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# Modeling of Electrostatic Fields for Harmattan Season in Northern Nigeria

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**Abstract:** This paper presents the modeling of the static electric field in Zaria, Nigeria during the harmattan season, based on the on-line data capturing mechanism, which involved the use of a data acquisition system, interfaced with a digital electrostatic field strength meter (model 257D), and a computer system. The acquired electric field data are captured by the computer using the Microsoft Office Excel Program and data captured for twenty-four months (February, 2007-February, 2009). The focus of the analysis is determining the effect of environmental factors such as temperature, pressure and relative humidity on the static electric field during the harmattan season. The plots of the electric field against the variation of the environmental factors were used as the qualitative analytical tools. The data were statistically analyzed using a non-linear regression model to obtain an equation model for the harmattan period as E =-269.65430 - 0.022853*H + 0.0004187*T + 0.3805523*P. The standard error between the model and experimental value was 0.009. This was found to be insignificant; hence, the mathematical model established could be relied upon to predict electrostatic fields during harmattan in the Northern part of Nigeria.

**Keywords:** Electric field, harmattan, measurement and non-linear regression

## INTRODUCTION

Zaria is located within the co-ordinate position of latitude 11ºN and Longitude 8ºE above sea level. This falls within the Sahara zone, where harmattan activities exist due to the operation of the North- East trade wind. Harmattan is a natural phenomenon which describe the very dry dust – laden atmosphere, which rises in the Sahara desert and is carried south by winds from that area within the West-Africa region periodically from October – March of every year. This is common to the dry season of the Savannah region-(Akinsanmi *et al.*, 2009). Measurement of a given quantity is the result of comparison between the quantity (whose magnitude is known and a defined standard). In order for the results of measurement to be meaningful, the standard used for the comparison purpose must be accurately defined and should be well acceptable. The apparatus used and the method adopted must be well defined. The measurement of the electric field in the atmosphere during dust storm in the Sahara region has been established in 2000 (Chubb, 2005). The measurement of electric field in Zaria is achieved using a digital field strength meter, model 257D. This is a high quality, portable non-contacting static meter which produces consistent readings, with ease and offers years of trouble-free operations. It indicates surface voltage and polarity on objects up to plus or minus 20kV at a spacing of one inch with an accuracy of 10% of full scale (Akinsanmi, *et al.*, 2009; Chubb, 2000; Manson, 2002 ). This model was chosen because of the peripheral facilities it has for interfacing with other devices that may be required for measurement purposes.

**Theoretical Background:** Electric Field: It is customary and useful to introduce the concept of the electric field at this point. Electric field is a vector field. Given, a vector function of x. It is written as E(x) and is defined as the force that would be experienced by a charge *q* at x, divided by $q^3$. Thus, for a distribution of charges $q_i$ at

$x_i$, i = l,2,...,n,

$$E(x) = \sum_{i=1}^{n} \frac{q_1(x - xi)}{|x - xi|^3} \qquad (1)$$

The electric field has the property of being independent of the 'test'

Charge *q*; it is a function of the change distribution which gives rise to the force on the test charge, and, of course, of the test charge's position. This object has dimension $Q/L^2$ or $M^{1//2}/L^1/^2T$.

At this point, let us introduce the charge density ρ*(x.)* is introduced, which is the charge per unit volume at, or very close to, x. This object is needed to integrate over a source distribution instead of summing over its constituent charges. Thus a sum is replaced by an equivalent integral,

$$\sum_{i=1}^{n} qi \to \int d^3 xp(x) \qquad (2)$$

The charge density has dimension $Q/L^3$. In terms of ρ, the expression for the electric field can be written as

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$$E(x) = \int d^3x' \, p(x) \frac{x - x'}{|x - x'|^3} \quad (3)$$

In the particular case of a distribution of discrete point charges, it is possible to recover the sum in Eq. (1) by writing the charge density in an appropriate way. To do so, we introduce the Dirac delta function δ(*x*- a). It is defined by the integral

$$f(a) = \int dx f(x) \delta(x - a) \quad (4)$$

Where *f(x)* is an arbitrary continuous function of x, and the range of integration includes the point x = a. A special case is *f*(x) =1 which leads to

$$\int dx \delta(x = a) = 1 \quad (5)$$

Demonstrating, the normalization of the delta functions. From the arbitrariness of *f(x),* it can be concluded that δ *(x* — a) is zero, when *x* is not a and sufficiently singular at x = a, to give the normalization property.

In other words, it is in essence, the charge density of a point charge (in one dimension) located at *x* = a.
Some important relations involving delta functions are as follows:

$$\int_{a_1}^{a_2} f(x) \frac{d\delta(x - a)}{dx} dx = - \frac{df(x)}{dx}\bigg|_{x=a} \quad (6)$$

$$\int_{a_1}^{a_2} \delta[f(x)] dx = \sum_{i=1}^{N} \left[ 1/\left| \frac{df(x)}{dx} \right|_{xi} \right] \quad (7)$$

In the final expression the $x_i$ are the O's of *f* (x) between $a_1$ and $a_2$.

