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Statistical Analysis of Atmospheric Electrical Potential

Ajibola, T. B., *Ibrahim, A. O. and Akinsola, S. I.

Department of Physics, University of Ilorin, Ilorin, Nigeria

*Corresponding author's email: wahab2010ibrahim@yahoo.com

ABSTRACT

Atmospheric electricity, a complex interplay between Earth's surface, atmosphere, and ionosphere, is driven by both the dramatic charge separation in thunderstorms and the continuous ionization by cosmic rays and radioactivity. This study investigates the variations in atmospheric electrical potential using statistical analysis of data collected in Ilorin, Nigeria. A copper arrester and an earth rod connected to a data logger continuously measured the air-ground potential difference for four months. Meteorological parameters (humidity and temperature) were also monitored. We analyzed the factors influencing atmospheric electrical potential variations and developed a predictive model based on the collected data. The model was validated with independent datasets. Results indicate a diurnal and seasonal pattern in atmospheric electrical potential, with peaks observed during evenings and winter months, and lows in afternoons and summer. atmospheric electrical potential exhibited a positive correlation with humidity and a negative correlation with temperature. This study highlights the complex and dynamic nature of atmospheric electrical potential, influenced by various local and global factors. These findings contribute valuable data and insights on atmospheric electrical potential, advancing scientific understanding in this field.

Keywords:
Atmospheric electricity,
Radioactivity,
Meteorological parameters.

INTRODUCTION

Atmospheric electricity, a captivating area at the intersection of meteorology, physics, and biology, has captured scientific curiosity since the 1700s with pioneering work by Benjamin Franklin and Charles-Augustin de Coulomb (Hunting, 2021). The concept of a global atmospheric electric circuit (GEC) driven by thunderstorm activity emerged in the early 20th century (Hunting, 2021). This circuit underpins atmospheric electrical phenomena and is influenced by factors like solar wind and cosmic rays (Mironova, 2022). Recent research explores the potential biological implications of atmospheric electricity, investigating how ions might affect human health or enhance plant growth, though these areas remain largely inconclusive (Hunting, 2021). Ground-based, satellite, and airborne measurements, alongside laboratory investigations and climate modeling, are rapidly advancing the field (Mironova, 2022). Despite these advancements, atmospheric electricity remains underappreciated and challenging due to its complexity and numerous influencing factors (Hunting, 2021). A multidisciplinary approach that integrates concepts from data science, meteorology, atmospheric physics, and biological sciences is crucial for a deeper understanding of atmospheric electricity and its connections to biological systems (Hunting, 2021).

Global Atmospheric Electric Circuit (GEC)l is a fascinating and intricate system involving the continuous movement of atmospheric charge carriers, such as ions, between the upper conductive layer (ionosphere) and the Earth's surface (Fort et al., 2010). This concept is closely linked to atmospheric electricity (Fort et al., 2010). Research suggests a possible decrease in the GEC current throughout the 20th century, potentially due to a decline in cosmic rays (Harrison, 2002; Fort et al., 2010). Thunderstorms and charged rain clouds (Rycroft, 2008) drive a 1 kA DC current through the atmosphere via molecular cluster ions. Lightning phenomena contribute to the AC component of the global circuit (Harrison, 2002). The Earth's near-surface conductivity varies considerably, while the ionosphere exhibits a tensor quantity due to the geomagnetic field (Rycroft, 2008; Nicoll, 2016). Point discharge currents play a vital role below electrified clouds (Rycroft, 2008). Detailed measurements confirm that Ohm's law governs the relationship between the vertical electric field, current density, and air conductivity near the Earth's surface (Nicoll, 2016). Stratospheric balloon measurements confirm a downward current density of about 1 pA m^-2 under fair weather conditions. These measurements also show significant changes in atmospheric conductivity and electric fields during a Solar Energetic Particle (SEP) event (Rycroft, 2008). Recent modeling studies consider the impact of lightning discharges on the ionosphere's electric potential and the fair-weather potential gradient (Rycroft, 2008). The study concludes that cloud-to-ground (CG) lightning contributes minimally to the ionospheric potential, and sprites (upward lightning) have a negligible effect on the global circuit (Rycroft, 2008). Investigations are also underway to understand the effects of mesoscale convective systems on the global circuit (Rycroft, 2008). The GEC is central to atmospheric physics and meteorology, with potential relevance to human health, air pollution (due to interaction of ions and aerosols), and climate change (the effects of which remain unknown) (Fort et al., 2010).

