrac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2 + \exp -\tfrac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right\} \quad (6)$$

where σ_y, σ_z are the dispersion coefficients along the y and z - direction respectively while the x-axis is oriented along the direction of the wind. The ground level concentration, (z = o) can be obtained from the equation:

$$C(x,y,\ 0,H) = \frac{Q_f}{\Pi\ u\ \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2} - \frac{H^2}{2\sigma_z^2}\right) \quad (7)$$

Equation 7 is important in assessing the health risk of pollutants in an industrial district in high risk areas such as schools, hospitals, markets etc.

The dispersion coefficients, determined from the travel time, are functions of the windspeed and the state of the incoming or outgoing radiation and have been determined for different atmospheric stability classes. Although Gifford (1961) provided separate graphs for the dispersion coefficient for different classes as a function of downwind distance, they are now expressed in power law forms as:

$$\sigma_z = a x^b$$
$$\sigma_y = c x^d \qquad (8)$$

where a,b,c,d are constant which depend on stability class

The effective stack height H is the sum of the actual stack height and the plume rise which arise from the buoyancy of the hot gases released into the atmosphere. The plume rise, Δh, is given by (Dobbin 1979) as:

$$\Delta h = \frac{V_s d}{u} \left(1.5\ 10^{-3} p + \frac{T_s - T_a}{T_s}\right) \qquad (9)$$

$$\Delta h = 1.32\ L_p \left(\frac{xp}{L_p}\right)^{2/3} \qquad (10)$$

$$\text{where } L_p = \frac{g(T_s - T_1)\ w_s b_s^2}{T_1 u^3} \qquad (11)$$

and X_p is the centre line distance from the stack mouth.

Other researchers have expressed the plume rise in terms of the windspeed and a coefficient (Moses 1968):

$$\Delta h = \frac{B}{u} \qquad (12)$$

where B is a coefficient that depends on effluent gas velocity, temperature, stack diameter and other parameters. Lalas and Karas (1977) postulated that the plume is of the form:

$$\Delta h = B u^n X^m \qquad (13)$$

where B depends on stack parameter, n and m are coefficients that take different values depending on stability prediction or windspeed concentration in the atmosphere.

Where the windspeed u, is required at position different from the reference point, z_o, the power law form of wind velocity is used:

$$u = u_o (z/z_o)^k \quad (14)$$

where

u_o is the reference windspeed,

k is a coefficients that depends on stability class and given by Klug (1969). Herman (1979) gave the average windspeed at a level H, including the effect of wind-shear as:

$$\bar{u} = \frac{u_o}{k+1} \left(\frac{H}{z_o}\right)^k \quad (15)$$

This gives the final form of the plume rise as:

$$\Delta h = \beta \left[u_o \left(h_s/z_o\right)^k\right]^n x^m \quad (16)$$

The effective stack height becomes:

$$H = h_s + \beta \left[u_o \left(h_s/z_o\right)^k\right]^n x^m \quad (17)$$

The dependence of the effective stack height , on the windspeed underscores the importance of windspeed in the Gaussian plume model.

2.3.2 OTHER MODELS

Ground deposition of pollutants is accounted for in Gaussian plume model by creating an image in which all materials falling on ground is reflected back into space. This condition often leads to overestimation of the ambient air concentration further from the point source and underestimation near the source. This defect is accounted for in the source depletion model proposed by Chamberlain (1960) which has received widespread use (Hosker 1973, Martin et al. 1974, Heffler and Ferber 1975) and is considered by Pasquil (1974) as a pertubation of the Gaussian

plume model. Ground deposition is accounted for by virtual decrease of the source strength downwind of the point source with the shape of the vertical plume profile assumed to be maintained.

Horst (1977) reported that better pollutant concentration can be obtained by selectively depleting the Gaussian plume in the vicinity of the deposition surface rather than throughout the vertical extent of the plume as done in the source depletion model. This is the so-called surface depletion model which is an aberration of the Gaussian plume model. The model was found to uncover the anomaly inherent in air pollutant concentration predicted by the source depletion model.

2.4 MODEL LIMITATIONS

Mahonney (1974) identified some conditions which must be satisfied by a model before it can be useful for urban planning studies and environmental impact analysis. Apart from being able to deal with completely arbitrary distribution of sources and emission rates variable in space and time, it must allow for temporal variations for wind and temperature structure. The need to predict the ground level concentrations for inert and chemically reacting pollutants must also be met. To be sure therefore, not one model meets all these requirements.

The analytic solutions of the atmospheric advection diffusion equations have not yielded very practical prediction of the pollutant concentration. Furthermore attempts made to solve the problem using the numerical method by finite difference have not yielded a generally acceptable numerical model. There

are as many models as there are researchers (Randerson 1970; Skarew (1970) Shir (1972) Ragland and Dennis 1975); Egan and Mahonney (1972). Each of the numeric model so developed may not be applicable in other areas (Szepesi 1987).

One model with widespread acceptance in impact analysis is the Gaussian plume model; though it still has a drawback of not incorporating the reacting component. In addition, most of its parameters such as the atmospheric stability class, dispersion coefficients and the plume rise are dependent on windspeed, temperature and pressure. Because the model is based on constant windspeed and direction, it cannot be presently forecast the likely pollutant concentrations at a future date. It is for this reason therefore that a time series analysis was carried out on the wind data, temperature and atmospheric pressure to see if it is possible to predict these parameters that are so important in this widely used model.

2.5 THEORY OF STUDY

2.5.1 NATURE OF TIME SERIES

Time series analysis is a powerful statistical tool for the analysis of time dependent records which can be decomposed into three major components: trend, period and stochastic. The trend and periodic components are said to be deterministic and can be determined for predictive purposes. On the other hand, the stochastic components consists of chance and chance-related effects which cannot be accounted for. One important characteristic that time series must possess is stationarity. They can also be ergodic or non-ergodic.

Time series can be decomposed into a model of the sort

$$X_t = T_t + P_t + E_t \qquad (18)$$

where T_t, P_t are the trend and the periodic component respectively. The stochastic component, E_t, can be divided into a sequentially dependent part and the completely random part. Other natural process may be more accurately fitted with a multiplicative model of the sort:

$$X_t = T_t P_t E_t \qquad (19)$$

Equation (19) can be linearised by taking logarithms. However most natural phenomena can be accurately described by linear models (Yevjevich 1972).

2.5.2

TREND ANALYSIS

Trend is the steady and regular movement in time series in which the values are either increasing or decreasing.

Polynominal, linear and exponential fittings can be made for trend analysis in a series. The fittings are of the forms: (Kottegoda, 1980).

$$X_t = X_o + \alpha_1 t + \alpha_2 t^2 + \ldots\ldots \alpha_n t^n + P_t + E_t \quad \text{(polynominal)} \tag{20a}$$

$$X_t = X_o + \alpha_1 t + P_t + E_t \quad \text{(linear)} \tag{20b}$$

$$X_t = X_o \exp(\alpha_1 t + \alpha_2 t^2 + \ldots\ldots \alpha_n t^n) + P_t + E_t \quad \text{(exponential)} \tag{20c}$$

where X_t is the datum at position t in the sequence and $X_o, \alpha_1, \alpha_2, \alpha_3 \ldots\ldots \alpha_n$ are regression coefficients.

The regression coefficients can be determined by regression analysis using least square method of which an algorithm was presented by Kendall (1976). However, the problem of prediction and estimation of the coefficients make the use of filtering methods more common. Common filtering methods are moving averaging and variate differencing with the moving average being most acceptable (Dawdy and Matalas 1964).

As an undesirable effect, trend removal can induce artificial cycles in the data. There is therefore the need for care when describing the oscillatory character of time series in which trend is removed by moving average (Dawdy and Matalas 1964). Kottegoda (1980) opined that trend analysis should only be carried out on long record of annual data.

2.5.3 HARMONIC ANALYSIS

The periodic component is imposed on the series by cyclic phenomenon such as the earth revolution in an elliptical orbit around the sun. The earth rotation also imparts periodic characteristic of a diurnal nature. In addition, the revolution of the moon around the earth results in lunar cycle.

The periodic components are represented by a system of sine functions on estimation and removal of the trend. For a trend-free set X_t t = 1, 2, 3 ..... N of a variable collected at the same time interval, the periodic component is of the form:

$$X_t = \mu + \sum_{i=1}^{L} C_i \sin\left(\frac{2\Pi\, i\, t}{T} + \lambda_i\right) + E_t \qquad (21)$$

where

u = population mean, $E(X_t)$

$\frac{i}{T}$ = frequency of harmonic i

$\frac{T}{i}$ = wavelength of harmonic i

C_i = amplitude, and λ_i phase angle of the ith harmonic, while T is the fundamental period. The maximum value of L in equation 21 is:

$$L = \begin{cases} N/2 & N, \text{ even} \\ (N-1)/2 & N \text{ odd} \end{cases} \qquad (22)$$

Equation 21 can also be written as:

$$X_t = \mu + \sum_{i=1}^{L} A_i \sin \frac{2\Pi it}{T} + \sum_{i=1}^{L} B_i \sin \frac{2\Pi it}{T} + E_t \qquad (23)$$

Kottegoda (1980) showed that the values of A_i, B_i can be determined by method of least square and are given by:

$$A_i = \frac{2}{N} \sum_{t=1}^{L} X_t \sin \frac{2\Pi it}{T} \; ; \; i = 1,2,\ldots \frac{L}{2} - 1 \qquad (24)$$

and

$$B_i = \frac{2}{N} \sum_{t=1}^{L} X_t \cos \frac{2\Pi it}{T} \; ; \; i = 1,2, \frac{L}{2} - 1 \qquad (25)$$

$$B_{L/2} = \frac{1}{L} \sum_{t=1}^{L} X_t (-1)^t \qquad (26)$$

The actual harmonics to be fitted can be found by analysis of variance. The variance of the ith harmonic

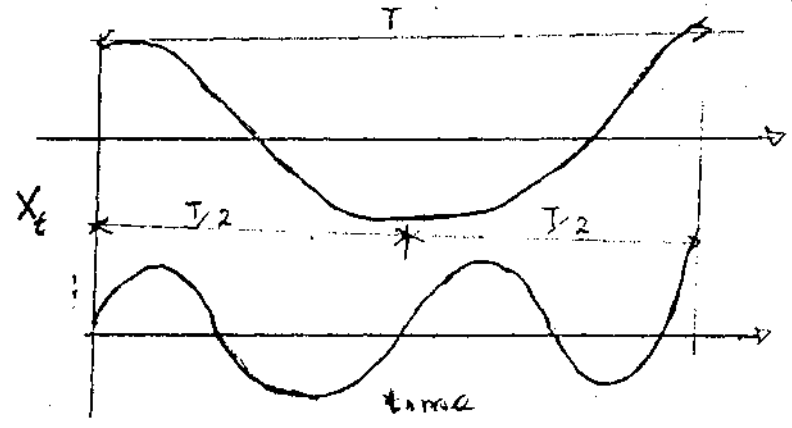


Fig. 1: Harmonic decomposition of time series.

is $C_i^2/2$, where

$$C_i^2 = A_i^2 + B_i^2 \qquad (27)$$

Significant harmonics can be determined by Fisher test (1940) which was presented in Yevjevich (1972).

2.5.3.1 TESTING THE SIGNIFICANCE OF HARMONICS

The significance of the ith harmonic is tested in terms of the variance $C_i^2/2$. Once the variance is found significant, its phase angle is estimated from the computed values of A_i, B_i.

Of the various tests available, Fisher's test is most acceptable which is based on the ratio

$$g_1 = C^2_{max}/2\, S_x^2 \qquad (28)$$

The ratio tests the significance of harmonic with C^2_{max} the largest value of the sequence of C_j^2 values and S_x^2, the estimate of the variance of the data. The probability that the g_1 values would exceed the critical is given by: (Yevjevich, 1972).

$$P_f = L(1-g)^{L-1} - \frac{L(L-1)}{2}(1-2g)^{L-1} + \\ + (-1)^{k-1} \frac{L!\,(1-kg)^{L-1}}{k!\,(L-k)!} \qquad (29)$$

where

k is the greatest integer less than L.

The first term gives a sufficient approximation of the g-critical.

Table 1 gives the values at P_f of 0.05 and 0.01.

Table 1: Number of harmonics and Fisher's g-values for time intervals of discrete series.

Time interval	W	L	g - critical P = 0.05	g - critical P_f = 0.01
1 day	365	182	0.04429	0.05275
2 days	182	91	0.08002	0.09632
7 days	52	26	0.22131	0.26986
14 days	26	13	0.37085	0.44982
1 month	12	6	0.61615	0.72179
2 months	6	3	0.87090	0.94226
3 months	4	2	0.97560	0.9950

Source Yevjevich (1972).

If two or more harmonics are significant, the C - values are arranged in a descending order of magnitude and each tested for significance using this equation. (Yevjevich, 1972).

$$g_i = \frac{C_i^2}{2 S_x^2 - \sum_{J=1}^{i-1} C_j^2} \qquad (29)$$

where each C_j^2 values in the sum is greater than C_i^2. This approach may however be biased since part of the variance corresponding to the random variable is deducted. In addition, all harmonics that per chance have the squares of amplitude at the tails of their distribution are automatically accepted as significant. A second approach put forward by Fishers (1940) investigates the significance of two or more harmonics at the same time with the g-critical given as:

$$P_f = \sum_{j=i}^{K} (-1)^{j-i} \frac{L!\ (1-jg)^{L-1}}{(L-j)!\ (j-i)!\ (L-i)!\ J!} \qquad (30)$$

Equation 30 is identical to (28) when i = 1. For i = 2, it becomes

$$P_f = L(-L-1)\ \frac{(1-2g)^{L-1}}{2} - \frac{(L-2)(1-3g)^{L-1}}{3} + \qquad (31)$$

The g - values may similarly be obtained if P_f is prescribed. It may be difficult to select significant harmonics where sets of g - values do not meet the requirement. This is usually resolved by variance spectrum analysis.

2.5.3.2 AUTOCORRELATION

The degree of linear dependence between events k - apart is measured by autocorrelation function. For continuous series, it is defined as (Kottegoda, 1980)

$$\rho_k = \frac{\frac{1}{T-k} \int_0^{T-k} (X_t - \mu)\ (X_{t+k} - \mu)\ dt}{\frac{1}{T} \int_0^{T} (X_t - \mu)^2\ dt} \qquad (32)$$

$$-1 \leq \rho_k \leq 1$$

Also, $\rho_{-k} = \rho_k$, i.e. ρ_k is an even function. For an observed discrete sequence X_t, t = 1, 2, ... N, the serial correlation coefficient is obtained by correlating X_t, t = 1, 2 .... N-k, and X_{t+k} t = 1, 2, ... N-k, using this equation:

$$r_k = \frac{\frac{1}{N-k} \sum_{t=1}^{N-k} X_t\, X_{t+k} - \frac{1}{(N-k)^2} \sum_{t=1}^{N-k} X_t \sum_{t=1}^{N-k} X_{t+k}}{\left[\mathrm{Var}\,(X_t) \cdot \mathrm{Var}\,(X_{t+k})\right]^{\frac{1}{2}}} \qquad (33)$$

where

$$\text{Var}(X_t) = \frac{1}{N-k}\sum_{t=1}^{N-k} X_t^2 - \frac{1}{(N-k)^2}\sum_{t=1}^{N-k} X_t \sum_{t=1}^{N-k} X_t$$

$$\text{Var}(X_{t+k}) = \frac{1}{N-k}\sum_{t=1}^{N-k} X_{t+k}^2 - \frac{1}{(N-k)^2}\left(\sum_{t=1}^{N-k} X_{t+k}\right)^2$$

Equation (33) can be approximated by

$$r_k = \frac{\sum_{t=1}^{N-k} (X_t - \bar{X})(X_{t+k} - \bar{X})}{\sum_{t=1}^{N} (X_t - \bar{X})^2} \qquad (34)$$

in which

$$\bar{X} = \frac{1}{N}\sum_{t=1}^{N} X_t$$

Equation (33) should be used when N is large and is especially recommended from spectral view point Jenkins and Watts (1968).

For a series with cyclic component, the serial correlation is given by:

$$r_k = \cos\frac{(2\Pi k)}{T} \qquad (35)$$

Generally, serial correlation increase with closeness of the spacing.

2.5.3.3 SPECTRAL ANALYSIS

A time series is regarded as a combination of basic frequencies of occurence of random variables which can be decomposed. According to Wienner (1949) and Khintchine (1954) the variance spectrum and the autocovariance function are Fourier transform of each other. This was proved by Lee (1960).

Oladipo (1988) examined three methods of spectral analysis and concluded that maximum enthropy spectral analysis gives better frequency resolution than either the periodogram or the non integer method. However, the method is sensitive to the number of terms of filter. The resolved periodicities cannot as at now be tested for significance. Therefore the periodogram method will be adopted in this work.

For a discrete series, the variance density is defined as:

$$V(f) = \sum_{k=-\infty}^{\infty} r_k \cos (2\Pi f K\Delta t)$$

$$\frac{1}{2\Delta t} \leq f \leq \frac{1}{2\Delta t} \qquad (36)$$

In most cases, the integral is finite. The truncation point M corresponds to the limiting frequency with a range of 0.2N - 0.5N (Haykin and Kesler 1979). The normalised operational form of the variance density is:

$$\bar{V} = (r_o + 2 \sum_{K=1}^{M-1} r_k \cos (2\Pi fk) + r_m \cos$$

$$2\Pi fM) \ /M \qquad (37)$$

Equation 37 gives a raw estimates of the variance density and to offset the small reliability at higher lags, a weight (Turkey Lag window) is applied.

$$\gamma_k = 0.5 \quad 1 + \cos (\Pi k/M) \qquad (38)$$

Smoothing may also be achieved by Hanning or Hamming method using the weighted average of three terms. By hanning,

$$V_k = 0.25\,\bar{V}_{k-1} + 0.50\,\bar{V}_k + 0.25\,\bar{V}_{k+1} \qquad (39)$$

where k = 2, 3 ..... M-1. The terminal spectral density estimates are given by.

$$V_1 = 0.50\,\bar{V}_1 + 0.50\,\bar{V}_2 \qquad (40)$$

$$V_m = 0.50\,V_{m-1} + 0.50\,\bar{V}_m$$

2.5.4 ANALYSIS OF THE STOCHASTIC COMPONENT

The stochastic component are chance and random component of an observed series and is analysed after the estimation and removal of the trend and periodic component. Stochastic models can be linear, autoregressive(AR) moving average,(MA) and autoregressive moving average(ARMA) Normally, a series is tested to see which of these models fit the observed sequence.

2.5.4.1 LINEAR AUTOREGRESSIVE MODEL (AR)

In this model, a current value of a variable is assigned to the weighted sum of a preassigned number of past values and a variate that is completely random. First proposed by Markov (1907), theoretical analysis made by Wold (1954) with a systematic methodology presented by Box and Jenkins (1976), the pth order AR(p) is of the form,

$$E_t = \sum_{i=1}^{p} \theta_{p,i}\, E_{t-i} + \eta_t \qquad (41)$$

where $\theta_{p,i}$ are the autoregressive parameters to be determined. E_t, and η_t have the following properties $E(E_t) = 0$, $E(\eta_t) = 0$,

Var $(E_t) = \sigma_E^2 = E(E_t^2)$, $E(\eta_t \eta_{t-k}) = E(\eta_t E_{t-k}) = 0$, and $\sigma_k = E(E_t E_{t-k})/\sigma_w^2$. For simplicity, $\sigma_E^2 = 1$ implying that all numbers generated must be multiplied by σ_E.

The estimation of the autoregressive parameters can be achieved by obtaining the Yule - Walker equation which was shown by Jenkins and Watts (1968) gives the approximate maximum likelihood estimate. A simpler but equally reliable method is by the general recursive formulae (Durbin 1960). For the pth order model, the recursive estimates are:

$$\theta_{p,p} = \frac{\left(r_p - \sum_{j=1}^{p-1} \theta_{p-1,\,j}\, r_{p-j}\right)}{1 - \sum_{j=1}^{p-1} \theta_{p-1,\,j}\, r_j} \qquad (42)$$

$$\theta_{p,j} = \theta_{p-1,\,j} - \theta_{p,p}\, \theta_{p-i,\,p-j} \qquad (43)$$

More sophisticated methods using maximum likelihood and modified least square principles (Box and Jenkins (1976), Hippel et al, 1977) were found to be practically unsuitable. (Kottegoda 1980). The variance of the random variate is computed using:

$$\sigma_\eta^2 = 1 - \sum_{i=1}^{p} \theta_{p,i}\, r_i \qquad (44)$$

The order p is indicated by a plot of the $\theta_{k,k}$ against k and is equal to the value of p when $\theta_{k,k}$ is theoretically equal to zero for $k > p$. Anderson (1942) gave the variance of the estimated partial autocorellation $\theta_{k,k}$ as:

$$\text{Var}\,(\theta_{k,k}) = \frac{1}{N},$$ N sample length and 95% confidence limit as $1.961/\sqrt{N}$.

The order can also be chosen by a plot of the estimated residual variance S_ζ^2

$$S_\zeta^2(k) = \frac{N-k}{N-2k-1} \prod_{i=1}^{k} (1-\theta_{i,i}^2)\, S_E^2 \qquad (45)$$

A suitable order p is that in which the residual variance is a minimum or does not decrease significantly.

2.5.4.7 AUTOREGRESSIVE MOVING AVERAGE (ARMA)

ARMA (p, q)

This is a combination of the autoregressive model of order p and the moving average of order q. It is of the form:

$$E_t = \sum_{i=1}^{p} \theta_{p,i}\, E_{t-i} + \zeta_t - \sum_{i=1}^{q} \phi_{q,i}\, \zeta_{t-i} \qquad (46)$$

The estimation of the parameters of the ARMA (p, q) model is not straight forward and can be formulated by following the method used for estimation of ARMA (1, 1). Kottegoda, (1980) also noted that ARMA (1, 1) is most adequate for natural process and would only be considered.