A delta function in three dimensions may be built as a product of three one-dimensional delta functions. In Cartesian coordinates,

$$\delta(x) = \delta(x)\delta(y)\delta(z) \quad (8)$$

This function has the property that

$$\int d^3x f(x) \delta(x - x_o) = f(x_o) \quad (9)$$

Returning to electrostatics, it can be seen that the charge density of a collection of point charges can be written as a sum of delta functions:

$$p(x) = \sum_{1=i}^{n} q_i \delta(x - x_i) \quad (10)$$

Thus

$$\begin{aligned} E(X) &= \int d^3x' p(x')(x - x') / |x - x'|^3 \\ &= \sum_{i=1}^{n} \int d^3x' q_i \delta(x' - xi)(x - x') / |x - x'|^3 \quad (11) \\ &= \sum_{i=1}^{n} q_i (x - x_i) / |x - x_i|^3 \end{aligned}$$

$$\oint D.ds = Qens \quad (12)$$

Lagrangian Formulation of Electrodynamics: Lagrangian formulation of electrodynamics applies to system consisting of charged particles and electromagnetic field. Thus, the expression for the system could be expressed as:

$$L = Lp + Li + Lf \quad (13)$$

Where

$$\begin{aligned} L_p &= MC^2 \sqrt{1 - \left(\frac{V}{c}\right)^2} \\ Li &= \frac{q}{c} A.V - q \quad (14) \\ Lf &= \frac{1}{16\pi} \int F_{\mu r} F^{\mu r} dr \end{aligned}$$

And M = mass of charge dust particles.
V = Velocity of charged particles
C = Velocity of charge particles in free space
q = Charge
$F_{\mu r}$ = Electromagnetic tensor
j = Scalar Potential

Where Lp depends on the generalized co-ordinates of the charged particles, Lf depends only on the generalized coordinates of the field and the interaction, while Li depends on the generalized coordinates of the charged particles and the field (Carpenter, 1989; 1993; 1993; Coulomb, 2000).

## MATERIALS AND METHODS

Measurement of Electric field in Zaria: Modern techniques of using Data Acquisition system (DAQ), Interfaced with the modern Electrostatic field meter was utilized. The study was conducted between February2007-February 2009 at the Thermodynamic Laboratory of the Department of Mechanical Engineering, Ahmadu Bello

University, zaria, Nigeria, where room for adequate consideration of the electrodynamics properties of the fields under consideration could be explored. The Electrostatic field meter has a very sensitive sensor to detect the presence of Electric field in an environment in KV/cm. An analogue to Digital converter (ADC) was used to convert the analogue output from the field meter to digital for the DAQ system to handle. With the DAQ system, the measured electric field strength could be monitored on the computer system along side with the time the measurement was made and the corresponding collected data logged and later exported to Microsoft Excel for onward graphical analysis of the recorded data-(Akinsanmi *et al.*, 2009; Manson, 2002; Akinsanmi *et al.*, 2008; Akinsanmi *et al.*, 2008).

The meter measures electric field strength in kilovolts per centimeter. Using the probe to surface separation as a calibration factor, it may also be used to measure surface voltage. The instrument utilizes all solid-state components including modern integrated and hybrid circuits. It may be operated from its internal re-chargeable battery system or optionally from AC power lines. The system provides an output signal proportional to the surface charge accumulation, while making no physical contact to the material being monitored. The measurement was done during harmattan months in and outside an enclosed place. The chosen enclosed place was the Thermodynamic laboratory of the Department of Mechanical Engineering, Ahmadu Bello University, Zaria, because of the available facilities which gives room for adequate consideration of the electrodynamics properties of the fields. (Akinsanmi *et al.*, 2009, Akinsanmi, *et al.*, 2008). The co-variant environmental factors to harmattan –Temperature, Atmospheric Pressure, Relative Humidity measurement devices are located around the test point. The Thermometer was used for the Temperature, and the Barometer was used the Pressure, whereas dry and wet hygrometer was used for the Relative Humidity. Electrostatic field are of significance to the power and telecommunication industries where effective protection is highly needed against earthing fault of their equipment, which could develop as a result of extreme dryness of the harmattan season, leading to the breakdown of electrical insulation properties for materials, used in power, telecommunication and avionics in the aerodrome. With subsequent prevalence of static electricity effect, bodies that become electrically charged may retain their charge for a long period. The presence of much dust in the atmosphere during this period leads to a substantial effect on the electric field production, which could induce excessive voltage into the equipment and damage such. (Akinsanmi *et al.*, 2009, Akinsanmi *et al.*, 2007; 2007)

**Non Linear Regression Model:** Scientists and Engineers often represent empirical data using a model based on mathematical equations. With the correct model and calculus, important characteristics of the data can be determined such as the rate of change anywhere on the curve (first derivative), the local minimum and maximum points of the function (zeros of the first derivative), and the area under the curve (integral). The goal of data (or curve) fitting is to find the parameter values that most closely match the data. The models to which data are fitted depend on adjustable parameters (Marko, 2003; Press, 1992; Draper and Smith, 1998; Weisstein, 2009).

For example, the formula Y = A+B*X1 +C*X2 +D*X3 (which is a third order polynomial with three independent variables and four parameters) in which X1,X2 and X3 are the independent variables, Y is the dependent variable, and A, B, C and D are the parameters. A is a constant. In this case Y is Electric Field (E), while X1, X2 and X3 are relative humidity (H), temperature (T) and pressure (P) respectively.

In an experiment, one typically measures variable *Y* at a discrete set of values of variables *X1, X2 and X3*. Curve fitting provides two general uses for this formula:

- To describe, the parameter values of A, B, C and D corresponding to the data.
- To determine which of several formulas best describes the data.

To perform fitting, some function is determined, which depends on the parameters that measures the closeness between the data and the model. This function is then minimized to the smallest possible value with respect to the parameters. The parameter values that minimize the function are the best-fitting parameters. In this case, the parameters are the coefficients of the terms of the model. In the simplest case, known as linear regression, a straight line is fitted to the data. However, in most scientific and engineering models like this, the dependent variable depends on the parameters in a nonlinear way. Thus, non-linear regression was found suitable to describe the experimental data of the phenomenon under study and was carried out using the following modeling software: SPSS version 15, DataFit version 9, GraphPad Prism version 5 and InStat version 3 (Wikipedia, 2007 and Motulsky 2009).

