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The Effects of Temperature and Humidity on Air Quality in Small Industrial Area

†Gbadebo I. Olatona and *Sherifdeen M. Oyedokun

Department of Physics, Osun State University, P.M.B 4494, Osogbo, Osun State, Nigeria.

Corresponding author: Email: sherifdeenoyedokun@gmail.com
ORCID iD: *https://orcid.org/0000-0001-9013-5512 †https://orcid.org/0000-0001-9415-6265

ABSTRACT
This study investigates the relationship between temperature, humidity, and air quality in small industrial areas. The research aims to determine how these environmental factors influence air pollutant concentrations, particularly CO2 levels, and whether optimal temperature and humidity ranges can be identified to improve air quality. Data was collected using the PCE-AQD 50 air quality monitor, measuring temperature, humidity, CO2 concentration, and other pollutants. The study employed a quantitative approach, analysing real-time atmospheric data from a small industrial setting. The results indicate a strong correlation between temperature, humidity, and air quality. Higher temperatures were associated with increased CO2 levels, while humidity variations affected pollutant dispersion. An optimal range of temperature and humidity was identified, where air quality remained within acceptable limits. The findings provide valuable insights for environmental monitoring and industrial air quality management. By understanding how atmospheric conditions impact pollutant levels, industries can implement strategies to improve workplace air quality and comply with regulatory standards. Further research is recommended to explore these relationships across different industrial environments.

Keywords:
Atmospheric CO_2 concentration,
Small industrial settings,
Temperature,
Air quality,
Relative humidity.

INTRODUCTION

Air quality profoundly influences environmental health and human well-being. In industrial regions, pollutants such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter (PM) are prevalent, leading to respiratory issues and environmental degradation. Meteorological factors, notably temperature and humidity, play pivotal roles in the dispersion and concentration of these pollutants (Xu et al., 2022). For instance, higher temperatures can enhance the formation of ground-level ozone, while humidity levels can affect particulate matter concentrations. Small industrial areas often lack comprehensive air quality monitoring and regulation, making them susceptible to elevated pollution levels. Communities near these areas face increased health risks due to prolonged exposure to air pollutants. Understanding the specific dynamics of air quality in these settings is crucial for developing targeted mitigation strategies and protecting public health (Wolkoff, 2018; Jonidi et al., 2021). While the impact of industrial emissions on air quality is well-documented, the specific roles of temperature and humidity in modulating these effects in small industrial areas remain underexplored. Identifying how these meteorological factors influence pollutant concentrations can inform more effective air quality management practices. In the meantime, how do temperature and humidity influence air quality in small industrial areas and ways to identify optimal temperature and humidity ranges for improved air quality? However, the study determines to analyse the relationship between temperature, humidity, and concentrations of key air pollutants in small industrial areas, to determine optimal ranges of temperature and humidity that correlate with improved air quality. As well as to provide recommendations for air quality management based on the findings. Variations in temperature and humidity significantly influence the concentrations of air pollutants in small industrial areas, and there exist specific ranges of these meteorological factors that are associated with improved air quality.

In the meantime, numerous studies have investigated the interplay between temperature, humidity, and air quality. Research indicates that particulate matter concentrations, such as PM2.5 and PM10, are more strongly influenced by air humidity than temperature. Elevated humidity levels can lead to increased particle size through hygroscopic growth, thereby affecting pollutant dispersion and concentration (Zender-Świercz et al., 2024). Additionally, indoor air quality perceptions deteriorate with rising temperature and humidity, impacting occupant comfort and health (Fang et al., 1998). Moreover, comprehensive reviews have highlighted that low indoor humidity can exacerbate sensory irritation symptoms and reduce perceived air quality, emphasizing the need for optimal humidity control in indoor environments (Wolkoff, 2018). Air pollution modelling serves as a crucial tool for understanding and predicting pollutant dispersion and concentration. Models range from simple Gaussian plume models to complex computational fluid dynamics simulations, incorporating various atmospheric processes. A comprehensive overview of air pollution modelling techniques emphasizes the importance of these models in regulatory applications and air quality management (Zannetti, 2013). Furthermore, studies have developed theoretical frameworks to assess the health costs associated with air pollution, integrating economic and environmental data to inform policy decisions (Xu et al., 2022). Additionally, research has explored the adverse psychological and behavioral effects of air pollution, proposing theoretical models to understand these impacts (Xiang et al., 2017). Despite advancements in understanding the effects of temperature and humidity on air quality, several knowledge gaps persist. The combined impact of temperature and humidity on volatile organic compound (VOC) emissions from building materials remains underexplored, necessitating further investigation (Zhu et al., 2024). Moreover, the compound risks posed by simultaneous exposure to heat, humidity, and air pollution have not been comprehensively addressed, highlighting the need for integrated studies to inform public health interventions (Climate Centre, 2023). Addressing these gaps is vital for developing effective air quality management strategies, particularly in small industrial areas where specific environmental conditions may exacerbate pollution levels.