ARMA (1, 1) model is of the form

$$E_t = \theta_{11}\, E_{t-1} + \zeta_t - \ell_{11}\, \zeta_{t-1} \qquad (47)$$

An initial estimate of the $\hat{\theta}_{11}$ and $\hat{\phi}_{11}$ can be obtained from the serial correlation coefficients which are related to θ_{11}, ℓ_{11} as follows:

$$r_1 = \frac{(1 - \theta_{11}\phi_{11})(\theta_{11} - \phi_{11})}{1 - \phi_{11}^2 - 2\theta_{11}\phi_{11}} \qquad (48a)$$

for $k \geq 2$

$$r_k = \theta_{11}\rho_{k-1} \qquad (48b)$$

Estimate of θ_{11} and ϕ_{11} can also be obtained by minimising the sum of squares of the residuals given as:

$$S = \sum_{t=1}^{N} \bar{E}_t \qquad (49)$$

where $\bar{E}_t = \bar{E}_t - \theta_{11} E_{t-1} + \phi_{11} \bar{E}_{t-1}$

Making a grid search, the set of values of θ_{11} and ϕ_{11} that gives the minimum S is the best estimate of θ_{11}, and ϕ_{11}.

The search is made subject to $1 - \leq \theta_{11} \leq 1$ and $-1 \leq \phi_{11} \leq$

This latter approach was adopted for this work.

2.5.4.3 VERIFICATION OF MODEL

To verify the suitability of the model used, a test of independence of the residuals is carried out. The residuals are estimated as follows. ((Kottegoda, 1980)

- pth order autoregressive model.

$$\zeta_t = E_t - \sum_{k=1}^{p} \hat{\theta}_{p,k} E_{t-k} \qquad (50)$$

- autoregressive moving average of order p, q

$$\zeta_t = E_t - \sum_{k=1}^{p} \theta_{p,k} E_{t-k} + \sum_{k=1}^{q} \phi_{q,k} \zeta_{t-k} \qquad (51$$

Graphical verification can be done by a plot of serial correlation of $\hat{\zeta}_t$. For the model to be suitable, the serial correlation must lie within the 95% confidence band. (Kottegoda, 1980).

CHAPTER THREE

3.0 DATA COLLECTION AND ANALYSIS

3.1 DATA COLLECTION

Usually, hourly record of most meteorological elements such as windspeed and direction, temperature, atmospheric pressure, relative humidity, etc. are kept by the Federal Meteorological Service. The data collected at most airports and aerodromes throughout the country are sent to the head-quarters in Oshodi, Lagos. For this work, three of the elements were collected, viz: windspeed, temperature and atmospheric pressure. They were chosen because they feature prominently in the Gaussian plume model which is used for air pollutant concentration modelling. Data for Kaduna and Lagos (Ikeja) between 1977 - 1988 were used.

In a work of this nature, the number of years of data collected is of paramount importance. Various researchers have suggested various periodicities for the common hydrologic and meteorological element. Kottegoda(1980) suggested that complete reversals of most meteorological observations occur over a period of 200 years. However most stations cannot have such length of data and shorter durations are often used. This was adopted by Thomann (1967) and Kothandaraman (1971), who on the basis of analysis of three years of average daily temperature and surface water got a model for predicting the parameters.

About 15 years of daily average of the elements were considered in this work. Gaps in the series were handled by a method suggested by Thomann (1967) where linear interpolation was used.

3.2 DATA ANALYSIS

The daily observations for the elements were [illegible] therefore require a computer facility. For this reason, a FORTRAN programme was developed consisting of a main programme and six subroutines. (See appendix I).

3.2.1 TREND ANALYSIS

Trend analysis is normally carried out on annual data series. Since the present work was limited to daily data, trend analysis was excluded. This decision is in consonance with the works of Thomann (1967) and Kothandaraman (1971) who analysed respectively hourly and daily records without trend analysis. Kottegoda (1980) suggested that trend analysis should be carried out on long record of annual data.

3.2.2 DATA INPUT

Files were opened for input and output. Because the analysis was carried out on a yearly basis, the year, NYE, the number of data per line NH, and the number of lines per element in a year, ND, the number of elements NP, the order of the linear autoregressive model to be fitted for each of the element subject to a maximum order of six (p = 6) and the period T were given in the first line of the input file. Where ARMA (1, 1) is to be fitted, 0 should be inputed for NA(I). For this work, NH, ND,

NP are respectively 16, 23 and 3. T could be 365.25 days while the data were input in this order: windspeed, temperature and atmospheric pressure. The data were read into an array XC(3, 23, 16) and serialised in X1(366).

3..2.3 HARMONIC ANALYSIS

The Fourier coefficients A_i, B_i, C_i and phase angles λ_i, were determined in the main programme for the first twenty [illegible]. Variance accounted for the first twenty harmonics were also computed.

3.2.4 AUTOCORRELATION AND VARIANCE SPECTRA

The mean, variance and standard deviation of each element were computed in the main programme. To determine the serial correlation coefficients for the first fifty lags, a subroutine AUTOCORR was used. The correlogram is plotted in another subroutine GRAPH 1. On the other hand, the spectral analysis is executed in the subroutine VARSP and the result plotted in another graphing subroutine GRAPH 2.

3.2.5 ANALYSIS OF THE STOCHASTIC COMPONENT

Before the stochastic components were analysed, the periodic components were removed from the original series. This is done in the main programme. The serial correlations of the non-seasonal components were analysed in the subroutine AUTOCORR and plotted in GRAPH 1 subroutine. The spectral densities of these residuals are computed in subroutine VARSP and plotted in GRAPH 2 subroutine.

The linear autoregressive analysis was executed in the subroutine AUTOREGRESS which was due to Kottegoda (1980) but modified into a 3x3 matrix. The maximum p was limited to 6 but could be changed by changing the dimensions. The autoregressive parameters were determined by recursive method. The random variate D, were therefore computed by removing the autoregressive part.

The coefficients of ARMA (1, 1) model were determined in subroutine ARMA by minimising the sum of squares of the residuals subject to the invertibility and stationarity conditions. Values of the parameters were increased in steps of 0.05 in both the positive and negative directions and considering all possible combinations. The minimum least square was selected in another section of the subroutine along with the values of parameters. The random variate were computed in the main programme as well as the variance and standard deviation of the residuals.

The flow chart for the programme is shown in Fig. 2 while the programme list is in appendix I.

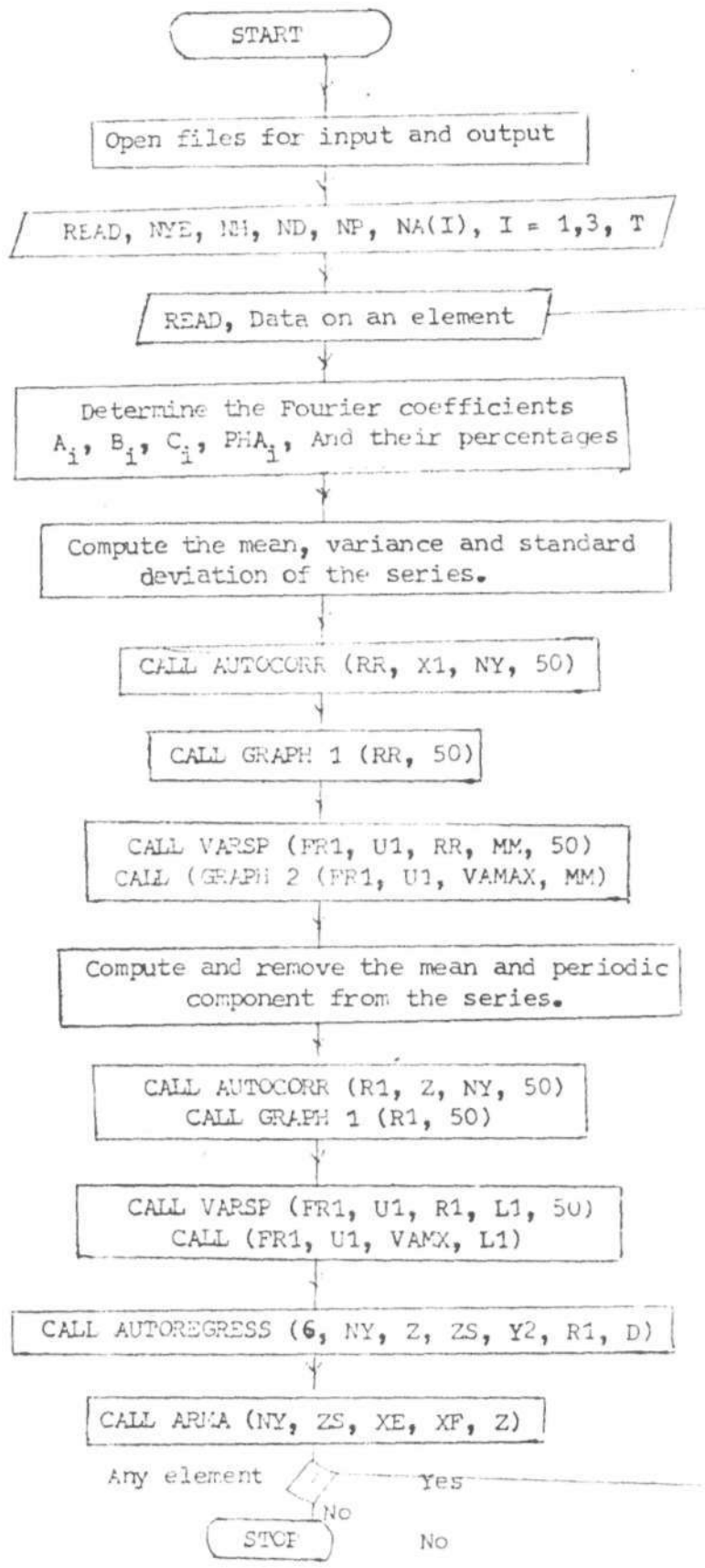


Fig. 2: Flow chart for the programme.

4.0 RESULTS AND DISCUSSIONS

4.1 I N T R O D U C T I O N

This section contains the summary of the results of the computer analysis for windspeed, temperature and atmospheric pressure data for the period 1970 - 1988. Following the procedure adopted by Thomann (1967) and Kothandaraman (1971), the data were analysed on a yearly basis giving a fundamental period of 365 days.

4.2 CHARACTERISTICS OF WINDSPEED, TEMPERATURE AND ATMOSPHERIC PRESSURE

Certain characteristics of the records were determined to see their variations, if any, from year to year, viz: mean, variance and standard deviation. Tables 2, 3 and 4 contain the values for windspeed, temperature and atmospheric pressure respectively. Because the mean, variance and standard deviations were determined on a yearly basis, the pooled values of these parameters are calculated using these equations.

$$\mu = \frac{\sum_{i}^{n} N_i \bar{X}_i}{N_i} \qquad (53a)$$

and

$$s^2 = \frac{\sum_{i=1}^{n} N_i S_i^2}{N_i - n} \qquad (53b)$$

where $\bar{X}_i$ is the mean of the element for the ith year, S_i^2, variance of ith year, N_i, the number of days in ith year and n is the number of years considered.

Table 2: Characteristics of Windspeed Record

YEAR	IKEJA, LAGOS Mean (m/s)	Variance (m^2/s^2)	Std. Dev. (m/s)	YEAR	KADUNA Mean (m/s)	Variance (m^2/s^2)	Std. Dev. (m/s)
1970	2.19	0.361	0.601	1970	3.13	0.814	0.902
1971	2.91	0.456	0.675	1972	2.43	0.758	0.871
1972	2.62	0.456	0.675	1973	2.42	1.133	1.064
1973	2.68	0.369	0.607	1974	2.35	1.591	1.261
1974	2.81	0.379	0.616	1975	2.79	1.382	1.176
1975	2.79	0.721	0.849	1976	2.65	0.909	0.953
1978	2.62	0.257	0.507	1977	3.01	1.575	1.255
1980	1.60	0.363	0.602	1978	2.60	1.305	1.142
1981	1.63	0.427	0.653	1979	2.40	1.148	1.07
1982	2.936	0.466	0.683	1980	2.82	1.623	1.274
1986	2.26	0.337	0.581	1981	2.79	1.530	1.237
1987	2.16	0.411	0.641	1984	2.84	1.114	1.055
1970-5	2.66	0.509	0.713	1985	2.95	1.095	1.047
1980-2	1.52	0.326	0.571	1986	2.75	0.960	0.980
1986-7	2.25	0.446	0.668	1987	2.63	1.106	1.052
				1972-81	2.62	1.33	1.157
				1984-87	2.80	1.082	1.040

Table 3: Characteristics of Temperature Records.

YEAR	IKEJA, LAGOS Mean °C	Variance °C²	Std. Dev. °C	YEAR	KADUNA Mean °C	Variance °C²	Std. Dev. °C
1970	25.87	2.10	1.45	1970	24.46	5.99	2.45
1971	25.61	2.66	1.63	1972	24.45	4.38	2.09
1972	26.19	1.52	1.23	1973	25.05	5.17	2.27
1973	26.58	2.23	1.49	1974	24.15	6.12	2.47
1974	25.74	1.73	1.32	1975	24.05	5.64	2.37
1975	25.63	1.87	1.37	1976	24.10	4.50	2.12
1978	26.22	3.63	1.91	1977	24.30	5.69	2.39
1980	26.29	2.11	1.45	1978	24.24	4.53	2.13
1981	26.04	5.43	2.33	1979	24.82	4.74	2.18
1982	26.24	2.72	1.65	1980	24.83	5.45	2.33
1986	26.49	2.27	1.51	1981	24.59	5.59	2.37
1987	27.14	2.98	1.73	1984	25.07	6.34	2.52
1970-5	25.94	2.12	1.46	1985	25.18	4.66	2.16
1980-2	26.91	2.41	1.55	1986	25.34	6.74	2.60
1986-7	26.19	3.42	1.85	1987	25.84	5.81	2.41
				1972-81	24.46	5.28	2.30
				1984-87	25.36	5.96	2.44

This computation was in respect of the years which were continous.

Table 4: Characteristics of Atmospheric Pressure.

YEAR	IKEJA, LAGOS Mean mbar	Variance $(mbar)^2$	Std. Dev. mb	YEAR	KADUNA Mean mb	Variance mb^2	Std. Dev. mb
1970	1006.52	3.13	1.77	1970	939.71	1.89	1.38
1971	1006.50	3.14	1.77	1972	939.32	2.21	1.49
1972	1006.73	2.58	1.61	1973	939.34	2.09	1.45
1973	1006.85	1.85	1.36	1974	939.26	2.57	1.60
1974	1006.59	2.70	1.64	1975	939.40	2.22	1.49
1975	1006.72	2.64	1.62	1976	939.66	2.97	1.73
1978	1007.40	1.98	1.41	1977	940.0	1.64	1.28
1980	1006.13	3.30	1.82	1978	940.08	2.09	1.45
1981	1006.24	3.72	1.93	1979	940.24	2.35	1.53
1982	1006.49	3.69	1.92	1980	940.16	1.91	1.38
1986	1005.69	4.33	2.08	1981	940.26	1.90	1.38
1987	1005.22	2.73	1.65	1984	941.03	2.25	1.50
1970-5	1006.65	2.68	1.64	1985	941.18	2.66	1.63
1980-2	1006.29	3.59	1.89	1986	941.54	2.23	1.49
1986-7	1005.48	3.56	1.89	1972-81	939.77	2.35	1.53
				1984-86	941.25	2.42	1.56

Table 5a – Result of Fourier analysis for windspeed, Ikeja, Lagos.

Year	1st Harmonic		2nd		3rd		4th		5th		6th		7th		8th		9th		10th	
	C		C		C		C		C		C		C		C		C		C	
1970	0.296	272.0°	0.317	64.0°	0.305	104.7	0.189	35.7	0.210	110.8	0.047	245.5	0.055	282.5	0.035	294.3	0.099	304.3	0.026	106.2
1971	0.358	283.0°	0.371	40.7	0.232	105.8	0.041	275.7	0.087	149.3	0.051	96.6	0.056	292.7	0.037	61.3	0.105	17.2	0.087	5.6
1972	0.269	306.5°	0.371	89.9	0.129	109.0	0.026	139.8	0.076	68.4	0.112	274.7	0.061	284.3	0.105	66.4	0.031	10.9	0.026	82.7
1973	0.272	277.9°	0.191	369.1	0.139	249.7	0.062	221.2	0.087	100.7	0.047	78.4	0.132	253.2	0.036	193.4	0.066	351.2	0.066	53.9
1974	0.139	215.6°	0.247	339.7	0.160	109.4	0.160	97.3	0.016	72.2	0.071	124.1	0.155	309.3	0.097	119.2	0.036	176.5	0.056	215.6
1975	0.242	315.4°	0.469	38.4	0.139	177.8	0.076	286.6	0.097	342.7	0.037	271.2	0.072	329.4	0.105	297.6	0.103	57.3	0.016	257.2
1978	0.190	271.1°	0.361	268.6	0.026	228.7	0.021	135.4	0.123	229.9	0.076	202.5	0.016	184.2	0.033	240.4	0.052	82.9	0.052	97.5
1980	0.130	329.3°	0.192	63.0	0.175	8.9	0.159	68.8	0.134	119.9	0.110	16.3	0.173	346.4	0.106	325.5	0.005	77.8	0.066	278.8
1981	0.510	283.9°	0.371	324.6	0.124	216.0	0.175	53.9	0.052	114.5	0.112	206.6	0.062	259.3	0.200	65.2	0.073	116.5	0.057	298.1
1982	0.278	331.6°	0.221	348.4	0.118	128.7	0.052	84.1	0.051	319.9	0.162	147.2	0.051	184.3	0.043	171.9	0.051	282.0	0.022	337.0
1986	0.479	246.1°	0.319	344.3	0.113	338.6	0.051	196.3	0.087	204.6	0.100	149.1	0.335	96.4	0.105	271.9	0.076	33.0	0.102	126.1
1987	0.494	274.3°	0.221	296.3	0.077	76.6	0.087	53.8	0.112	202.3	0.072	46.6	0.061	277.0	0.045	158.5	0.046	110.2	0.041	12.2
1988	0.319	311.3°	0.232	351.4	0.165	106.8	0.108	295.7	0.026	25.0	0.093	243.2	0.105	150.3	0.065	355.0	0.088	325.2	0.206	114.9
1970-5	0.294	291.5°	0.304	37.6	0.165	111.7	0.026	254.2	0.021	146.7	0.106	31.8	0.061	273.4	0.016	77.9	0.036	43.5	0.021	6.3
1980-2	0.232	303.7°	0.316	328.1	0.077	139.8	0.021	77.8	0.071	348.5	0.016	283.1	0.036	17.7	0.100	358.0	0.042	250.4	0.051	281.4
1986-7	0.398	281.3°	0.268	356.7	0.021	227.7	0.072	0.05°	0.021	201.9	0.065	177.1	0.092	256.5	0.037	181.3	0.042	125.7	0.051	22.9

Table 5b - Result of Fourier analysis for windspeed, Kaduna.

Year	1st Harmonic C		2nd C		3rd C		4th C		5th C		6th C		7th C		8th C		9th C		10th C	
1970	0.208	40.1	0.300	152.3	0.144	238.7	0.227	221.3	0.200	208.5	0.015	113.4	0.175	121.8	0.200	252.0	0.144	184.3	0.185	308.0
1972	0.340	170.6	0.371	121.1	0.165	110.4	0.067	312.4	0.196	192.5	0.088	120.7	0.113	213.7	0.129	261.4	0.051	0.9	0.032	62.9
1973	0.0581	75.5	0.247	65.0	0.155	288.7	0.191	310.5	0.108	312.6	0.268	82.0	0.232	50.0	0.247	342.1	0.156	239.8	0.170	112.0
1974	0.788	31.3	0.706	173.3	0.433	169.9	0.196	67.5	0.283	312.7	0.036	187.2	0.196	347.5	0.056	255.1	0.134	140.1	0.154	166.3
1975	0.639	73.5	0.546	174.4	0.525	14.0	0.118	68.3	0.124	47.5	0.303	146.2	0.242	92.3	0.185	298.8	0.200	192.4	0.154	298.7
1976	0.208	92.7	0.361	169.3	0.417	154.1	0.139	186.7	0.221	233.5	0.077	338.3	0.232	280.4	0.263	319.1	0.185	185.2	0.065	224.0
1977	0.798	67.8	0.570	145.0	0.330	275.0	0.129	229.5	0.417	171.4	0.417	16.2	0.216	3.2	0.330	107.4	0.190	119.7	0.304	128.1
1978	0.208	139.7	0.824	165.5	0.144	108.4	0.093	177.5	0.185	201.3	0.88	16.2	0.211	64.0	0.190	70.1	0.200	36.0	0.145	137.4
1979	0.314	94.9	0.679	4.8	0.350	162.7	0.134	143.5	0.129	19.9	0.056	226.3	0.319	331.5	0.221	245.6	0.155	189.5	0.156	79.3
1980	0.596	88.0	0.546	0.2	0.103	1.7	0.180	104.0	0.288	100.3	0.221	118.2	0.376	244.6	0.407	115.8	0.128	149.2	0.036	137.4
1981	0.345	39.7	0.695	21.8	0.144	29.7	0.520	302.6	0.577	276.0	0.309	324.5	0.252	331.9	0.200	327.6	0.262	349.5	0.247	0.5
1984	0.484	54.9	0.361	7.0	0.294	6.5	0.056	94.4	0.200	231.4	0.134	229.7	0.180	271.2	0.118	316.4	0.206	354.2	0.191	318.9
1985	0.607	71.7	0.427	10.1	0.185	330.2	0.247	202.5	0.041	116.7	0.139	131.8	0.185	269.9	0.093	0.2	0.155	45.2	0.095	124.4
1986	0.208	84.2	0.575	179.1	0.144	179.7	0.067	234.8	0.231	209.2	0.149	159.5	0.106	54.3	0.139	191.5	0.180	315.5	0.243	118.6
1987	0.592	77.3	0.319	159.7	0.098	167.3	0.062	156.0	0.129	211.6	0.100	245.3	0.021	243.5	0.134	299.7	0.380	223.7	0.135	149.3
1972-81	0.371	61.8	0.494	4.8	0.175	159.3	0.056	301.4	0.67	26.8	0.100	336.12	0.037	223.1	0.052	113.3	0.072	165.5	0.049	51.7
1984-7	0.474	71.3	0.422	1.1	0.118	22.5	0.077	231.6	0.139	227.7	0.092	110.5	0.043	226.2	0.066	291.9	0.088	294.7	0.049	192.1

Table 6a – Result of Fourier Analysis for Temperature for Iraia, Lamps.