## RESULTS AND DISCUSSION

The measurement was done between October 2007 and March 2008 in and outside the Thermodynamic Laboratory of the Department of Mechanical Engineering, Ahmadu Bello University, Zaria, Nigeria. The co-related climatic parameters to harmattan such as temperature, pressure and relative humidity were also measured and analyzed relative to the measured electric field in Zaria. Typical results are presented in Fig. 1 – 6 below:

The measurements during harmattan, for which typical values are presented in Fig. 1 – 6, were further analyzed using nonlinear regression, since the relationships between the variables are non-linear.

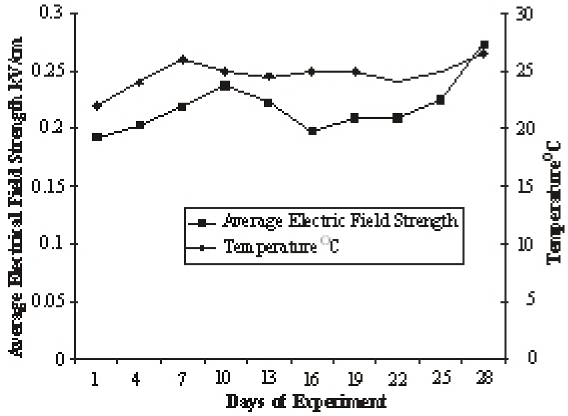



Fig. 1: Inside Average Electric Field Strength and Temperature against Days of Experiment in February, 2008.

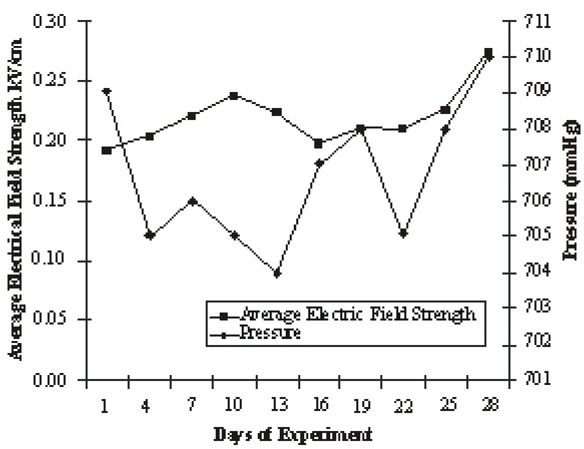



Fig. 2: Inside Average Electric Field Strength and Pressure against Days of Experiment in February, 2008.

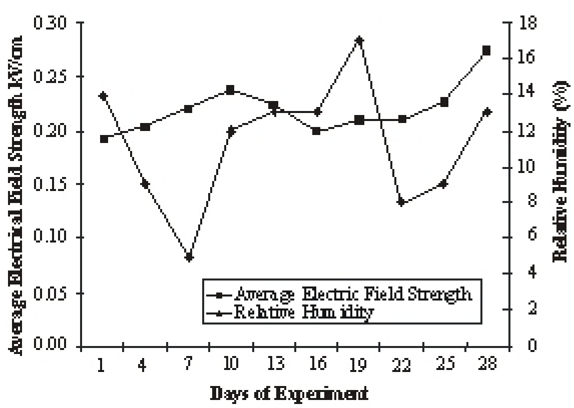



Fig. 3: Inside Average Electric Field Strength and Relative Humidity against Days of Experiment in February, 2008.

Fig. 7 is obtained by plotting electrostatic field measurements against the days in the harmattan period (October 2007 – March 2008) for inside scenario.(Marko, 2003; Draper and Smith, 1998; Press, 1992)

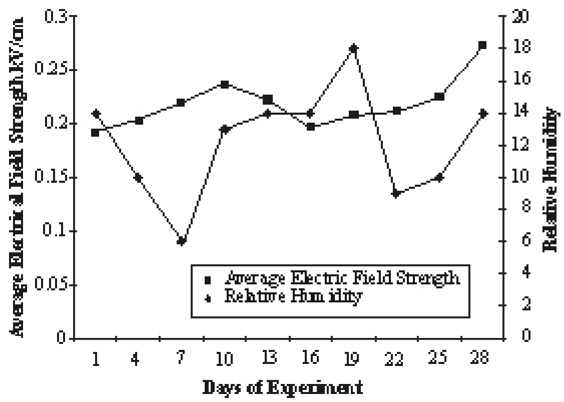



Fig. 4: Outside Average Electric Field Strength and Outside Relative Humidity against

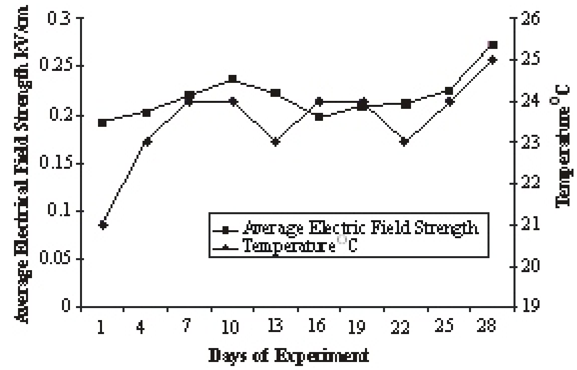



Fig. 5: Outside Average Electric Field Strength and Outside Temperature against Days of xperiment in February, 2008.