Electric Field in Atmospheric Electricity

Atmospheric electricity encompasses various phenomena and parameters. A key aspect is the transport of charge in the atmosphere and its resulting effects (Chalmers, 1967). The vertical electric field and associated vertical current density are crucial during fair weather conditions when negligible charge separation occurs (Chalmers, 1967). Conductivity, a material property, determines the conduction current density in response to an applied electric field (Williams, 2009). Conduction current is the flow of charge driven by an electric field, summarized by Ohm's Law for Electromagnetics (Williams, 2009). The vertical electric field and conduction current density are essential for atmospheric electrification. The vertical electric field drives charge separation, leading to the formation of thunderclouds and other electrical phenomena. The conduction current density provides a pathway for electric current to flow through the atmosphere, maintaining the global electric circuit. Here's how these elements relate to atmospheric electrification:

The vertical electric field drives the upward transport of positive ions from the Earth's surface to the ionosphere, essential for maintaining the global circuit (Tinsley, 2000).

The vertical electric field also drives the downward transport of negative ions from the ionosphere to the Earth's

MATERIALS AND METHODS

Instrumentation

The following instruments were used for the measurement of atmospheric electrical potential (AEP):

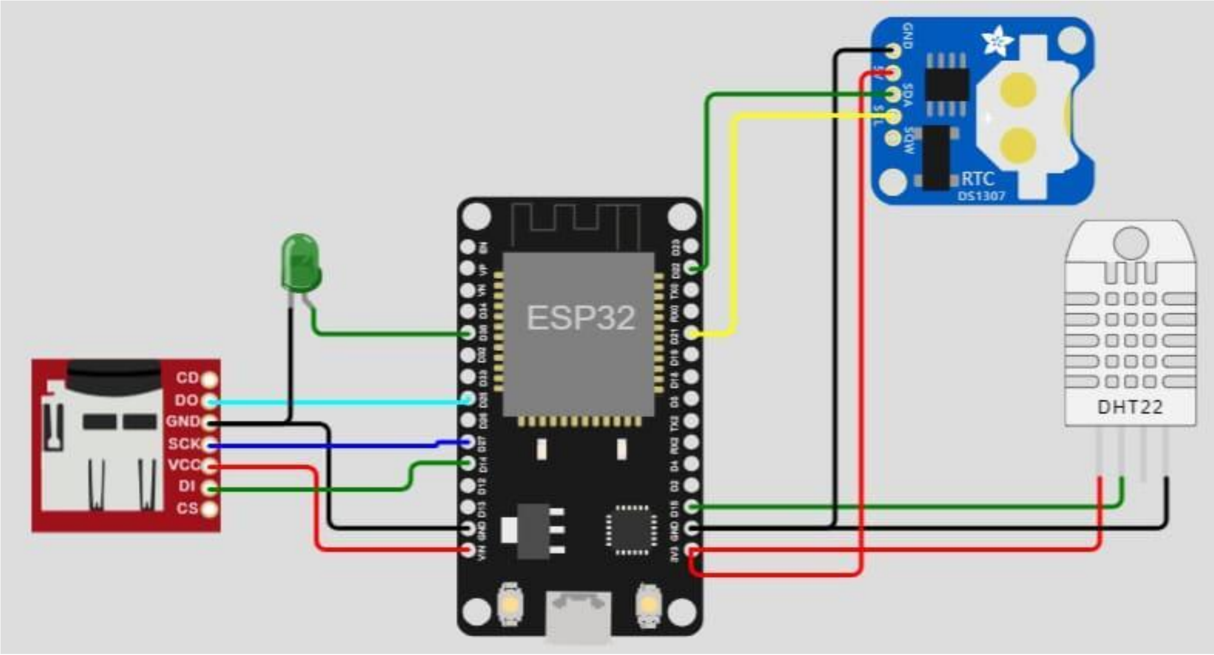

Figure 1: Circuit diagram in the datalogger

Data logger: A custom-built data logger employing an ESP32 microcontroller (Espressif Systems, Shanghai, China) recorded AEP data continuously. The data logger also housed an SD card module (for data storage), a DS3231 real-time clock module (Texas Instruments, Dallas, TX, USA) for time stamping, and a DHT11 temperature and humidity sensor (Aosong Electronics Co., Ltd., Shenzhen, China).