Year	1st Harmonic		2nd		3rd		4th		5th		6th		7th		8th		9th		10th	
	Ampl.	Phi	Ampl.	Ph 0	Ampl.	0	Ampl.	0	Ampl.	0	Ampl.	0	Ampl.	0	Ampl.	0	Ampl.	0	Ampl.	0
1970	1.5626	61°.0*	0.41	201°.5*	0.72	191°.42*	0.17	98° 0*	0.01	116° 1*	0.11	169° 11*	0.22	176° 30*	0.30	162°24*	0.33	17°6*	0.09	326°27*
1971	1.11	60°.5*	0.90	221°.5*	0.20	310° 24*	0.19	289° 0*	0.21	200° 0*	0.17	342° 18*	0.37	135 18	0.11	145 18	0.26	175 51	0.23	82 30
1972	1.31	41 9	0.52	236 2	0.21	228 18	0.10	278 6	0.17	101 18	0.09	63 24	0.08	94 24	0.06	26 30	0.10	135 36	0.04	142 36
1973	1.72	61 1	0.31	191 6	0.24	287 30	0.22	297 30	0.16	273 54	0.20	177 30	0.05	24 30	0.17	74 54	0.29	150 30	0.10	149 36
1974	1.29	59 4	0.34	221 9	0.27	213 18	0.38	203 48	0.14	224 18	0.12	229 42	0.11	26 57	0.12	230 48	0.25	117 42	0.19	134 30
1975	1.41	65 4	0.58	219 0	0.32	273 42	0.08	189 58	0.06	156 0	0.12	188 6	0.12	239 24	0.24	112 0	0.03	243 0	0.09	161 15
1978	1.25	35 6	0.79	191 0	0.23	352 36	0.42	230 42	0.08	261 54	0.27	198 24	0.39	208 54	0.23	0 43	0.27	177 6	0.26	252 30
1987	1.51	59 7	0.65	240 1	0.26	260 18	0.47	305 24	0.30	199 36	0.21	9 40	0.16	333 48	0.16	200 0	0.16	335 48	0.11	108 18
1982	1.79	57 1	0.59	203 6	0.19	169 48	0.10	11 48	0.24	322 6	0.15	201 54	0.27	100 42	0.21	145 18	0.15	131 30	0.10	123 30
1988	1.61	54 9	0.61	194 0	0.27	277 42	0.24	189 12	0.20	147 36	0.20	286 36	0.19	253 50	0.34	47 48	0.38	318 0	0.33	102 0
1970–75	1.39	50 98	0.53	215 9	0.22	286 21	0.15	389 9	0.09	223 16	0.05	15 27	0.05	7 54	0.09	148 48	0.15	153 18	0.05	15 57
1980–87	1.97	57 0	0.46	246 2	0.26	233 36	0.30	337 29	0.15	43 71	0.22	263 21	0.14	201 3	0.21	52 9	0.03	24 42	0.13	94 2
1986–87	1.55	60 9	0.67	231 4	0.06	235 58	0.36	291 48	0.26	187 15	0.16	155 42	0.09	-350 9	0.13	318 51	0.10	327 57	0.14	123 42

Table 5b – Result of Fourier Analysis for Temperature for Kaduna.

Year	1st Harmonic		2nd		3rd		4th		5th		6th		7th		8th		9th		10th	
	AMPL	0	AMPL	0	AMPL	0	AMPL	0	AMPL	0	AMPL	0	AMPL	0	AMPL	0	AMPL	0	AMPL	0
1970	2.11	354 18	1.73	196 18	0.[illegible]	186 24	0.70	33 40	0.18	29 36	0.58	140 48	0.[illegible]	52 18	0.29	49 18	0.51	161 15	0.19	3 30
1972	2.03	354 54	1.49	273 48	0.[illegible]	206 42	0.35	31 30	0.26	129 36	0.16	115 36	0.[illegible]	131 36	0.14	286 40	0.11	151 00	0.20	142 24
1973	2.36	352 0	1.26	201 36	0.[illegible]	239 53	0.35	15 24	0.29	175 15	0.24	142 20	0.[illegible]	97 33	0.27	68 40	0.23	45 25	0.46	331 12
1974	2.21	339 24	1.94	192 48	0.[illegible]	196 12	0.07	294 42	0.42	33 12	0.30	105 42	0.[illegible]	160 42	0.04	9 54	0.28	254 40	0.37	153 40
1975	1.89	347 12	1.96	201 40	0.[illegible]	228 56	0.34	95 51	0.25	207 24	0.45	220 24	0.[illegible]	254 24	0.45	174 24	0.29	173 30	0.48	179 42
1978	1.74	355 54	1.61	275 30	0.[illegible]	271 24	0.13	105 18	0.18	00 30	0.42	230 24	0.[illegible]	236 36	0.31	151 24	0.28	289 18	0.20	286 30
1979	1.84	354 48	1.68	210 12	0.[illegible]	270 48	0.40	336 54	0.27	39 30	0.12	55 0	0.[illegible]	65 54	0.18	39 40	0.29	257 00	0.45	182 42
1980	2.09	350 6	1.88	188 16	0.[illegible]	232 48	0.35	50 24	0.32	317 54	0.07	311 48	0.[illegible]	05 10	0.42	321 36	0.37	326 59	0.21	356 18
1981	1.83	351 45	1.93	189 30	0.60	220 10	0.40	166 48	0.52	5 4	0.46	358 51	0.51	152 12	0.20	37 18	0.42	208 48	0.08	79 24
1984	2.01	356 21	2.19	182 18	0.[illegible]	216 18	0.13	163 18	0.37	62 6	0.07	120 45	0.[illegible]	47 24	0.33	17 0	0.14	35 9	0.23	129 12
1985	1.75	357 36	1.68	216 6	0.[illegible]	94 12	0.19	357 24	0.41	54 12	0.41	70 6	0.[illegible]	332 58	0.27	305 30	0.08	65 42	0.17	48 18
1986	2.44	350 36	2.04	189 42	0.[illegible]	276 42	0.50	315 58	0.22	309 45	0.18	94 40	0.13	111 54	0.36	22 45	0.21	170 6	0.30	171 18
1987	2.26	348 46	1.75	201 18	0.[illegible]	244 1	0.16	31 45	0.48	237 12	0.18	46 20	0.43	301 42	0.07	215 18	0.48	77 42	0.22	317 50
1978–81	1.98	345 3	1.67	190 54	0.42	213 54	0.16	35 42	0.10	25 45	0.16	264 36	0.13	162 6	0.14	22 18	0.02	358 51	0.13	34 24
1984–87	2.11	347 43	1.89	194 59	0.[illegible]	210 24	0.23	324 30	0.10	354 18	0.10	45 49	0.25	328 58	0.13	17 0	0.15	52 54	0.10	15 48

Table 7 – Result of Fourier analysis for atmospheric pressure for Kaduna and Ikeja, Lagos.

Year	IKEJA, LAGOS				Year	KADUNA			
	1st Harmonic		2nd			1st Harmonic		2nd	
Year	AMPL	0	AMPL	0	Year	AMPL	0	AMPL	0
1970	1.16	234 36	1.80	14 42	1970	0.64	121 20	1.78	110 30
1971	1.82	259 42	1.37	0 3	1972	1.25	104 6	1.56	175 30
1972	1.32	247 6	1.24	8 6	1973	1.10	133 45	1.57	18 12
1973	1.02	268 2	1.50	17 30	1974	1.37	107 18	1.69	179 12
1974	1.43	249 18	1.12	4 12	1975	1.03	124 6	1.76	19 54
1975	1.36	257 30	1.32	25 12	1978	1.42	131 54	1.63	3 1
1978	1.00	255 30	1.37	25 18	1979	0.80	113 12	1.96	6 21
1987	9.82	104 1	1.38	8 48	1980	1.03	96 30	1.65	5 39
1982	1.69	236 36	1.43	8 49	1981	1.24	123 48	1.59	7 28
1988	1.29	243 6	1.58	10 36	1984	1.24	122 30	1.58	7 9
1970–75	1.53	236 33	0.93	17 45	1985	1.01	93 18	1.66	16 45
1980–82	1.41	253 12	1.97	7 18	1987	1.27	141 10	1.62	8 9
1986–87	2.04	220 54	0.33	67 57	1972–81	1.23	127 36	1.84	8 18
					1984–86	1.43	140 51	2.01	9 30

4.3 PERIODIC VARIATIONS

Information on the periodic variations of the elements were obtained from the harmonic analysis, the result of which were presented in tables 5a, b, 6a, b and 7 for the two stations. For brevity, only the amplitudes and phase angles were shown for the first ten harmonics. In addition, the percentage of the total variance accounted for by each harmonics are presented in appendix II.

In conforming the important harmonics deciphered from appendix II, a test of significance of harmonics was carried out for first five harmonics with the highest amplitudes. The test was conducted based on a procedure due to Fisher (1940).

It is also possible to demonstrate the importance of each harmonics by spectral analysis. Fig. 3, 4 and 5 gives typical graphs obtained. In addition, the serial correlation functions were plotted against lags for further insight into the behaviour of the elements (Fig. 6, 7 and 8).

4.4 THE STOCHASTIC VARIATIONS

After the determination of harmonics of importance, the periodic components were computed and substracted from the residuals. The major characteristics of these residuals are presented in table 8, 9 and 10, for windspeed, temperature and atmospheric pressure respectively.