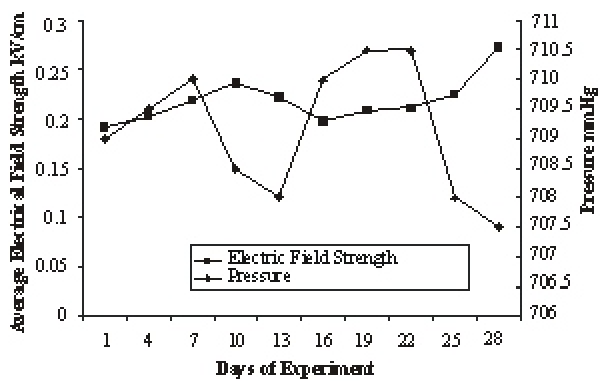



Fig. 6: Outside Average Eletric Field Strength and Outside Pressure against Days of Experiment in February, 2008

Fig. 8 is obtained by plotting electrostatic field measurements against the days in the harmattan period (October 2007 – March 2008) for outside scenario.

**Harmattan Inside Scenario Model Fitting:** Fig. 9 is the model fitting plot for the harmattan period, inside the test location.

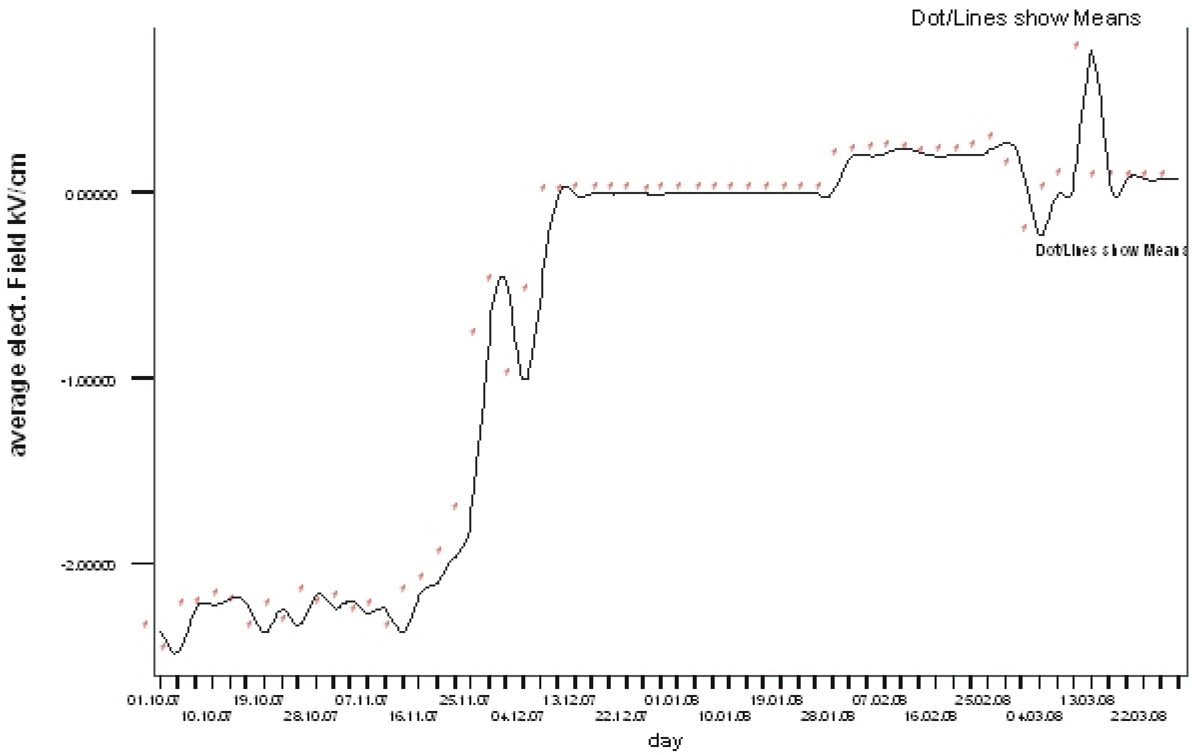



Fig. 7: Plot of Average Electrostatic Field during Harmattan between October to March (Inside Scenario)