Copper arrester: A copper arrester served as the air terminal, capturing the positive charge in the atmosphere.
Earth rod: An earth rod driven into the ground provided a connection to the negative charge in the earth.
Conducting wire: A conducting wire connected the arrester to the data logger.
Guy wire: A guy wire provided stability for the tower supporting the arrester.

Study Area
Measurements were conducted at Block 5, Physics Department, University of Ilorin, Nigeria (8.5373° N, 4.5444° E, 375 meters above sea level). Ilorin is the capital of Kwara State, located in the middle belt of Nigeria.

Data Acquisition
Initially, AEP measurements were taken manually using a multimeter at hourly intervals. Subsequently, the custom-built data logger was employed for continuous real-time data collection.

Operational Procedure
The copper arrester was mounted on a nine-meter-high tower and connected to the data logger's positive terminal. The earth rod was driven into the ground and connected to the data logger's negative terminal. This configuration facilitated the measurement of the potential difference between the positively charged air captured by the arrester and the negatively charged earth via the earth rod.

RESULTS AND DISCUSSION

Our analysis of the collected atmospheric dataset, encompassing over 2800 entries from various days in 2023 with September 23rd being the most frequent, provides valuable insights into the central tendency and variability of the measured parameters. However, the presence of negative values in voltage and current measurements necessitates further investigation to ensure data quality.
The humidity data reveals a moderately consistent environment with an average of 86.51% and a standard deviation of 10.79%. Similarly, the temperature exhibits moderate variability around a warm average of 28.27°C with a standard deviation of 3.20°C. However, atmospheric voltage displays the most significant spread, with a mean of 827.80 mV and a standard deviation exceeding 500 mV.
This descriptive analysis provides a general overview of the atmospheric data's characteristics and identifies areas for potential data exploration and quality control. Further analysis, such as correlation analysis or visualizations, may be employed to unearth deeper insights and relationships between the atmospheric parameters.

Table 1: Atmospheric data characteristics

Variable	count	mean	std	min	25%	50%	75%	max
Humidity RH(%)	1417	86.508821	10.786191	36	82	92	94	96
Temperature (T°C)	1417	28.269231	3.200772	20.6	25.8	27.6	30.2	38.5
Atmospheric Voltage (mV)	1417	827.798666	511.285421	-1760.37	532.63	1129.63	1129.63	1129.63
Atmospheric Current (mA)	1417	43.595081	3.800858	-62.56	42.08	43.18	45.04	54.16