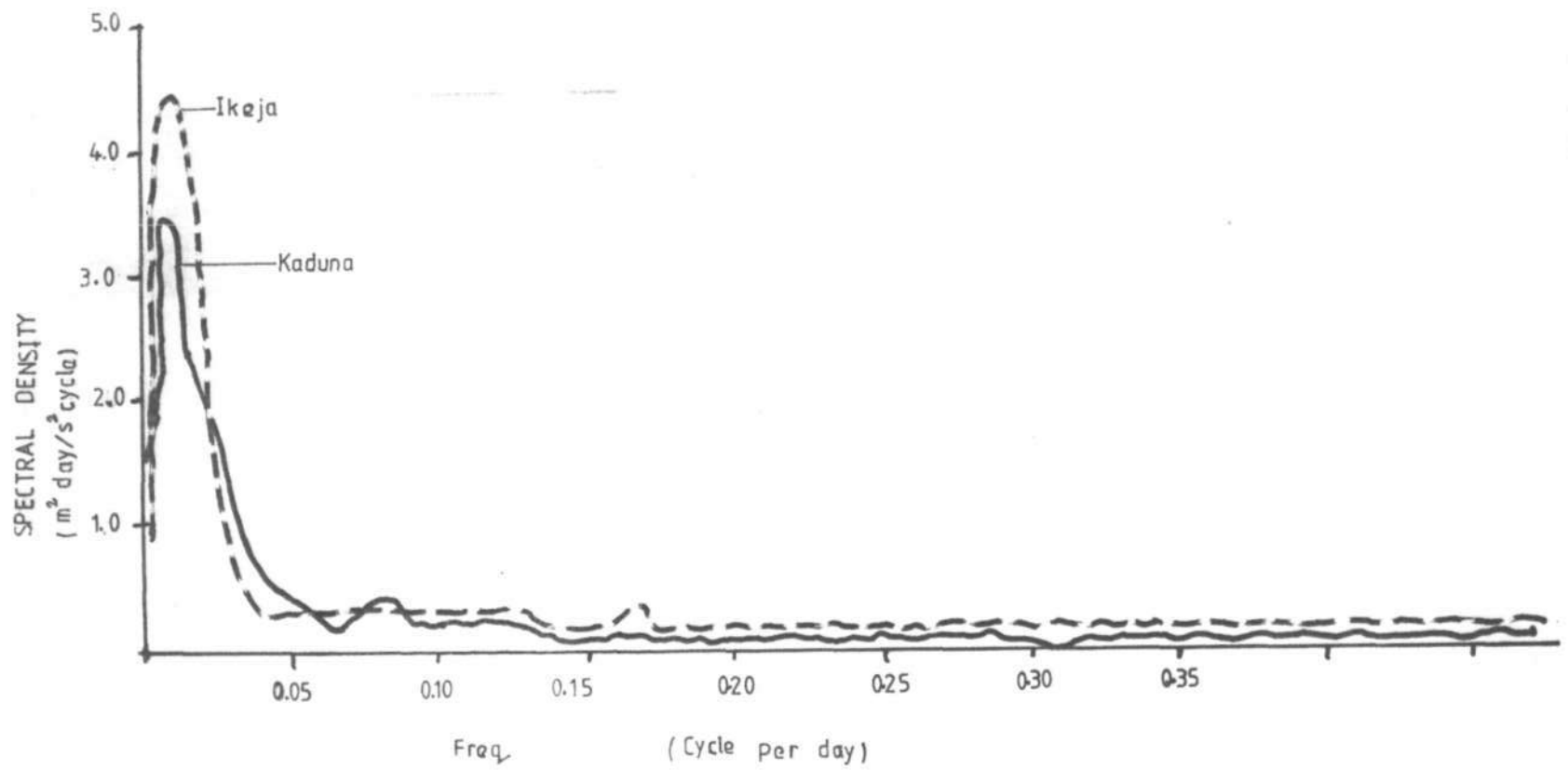


FIG 3 SPECTRAL DENSITY FOR WINDSPEED

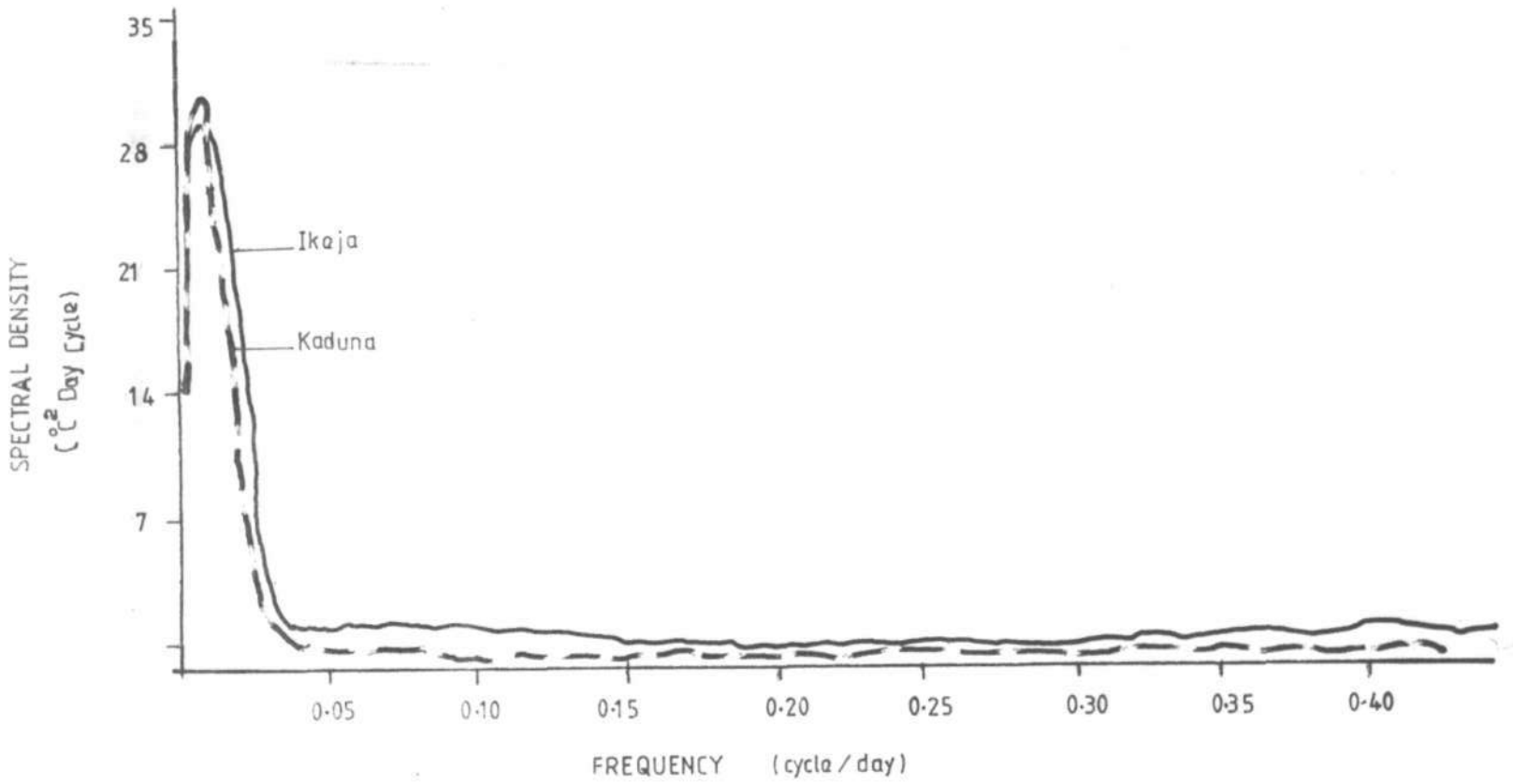


FIG 4 SPECTRAL DENSITY FOR TEMPERATURE

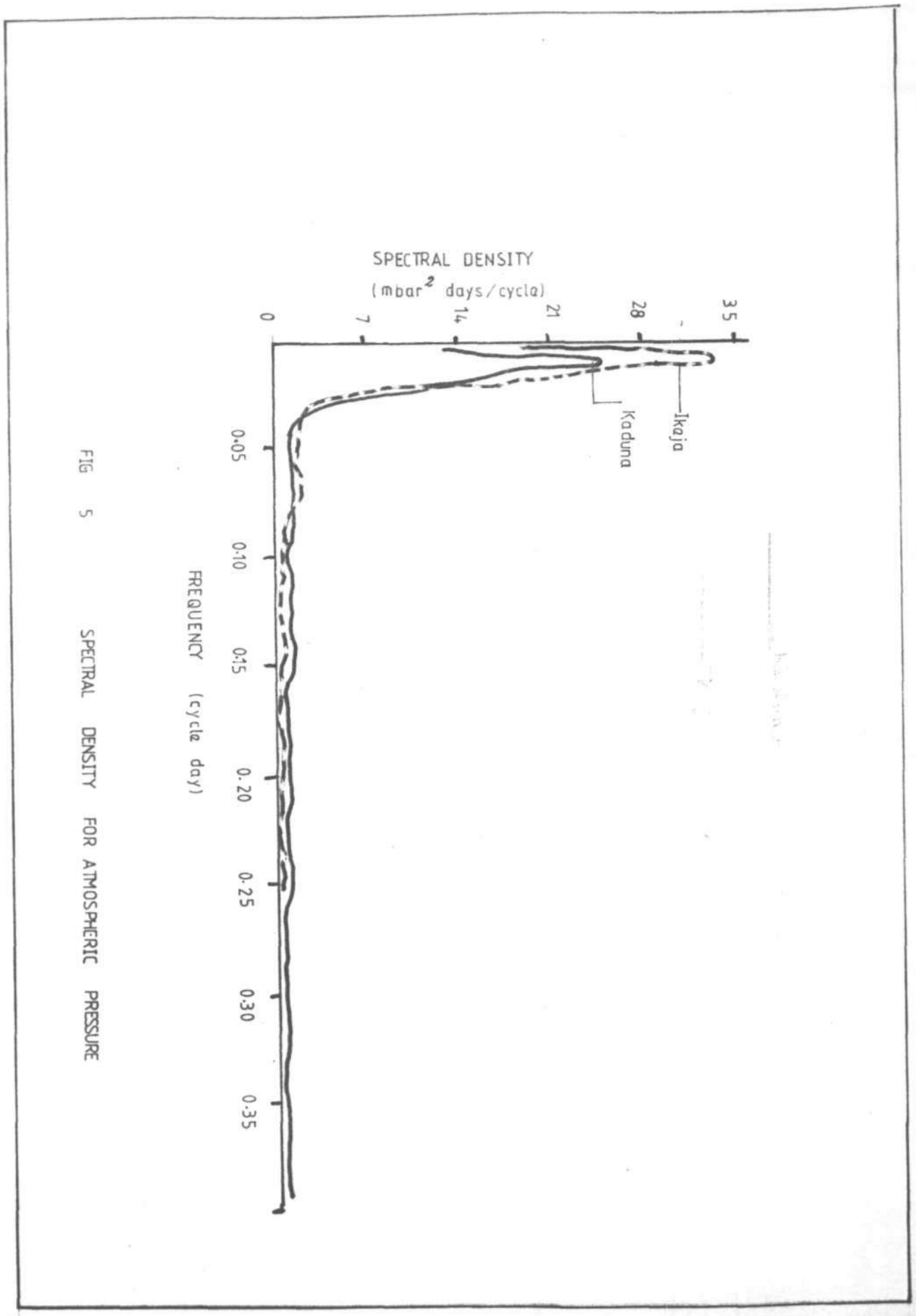


FIG 5 SPECTRAL DENSITY FOR ATMOSPHERIC PRESSURE

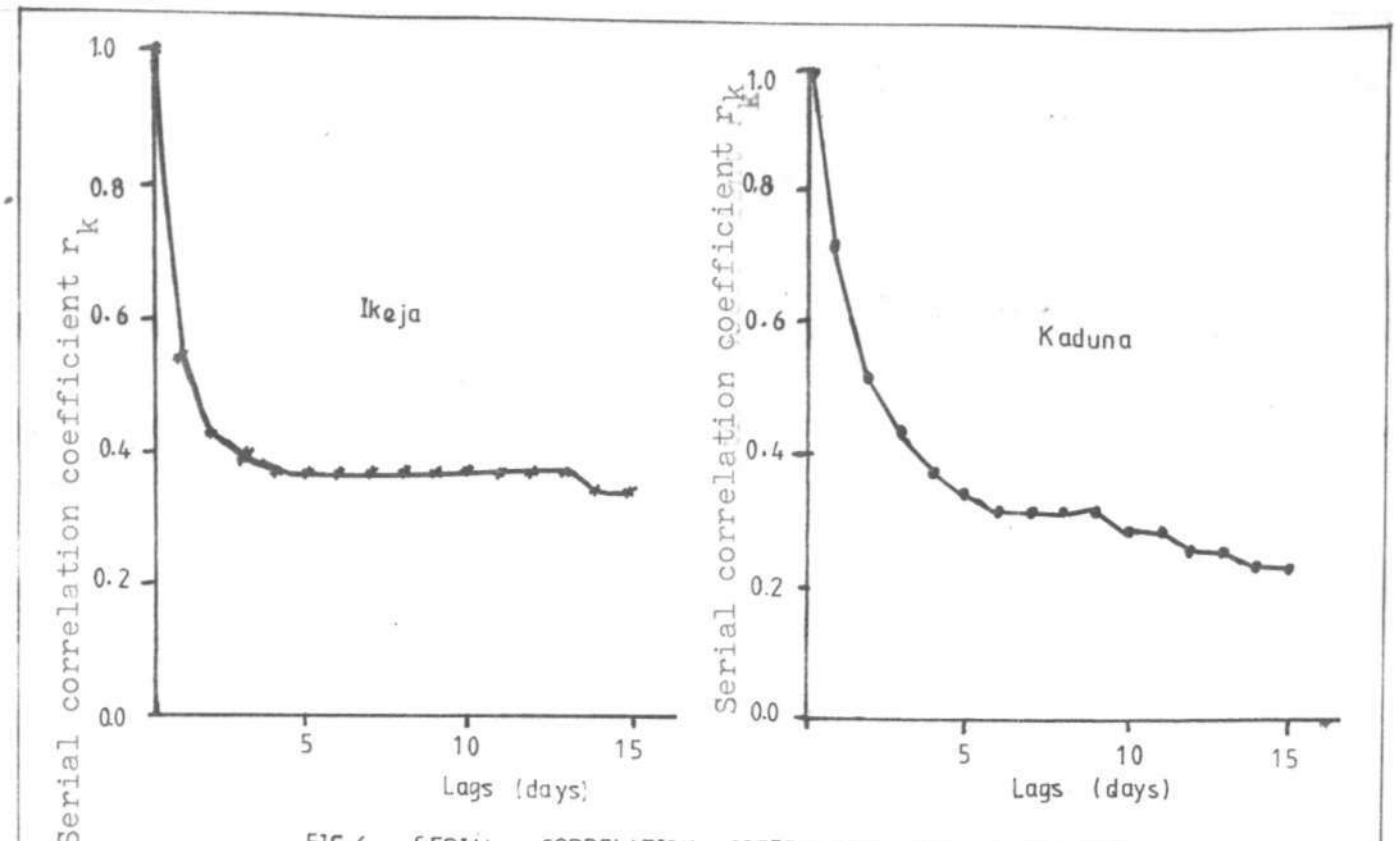


FIG 6 SERIAL CORRELATION COEFFICIENTS FOR WINDSPEED

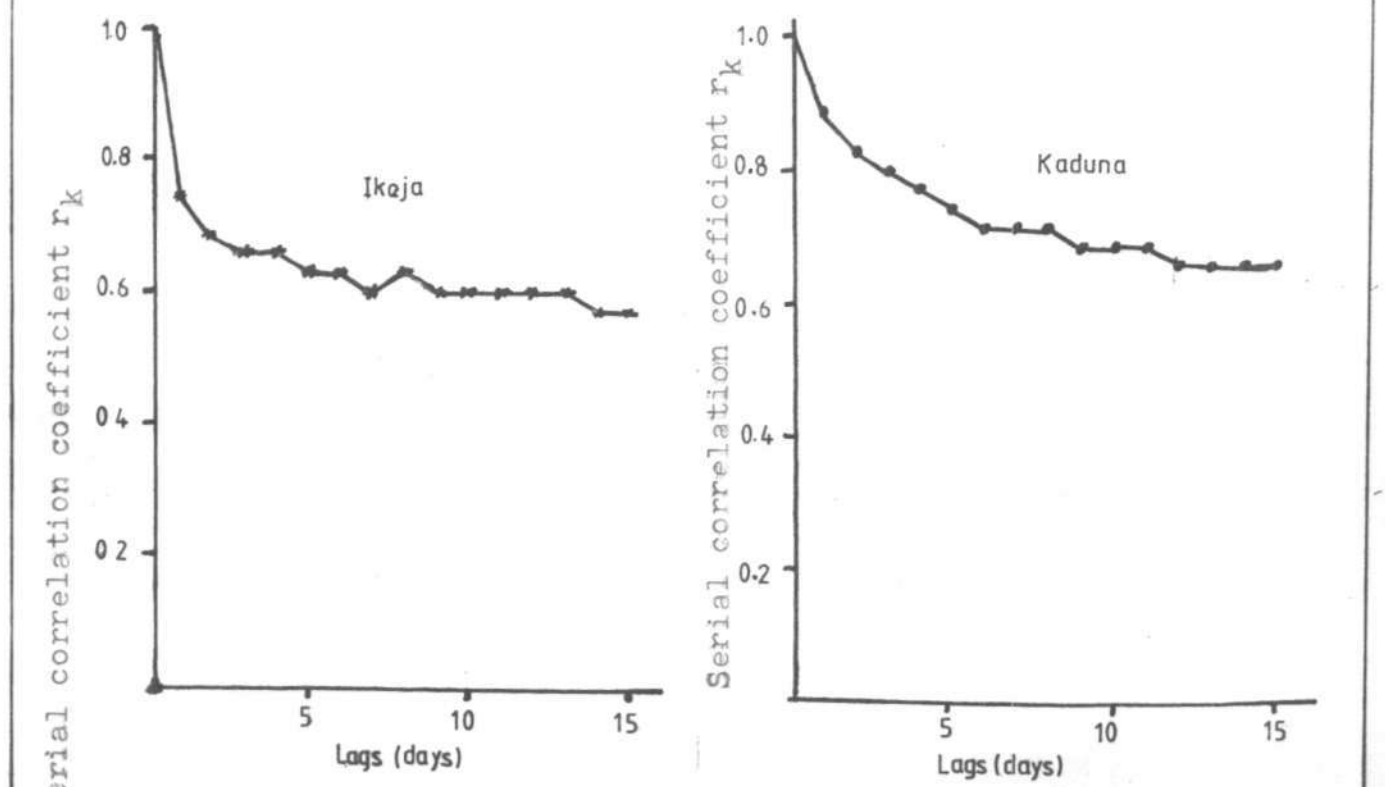


FIG 7 SERIAL CORRELATION COEFFICIENT FOR TEMPERATURE

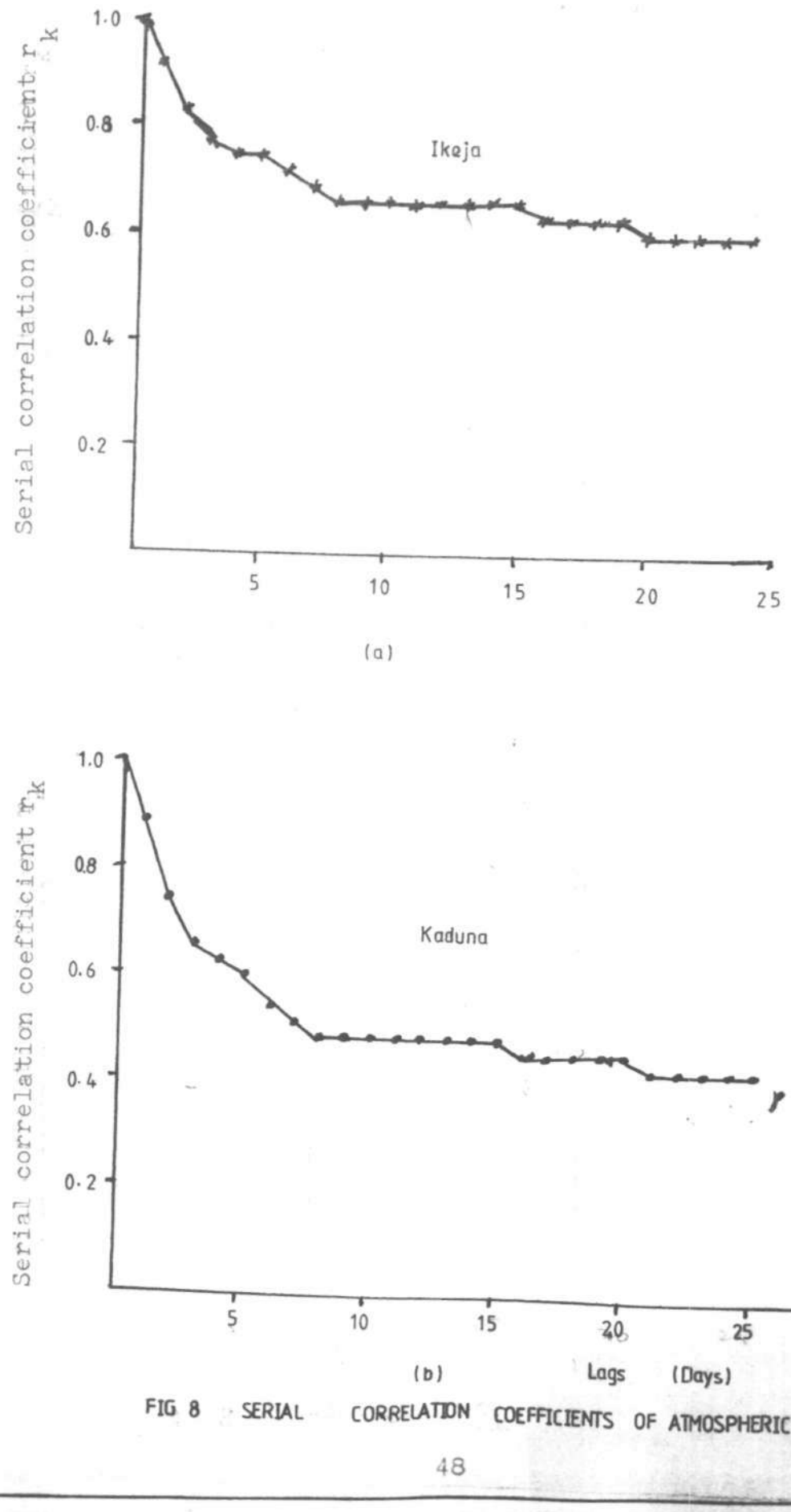


FIG 8 SERIAL CORRELATION COEFFICIENTS OF ATMOSPHERIC PRESSURE

Table 8: Characteristics of Windspeed Residuals.

YEAR	IKEJA, LAGOS Mean (m/s)	Variance m^2/s^2	Std. Dev. (m/s)	YEAR	KADUNA Mean (m/s)	Variance m^2/s^2	Std. Dev. m/s
1970	0.00	0.904	0.951	1970	0.000	2.706	1.645
1971	0.00	1.239	1.111	1972	0.00	2.307	1.519
1972	0.00	1.294	1.138	1973	0.00	3.471	1.863
1973	0.00	1.191	1.091	1974	0.00	3.538	1.881
1974	0.00	1.230	1.109	1975	0.00	3.359	1.833
1975	0.00	1.232	1.110	1976	0.00	2.700	1.643
1978	0.00	0.676	0.822	1977	0.00	3.929	1.982
1980	0.00	1.033	1.016	1978	0.00	3.469	1.862
1981	0.00	0.832	0.912	1979	0.00	3.046	1.745
1982	0.00	1.491	1.223	1980	0.00	4.940	2.225
1986	0.00	0.621	0.788	1981	0.00	4.624	2.150
1987	0.00	1.054	1.051	1984	0.00	3.349	1.830
				1985	0.00	3.02	1.739
				1986	0.00	2.798	1.673
				1987	0.00	3.29	1.815

Table 9: Characteristics of Temperature Residuals

YEAR	IKEJA, LAGOS Mean	Variance	Std. Dev.	YEAR	KADUNA Mean	Variance	Std. Dev.
1970	0.000	0.6972	0.8349	1970	0.000	1.8255	1.3511
1971	0.000	1.6389	1.280	1972	0.000	1.2095	1.0997
1972	0.000	0.5268	0.7258	1973	0.000	1.824	1.3504
1973	0.000	0.7027	0.8383	1974	0.000	1.7961	1.3402
1974	0.000	0.8401	0.9166	1975	0.000	1.9331	1.3903
1975	0.000	0.6794	0.8242	1976	0.000	1.4297	1.1957
1978	0.000	2.8067	1.6753	1977	0.000	1.5730	1.2542
1980	0.000	0.6780	0.8254	1978	0.000	1.7202	1.3115
1981	0.000	2.4400	1.5600	1979	0.000	1.6355	1.2789
1982	0.000	0.9439	0.9715	1980	0.000	1.698	1.2998
1986	0.000	0.7620	0.8729	1981	0.000	2.053	1.4332
1987	0.000	1.6287	1.2763	1984	0.000	1.922	1.3860
				1985	0.000	1.725	1.3140
				1986	0.000	1.6997	1.3034
				1987	0.000	1.6610	1.2885

Table 10: Characteristics of the Atmospheric Pressure Residuals.

YEAR	IKEJA, LAGOS Mean	Variance	Std. Dev.	YEAR	KADUNA Mean	Variance	Std. Dev.
1970	0.000	1.017	1.008	1970	0.000	0.09	0.3[illegible]
1971	0.000	0.545	0.7382	1972	0.000	0.21	0.456
1972	0.000	0.930	0.9644	1973	0.000	0.24	0.4898
1974	0.000	1.05	1.0247	1974	0.000	0.19	0.4358
1975	0.000	0.85	0.9219	1975	0.000	0.14	0.3742
1978	0.000	0.541	0.7355	1976	0.000	0.46	0.6782
1980	0.000	1.005	1.002	1977	0.000	0.34	0.583
1981	0.000	1.143	1.069	1978	0.000	0.24	0.4899
1982	0.000	1.210	1.100	1979	0.000	0.09	0.3[illegible]4
1986	0.000	1.4300	1.1958	1980	0.000	0.03	0.16
1987	0.000	1.4300	1.1958	1981	0.000	0.35	0.59
				1984	0.000	0.36	0.60
				1985	0.000	0.348	0.59
				1987	0.000	0.56	0.75