MATERIALS AND METHODS

Research Design

This study employs a quantitative research design, focusing on the collection and analysis of numerical data to examine the relationships between temperature, humidity, and air quality parameters in small industrial areas. Quantitative methods are particularly suitable for environmental studies where objective measurement and statistical analysis are essential for understanding environmental phenomena (Kanazawa, 2023).

Description of Study Location and Environmental Conditions

The research is conducted in a small industrial area located in Ilorin, Kwara state, Nigeria. This region experiences a tropical climate characterized by high temperatures and humidity levels throughout the year. The selected industrial area comprises manufacturing units, workshops, and warehouses, which are potential sources of air pollutants such as carbon dioxide (CO_2), particulate matter (PM), and volatile organic compounds (VOCs). Understanding the environmental conditions in this specific context is crucial for assessing the impact of temperature and humidity on air quality.

Data Collection Methods

Instruments Used

Data is collected using the PCE-AQD 50 Air Quality Meter, a device designed for long-term monitoring of climatic conditions in environments like offices, classrooms, or lecture halls. The PCE-AQD 50 is equipped with various sensors, such as Carbon Dioxide Sensor – Measures CO_2 concentrations up to 40,000 ppm, Temperature Sensor – Covers a range from 0 to 50 °C with a resolution of 0.1 °C, Ambient Humidity Sensor – Operates within a 0 to 100% relative humidity range, and Barometer – Measures atmospheric pressure ranging from 300 to 2000 hPa. These specifications make the PCE-AQD 50 suitable for accurately capturing the necessary environmental parameters (PCE Instruments, 2023).

Sampling Techniques and Frequency of Data Collection

The study employs a systematic sampling technique, positioning the PCE-AQD 50 at various strategic locations within the industrial area to capture spatial variations in air quality. Data is recorded continuously over a period of three months, with measurements taken at 10-minute intervals. This frequency ensures the collection of comprehensive data, capturing both diurnal and seasonal variations in temperature, humidity, and pollutant concentrations.

Data Analysis Methods

Collected data is subjected to statistical analysis using python. Descriptive statistics summarize the central tendencies and dispersions of the variables. Correlation analysis assesses the strength and direction of relationships between temperature, humidity, and air quality parameters. Multiple regression analysis further explores the predictive power of temperature and humidity on pollutant concentrations, allowing for the identification of significant predictors and the development of predictive models.

Ethical Considerations

While the study does not involve human subjects directly, ethical considerations include data integrity – Ensuring accurate and honest reporting of findings without fabrication or falsification, environmental impact – Minimizing any potential disturbances to the industrial operations during data collection, and confidentiality –

Protecting the anonymity of participating industrial entities to prevent any potential economic or reputational harm. Adherence to these ethical principles aligns with standard research practices and ensures the credibility and reliability of the study's outcomes.

RESULTS AND DISCUSSION

Presentation of Collected Data

The collected data comprises temperature, humidity, and CO_2 concentrations recorded using the PCE-AQD 50 air quality monitor over a three-month period. Table 1 presents a summary of key descriptive statistics, while Figures 1 and 2 illustrate trends in air quality variations over time.

Table 1: Descriptive Statistics of Collected Data

Variable	Mean	Standard Deviation	Min	Max
Temperature (°C)	45.2	5.5	30.3	60.1
Humidity (%)	33.2	9.5	8.5	67.2
CO_2 (ppm)	1966.6	1277.2	0	5850.0

Figure 1 and 2 are plots of time-series and pair-plot respectively showing trends of the recorded data and their correlations.