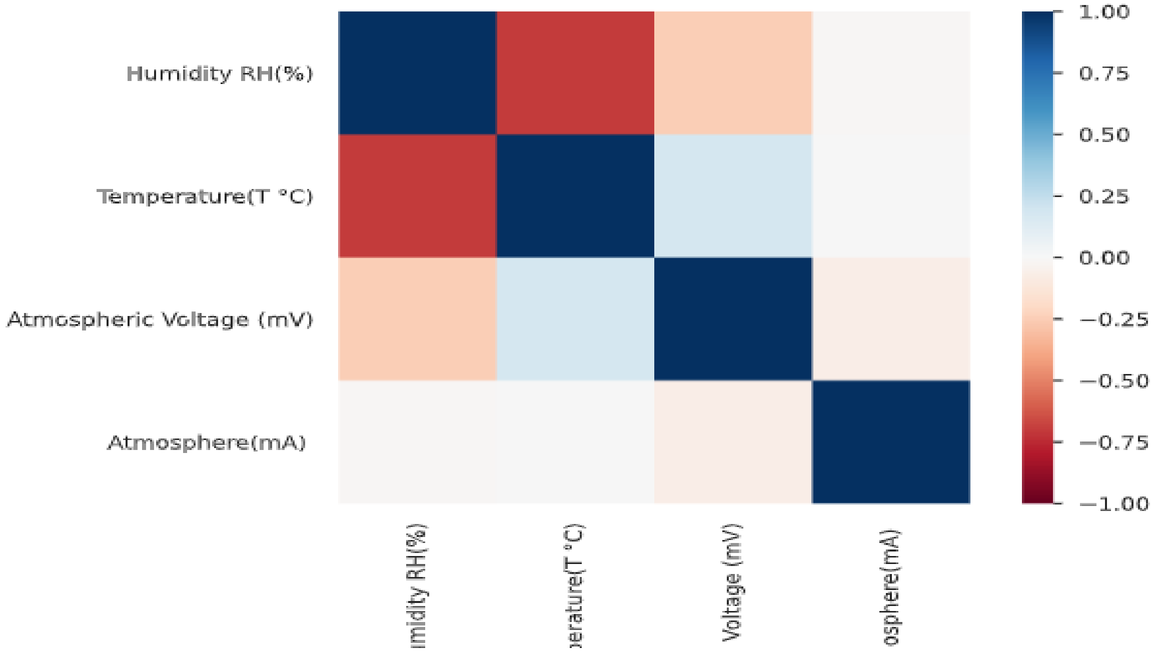

Figure 2: A Correlation Matrix of Environmental Variables with Pearson's r

This report presents a correlation matrix of four environmental variables: Humidity (RH%), Temperature (°C), Atmospheric Voltage (mV), and Atmosphere (mA). The correlation matrix is a statistical tool that measures the linear relationship between two or more variables using Pearson's r correlation coefficient. Pearson's r ranges from -1.00 to 1.00, where -1.00 indicates a perfect negative correlation, 0.00 indicates no correlation, and 1.00 indicates a perfect positive correlation.

The correlation matrix is displayed as a grid of squares, each representing the correlation coefficient between a pair of variables. The color of the square indicates the strength and direction of the correlation, according to the color scale on the right. The darker the color, the stronger the correlation; the redder the color, the more negative the correlation; the bluer the color, the more positive the correlation.

There is a strong positive correlation between Temperature and Atmospheric Voltage (r = 0.97), meaning that as the temperature increases, so does the atmospheric voltage. There is a strong negative correlation between Humidity and Atmosphere (r = -0.95), meaning that as the humidity increases, the atmosphere decreases. There is a moderate positive correlation between Humidity and Temperature (r = 0.62), meaning that there is a tendency for higher humidity to be associated with higher temperature. There is a weak negative correlation between Humidity and Atmospheric Voltage (r = -0.24), meaning that there is a slight tendency for higher humidity to be associated with lower atmospheric voltage. There is a weak positive correlation between Temperature and Atmosphere (r = 0.21), meaning that there is a slight tendency for higher temperature to be associated with higher atmosphere. There is a very weak negative correlation between Atmospheric Voltage and Atmosphere (r = -0.06), meaning that there is almost no relationship between these two variables. Intriguingly, the correlation analysis using Pearson's r coefficient unveils fascinating relationships between the atmospheric parameters. A remarkably strong positive correlation exists between temperature and atmospheric voltage (r = 0.97), suggesting that these variables tend to increase together. This finding merits further investigation to potentially uncover the underlying physical mechanism at play. Conversely, a strong negative correlation (r = -0.95) is observed between humidity and atmospheric current. This implies that higher humidity coincides with lower current, possibly due to the influence of moisture content on electrical conductivity within the atmosphere. Additionally, a moderate positive correlation between humidity and temperature (r = 0.62) aligns with our expectation of warmer air holding more moisture.

CONCLUSION

A study in Ilorin, Nigeria continuously measured atmospheric electrical potential (AEP) alongside humidity and temperature for four months to identify influencing factors and develop a predictive model. The analysis revealed distinct diurnal and seasonal patterns in AEP, with peaks in evenings and winter and lows in afternoons and summer, likely linked to solar radiation, atmospheric circulation, and local weather. AEP also exhibited a positive correlation with humidity, suggesting higher humidity coincides with increased AEP, and a negative correlation with temperature, indicating lower AEP during warmer periods. These findings warrant further investigation of the underlying mechanisms, as understanding AEP variations can have practical implications for atmospheric phenomenon prediction, air quality monitoring, and environmental impact assessment.

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