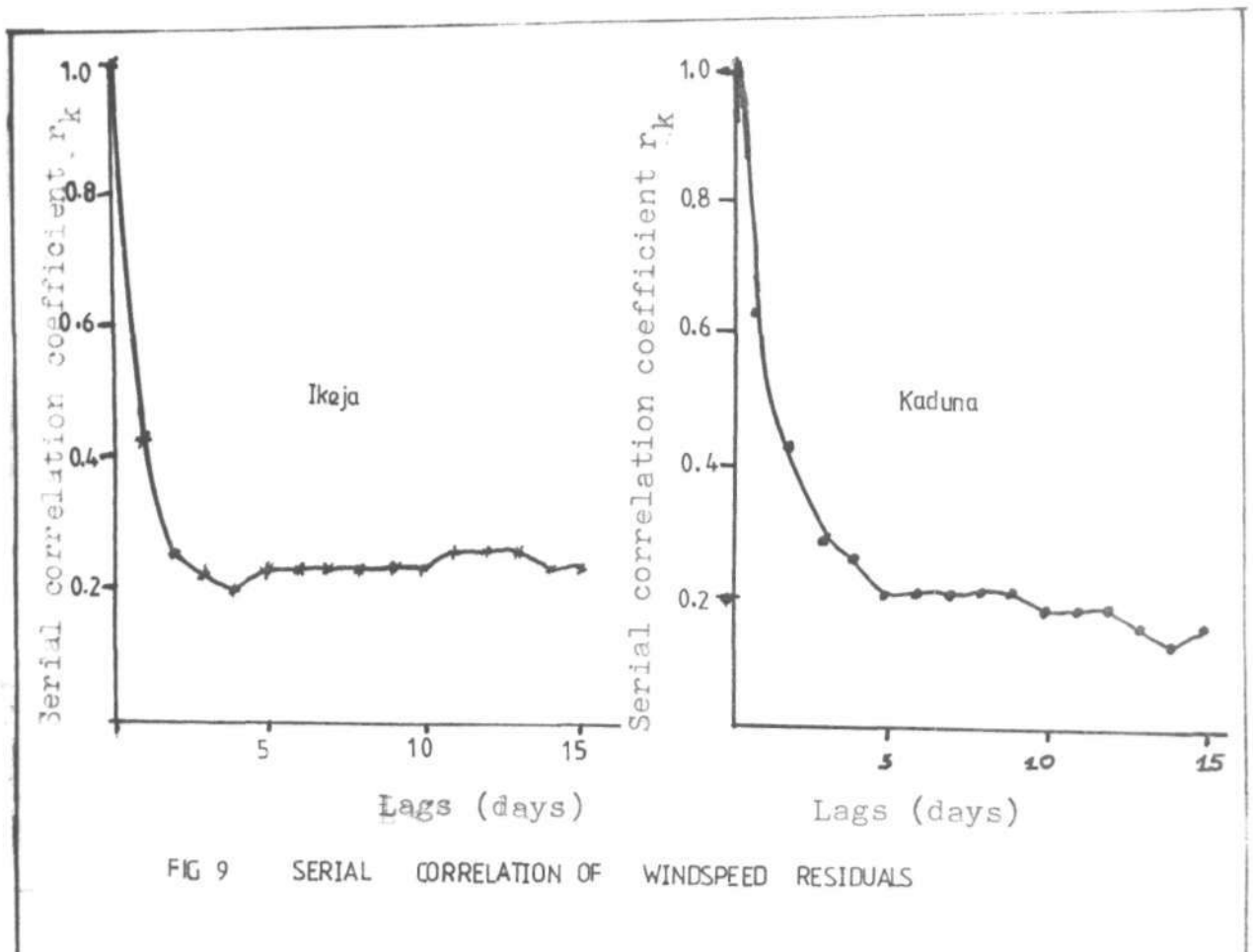


FIG 9 SERIAL CORRELATION OF WINDSPEED RESIDUALS

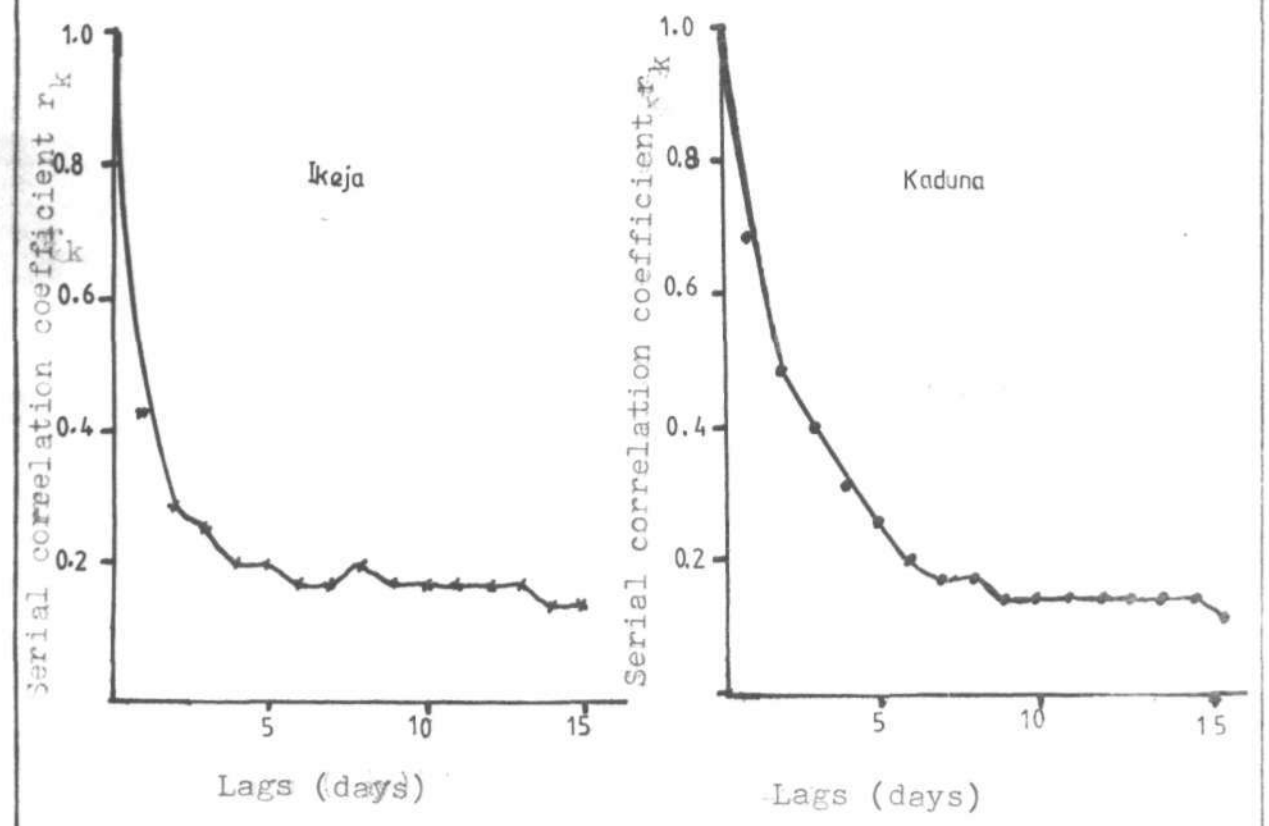


FIG 10 SERIAL CORRELATION OF TEMPERATURE RESIDUALS

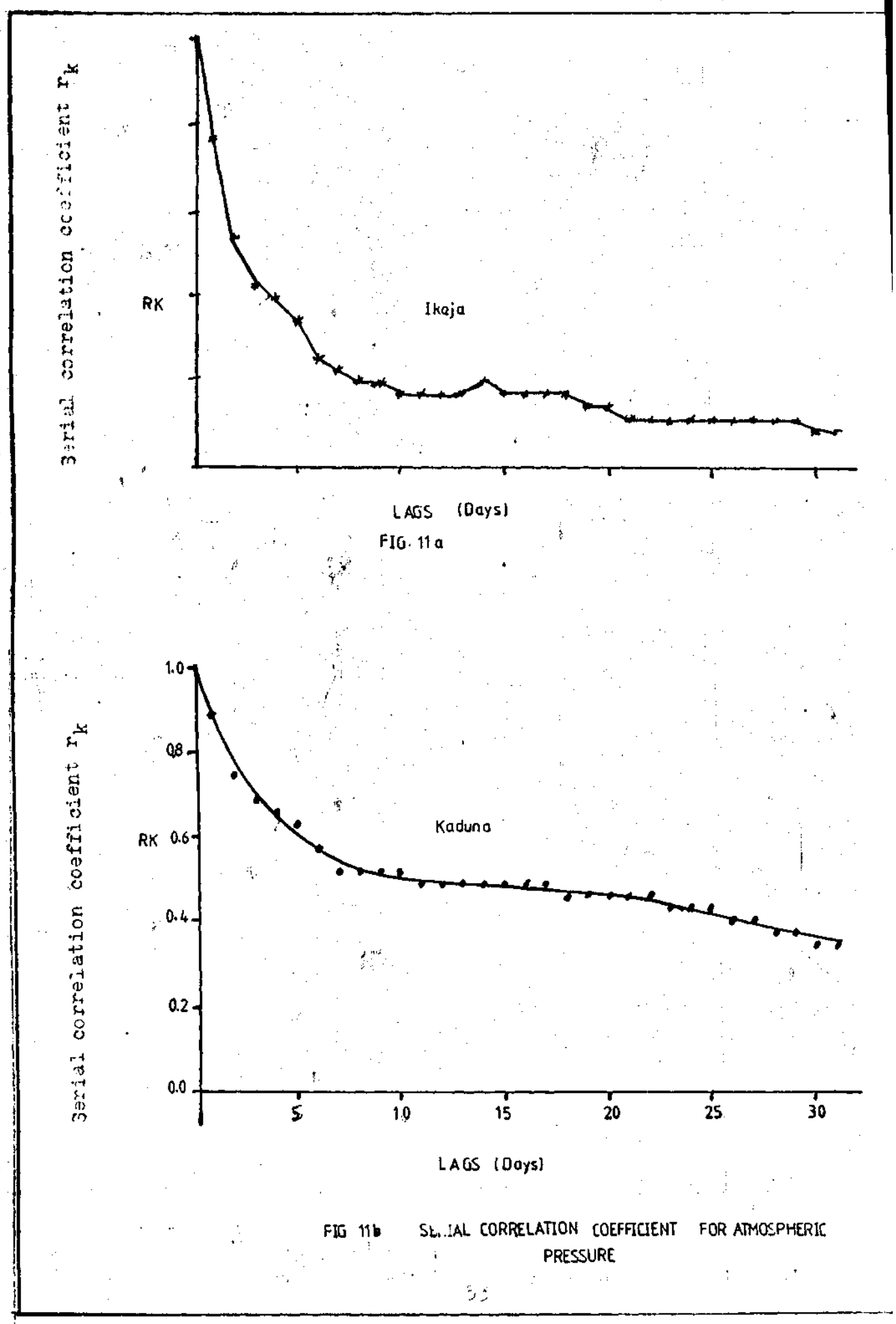


FIG. 11a

FIG 11b SERIAL CORRELATION COEFFICIENT FOR ATMOSPHERIC PRESSURE

As a result of the high values of the standard deviation of the windspeed in relation to the mean, it was considered necessary to examine the residual correlations. To this end, serial correlation coefficients were computed for the elements (Fig. 9, 10 and 11).

Also examined were the variance spectra of the residuals. Figure 12, 13 and 14 were the results obtained from such analysis.

The yearly analysis produced a lot of data on the linear autoregressive coefficients for the elements. The average values of these parameters are given in table 11, 12 and 13.

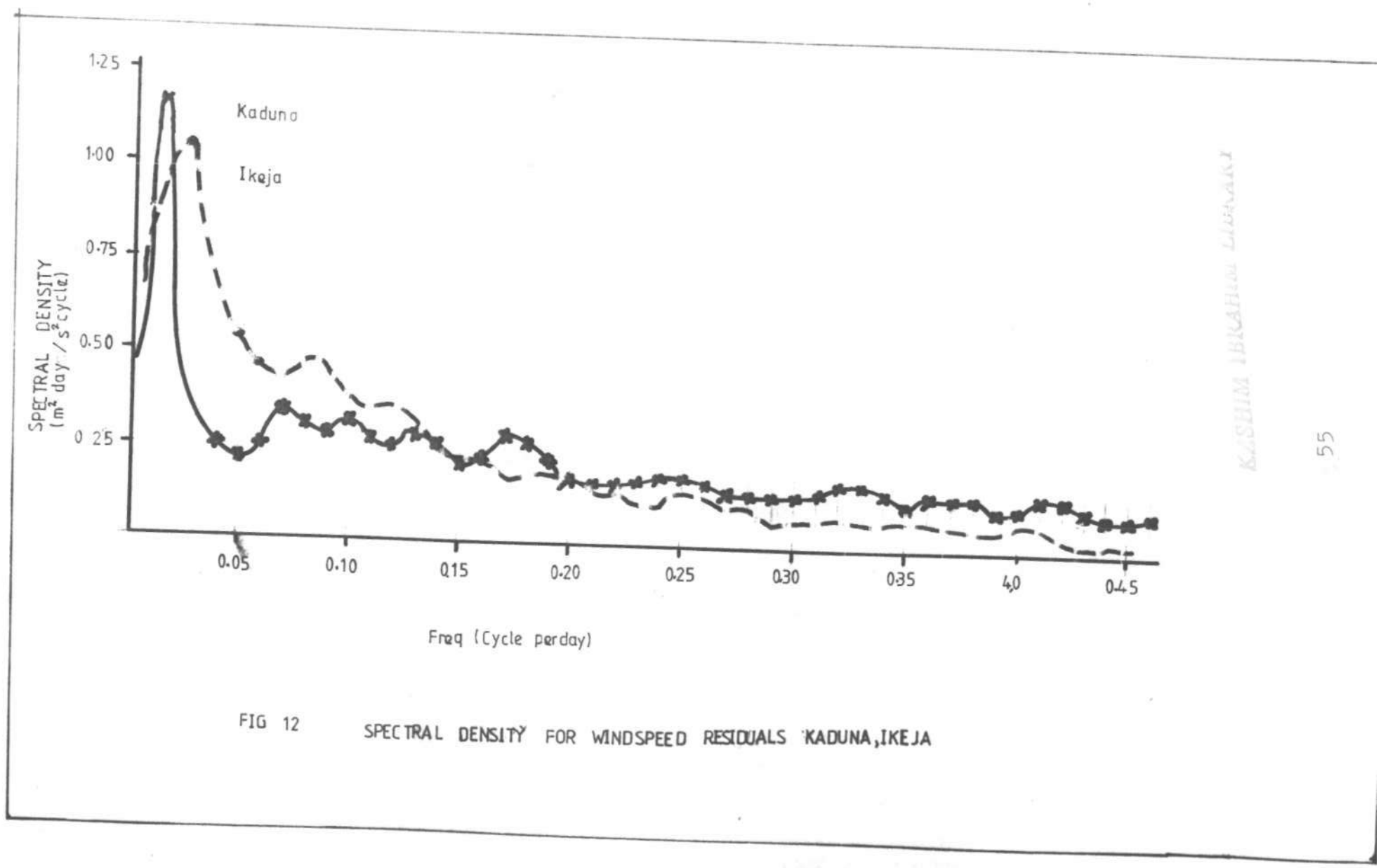


FIG 12 SPECTRAL DENSITY FOR WINDSPEED RESIDUALS KADUNA, IKEJA

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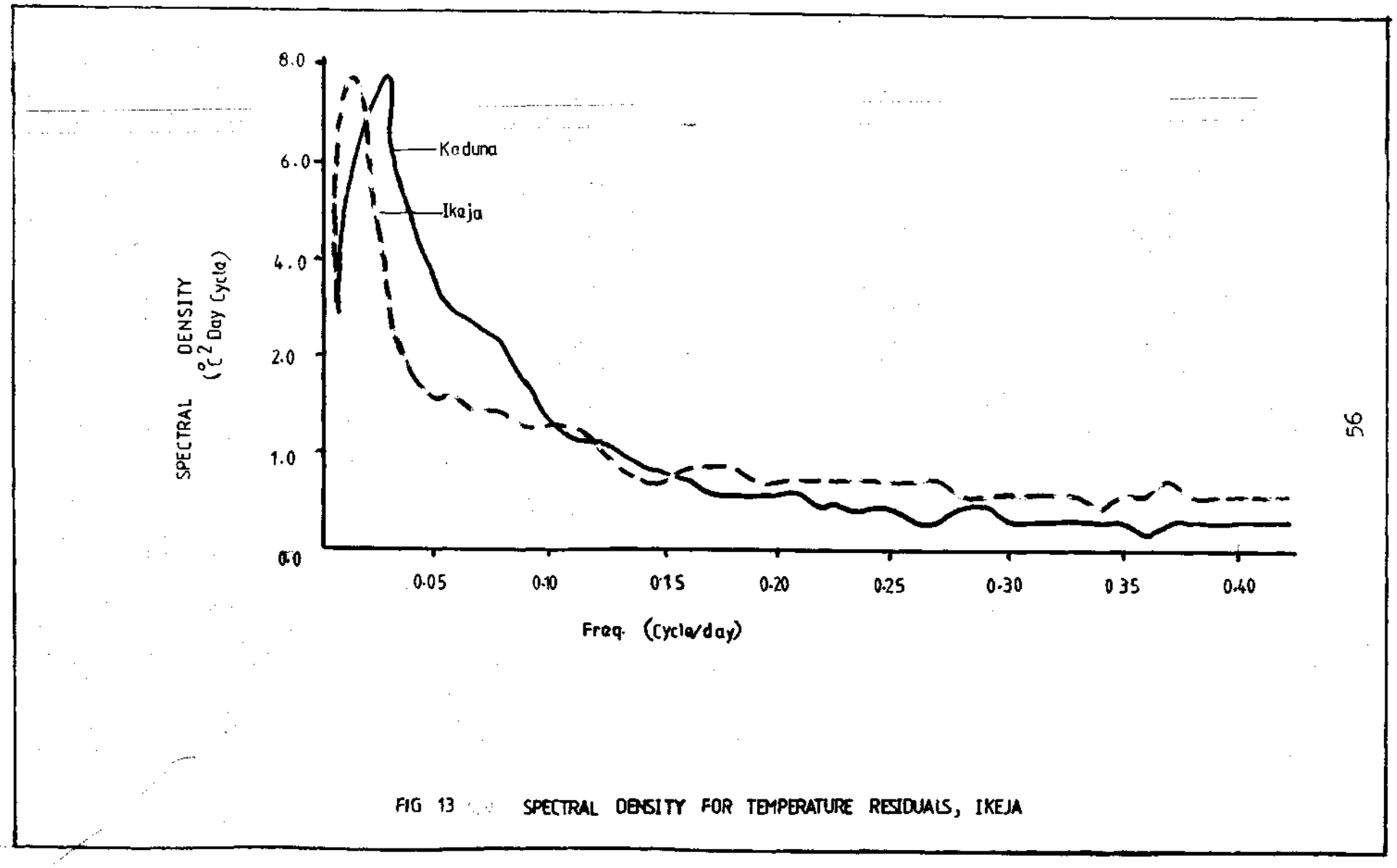


FIG 13 SPECTRAL DENSITY FOR TEMPERATURE RESIDUALS, IKEJA

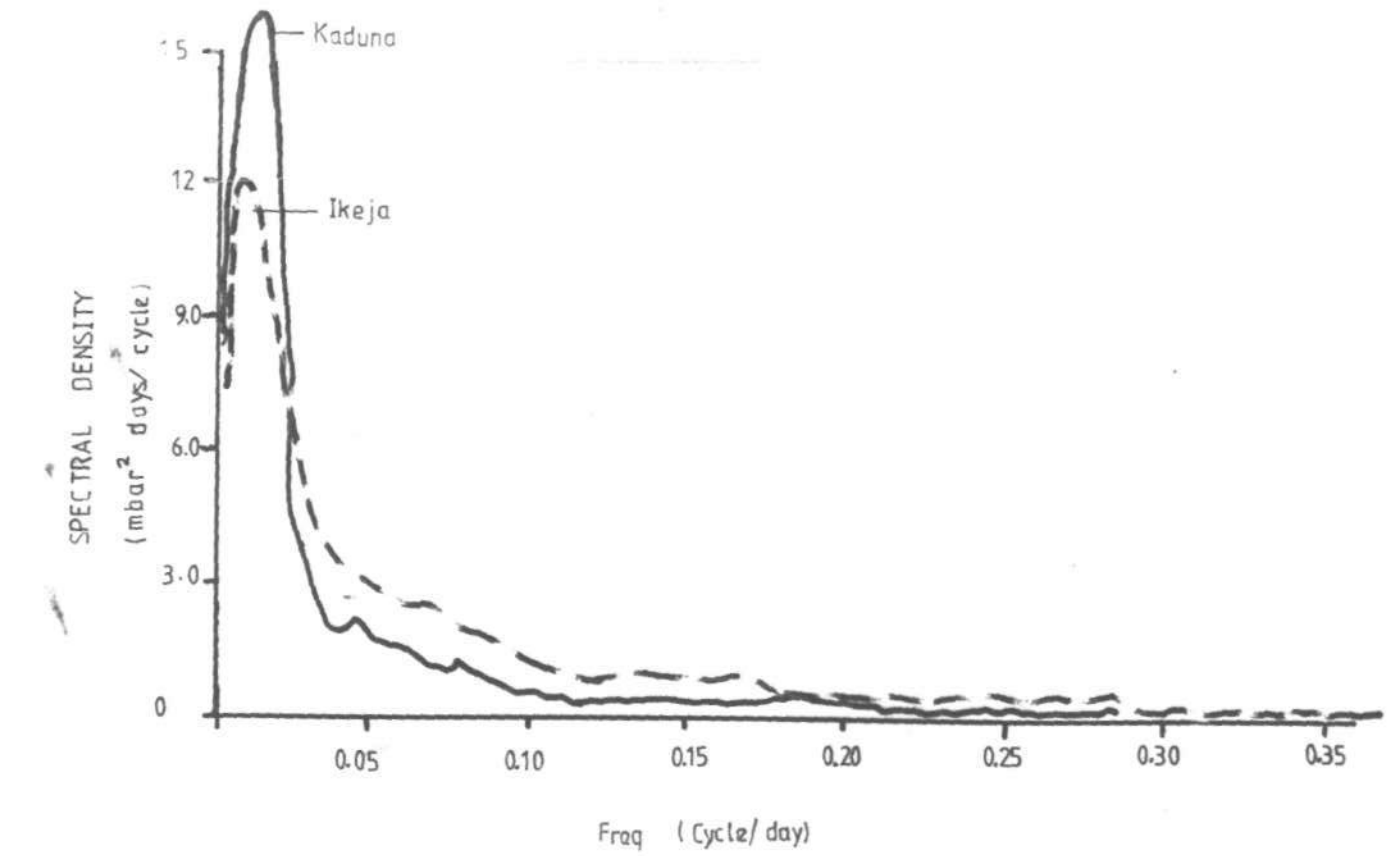


FIG 14 SPECTRAL DENSITY FOR ATMOSPHERIC PRESSURE RESIDUALS IKEJA, LAGOS

Table 12: Linear autoregressive coefficients for windspeed, Ikeja and Kaduna.

	Order	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	R^2
Ikeja	1	0.5264						0.22
	2	0.4083	0.1269					0.24
	3	0.4479	0.0643	0.1499				0.26
	4	0.3721	0.0578	0.1097	0.1041			0.27
	5	0.3577	0.0432	0.1021	0.0550	0.1323		0.28
	6	0.3522	0.0415	0.0927	0.0528	0.1153	0.0462	0.29
Kaduna	1	0.5839						0.34
	2	0.5756	0.0128					0.35
	3	0.5752	0.0198	-0.0478				0.35
	4	0.5735	0.0199	-0.0300	-0.0211			0.36
	5	0.5718	0.0190	-0.0295	-0.0020	-0.0389		0.36
	6	0.5710	0.0184	-0.0297	0.0201	-0.0310	-0.0129	0.36

Table 13: Linear autoregressive coefficients for temperature, Ikeja, Kaduna.

	Order	$\theta_{p,1}$	$\theta_{p,2}$	$\theta_{p,3}$	$\theta_{p,4}$	$\theta_{p,5}$	$\theta_{p,6}$	R^2
Ikeja	1	0.5264						0.28
	2	0.4863	0.1203					0.29
	3	0.4789	0.0821	0.897				0.30
	4	0.4732	0.0745	0.0889	0.0751			0.30
	5	0.4687	0.1098	0.0513	0.0381	0.0772		0.31
	6	0.4658	0.0272	0.0491	0.0386	0.0614	**0.0325**	0.31
Kaduna	1	0.6708						0.45
	2	0.6420	0.0429					0.45
	3	0.6391	−0.0106	0.0659				0.46
	4	0.6391	−0.0107	0.0651	−0.0084			0.48
	5	0.6462	0.0077	0.056	−0.0016	0.0251		0.48
	6	0.6389	−0.0119	0.0661	−0.0162	0.0256	−0.0085	0.48

Table 14: Linear autoregressive coefficients for atmospheric pressure, Ikeja, Kaduna.

	Order	$\theta_{p,1}$	$\theta_{p,2}$	$\theta_{p,3}$	$\theta_{p,4}$	$\theta_{p,5}$	$\theta_{p,6}$	R^2
Ikeja	1	0.8314						0.69
	2	0.9477	−0.1403					0.70
	3	0.9781	−0.3454	0.2141				0.71
	4	0.9615	−0.3189	0.1344	0.0815			0.71
	5	0.9619	−0.3229	0.1398	0.0718	0.0265	0.115	0.71
	6	0.9629	−0.3257	0.1446	0.1154	−0.0257	−0.0520	0.71
Kaduna	1	0.8910						0.79
	2	1.051	−0.1805					0.80
	3	1.101	−0.4672	0.2728				0.82
	4	1.082	−0.4352	0.1975	0.0685			0.82
	5	1.084	−0.4309	0.1887	0.0895	−0.0197		0.82
	6	1.084	−0.4338	0.1822	0.1043	−0.0575	0.1520	0.82

4.5 DISCUSSION OF RESULTS

The following discussions are in respect of the results presented in the previous section and the appendix II.

4.5.1 WINDSPEED

4.5.1.1 CHARACTERISTICS

From table 2 which contains the characteristics of the windspeed record, it is clear that the means are within close range in Kaduna being 2.35 - 3.13m/s. However the range is higher in Ikeja (1.33 - 2.93m/s). The gradual decrease in the mean from 1975 - 1982 could not be attributed to change in recording or a marked trend because of the increase noticed as from 1986 upwards. When compared with the record in Kaduna, no such decrease is observed.

The high variance and standard deviation of the yearly mean in Kaduna is a pointer to the high extremes of windspeed. The standard deviation is as high as 40% of the overall mean. This contrasts greatly with the records in Ikeja where the standard deviations are usually small not exceeding 0.85m/s. It is clear from this result that the wind is steadier in Lagos than in Kaduna.

Considering the range of mean obtained, one may doubt the stationarity of windspeed data which are expected to have same mean for any subseries of the record. However Yevjevich (1972) observed that provided the individual characteristic (i.e. mean, variance and standard deviation) of the subseries

are contained within the 95% confidence band of the overall mean, the data can be assumed stationary. This band is 1.57 - 2.94m/s in Ikeja and 2.00 - 3.33m/s in Kaduna. The criterion is hence satisfied for the two stations except for the lone 1982 record in Ikeja. Windspeed records are therefore of second order stationarity.

The wide extremes of windspeed in Kaduna has obvious implications on air pollution episodes. Because pollutant concentration downwind are inversely proportional to the windspeed, period of high windspeed will witness low pollution and vice versa for low windspeed period. From the windspeed records these fall respectively in July and October - November of each year. As for the situation in Lagos, the small diurnal variation implies small diurnal variations in the concentrations of pollutants in the environ to an emitting factory. This condition would lend itself to more accurate prediction using the Gaussian plume model. Forcasting of likely pollutant concentration could also be achieved when the pertinent predictive equations of the parameters required in the predictive model as is expected in this work.

4.5.1.2 PERIODIC VARIATIONS

The periodic variations are slightly different from year to year when considered in terms of the amplitudes and the phase angles (Tables 6a, b). Although many harmonics were fitted, it is observed that only few are important.