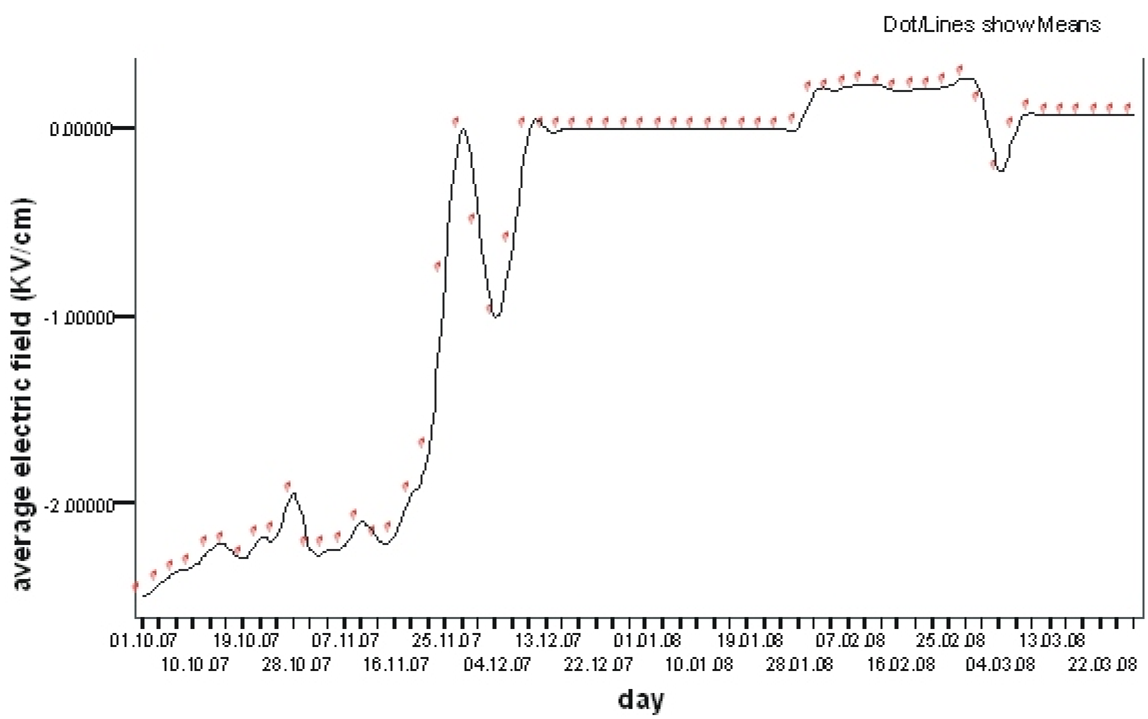



Fig. 8: Plot of Average Electrostatic Field during Harmattan between October to March (Outside Scenario)

**Harmattan Outside Scenario Model Fitting:** Fig. 10 is the model fitting plot for the harmattan period, outside the test location.

For the Harmattan, from the model equation Y = a +b*x1 + c*x2 + d*x3 the parameters are a = -269.65430, b=-0.022853, c=0.0004187 and d= 0.3805523 Where

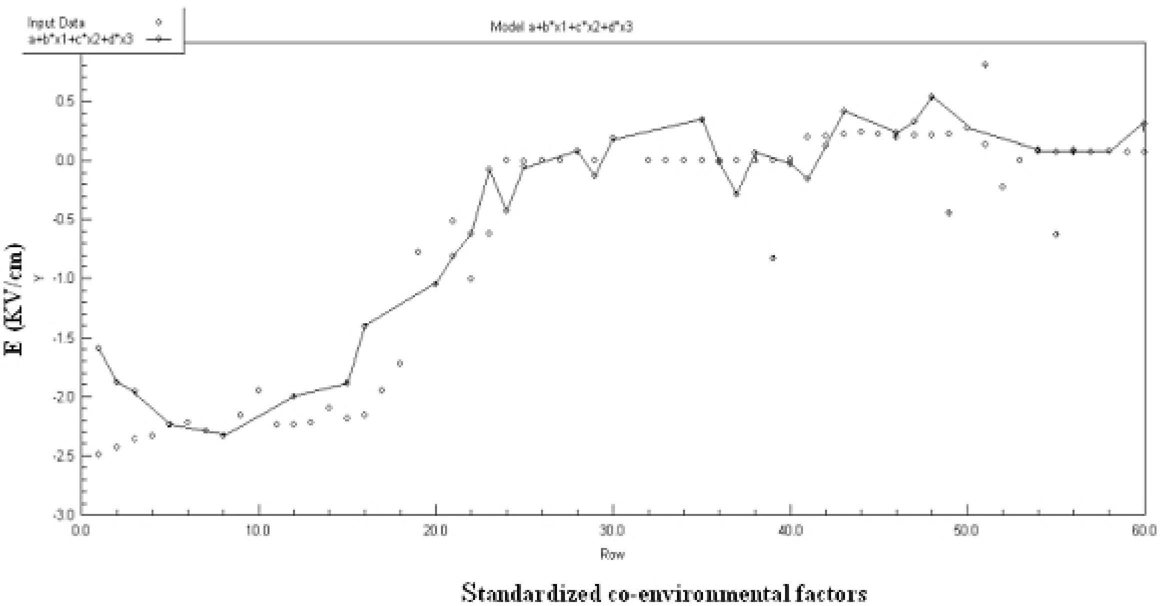



Fig. 9: Harmattan Inside Model Plot

Y= electrostatic field (kV/cm), X1= Relative Humidity, X2=Temperature and X3= Pressure (mmHg)

This was used to evaluate the value of Y at x1= 93.0, X2 = 29.5 and X3 = 708.0, the predicted value is very close to the observed value.

Predicted value= -2.299009 and the Observed value = -2.2397. (22/10/07).

From the model summary, the standard error of the estimate is minimal (.009). The individual percent error will not carry much weight (Table 1).

Table 1: Model Summary for Harmattan period

| | |
|---|---|
| MultipleR | .809 |
| R Square | .654 |
| Adjusted R Square | .635 |
| Std.Error of the Estimate | .009 |
| Value | -51.865 |

The results presented in Fig. 1, for the month of February indicate that, both the average electrostatic field strength and the temperature exhibit a similar behavioral pattern, which indicates that an increase in temperature will lead to a relative increase in the average electric field strength. This is also corroborated in Fig. 5 for the outside environment. Fig. 2, which plots average field strength against atmospheric pressure, indicates that, with decrease in pressure, there is relative increase in the average electric field strength for most part of the observation window. Compared with relative humidity in Fig. 3, the plot indicates a reciprocal relationship with relative humidity decreasing, as the average electric field strength experiences a relative increase and vice versa. The same is observed in Fig. 4. Fig. 6, however, when compared against outside atmospheric pressure, shows a clear deviation from the results for the inside scenario, as decrease in pressure lead to a relative increase in the average field strength and vice versa.

The cumulative plot of the average field strength between October, 2007 – March, 2008 for the two scenarios (inside and outside) of the test environment displayed a similar pattern with little or no variation in the average electric field strength for both scenarios as depicted in Fig. 7 and 8. The foregoing description is applicable to the plots of Fig. 9 and 10 , when fitted to the model. The relative variations in the co-environmental factors for the harmattan produce a corresponding change in the electrostatic field in accordance to the equation model arrived at.