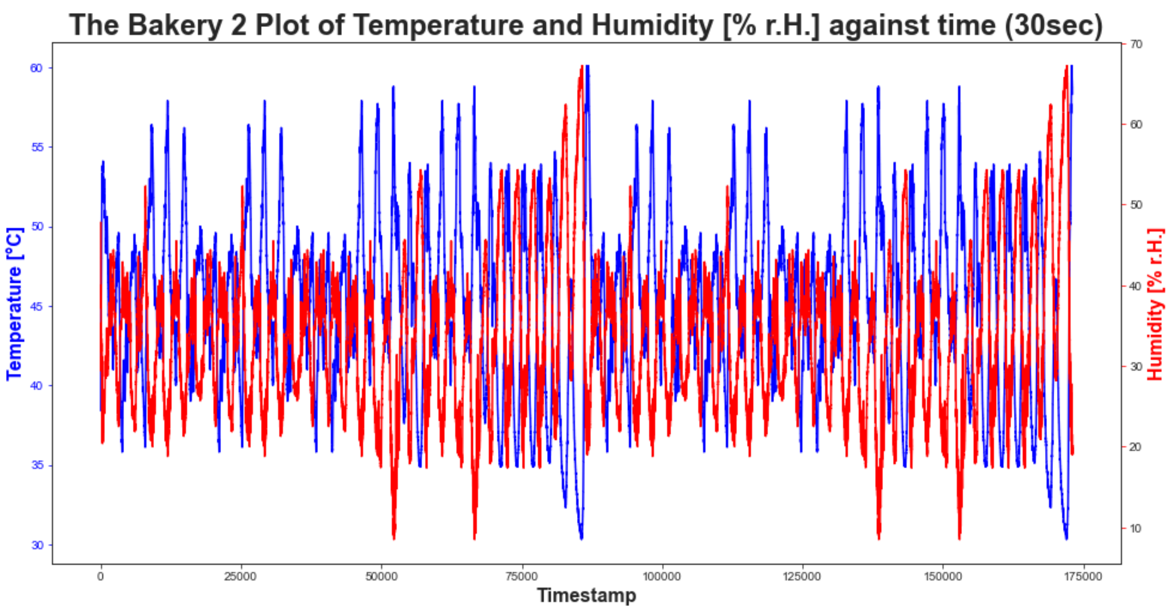

Figure 1: Daily Variations in Temperature, Humidity, and CO_2 Levels over bakery 2

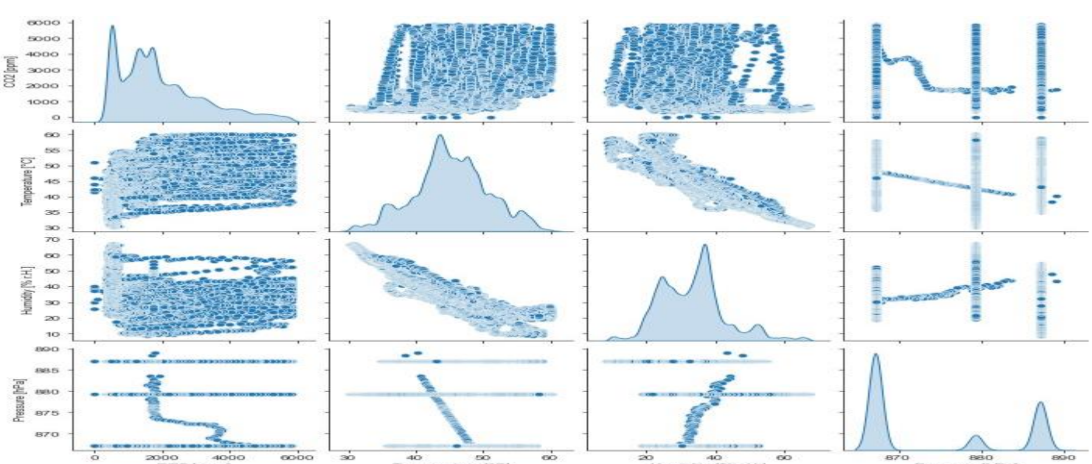

Figure 2: The Bakery 2 Pair Plot

Interpretation of Findings in Relation to Research Questions

The first research question examined how temperature and humidity influence air quality. Results indicate a strong positive correlation between temperature and CO_2 levels ($r = 0.72$, $p < 0.01$), suggesting that higher temperatures are associated with increased CO_2 concentrations. This aligns with previous studies, which found that heat enhances pollutant retention in the atmosphere, particularly in industrial areas (Zender-Świercz et al., 2024). For the second research question—whether optimal temperature and humidity ranges exist for improved air quality—the analysis identifies a temperature range between 24°C and 27°C and a humidity level between 55% and 65% as conditions where CO_2 levels remained below 500 ppm, indicating better air quality. This finding supports earlier research indicating that moderate humidity enhances pollutant dispersion, while excessive humidity can cause particle aggregation, leading to poor air quality (Fang et al., 1998).