The first and second harmonics have the most consistent amplitudes and phases for all the years with ranges of 0.29 - 0.80m/s and 0.30 - 0.62m/s respectively in Kaduna. For the first harmonic, a change in phase shift is noticed from the first quadrant to the second in only two out of the 15 years studied. This fact underscored the homogeneity of the windspeed record for the station. As for the second harmonics, the phase shifts lie in the second quadrant most times.

The high range of annual mean has a carry over effect on the amplitude for both the first and second harmonics in Ikeja. They stand at 0.14 - 0.74 and 0.18 - 0.47m/s respectively. As for the phase angles, they are contained in the fourth quadrant (270 - 360°) and the first (0 - 90°). As is evident, the range of amplitude is smaller for the second than the first harmonics. The record can also be accepted as homogenous.

One other harmonics that seem of importance from the values of the amplitudes is the third. However, it has greater variability than other higher harmonics.

To confirm the harmonics of importance, Fisher's test of significance of harmonics was applied to five of the amplitudes of each year arranged in descending order of magnitude. The test was conducted at 5% significance level with a period of 365 days giving a critical g* value of 0.04429. From the test's result the first and second harmonics were significant for all the years with values of computed g exceeding the critical. The third bearly meet the criterion judging from the number of years in which it was found significant.

The above conclusion is further corroborated by the percentage of variance accounted for by each harmonics (appendix II). The first and second harmonics accounted for 3 - 17% and 5 - 20% respectively. The third is less important accounting for less than 5% in all the years. In all, the periodic variation can account for less than 25% of the variance of the record. Other pockets of harmonics which were significant but not in enough frequency were rejected.

The spectral density curves (variance spectra) also furnish vital information on the harmonics. Result of the spectral analysis showed that the variance are concentrated within the first few frequency bands of the spectra. For the first four spectra, range of values are 2.28 - 3.76, 1.87 - 2.65, 0.74 - 1.14 and 0.58 - 0.69m^2 day for 0.01, 0.02, 0.03 and 0.04 cycles/day respectively in Kaduna. The corresponding range in Ikeja are respectively 4.68 - 5.57, 2.73 - 3.68, 0.55 - 1.25 and 0.24 - 0.53m^2 day/s^2 cycle. The importance of the first three harmonics is again brought to light by this result.

The dependence in the windspeed data are brought to light by the result of the serial correlation analysis (Fig. 6). It is found that the coefficients are significantly greater than zero for lags of up to 50 days. For instance, the first three lags have values of 0.64 - 0.70, 0.45 - 0.52, 0.31 - 0.42 and 0.52 - 0.70, 0.38 - 0.61, 0.37 - 0.59 in Kaduna and Ikeja respectively showing that the first and second lag have greater correlations than the others. The positive persistence of the record indicate that high windspeed average in a day is likely to be followed by same next day and vice versa.

4.5.1.3 NON - SEASONAL VARIATIONS

The analysis of the non-seasonal residuals are based on the assumptions that they have zero mean. This was upheld by the result as seen in table 5. The extremes in the variance of the residuals as a whole were evenned out by the periodic analyses resulting in almost uniform values for the stochastic residuals. The range of the variance and standard deviations in Kaduna are most obviously affected (0.72 - 1.03m^2/s^2 and 0.84 - 1.02m/s). Although, with a higher range, values in Lagos are smaller (0.18 - 0.39m^2/s^2 and 0.42 - 0.63m/s).

Hidden periodicities that cannot be illuminated in the spectral analysis of the observed series are usually identifiable from the result of spectral analysis of the non-seasonal residuals. In this wise, three peaks at frequencies of 0.20, 0.30 and 0.39 cycles/day were identified in Ikeja with spectra range of 2.64 - 0.73, 0.08 - 0.10 and 0.20 - 0.37m^2 day/s^2 cycle. However four were found in Kaduna as 0.10, 0.20, 0.29 and 0.39 cycles/day with 0.92, 0.52, 0.40 and 0.26 m^2/day/s^2cycle respectively. The causes of these variations with respective period of 10, 5, 3½, 2½ days are unknown.

The serial correlations of the non-seasonal residuals oscillate and are generally smaller than those for the observed data (Fig. 9). However, they are higher enough to warrant an investigation into the nature of dependent components of the residuals; being about 0.42, 0.25, 0.23 and 0.64, 0.42, 0.30 respectively in Ikeja and Kaduna for lag 1, 2 and 3. This need is further buttressed by the small percentage of the total variance accounted for by the periodic components.

In determining the appropriate model, the serial correlation and the partial autocorrelation coefficients were used. The oscillation of the serial correlations and the fact that the partial autocorrelations are non-zero at higher lags satisfy the criteria for choice of the linear autoregressive moving average as describing the non-seasonal residuals for windspeed. The order was limited to 1. For satisfying one of the conditions for the linear autoregressive process, AR(p) of order p, the order p was considered to the sixth.

From table 12 a,b which showed the values of the linear autoregressive coefficients, it is found that the coefficients are within a close range. However, the coefficient of determination R^2 are low showing that the non-seasonal residuals are composed essentially of the independent random variate.

4.5.1.4 PREDICTIVE EQUATION FOR WINDSPEED

Based on the facts that three harmonics were found significant and that linear autoregressive model and ARMA model of orders 1 and 3 can fit into the non-seasonal residuals, the predictive equation for windspeed is of the form:

$$X_t = \mu_w + \sum_{i=1}^{3} C_i \sin\left(\frac{2\Pi it}{365} + \lambda_i\right) + \theta_{1,1} \varepsilon_{t-1} + \eta_t - \rho_1 \eta_{t-1} \qquad (54a)$$

(ARMA (1,1))

$$X_t = \mu_w + \sum_{i=1}^{3} C_i \sin\left(\frac{2\Pi\, i\, t}{365} + \lambda_i\right) + \sum_{i=1}^{3} \theta_{3,i}\, E_{t-i} + \eta_t \qquad (54b)$$

where the subscript t refer to the day and μ is the expected value of the mean windspeed for the last three years. Note that three years is used because it is the period beyond which the mean may be unreliable. The values of C_i, λ_i, $\theta_{p,i}$ and β are given below.

4.5.1.5 VERIFICATION OF THE MODEL

The random variate η_t are tested for independence. For the first order ARMA (1, 1, model, the residuals were estimated using equation (55a).

$$\bar{\eta}_t = E_t - \theta_{11} E_{t-1} + \eta_t + \theta_{11} \eta_{t-1} \qquad (55a)$$

For AR(B) model, it is

$$\bar{\eta}_t = E_t - \sum_{i=1}^{3} \theta_{3,i} E_{t-i} \qquad (55b)$$

Fig. 15 is the graphical verification of the random variate independence. The dotted lines are the 95% confidence level. The figure showed the η_t have approximate independent normal distribution. The small values of the serial correlations also point to the randomness of the data.

	i	C_i	i	$\theta_{3,1}$	$\theta_{3,2}$	$\theta_{3,3}$
Kaduna	1	0.82	$60^{\circ}30$			
	2	0.89	$2^{\circ}57$	0.5986	0.0132	0.0100
	3	0.29	$159^{\circ}18$			
	ARMA coefficients θ_{11} = 0.95, ϕ_{11} = 0.60					
Ikeja	1	0.48	$297^{\circ}36$	0.3879	0.0643	0.1499
	2	0.51	$341^{\circ}51$			
	3	0.17	$1264^{\circ}12$			
	ARMA coefficients θ_{11} = −0.45, ϕ_{11} = 0.05					

The predictive equation was tested for 1988 using the random variate for 1987. The result (Fig.) showed that there is good agreement between the observed and the predicted values.

4.5.2 TEMPERATURE

4.5.2.1 CHARACTERISTICS

The annual means of temperature are fairly constant and stood at 25.61 - 27.14°C in Ikeja and 24.10 - 25.05°C in Kaduna. The upper and low mean occurs in 1971, 1987 and 1976, 1973 in Ikeja and Kaduna respectively. Slight increase in the mean is found between 1982 and 1987 in Ikeja while no pattern of increase exist in Kaduna.

The variance has a small range in Lagos (1.52 - 3.63°C²) and a little higher in Kaduna (4.50 - 6.12°C²) despite smaller annual means. This shows that Kaduna has extremes of temperature compared with the small variations in Lagos. On the whole, the

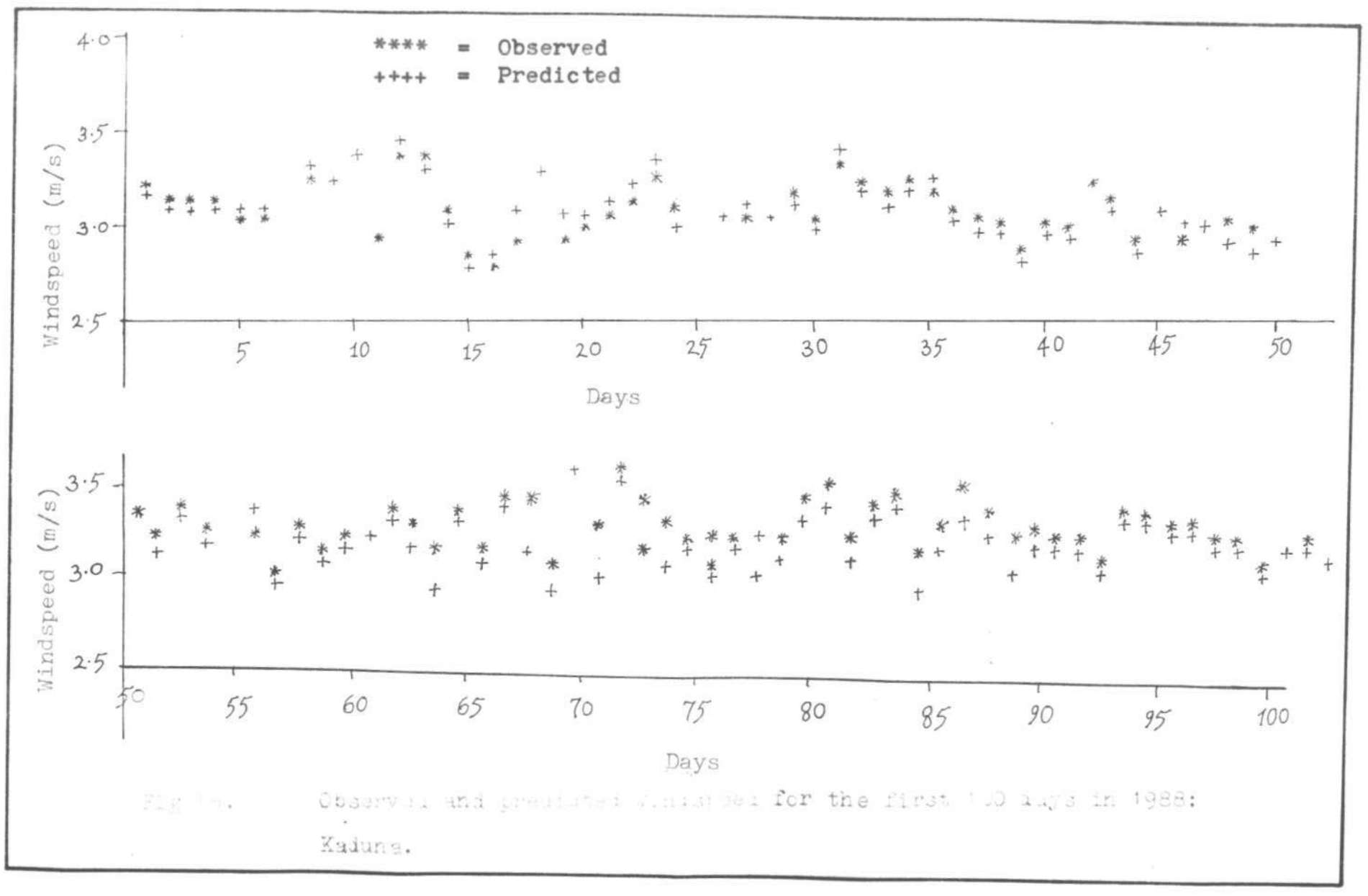


Fig 1a. Observed and predicted windspeed for the first 100 days in 1988: Kaduna.

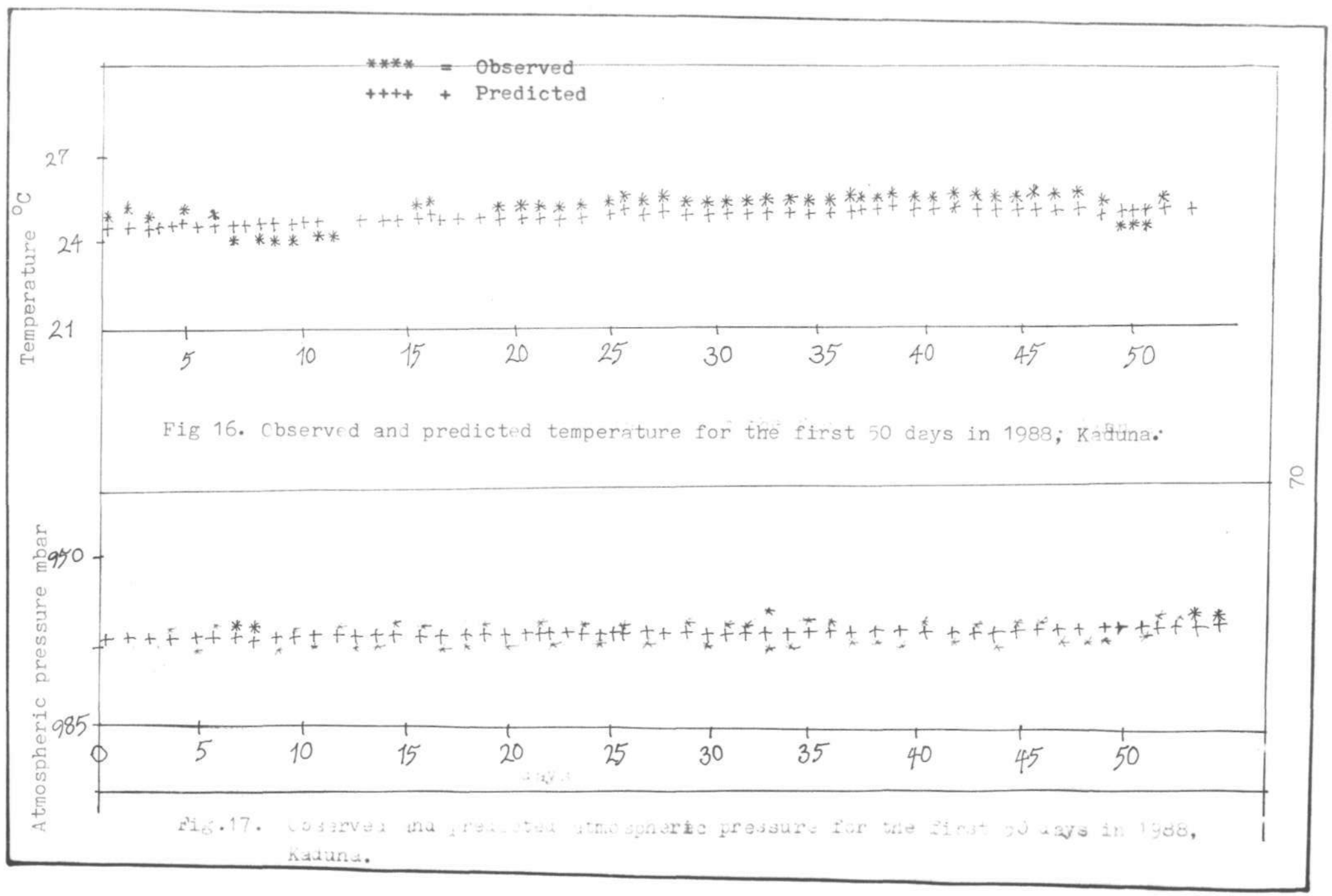


Fig 16. Observed and predicted temperature for the first 50 days in 1988; Kaduna.

Fig.17. Observed and predicted atmospheric pressure for the first 50 days in 1988, Kaduna.

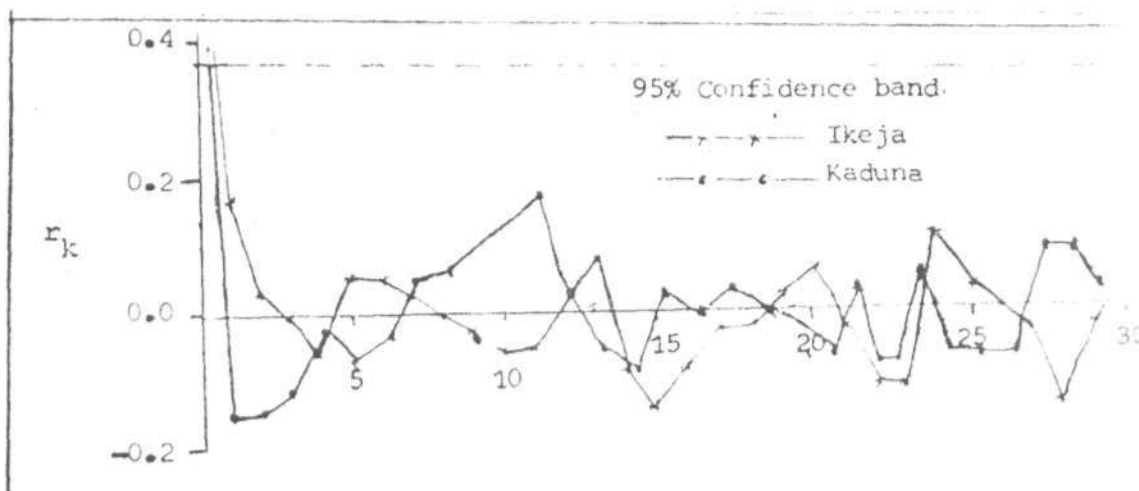


Fig. 18. Serial correlation of the random variates for windspeed.

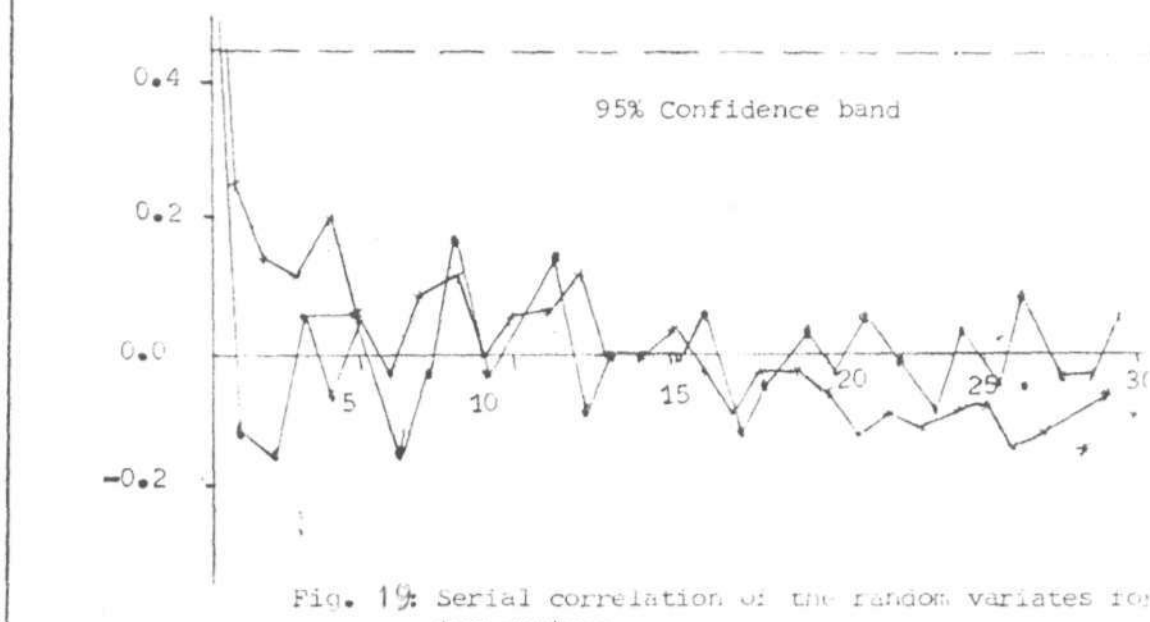


Fig. 19: Serial correlation of the random variates for temperature.

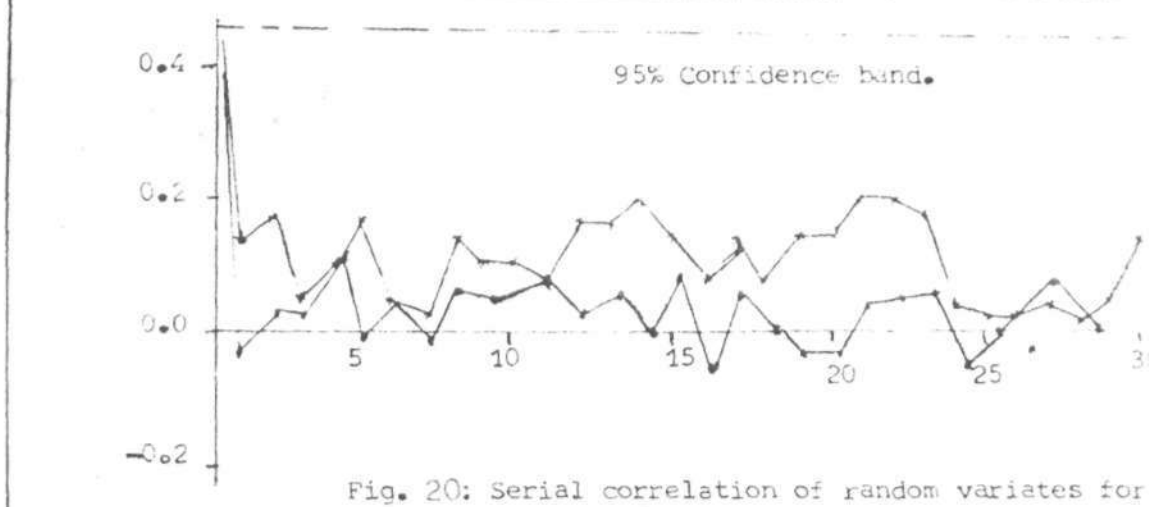


Fig. 20: Serial correlation of random variates for atmospheric pressure.

this characteristics point to a greater level of predictability of temperature than the windspeed.