A typical screen capture of the application software for the statistical analysis of the data is shown in Fig. 11 and 12, while Table 1 presents the summary of the model parameters. The maximum electrostatic field recorded was 0.237 KV/cm as compared to 0.0015 KV/cm for a particular day during the harmattan (February 4, 1967) recorded earlier by Harris (1967). By standards, these values though significant, fall within hazardous levels for electronics and telecommunication devices. (Dicken, 1978, and NTIA,1979)

**Validation of the Equation Model:** The following presents the result of the model fitting for electric field distribution during the Harmattan period. The model equation is E = A+B*H + C*T + D*P from third order polynomial Y=A+B*X1 + C*X2 + D*X3. Where, Y= Electrostatic field, X1= Relative Humidity,

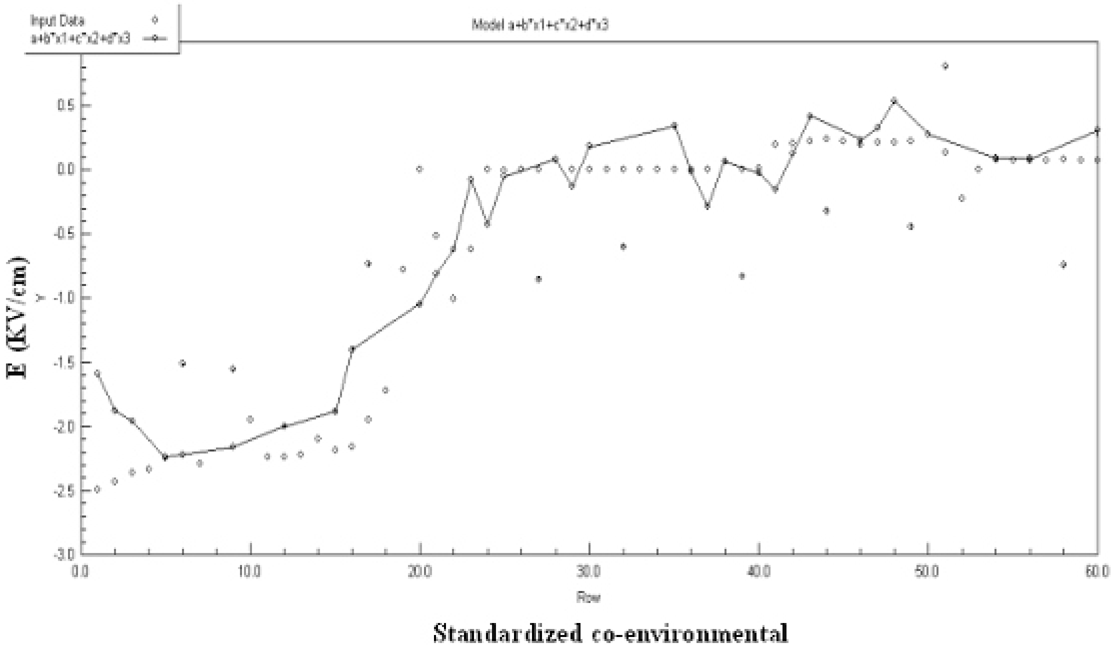
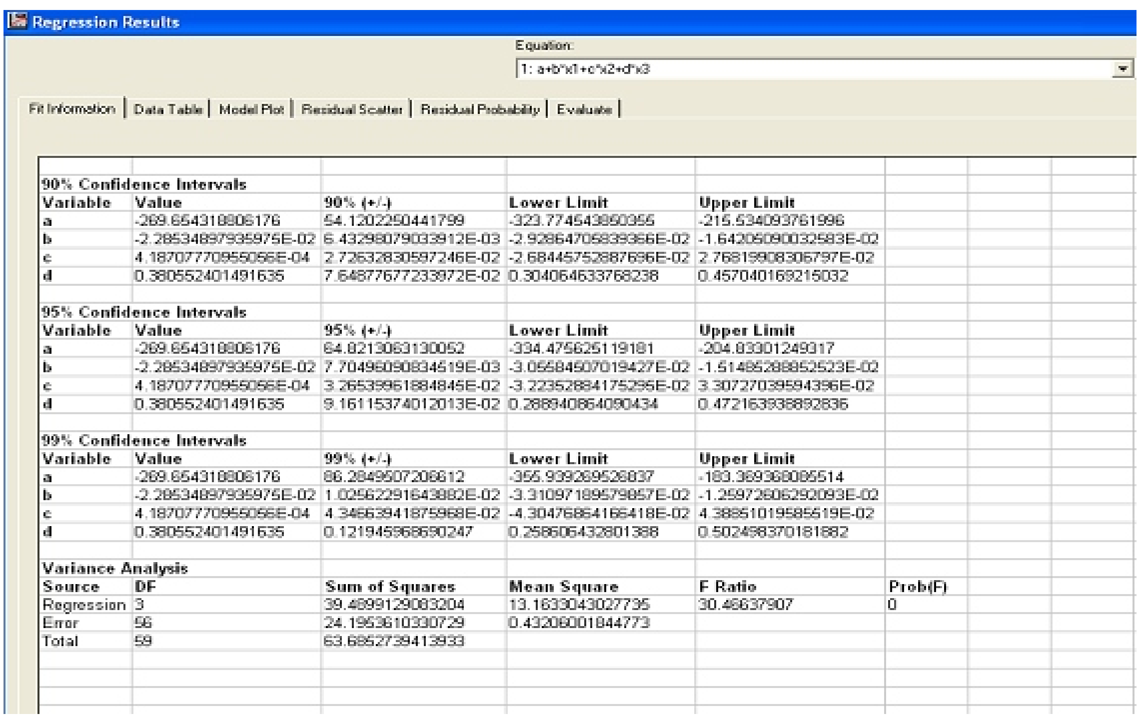