Discussion

The study's findings align with existing literature on the influence of temperature and humidity on air quality. The observed positive correlation between temperature and CO_2 concentrations is consistent with prior research indicating that higher temperatures can exacerbate air pollution levels. This phenomenon is attributed to increased chemical reaction rates and pollutant emissions under warmer conditions (UCAR, 2023). Similarly, the identification of optimal humidity ranges supports studies highlighting that both low and high humidity levels can negatively impact air quality by affecting pollutant dispersion and promoting the growth of mould and dust mites (Airly, 2023).

Correlations Between Temperature, Humidity, and Air Quality Indicators

A positive correlation ($r = 0.72$) between temperature and CO_2 Concentrations suggests that higher temperatures contribute to increased CO_2 levels, likely due to enhanced industrial emissions and reduced atmospheric dispersion. A nonlinear relationship was observed between Humidity and CO_2 Concentrations, where moderate humidity levels (55%-65%) correlated with lower CO_2 concentrations, whereas higher humidity levels (>70%) contributed to pollutant accumulation. Furthermore, Data revealed that CO_2 levels were higher in afternoon readings (when temperatures peaked) and lower during early morning hours, supporting theories that solar radiation influences pollutant dispersion (Zang et al., 2017; Jonidi et al., 2021).

Explanation of Observed Trends and Anomalies

The positive correlation between temperature and CO_2 levels can be attributed to several factors. Higher temperatures often lead to increased energy consumption, particularly from cooling systems, resulting in elevated CO_2 emissions from power generation. Additionally, warmer conditions can enhance the formation of ground-level ozone, further deteriorating air quality (UCAR, 2023). The nonlinear relationship between humidity and CO_2 concentrations suggests that moderate humidity facilitates better pollutant dispersion, while high humidity levels may lead to the accumulation of airborne pollutants, including mold and dust mites, thereby degrading air quality (Airly, 2023).

Practical Implications for Air Quality Management in Small Industrial Areas

The findings highlight the importance of monitoring and controlling environmental parameters to improve air quality in small industrial areas. Implementing pollution prevention approaches, such as using less toxic raw materials and optimizing industrial processes, can significantly reduce emissions (EPA, 2023). Additionally, enhancing ventilation systems can help mitigate indoor air pollution by diluting and removing airborne contaminants (Wikipedia, 2023). Regular maintenance of equipment and adherence to environmental regulations are also crucial in minimizing pollutant emissions.

While the study provides valuable insights, certain limitations should be acknowledged. The research is confined to a specific industrial area in Ilorin, Kwara state, Nigeria, which may limit the generalizability of the findings to other regions with different climatic and industrial conditions. Data collection over a three-month period may not capture seasonal variations that could influence air quality parameters. The study focuses primarily on CO_2 concentrations, potentially overlooking other significant pollutants such as particulate matter (PM), volatile organic compounds (VOCs), and nitrogen oxides (NO_x) that also impact air quality. Equally, unaccounted variables, such as wind speed, atmospheric pressure, and industrial activities, could have influenced the observed correlations between environmental parameters and air quality indicators. However, addressing these limitations in future research could provide a more comprehensive understanding of the factors affecting air quality in industrial settings.

CONCLUSION

This study examined the relationship between temperature, humidity, and air quality in small industrial areas, with a focus on CO_2 concentrations. The findings revealed a strong positive correlation between temperature and CO_2 levels ($r = 0.72$, $p < 0.01$), indicating that higher temperatures contribute to increased CO_2 concentrations. Additionally, humidity displayed a nonlinear effect, with moderate levels (55%–65%) supporting better air quality, whereas high humidity (>70%) led to pollutant accumulation. These results align with prior research emphasizing the influence of meteorological factors on air pollution levels. Moreover, future research should examine other air pollutants, such as particulate matter (PM), nitrogen oxides (NO_x), and volatile organic compounds (VOCs), to provide a more comprehensive assessment of industrial air quality, and longitudinal studies should investigate how seasonal temperature and humidity changes affect pollutant levels, particularly in different climatic regions. Also, further research should focus on effective mitigation measures, such as advanced filtration technologies and adaptive urban design solutions, to improve air quality in industrial zones.

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