When the mean, variance and standard deviations were tested for stationarity, at 5% confidence level, all the annual means are contained within the 22.76 - 25.94°C band in Kaduna and 25.24 - 27.16°C in Lagos. [illegible] variance and standard deviation. Hence the data are stationary.

4.5.2.2 PERIODIC VARIATIONS

The harmonic analysis showed that two harmonics are responsible partly for the annual variations in temperature data as is evident in amplitudes. Other higher harmonics were found of little worth. The amplitudes of the first harmonics have closer range in Kaduna (1.89 - 2.31°C) than in Lagos (1.11 - 1.79°C) and are appreciably greater than those of others higher ones. Each station has separate phase shifts, being 330 - 355°C in Kaduna and 50 - 70° in Lagos. In addition, the annual variability is low. From the results (table 7), it is also found that the second harmonic has high amplitudes, although smaller than the first, with range of 0.58 - 0.90°C in Ikeja and 1.26 - 1.96°C in Kaduna, all the phase shifts are contained in the third quadrants. Other higher harmonics have highly variable amplitudes and phase angles for all the years. From the consistency of the shifts, it is evident that the records are homogenous.

In confirming the harmonics of significance, using Fisher's test at 5% significant level, the first two are important judging from their respective computed g value which are appreciably greater than the critical g*. No consistent behaviour was found in other higher harmonics and were thus rejected.

The harmonics of importance can also be identified by determining the percentage of variance accounted for by each harmonics. It is confirmed that the first two harmonics are important, accounting for 65 - 70% in Kaduna and 50 - 60% in Ikeja. It is also evident that the first harmonics accounted for higher percentage (55%) in Ikeja than the first in Kaduna. The reverse is the case for the second harmonics. As for the higher order harmonics, they account for less than 1% of the variance in most cases (appendix II).

The two significant harmonics in this work contrasts with the findings of Kothandaraman (1971) and Thomann (1967) that the first harmonic is important accounting for over 90% of variance. While they accounted for less than 70%, there is difference between the percentage accounted for by the first and second harmonics for any two stations.

The spectra of the observed temperature records fall assymptotically to the frequency axis showing that higher frequencies (and hence higher order harmonics) contribute less to the variance. As earlier found, the variance is contained within the first few frequency band (0.01 - 0.04 cycles/day) with range as 29.48 - 32.50, 16.52 - 16.28, 2.23 - 3.71 and 0.82 - 1.20 $^{o}C^{2}$ day/cycle in Ikeja and 32.57 - 33.12, 19.39 - 19.61,

3.57 - 3.60 and 0.72 - 1.11 in Kaduna. Higher frequency spectra are less than $1.0^{o}C^{2}$ day/cycle in most cases (Fig. 7).

The result of the serial correlation analysis showed that the observed temperature records have greater correlations at lags 1 and 2 than at higher lags, although all the coefficients are significantly greater than zero for lags of up to 50 days. (Fig. 7). The typical values of 0.90, 0.84 and 0.80 in Kaduna and 0.74, 0.68 and 0.67 in Ikeja, for the three lags show a very high degree of positive persistence for temperature.

4.5.2.3 NON-SEASONAL VARIATIONS

The characteristics of the non-seasonal residuals on removing the mean and the periodic component is almost constant with mean zero (table 10). The standard deviation has small range indicating that temperature data are stationary.

The spectra analysis identify four hidden periodicities in both Ikeja and Kaduna. The peaks occur at 0.10, 0.20, 0.29, and 0.39 cycles per day. These peaks indicate the influence of weekly and fortnightly events on temperature.

The removal of the mean and periodic components from the observed series have little influence on the dependence of the non-seasonal residual series judging from their correlations at the first three lags (Fig. 10). However, the correlation are higher in Kaduna (0.65 - 0.69, 0.45 - 0.50 and 0.35 - 0.40) than in Ikeja (0.43 - 0.54, 0.20 - 0.30, 0.22 - 0.26). This dependence showed in part, that temperature is a linear autoregressive process requiring some model fittings. This is necessary considering the fall that the harmonic components accounted for less than 70% of the variance.

To confirm the linear autoregressive model, the serial correlations and the partial autocorrelations functions are used. The oscillations of the coefficients coupled with the fact that the partial autocorrelations function approach zero at higher order identify the process as autoregressive ($\theta_{k,k} \simeq 0$ as k greater than 3, Fig. 10 and table 13).

The result of the linear autoregressive analysis showed that the coefficient of determination R^2 increases slightly with increase in the order of the model fitted. For instance, when the order was increased from 1 to 4, R^2 increases by about 1% and remain constant thereafter to the sixth order in both Kaduna and Ikeja.

The use of the model could therefore be limited to the second order AR(2). However, R^2 are less than 0.50 in all the years showing that the dependent components account for less than 50% of the non-seasonal residuals.

4.5.2.4 PREDICTIVE EQUATION FOR TEMPERATURE

The periodic analysis showed that the first and second harmonics were significant for temperature records. In addition, the non-seasonal residuals could be predicted by linear autoregressive models of order 2. Therefore the predictive equation for temperature is of the form:

$$t = \mu_T + \sum_{i=1}^{2} C_i \sin\left(\frac{2\Pi i t}{365} + \lambda_i\right)$$

$$+ \sum_{i=1}^{2} \theta_{2,i} E_{t-i} + \zeta_t \qquad (56$$

where μ_T is the expected value of temperature; values of C_1, and $\theta_{2,i}$, i = 1, 2 are given below.

4.5.2.4 VERIFICATION OF THE MODEL

For verification, the random variates were tested for independence. For the second order AR model, the residuals were estimated using equation:

$$\bar{\zeta}_t = E_t - \sum_{i=1}^{2} \theta_{2,i} E_{t-i} \qquad (57)$$

From Fig. 16, it is clear that the serial correlations v_e of the estimated random variates are within the 95% confidence band. In addition, the values of the serial correlations are very small showing the independence of the variates.

	i	C_i	λ_i	$\theta_{2,1}$	$\theta_{2,2}$
Kaduna	1	2.01	$345^{\circ}41$		
	2	1.72	$191^{\circ}52$	0.642	0.0429
Ikeja	1	1.56	$58^{\circ}46$	0.4863	0.0811
	2	0.53	$224^{\circ}18$		

The above predictive model was tested for 1988. Good agreement was found between the observed and predicted values. (see fig 16).

4.5.3 ATMOSPHERIC PRESSURE

4.5.3.1 CHARACTERISTICS

Atmospheric pressure has the most consistent characteristics of the three considered in this research. Although the annual means are different for Ikeja and Kaduna, the individual values for the years are within a close range. The same conclusion can be reached for the variances and the standard deviation. (Table 5). For instance, the mean stood consistently at 1006mbar in Lagos and at about 939mbars through the periods of study. The standard deviations do not exceed 2mbars in Lagos and 1.80mbar in Kaduna.

4.5.3.2 PERIODIC VARIATIONS

From the preliminary result of analysis, it was found that there exist a limited number of harmonics that can be fitted to the atmospheric pressure record within which one can obtain a reasonable result. This was found to be two beyond which the residual variance of the non-seasonal component simply does not make sense. However, the consistency in the annual mean and generally the pressure record is reflected in the amplitudes and phase angles for the years, where the range is small. For the first and the second harmonics, they are respectively 0.81 - 1.93 mbar and 1.12 - 1.80 mbar in Lagos respectively. The range is even smaller in Kaduna with respective values of 0.64 - 1.42 and 1.20 - 1.78 mbar. As for the phase angles, they are located in the fluid and first quadrants respectively for the first and second harmonics. However the two lies in the second quadrant in Kaduna.

Considering the results, not only is it evident that the amplitudes are different for Ikeja and Kaduna, the phase angles lie in different quadrant. It is necessary therefore that the values be determined for any separate station considered.

A test of significance conducted showed that the first two harmonics are important accounting for over 90% of the total residual variances (Appendix II). The importance of these two harmonics is corroborated by the result of the spectral analysis (Fig. 5) in which the first, second and third frequencies have spectral densities range of 27 - 35, 16.66 - 19.39 and 2.23 - 3.84 $mbar^2 day/cycle$. Other higher frequencies have values that are less than 1.0 $mbar^2 day/cycle$.

The dependent nature of the atmospheric pressure records is also evident from the serial correlation coefficients which are significantly greater than zero for lags of up to 50 days. Values as high as 0.89 - 0.92, 0.77 - 0.83, 0.72 - 0.74 are obtainable for the first three lags in Ikeja and 0.87 - 0.88, 0.71 - 0.73 and 0.63 - 0.66 in Kaduna. The degree of correlations in Ikeja is higher than in Kaduna (Fig. 11).

4.5.3.3 NON-SEASONAL VARIATIONS

The results in table II showed that the mean of the non-seasonal residuals are zero while the standard deviations have small variations from year to year. They tend to 1.0 mbar and 0.50 mbar respectively in Ikeja and Kaduna respectively and are very small (less than 1% of annual mean) when compared with observed series.

The spectral analysis on the non-seasonal residuals unearth three hidden periods at 0.20, 0.29 and 0.39 cycles per day in Lagos indicating the weekly effects on the data. These frequencies have spectra of 7.75 - 9.68, 2.29 - 2.50 and 4.62 - 6.39 $mbar^2 day/cycle$. The effect of diurnal variation (frequency of 0.39) is comparable to the weekly effect (Fig. 14). Values for Kaduna are slightly higher at 14.95 - 16.67, 1.39 - 2.02 and 7.74 - 8.81 $mbar^2 day/cycle$ respectively.

The non-seasonal residuals are still highly correlated judging from the serial correlations and are as high as 0.88 - 0.90, 0.74 - 0.77 and 0.68 - 0.70 in Kaduna. The correlation is a bit lower in Lagos being 0.83 - 0.89, 0.63 - 0.77 and 0.55 - 0.71 for lag 1, 2 and 3 days respectively.

An examination of the partial autocorrelation coefficients $\theta_{k,k}$ of the non-seasonal residuals revealed that $\theta_{k,k}$ are almost zero after the third order for the two stations. This condition satisfies the linear autoregressive model of order 3 AR(3). However, the order was considered to the sixth to see the effect on accuracy.

The result of the linear autoregressive model showed that the coefficient of determination is high being in the range of 0.63 - 0.81 and 0.81 - 0.83 at the six order in Lagos and Kaduna respectively. The high correlation at the third order coupled with the additional computational efforts required may make consideration of higher orders worthless. Hence order 3 is suggested.

4.5.3.4 PREDICTIVE EQUATION FOR ATMOSPHERIC PRESSURE

The sole aim of the above discussion is to understand the behaviour of the various components of atmospheric pressure record with a view to proposing and verifying a predictive model. From such discussions, the predictive equation for atmospheric pressure is of the form:

$$t = \mu_p + \sum_{i=1}^{2} C_i \sin\left(\frac{2\Pi it}{365} + \lambda_i\right)$$

$$+ \sum_{i=1}^{3} \theta_{3,i} E_{t-i} + \zeta_t \qquad (58)$$

where t is the day; and u_p = the expected value of the atmospheric pressure. Values of C_i, λ_i and $\theta_{3,i}$, i = 1, 3 are given as follows.

	i	C_i	λ_i	$\theta_{3,i}$	$\theta_{3,2}$	$\theta_{3,3}$
Kaduna	1	1.28	$130^{o}34$			
	2	1.81	$8^{o}34$	1.0943	-0.4736	0.2844
Ikeja	1	1.58	$238^{o}14$			
	2	1.10	$24^{o}16$	0.9550	-0.3165	0.1912

For the u_p, the mean of the next three preceeding years can be used.

4.5.3.5 VERIFICATION OF THE MODEL

For equation (58) to be acceptable as the predictive model for atmospheric pressure in Ikeja and Kaduna, the random variates $\bar{\zeta}_t$ must be independent. For the 3rd order, the residuals were estimated by equation (59):

$$\bar{\zeta}_t = \bar{E}_t - \sum_{i=1}^{3} \theta_{3,i} E_{t-i} \qquad (59)$$

where $E_{t-i} = 0$ if $t-i \leq 1$.

From Fig. 17 it is clear that the serial correlation r_k of the estimated random variates have approximately normal distribution since the r_k lie within the 95% confidence band.

In addition, the predictive equation was tested using the 1988 record. The result showed that there is good agreement between the observed and the predicted values (Fig. 17).

4.5.4 SIGNIFICANCE TO AIR POLLUTANT FORECASTING

The pollutant concentration at a point downwind of emission is highly dependent on the windspeed, temperature and atmospheric pressure. The most important of these is the windspeed which comes in prominently in the Gaussian plume model. When the plume rise is determined from Holland (1953) equation, the average daily ambient temperature and pressure are required.

Based on the result of this work, it is clear that windspeed, temperature and atmospheric pressure can be predicted to some degree. Although the most difficult of the elements from the prediction point of view is windspeed the accuracy of the predicted values can be of acceptable standard if the AR(3) model is used. The small differences of the average daily temperature make the predicted values more accurate. The average daily atmospheric pressure are highly dependent on each other.

By incorporating these results into the Gaussian plume model, the average daily concentrations of the pollutants can be forcast. The value of the data generated therefore is very important in determining the reliabilities of maintaining specific emission levels set by air pollution control authorities in an air basin. Where a particularly hazardous materials are emitted into the atmosphere, the forcast can be very helpful in dictating the precautionary measures that should be taken on the day in question. This will be vital to safety of life, plants and property.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Based on this work, the following conclusions and recommendations can be arrived at:-

1. The mean of the windspeed are slightly variable with years. However, t test showed that it is of second order stationarity.
2. On the other hand, the mean, the variance and standard deviations of temperature and atmospheric data for Ikeja and Kaduna are fairly constant.
3. Periodic analysis of the record for windspeed showed that the first three harmonics are important. They account for 30 - 40% of the total residual variance. As for the temperature and atmospheric pressure records, the first two harmonics are significant. They accounted for 65%-75% and over 90% of total residual variance.
4. The serial correlations of the windspeed, temperature and atmospheric pressure records are significantly greater than zero for lags of up to 50 days. It is as high as 0.50 for the first three lags for windspeed and over 0.60 and 0.80 for temperature and atmospheric pressure respectively. These showed a high degree of positive persistence for the records most especially temperature and atmospheric pressure.
5. The spectral analysis corroborated the result of the harmonic analysis in that most of the variance of the records were contained within the first three frequencies for the three elements.

6. As for the non-seasonal analysis for windspeed, the serial correlogram of the non-seasonal residuals oscillate greatly. In addition, the spectra showed peaks at frequencies of 0.1, 0.20, 0.29 and 0.39 cycles per day. These peaks correspond to weekly and fortnightly periods.

7. The serial correlograms of the non-seasonal residuals for temperature oscillate also but are generally of higher values than the windspeed. Peaks corresponding to the frequencies is 6 are also common.

8. As for the atmospheric pressure, the serial correlations showed values that are greater than zero. However four peaks were identified in the spectra of the non - seasonal residuals.

9. The linearly dependent part of the residuals component accounted for less than 35% and 50% of the non-seasonal variance for windspeed, temperature and atmospheric pressure in Ikeja and Kaduna respectively. The difference in the linear autoregressive coefficients in the two stations showed that the coefficients must be determined for any station for which a predictive equation is required.

10. The number of models that can be fitted is the same in the two stations for the elements. Therefore, when other stations are considered, the number can be three, two, and two respectively for windspeed, temperature and atmospheric pressure.

11. The high variability in the windspeed data require that mean of shorter duration such as three years be used. Thus the three preceeding year should be useful in determining the fourier coefficients, and linear autoregressive parameters. The coefficients should be reviewed periodically to increase the accuracy of the predictive models.

12. The linear autoregressive coefficients of the third order for parameters for windspeed. The coefficients should be reviewed periodically to increase the accuracy of the predictive models.

13. In predicting the windspeed, the recommended number of harmonic should be limited to three and two for temperature and atmospheric pressure. In addition, the linear autoregressive models should be considered up to the third order for windspeed and pressure and 2 for temperature because of the small significance gained by further considerations of higher orders.

14. Efforts should be geared towards determining the emission levels at some industries such as cement, petroleum refinery, petro-chemicals and fertilizer to enable assessment of their health risk to the population and properties.

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APPENDIX I - LIST OF PROGRAMMES

```
      PROGRAM ELIASS (INPUT, OUTPUT, TAPE 4 = INPUT, TAPE 3 = OUTPUT)
            DIMENSION XC (3, 23, 16), X1 (366), A (20), B (20), C (20)
            DIMENSION PHA (20), PERVAR (20), RR (50), R1 (50), D (366)
            DIMENSION Z (366), Y2 (6,6) FR1 (55), U1 (55), NA (3)
C
C           OPEN FILES FOR THE INPUTS AND THE OUTPUTS
            OPEN (3, FILE =  IKEJA )
            OPEN (4, FILE =  WS1 )
            READ (4, 10) NYE, NS, ND, NP, (NA (I), I = 1, 3), T
10          FORMAT (2X, 7 (14, 2X), F5.1)
            WRITE (3, 6) NYE
6           FORMAT ( ANALYSIS FOR THE YEAR  , 2X, 14)
            DO 505 N1 = 1, NP
            WRITE (3, 501) N1
501         FORMAT ( PARAMETER     , 15)
            DO 7 I = 1, NO
7           READ (4, 15)  (XC (N1, I, J), J = 1, NH)
15          FORMAT (16F5.1)
            KK = 0
            DO 20 K = 1, NO
            DO 20 L = 1, NH
            KK = KK + 1
            IF (N1.EQ.1)  X1(KK) = XC (N1,K,L)
            IF (N1.EQ.2)  X1(KK) = XC (N1,K,L) + 20.0
20          IF (N1.EQ.3)  X1(KK) = XC (N1,K,L) + 1000.0
            WRITE (3, 27)
27          FORMAT (          )
```

```
      WRITE (3, 28)
28    FORMAT (          )
      WRITE (3, 29)
29    FORMAT (      N1      M       A       B       C       PHA )
      YU = 44.0/(7.0 * T)
      NM = MOD (NYE, 4)
      IF (NM.EQ.0) NY = 366
      IF (NM.NE.0) NY = 365
      IF (N1.LE.2) KD = 3
      IF (N1.EQ.3) KD = 2
      DO 30 M = 1, KD
      AS = 0.00
      BS = 0.00
      YY = YU * FLOAT (M)
      DO 35 N = 1, NY
      YK = YY * FLOAT (N)
      BI = X1 (N) * SIN (YK)
      BII = X1 (N) * COS (YK)
      AS = AS + BI
      BS = BS + BII
35    CONTINUE
      A(M) = 2.0 * AS/FLOAT (NY)
      B(M) = 2.0 * BS/FLOAT (NY)
      C(M) = SQRT (A(M) ** 2 + B(M) ** 2)
      PHA(M) = ATAN (A(M)/B(M) * (180.00/3.14159
30    WRITE (3,40) N1,M,A(M), B(M), C(M), PHA(M)
40    FORMAT (2X, 2I4, 4F12.5)
      WRITE (3, 51)
51    FORMAT (          )
      WRITE (3, 52
```

```
52      FORMAT (          )
        S = 0.00
        DO 50 J = 1, NY
50      S = S + X1 (J)
        XM = S/FLOAT (NY)
        WRITE (3, 55) XM
55      FORMAT (   THE MEAN =   , F12.5)
        S2 = 0.00
        DO 60 K = 1, NY
60      S2 = S2 + (X1(K) - XM) ** 2
        VRX = S2/FLOAT (NY - 1)
        STDX = SQRT (VRX)
        WRITE (3, 61) VRX
61      FORMAT (   THE VARIANCE =   , F12.5)
        WRITE (3, 62) STDX
62      FORMAT (   THE STANDARD DEVIATION =   , F12.5)
        WRITE (3, 842)
842     FORMAT (      )
        WRITE (3, 843)
843     FORMAT (      )
        WRITE (3, 844)
844     FORMAT (      N1    J          C(J)        PERVAR )
        DO 90 J = 1, KD
        PERVAR (J) = (C(J) ** 2/(2.0 * VRX)) * 100.00
90      WRITE (3, 86) N1,J,C(J), PERVAR(J)
86      FORMAT (2X,214,2F 16.5)
C       THIS SECTION DETERMINES THE AUTOCORRELATION COEFFICIENTS.
        CALL AUTOCORR (RR, X1, NY, 50)
```

```
C       THIS SUBROUTINE PLOT THE AUTOCORRELATION COEFFICIENTS WITH LAG.
        WRITE (3,820)
820     FORMAT (        )
        WRITE (3,821)
821     FORMAT (        )
        WRITE (3,822)
822     FORMAT (        )
        WRITE (3,823)
823     FORMAT (        )
        WRITE (3,824)
824     FORMAT (        )
        CALL GRAPH 1 (RR,50)
C       THIS SECTION DETERMINES THE VARIANCE SPECTRUM AND PLOT
        WITH THE FREQ.
        M = 50
        MM = M + 1
        CALL VARSP (FR1,U1,RR,MM,50)
        WRITE (3,825)
825     FORMAT (        )
        WRITE (3,826)
826     FORMAT (        )
        WRITE (3,827)
827     FORMAT (        )
        WRITE (3,828)
828     FORMAT (        )
        WRITE (3,829)
829     FORMAT (        )
        IF (N1.EQ.1) VAMAX = 20.0
        IF (N1.EQ.2) VAMAX = 35.
        IF (N1.EQ.3) VAMAX = 35.0
```

```
      CALL GRAPH 2 (FR1,U1,VAMAX,MM)
      WRITE (3,841)
841   FORMAT (          )
C     COMPUTE THE PERIODIC COMPONENTS OF THE RESIDUALS OF THE
      OBSERVED
C     DATA USED IN THE PERIODIC (HARMONICS) ANALYSIS
      TI = 44.0/(7.0 * T)
      DO 110 J = 1, NY
      AS = 0.00
      DO 115 K = 1, KD
      U1 = TI * FLOAT (K * J)
      TU = A(K) * SIN(UI)
      TK = B(K) * COS(UI)
115   AS = AS + TU + TK
      ZI = XM + AS
110   Z(J) = X1(J) - ZI
      SS1 = 0.00
      DO 113 K = 1, NY
113   SS1 = SS1 + Z(K)
      ZM = SS1/FLOAT (NY)
      ZE = 0.000
      DO 111 L = 1,NY
111   ZE = ZE + (Z(L) - ZM) ** 2
      ZX = ZE/(FLOAT (NY - 1))
      ZS = SQRT (ZX)
      SHB = VRX - SHA/2.0
C     THIS SECTION DETERMINES THE AUTOCORRELATION COEFFICIENTS
C     OF THE STOCHASTIC COMPONENTS
      CALL AUTOCORR (R1,Z,NY,50)
```

```
      WRITE (3,810)
810   FORMAT (          )
      WRITE (3, 811)
811   FORMAT (          )
      WRITE 3,812)
812   FORMAT (          )
      WRITE 3,813)
813   FORMAT (          )
      WRITE 3,814)
814   FORMAT (          )
      WRITE 3,817)
817   FORMAT (          )
      CALL GRAPH 1 (R1,50)
      L = 50
      LI = L + 1
      CALL VARSP (FR1,U1,R1,LI,50)
      WRITE (3,806)
806   FORMAT (          )
      WRITE (3,807)
807   FORMAT (          )
      WRITE 3,808)
808   FORMAT (          )
      WRITE (3,809)
809   FORMAT (          )
      WRITE (3,815)
815   FORMAT (          )
      WRITE (3,816)
816   FORMAT (          )
      IF (N1.EQ.+) VAIX = 5.0
```

```
      IF (N1.EQ.2) VAMX = 5.0
      IF (N1.EQ.3) VAMX = 15.0
      CALL GRAPH 2 (FR1,U1,VAMX,LI)
C     THIS SECTION DETERMINES THE AUTOREGRESSIVE COEFFICIENTS
C     OF THE DATA
      NL = NA(N1)
      IF (NL.EQ.0) GO TO 626
      CALL AUTOREGRESS (NL,6,NY,Z,ZS,Y2,R1,D)
      GO TO 627
626   CALL ARMA (NY,ZS,Z,D)
627   WRITE (3,612)
612   FORMAT (  THE SERIAL CORRELATION OF INDEPENDENT RANDOM
     VARIATE  )
      CALL AUTOCORR (R1,D,NY,50)
      Q = 0.00
      DO 633 LO = 1,25
633   Q = Q + R1 (LO) ** 2
      Q = Q * T
      WRITE (3,634) Q
634   FORMAT (  THE "Q" STATISTICS  , F12.5)
      CALL GRAPH 1 (R1,50)
505   CONTINUE
      STOP
      END
      SUBROUTINE AUTOCORR (R,X,NJ,KV)
      DIMENSION R(KV), X(NJ)
      MK = NJ - M
      S3 = 0.00
      S4 = 0.00
```

```
      S5 = 0.00
      S6 = 0.00
      S7 = 0.00
      DO 80 K = 1,MK
      S3 = S3 + X(K) * X(K + M)
      S4 = S4 + X(K)
      S5 = S5 + X(K + M)
      S6 = S6 + X(K) ** 2
80    S7 = S7 + X(K + M) ** 2
      S3 = S3/FLOAT (MK)
      S45 = S4 * S5/FLOAT (MK ** 2)
      S8 = S3 - S45
      S6 = S6/FLOAT (MK)
      S9 = (S4/FLOAT (MK)) ** 2
      S7 = S7/FLOAT (MK)
      S10 = (S5/FLOAT (MK)) ** 2
      S11 = SQRT (S6 - S9)
      S12 = SQRT (S7 - S10)
      S13 = S11 * S12
      R(M) = S8/S13
75    CONTINUE
      RETURN
      END
      SUBROUTINE VARSP (FR,U,R2,MI)
      DIMENSION FR(MI), U(MI), R2(MI), V(51)
      DO 401 J = 1,MI
      VS = 0.00
      DO 402 K = 1,MI - 1
```