Fig.10: Harmattan Outside Model Plot



Regression Results

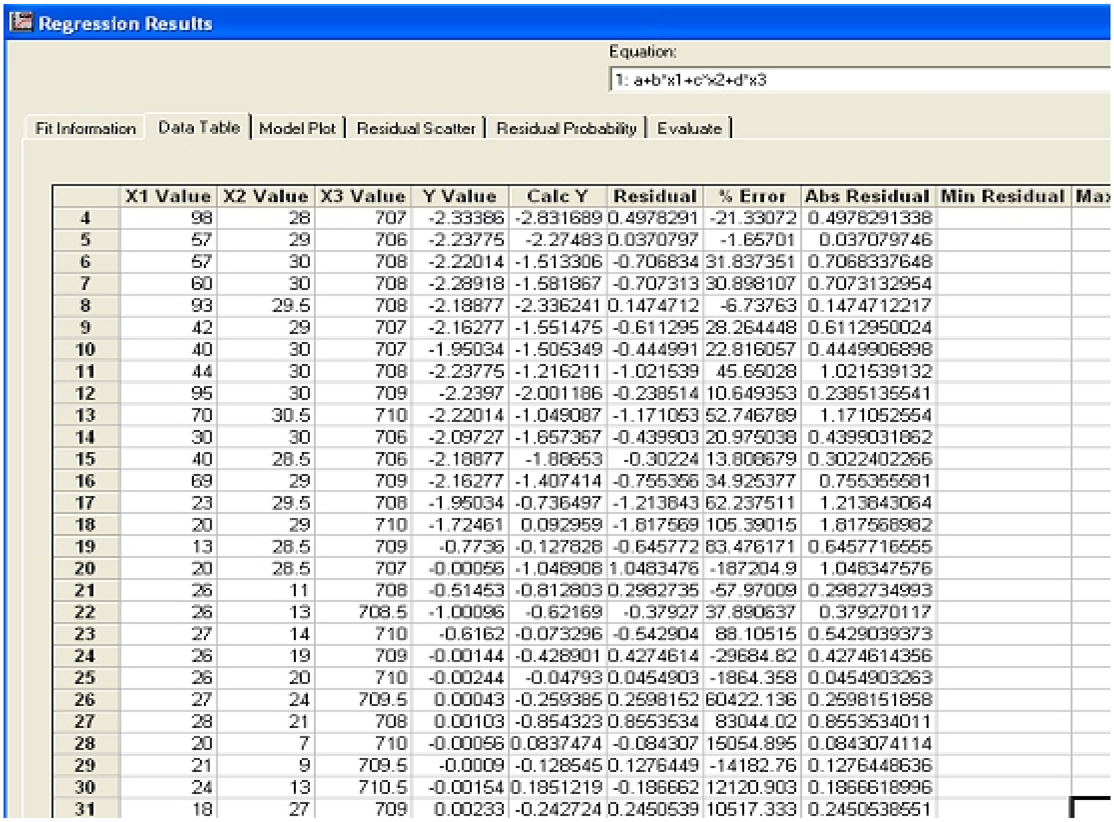
Equation:
1: a+b*x1+c*x2+d*x3

Fit Information | Data Table | Model Plot | Residual Scatter | Residual Probability | Evaluate

| | | | | | |
|---|---|---|---|---|---|
| **90% Confidence Intervals** | | | | | |
| **Variable** | **Value** | **90% (+/-)** | **Lower Limit** | **Upper Limit** | |
| a | -269.654318806176 | 54.1202250441799 | -323.774543850355 | -215.534093761996 | |
| b | -2.28534897935975E-02 | 6.43298079033912E-03 | -2.92864705839366E-02 | -1.64205090032583E-02 | |
| c | 4.18707770955056E-04 | 2.72632830597246E-02 | -2.68445752887696E-02 | 2.76819908306797E-02 | |
| d | 0.380552401491635 | 7.64877677233972E-02 | 0.304064633768238 | 0.457040169215032 | |
| **95% Confidence Intervals** | | | | | |
| **Variable** | **Value** | **95% (+/-)** | **Lower Limit** | **Upper Limit** | |
| a | -269.654318806176 | 64.8213063130052 | -334.475625119181 | -204.83301249317 | |
| b | -2.28534897935975E-02 | 7.70496090834519E-03 | -3.05584507019427E-02 | -1.51485288852523E-02 | |
| c | 4.18707770955056E-04 | 3.26539961884845E-02 | -3.22352884175295E-02 | 3.30727039594396E-02 | |
| d | 0.380552401491635 | 9.16115374012013E-02 | 0.288940864090434 | 0.472163938892836 | |
| **99% Confidence Intervals** | | | | | |
| **Variable** | **Value** | **99% (+/-)** | **Lower Limit** | **Upper Limit** | |
| a | -269.654318806176 | 86.2849507206612 | -355.939269526837 | -183.369368085514 | |
| b | -2.28534897935975E-02 | 1.02562291643882E-02 | -3.31097189579857E-02 | -1.25972606292093E-02 | |
| c | 4.18707770955056E-04 | 4.34663941875968E-02 | -4.30476864166418E-02 | 4.38851019585519E-02 | |
| d | 0.380552401491635 | 0.121945968690247 | 0.258606432801388 | 0.502498370181882 | |
| **Variance Analysis** | | | | | |
| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Ratio** | **Prob(F)** |
| Regression | 3 | 39.4899129083204 | 13.1633043027735 | 30.46637907 | 0 |
| Error | 56 | 24.1953610330729 | 0.43206001844773 | | |
| Total | 59 | 63.6852739413933 | | | |