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```
      VE = FLOAT (K * (J-1)) * 3.14159/FLOAT (MI-1)
      VF = R2(K) * COS(VE)
402   VS = VF + VS
401   V(J) = 2.0 * VS+R2(MI-1) * COS(FLOAT(J-1) * 3.14159) + 1.00
      U(1) = 0.5 * (V(1) + V(2)
      FR(1) = 0.000
      DO 403 JK = 2,MI-1
      FR(JK) = FLOAT(JK-1)/(2.0 * FLOAT(MI-1)
403   U(JK) = 0.25 * V(JK-1) + 0.50 * V(JK) + 0.25 * V(JK+1)
      U(MI) = 0.50 * (V(MI-1) + V(MI))
      FR(MI) = FLOAT (MI-1)/(2.0 * FLOAT(MI-1))
      RETURN
      END
      SUBROUTINE GRAPH 1 (RHO,MO)
      REAL LINE (71)
      DIMENSION RHO(MO), RK(11)
      DATA BLANK,DOT,STAR,PLUS/1H ,1H.,1H*,1H+/
      DO 705 J = 1,11
705   RK(J) = 0.20 * FLOAT (J-1) - 1.0
      WRITE (3,800)
800   FORMAT (9X,                Autocorrelation Coeff.   RK )
      WRITE (3,801)
801   FORMAT (          )
      WRITE (3,802)
802   FORMAT (          )
C     WRITE (3,706) (RK(J), J = 1,11)
C706  FORMAT (1H5, 4X, F4.1, 9(3X, F4.1), 3X, F4.1)
      DO 701 J = 1,71
```

```
701   LINE(J) = DOT
      DO 707 J = 1,71,7
707   LINE(J) = PLUS
      WRITE (3,702) (LINE(J), J = 1,71)
702   FORMAT (9X, 71A1)
      DO 703 J = 1,71
703   LINE(J) = BLANK
      LINE(36) = DOT
      DO 704 J = 1,MO
      I = 35.0 * (RMD(J) + 1.0) + 1.5
      ME = MOD(J,5)
      IF (ME.EQ.0)  LINE(36) = PLUS
      LINE(I) = STAR
      WRITE (3,708) (LINE(LI), LI = 1,71)
708   FORMAT (9X,71A1)
      DO 709 K = 1,71
709   LINE(K) = BLANK
704   LINE(36) = DOT
      RETURN
      END
      SUBROUTINE GRAPH 2 (FREQ,VA,VAMAX,N)
      REAL LINE(71)
      DIMENSION FREQ(N), VA(N), VO(51), VAM(11)
      DATA BLANK,DOT,STAR,PLUS/1H , 1H., 1H*, 1H+/
      WRITE (3,830) VAMAX
830   FORMAT (9X,  VAMAX =  , F5.1)
      WRITE (3,831)
```

```
831   FORMAT (          )
      VAMA = 0.2 * VAMAX
      DO 716 J = 1,11
716   VAM(J) = VAMA * FLOAT(J-1) - VAMAX
      WRITE (3,803)
803   FORMAT (9X,                          Spectral Density  )
      WRITE (3,804)
804   FORMAT (          )
      WRITE (3,805)
805   FORMAT (          )
C     WRITE (3,717) (VAM(J), J = 1,11)
C717  FORMAT (1HS,4X,F5.1,2X,9(F5.1,2X),2X,F5.1
      DO 719 J = 1.71
719   LINE (J) = DOT
      DO 718 J = 1,71,7
718   LINE (J) = PLUS
      WRITE (3,720) (LINE(J), J = 1,71)
720   FORMAT (9X,71A1)
      DO 724 K = 1,71
724   LINE(K) = BLANK
      DO 721 J = 1,N
      VO(J) = VA(J)/VAMAX
      I = 35.0 * (VO(J) + 1.0) + 1.5
      MU = MOD(J,5)
      IF(MU.EQ.0) LINE(36) = PLUS
      LINE(I) = STAR
      WRITE (3,722) (LINE(L), L = 1,71)
```

```
722     FORMAT (9X,71A1)
        DO 723 JI = 1,71
723     LINE(JI) = BLANK
721     LINE(36) = DOT
        RETURN
        END
        SUBROUTINE AUTOREGRESS (NX,M,NJ,Z1,ZK,YK,R2,Y)
        DIMENSION YK(M,M), Y(NJ), R2(M), Z1(NJ), SL(6), SE(6)
        PRINT*,M,NJ,ZK,NX
        YK(1,1) = R2(1)
        RSB(1) = R2(1)**2
        RSN(1) = 1. - RSB(1)
        N = 1
        SS1 = (1.0 + R2(1)) * (1.00 - R2(1))
        SZ(1) = SS1 * (FLOAT(NJ)-1.)/(FLOAT(NJ) - 3.0)
        SL(1) = SZ(1) * ZK
        SE(1) = SQRT(SL(1)/FLOAT(NJ))
      ; DO 150 N = 2,M
        MN = N - 1
        AA = R2(N)
        BB = 1.00
        DO 155 I = 1,MN
        AA = AA - YK(MN,I) * R2(N-I)
155     BB = BB - YK(MN,I) * R2(I)
        YK(N,N) = AA/BB
        DO 160 I = 1,MN
160     YK(N,I) = YK(MN,I) - YK(N,N) * YK(MN,N-I)
C
```

```
C       THIS SECTION CALCULATES THE COEFFICIENT OF DETERMINATION
C       OF THE OR THE SQUARE OF THE MULTIPLE CORRELATION.
        RSB(N) = 0.00
        DO 166 I = 1,N
166     RSB(N) = YK(N,I) * R2(I) + RSB(N)
        RSN(N) = 1.0 - RSB(N)
C
C       THIS SECTION THE RESIDUAL VARIANCE THAT FORMS THE
C       CRITERION FOR THE ORDER OF THE MODEL TO USE.
        SS1 = SS1 * (1.0 - YK(N,N)) * (1.0 + YK(N,N))
        SZ(N) = SS1 * (FLOAT(NJ) - FLOAT(1))/(FLOAT(NJ) - 1.0-2.0 *
        FLOAT(N))
        SL(N) = SZ(N) * ZK
        SE(N) = SQRT(SL(N)/FLOAT(NJ))
150     CONTINUE
        WRITE (3,139)
139     FORMAT ( ORDER   PARAMETERS OF THE AUTOREGRESSIVE MODEL )
        DO 620 K = 1,6
620     WRITE (3,162) K,(YK(K,J), J = 1,K
162     FORMAT (3X,I4,6F12.6)
        WRITE (3,170)
170     FORMAT (          )
        WRITE (3,167)
167     FORMAT ( ORDER        STD. VAR.        VAR.    STD ERROR      R
        1. - R  )
        DO 168 J = 1,6
168     WRITE (3,169) J,SZ(J), SL(J), SE(J), RSB(J), RSN(J)
169     FORMAT (I5,F8.6, 5X, F6.4, 2X, F8.4, 2X, F7.4, 2X, F8.4)
        WRITE (3,171)
```

```
171     FORMAT (            )
        WRITE (3,172)
172     FORMAT (            )
C       THIS SECTION CALCULATES THE INDEPENDENT RANDOM VARIATES I
C       ANY ORDER CHOSEN.
        WRITE (3,625) NX
625     FORMAT (  THE RANDOM VARIATES FOR ORDER , 17)
        Y(1) = Z1(1)
        DO 506 K = 2,NJ
        YRS = 0.000
        DO 507 J = 1,NX
        N5 = K-J
507     YRS = YRS + YK(NX,J) * Z1(NS) * ZK
        Y(K) = Z1(K) - YRS
506     CONTINUE
        DO 611 J = 1,25
        JK = 15 * (J-1)
611     WRITE (3,619) (Y(JK+1), I = 1,15
619     FORMAT (15(F5.2))
        RETURN
        END
        SUBROUTINE ARMA (NT,ZK,Z1,F)
        DIMENSION Z1(NT), F(NT), E(20,20,366)
C       THIS SUBROUTINE COMPUTES THE COEFFICIENTS OF THE ARMA MO
C       BY MINIMISING THE SUM OF THE LEAST SQUARES
        DO 605 I = 1,4
        IF (I.EQ.1) U1 = 1.
        IF (I.EQ.1) U2 = 1.
```

```
      IF (I.EQ.2) U1 = 1.
      IF (I.EQ.2) U2 =-1.
      IF (I.EQ.3) U1 = -1
      IF (I.EQ.3) U2 = -1.
      IF (I.EQ.4) U1 = -1
      IF (I.EQ.4) U2 = 1
      DO 601 K = 1,20
      KJ = 1 * K
      DO 602 J = 1,20
      KX = KJ * J
      XL = 0.05 * U1 * FLOAT(K)
      XK = 0.05 * U1 * FLOAT(J)
      E(K,J,1) = Z1(1)
      S = E(K,J,1) ** 2
      DO 603 M = 2,NT
      EQ1 = XK * Z1 (M-1)
      EU = XL * E(K,J,M-1)
      E(K,J,M) = Z1(M) - EQ1 + EU
603   S = S + E(K,J,M) ** 2
      IF (KX.EQ.1) SMIN = S
      IF (KX.EQ.1) GO TO 602
      IF (SMIN.GT.S) GO TO 616
      GO TO 617
616   SMIN = S
      XF = XL
      XE = XK
      GO TO 602
617   SMIN = SMIN
      XF = XF
      XE = XE
```

```
602     CONTINUE
601     CONTINUE
605     CONTINUE
        WRITE (3,622) SMIN
622     FORMAT (  THE LEAST SQUARE =   , F12.7)
620     WRITE (3,619) XF,XE
619     FORMAT (  THE ARMA(1,1) PARAMETERS,TETA & PHI =   , 2F12.6)
        WRITE (3,621
621     FORMAT (              )
C       THE VARIANCE OF THE RESIDUALS REMAINING AFTER THE FITTING
C       OF ARMA (1,1) MODEL
        UN = 1.0 + XF**2-2. * XF * XE
        HY = 1.0 - XE ** 2
        STD = HY/UN
        ST = ZN * STD
        SJ = SQRT(ST/FLOAT(NT))
        WRITE (3,610) STD
610     FORMAT (     THE VARIANCE OF THE RESIDUAL OF ARMA (1,1) =
        F8.6)
        WRITE (3,611) ST
611     FORMAT (  THE VARIANCE OF THE RESIDUAL OF ARMA(1,1) = ,F8.6)
606     WRITE (3,612) SJ
612     FORMAT (  THE STANDARD ERROR OF THE MEAN =   , F8.6
        WRITE (613)
613     FORMAT (          )
        WRITE (3,614)
614     FORMAT (          )
```

```
C       THIS SECTION COMPUTES THE RESIDUALS AFTER FITTING ARMA
C       MODEL TO THE TOTAL RESIDUALS.
        WRITE (3,628)
628     FORMAT (    THE INDEPENDENT RANDOM AFTER FITTING ARMA   )
        F(1) = Z1(1) * ZN
        DO 607 L = 2,NT
        FT = Z1(L-1) * XE - XF * F(L-1)
        F(L) = (Z1(L) - FT) * ZN
607     CONTINUE
        DO 629 J = 1,25
        JI = 15 + (J-1)
629     WRITE (3,630) (F(JI + I), I = 1,15)
630     FORMAT (15F5.2)
        RETURN
        END
```

Appendix II - Percentage of Variance accounted for by the first ten harmonics.
windspeed, Kaduna.

Year Harm.	1970	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1984	1985	1986	1987	1978-81	1984-86
1	5.21	7.52	14.86	19.48	14.85	4.57	20.31	3.41	4.28	9.59	3.28	10.55	16.90	2.85	15.84	9.13	10.32
2	5.40	9.04	2.75	15.61	16.71	7.12	10.17	26.24	19.95	9.24	15.89	5.76	8.37	18.92	4.62	9.10	8.16
3	1.31	1.74	1.02	5.86	9.78	9.46	3.43	7.95	5.50	0.32	0.69	3.93	1.56	1.10	0.42	1.14	0.64
4	3.21	0.29	1.62	1.20	0.49	1.05	0.54	0.33	0.78	1.01	8.87	0.14	2.82	0.24	0.17	0.13	0.28
5	2.48	2.56	0.52	2.53	0.57	2.77	5.59	1.34	0.69	2.55	10.87	1.84	0.09	2.75	0.78	0.16	0.93
6	0.01	0.48	3.19	0.04	3.47	0.32	5.49	0.30	0.13	1.49	3.12	0.80	0.90	1.13	0.44	0.16	0.39
7	1.86	0.84	2.43	1.18	2.77	2.94	1.46	1.72	4.38	4.36	2.07	1.45	1.52	0.98	0.01	0.35	0.08
8	2.51	1.13	2.72	0.10	1.23	3.85	3.47	1.38	2.14	5.12	1.33	0.64	0.41	0.97	0.83	0.05	0.21
9	1.32	0.16	1.12	0.57	1.49	1.90	1.13	1.55	1.13	0.42	2.25	1.88	1.17	1.73	6.63	0.10	0.37
10	2.10	0.07	1.27	0.74	0.68	0.73	2.94	0.83	1.14	0.04	1.97	1.61	0.40	3.10	0.83	0.10	0.10

Appendix II – Percentage of variance accounted for by each of the first ten harmonics

(Temperature) Kaduna

Year / Harm	1970	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1984	1985	1986	1987	1972–81	1984–87
1	44.75	47.17	49.49	39.79	31.84	43.46	42.97	33.29	35.69	36.62	29.97	31.90	32.79	43.99	44.95	37.13	37.30
2	25.16	25.26	15.43	30.84	34.04	24.30	29.45	28.63	29.81	32.40	33.83	37.76	30.27	30.86	36.53	26.49	29.94
3	0.55	0.48	0.13	4.44	8.36	0.84	0.56	4.49	6.24	1.85	3.11	6.26	0.30	3.17	0.39	1.67	1.43
4	4.08	1.43	1.16	0.05	1.03	0.06	1.51	0.17	1.65	1.15	1.13	0.13	0.37	1.83	1.36	0.25	0.43
5	0.28	0.78	0.79	1.42	0.52	0.05	1.20	0.36	0.75	0.91	2.38	1.10	1.77	0.35	1.99	0.10	0.84
6	2.76	0.31	0.55	0.73	1.82	0.86	0.85	1.92	0.17	0.05	1.72	0.04	1.78	0.25	0.23	0.23	0.08
7	1.27	0.38	2.05	0.57	0.096	2.89	0.81	1.43	0.59	2.27	2.34	0.58	4.57	0.13	1.60	0.15	0.51
8	0.71	0.23	0.70	0.01	1.81	2.69	0.70	1.09	0.34	1.59	0.37	0.88	0.76	0.96	0.66	0.18	0.14
9	2.19	0.13	0.52	0.65	0.78	0.48	0.19	0.89	0.91	1.24	1.16	0.16	0.06	0.34	1.32	0.00	0.19
10	0.30	0.46	2.00	1.12	2.04	0.16	0.83	0.43	2.09	0.42	0.45	0.41	0.30	0.66	0.48	0.15	0.08

Appendix II - Percentage of total Variance accounted by Harmonics for windspeed, Ikeja

Year / Harm	1970	1971	1972	1974	1975	1978	1980	1970–75	1980–82	1986–87
1	**12.11**	7.94	1.13	38.78	4.96	15.87	29.78	8.37	8.26	5.34
2	**8.43**	12.91	6.35	13.54	25.00	4.40	5.87	9.12	7.18	3.17
3	**12.84**	1.39	2.40	0.85	0.11	4.20	0.71	2.62	0.77	0.05
4	**4.87**	0.21	3.62	0.30	0.09	17.74	0.05	0.43	5.92	0.05
5	**6.12**	0.29	0.41	1.22	1.49	2.17	0.93	0.08	0.06	0.59
6	**0.32**	1.93	0.15	0.28	1.10	1.55	0.60	0.07	0.03	0.45
7	**0.41**	0.12	2.40	0.34	0.04	4.29	0.35	0.36	0.48	0.97
8	**0.07**	0.68	0.16	0.70	0.16	1.67	0.23	0.25	1.41	0.14
9	**1.36**	0.24	0.79	0.97	0.56	0.00	0.35	0.14	0.23	0.17
10	**0.10**	0.10	0.39	0.06	0.50	0.60	0.05	0.02	0.40	0.18

Appendix II – Percentage of total variance accounted by each harmonics Temperature, Ikeja.

Year Harm.	1970	1972	1974	1975	1978	1980	1987	1970–75	1980–82	1986–87
1	58.35	56.47	48.10	54.82	55.27	59.88	29.04	45.60	58.73	50.28
2	8.80	9.01	3.36	9.09	0.87	7.92	1.5	6.68	3.10	8.30
3	1.14	1.51	2.1	2.68	0.69	0.57	1.80	1.15	1.00	0.08
4	0.32	0.35	4.32	0.15	4.87	1.16	7.30	0.57	1.30	2.76
5	0.00	0.91	0.55	0.11	0.18	1.10	0.07	0.18	0.34	1.39
6	2.29	0.29	0.40	0.37	2.21	0.23	0.97	0.05	0.72	0.56
7	1.11	0.19	0.35	0.37	2.14	0.80	0.75	0.06	0.30	0.16
8	2.10	0.11	0.42	1.54	2.23	1.34	0.30	0.19	0.64	0.32
9	2.65	0.33	1.75	0.02	0.17	1.24	3.16	0.52	0.01	0.21
10	0.18	0.06	1.01	0.20	0.12	0.08	2.11	0.06	0.26	0.43

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