Fig. 11: Screen Capture of Harmattan Model parameters (cont'd)

X2=Temperature and X3= Pressure (mmHg) and A=Constant of the polynomial model. For the Harmattan scenario, from the model equation E = A + B*X1 + C*X2 + D*X3 the parameters are A =-269.65430, B = -0.022853, C = 0.0004187 and D = 0.3805523. This was used to evaluate the value of E at x1= 93.0, X2 = 29.5 and X3 = 708.0, the predicted value is very close to the observed value. Predicted value of electrostatic field = -2.299009 and the Observed value of electrostatic field = -2.2397 (inside scenario on 22/10/07).




| | X1 Value | X2 Value | X3 Value | Y Value | Calc Y | Residual | % Error | Abs Residual | Min Residual | Max |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 98 | 28 | 707 | -2.33386 | -2.831689 | 0.4978291 | -21.33072 | 0.4978291338 | | |
| 5 | 57 | 29 | 706 | -2.23775 | -2.27483 | 0.0370797 | -1.65701 | 0.037079746 | | |
| 6 | 57 | 30 | 708 | -2.22014 | -1.513306 | -0.706834 | 31.837351 | 0.7068337648 | | |
| 7 | 60 | 30 | 708 | -2.28918 | -1.581867 | -0.707313 | 30.898107 | 0.7073132954 | | |
| 8 | 93 | 29.5 | 708 | -2.18877 | -2.336241 | 0.1474712 | -6.73763 | 0.1474712217 | | |
| 9 | 42 | 29 | 707 | -2.16277 | -1.551475 | -0.611295 | 28.264448 | 0.6112950024 | | |
| 10 | 40 | 30 | 707 | -1.95034 | -1.505349 | -0.444991 | 22.816057 | 0.4449906898 | | |
| 11 | 44 | 30 | 708 | -2.23775 | -1.216211 | -1.021539 | 45.65028 | 1.021539132 | | |
| 12 | 95 | 30 | 709 | -2.2397 | -2.001186 | -0.238514 | 10.649353 | 0.2385135541 | | |
| 13 | 70 | 30.5 | 710 | -2.22014 | -1.049087 | -1.171053 | 52.746789 | 1.171052554 | | |
| 14 | 30 | 30 | 706 | -2.09727 | -1.657367 | -0.439903 | 20.975038 | 0.4399031862 | | |
| 15 | 40 | 28.5 | 706 | -2.18877 | -1.88653 | -0.30224 | 13.808679 | 0.3022402266 | | |
| 16 | 69 | 29 | 709 | -2.16277 | -1.407414 | -0.755356 | 34.925377 | 0.755355581 | | |
| 17 | 23 | 29.5 | 708 | -1.95034 | -0.736497 | -1.213843 | 62.237511 | 1.213843064 | | |
| 18 | 20 | 29 | 710 | -1.72461 | 0.092959 | -1.817569 | 105.39015 | 1.817568982 | | |
| 19 | 13 | 28.5 | 709 | -0.7736 | -0.127828 | -0.645772 | 83.476171 | 0.6457716555 | | |
| 20 | 20 | 28.5 | 707 | -0.00056 | -1.048908 | 1.0483476 | -187204.9 | 1.048347576 | | |
| 21 | 26 | 11 | 708 | -0.51453 | -0.812803 | 0.2982735 | -57.97009 | 0.2982734993 | | |
| 22 | 26 | 13 | 708.5 | -1.00096 | -0.62169 | -0.37927 | 37.890637 | 0.379270117 | | |
| 23 | 27 | 14 | 710 | -0.6162 | -0.073296 | -0.542904 | 88.10515 | 0.5429039373 | | |
| 24 | 26 | 19 | 709 | -0.00144 | -0.428901 | 0.4274614 | -29684.82 | 0.4274614356 | | |
| 25 | 26 | 20 | 710 | -0.00244 | -0.04793 | 0.0454903 | -1864.358 | 0.0454903263 | | |
| 26 | 27 | 24 | 709.5 | 0.00043 | -0.259385 | 0.2598152 | 60422.136 | 0.2598151858 | | |
| 27 | 28 | 21 | 708 | 0.00103 | -0.854323 | 0.8553534 | 83044.02 | 0.8553534011 | | |
| 28 | 20 | 7 | 710 | -0.00056 | 0.0837474 | -0.084307 | 15054.895 | 0.0843074114 | | |
| 29 | 21 | 9 | 709.5 | -0.0009 | -0.128545 | 0.1276449 | -14182.76 | 0.1276448636 | | |
| 30 | 24 | 13 | 710.5 | -0.00154 | 0.1851219 | -0.186662 | 12120.903 | 0.1866618996 | | |
| 31 | 18 | 27 | 709 | 0.00233 | -0.242724 | 0.2450539 | 10517.333 | 0.2450538551 | | |

Fig. 12: Output for Harmattan Outside

## CONCLUSION

It can be concluded that an increase in temperature, decrease in pressure and relative humidity will lead to an increase in the electrostatic field strength. The increases will be noticeable if they exceed 200V/cm in magnitude and will begin to constitute a danger to electronic as well as communication devices (Dicken, 1978; NTIA 1979). The established equation model will find application in the Northern part of Nigeria where harmattan phenomenon is prevalent, depending on the variation in the co-environmental factors to harmattan viz-a-viz humidity, temperature and pressure of the various locations. These co-environmental factors which are already defined within the equation model making it easier to use this model to predict the electrostatic field during the harmattan within the region.

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