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Dumpsite Emissions in Southwestern Nigeria: Assessing the Relationships Between Atmospheric Conditions, Ghgs and Air Pollutant.

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Abstract: `Seasonally, this study investigates the relationship between atmospheric parameters (temperature, relative humidity and oxygen) levels of greenhouse gases (GHGs: CH_4 and CO_2), criteria air pollutants (CAPs: $PM_{2.5}$, PM_{10}, O_3, CO, SO_2, and NO_2), and other gaseous pollutants (HCHO, NO, NH_3, and VOC) at selected dumpsites in metropolitan cities of southwestern Nigeria. The city's dumping sites (State) were Olusosun Ojota (Lagos), Saje Abeokuta (Ogun), Agodi Ibadan (Oyo), Akure (Ondo), Ado Ekiti (Ekiti), and Osogbo (Osun). The portable meteorological station (Kestrel model: 3000 NV, Boothwyn, USA) measured atmospheric parameters, while the Multimeter BOSEAN T Z01 and AEROQUAL 500 series air quality meter measured the pollutants' levels. Utilizing correlation heat maps, the analysis revealed significant associations between meteorological parameters and pollutant emissions. During the dry season, methane (CH_4) and carbon dioxide (CO_2) exhibited strong positive correlations with temperature ($r = 0.99$ and 0.65, respectively), driven by microbial activity under anaerobic conditions. Ammonia (NH_3) and nitric oxide (NO) showed close linkages with CH_4 and CO_2 ($r = 0.80–0.88$), suggesting shared nitrogen transformation pathways. In the wet season, temperature similarly influenced CH_4 ($r = 0.99$) and CO_2 ($r = 0.81$), while combustion related pollutants like nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) displayed near perfect correlations ($r = 1.00$). Ozone (O_3) exhibited strong inverse relationships with precursors (CO, NO) due to photochemical dynamics. Findings show temperature, microbial processes, and combustion drive pollutant emissions, stressing the need for region-specific waste strategies to mitigate air quality and climate impacts in tropical urban areas.

Keywords: heat maps, climate change, criteria air pollutant, dry and raining season, dumpsite, greenhouse gases.

I. Introduction

Urban dumpsites are critical yet under regulated sources of greenhouse gases (GHGs) and criteria air pollutants (CAPs), posing dual threats to climate stability and public health, particularly in low resource regions of sub Saharan Africa (SSA) [1]. Globally, landfills and open dumps contribute approximately 11% of anthropogenic methane (CH_4) emissions, a potent GHG with 28–36 times the warming potential of carbon dioxide (CO_2) over a century [2]. In SSA, where over 90% of waste is openly dumped or burned, these sites exacerbate air quality crises and climate vulnerabilities in rapidly urbanizing cities [3]. Nigeria, Africa's most populous nation, generates 32 million tonnes of municipal solid waste annually, with 70% disposed of in unmanaged dumpsites [4]. The southwestern region, home to megacities like Lagos and Ibadan, faces acute challenges due to tropical climatic conditions high temperatures, prolonged wet seasons, and humidity that intensify waste decomposition and pollutant release [5]. However, the interplay between these atmospheric factors and pollutant dynamics remains poorly characterized, limiting effective mitigation strategies tailored to tropical urban environments.

Existing research on landfill emissions has largely focused on temperate regions, where controlled waste management systems and seasonal thermal variability yield distinct gas profiles. For instance, studies in Europe and North America emphasize CH_4 capture technologies and microbial oxidation processes under moderate temperatures [6]. Conversely, in tropical climates, persistent heat accelerates anaerobic decomposition, fostering year-round CH_4 and CO_2 fluxes [7]. Recent work in Accra, Ghana, revealed that temperatures above 30°C doubled organic waste degradation rates, amplifying CO_2 emissions [8]. Similarly, in Addis Ababa, Ethiopia, nitrogen rich waste decomposition under high humidity drove significant ammonia (NH_3) and nitric oxide (NO) emissions, linked to respiratory health risks [9]. Despite these insights, few studies have explored how seasonal meteorological shifts in tropical SSA modulate interactions between GHGs, CAPs, and secondary pollutants like ozone (O_3) and formaldehyde a gap this study addresses.

In Nigeria, localized factors further complicate emission dynamics. Open burning of waste a common practice due to inadequate collection services releases CAPs such as nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO) [10]. Combustion derived pollutants interact with biogenic gases (e.g., CH_4, NH_3) through photochemical pathways, yet the seasonal behavior of these interactions remains unquantified [11]. For example, O_3 formation in tropical urban areas is highly sensitive to precursor gases (NO_x, VOCs) and solar radiation, but its relationship with dumpsite emissions is understudied [12]. Furthermore, microbial communities in anaerobic waste layers exhibit temperature dependent metabolic shifts, favoring CH_4 production over CO_2 during wet seasons a phenomenon observed in Brazilian landfills but not yet documented in West Africa [13].

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This study bridges these knowledge gaps by investigating the seasonal relationships between atmospheric conditions (temperature, humidity), GHGs (CH_4, CO_2), CAPs (NO_2, SO_2, CO), and secondary pollutants (O_3, formaldehyde) at open dumpsites in southwestern Nigeria's metropolitan cities. Using correlation heat maps and multivariate analysis, we address three objectives:

1. Quantify temperature driven emission mechanisms for GHGs and CAPs across dry and wet seasons.

2. Elucidate seasonal shifts in pollutant interactions, including photochemical O_3 formation and combustion derived CAP linkages.

3. Contextualize findings within Nigeria waste management challenges, contrasting tropical emission profiles with temperate region dynamics.

The results hold significance for policymakers and environmental agencies grappling with Nigeria's waste crisis. By identifying dominant emission pathways and their climatic drivers, this work informs targeted interventions such as methane capture, waste segregation, and bans on open burning to mitigate both climate and health impacts in tropical urban settings.

II. Materials and Methods

Study Area

The research was conducted across municipal dumpsites in six states (Lagos, Ogun, Oyo, Osun, Ondo, and Ekiti) within the Southwestern region of Nigeria (latitudes 5°N–9°N, longitudes 2.5°E–5.5°E). This region exhibits rapid urbanization, high population density, and intense industrial activity, contributing to substantial municipal solid waste generation. Selected dumpsites were chosen to reflect diverse environmental conditions, waste management practices, and community impacts, enabling a robust assessment of greenhouse gas (GHG) emissions.

The humid tropical climate features distinct wet (April–October) and dry (November–March) seasons, critical to waste decomposition dynamics. Annual rainfall ranges from 1,500–2,000 mm during the wet season, accompanied by high humidity, while dry-season temperatures average 28–32°C. Topographical variability from coastal lowlands in Lagos to hilly terrain in Ekiti and Ondo further influences waste degradation rates and gas emission profiles.

Air Sampling and Analysis

A stratified sampling approach was employed across six state capitals during both wet and dry seasons (2024). Each dumpsite was sampled three times per season to capture seasonal variations in atmospheric parameters (temperature, relative humidity, oxygen levels), greenhouse gases (CH_4, CO_2), criteria air pollutants ($PM_{2.5}$, PM_{10}, O_3, CO, SO_2, NO_2), and additional gaseous pollutants (HCHO, NO, NH_3, VOC). Field measurements utilized the following calibrated instruments:

Aeroqual Series 500 multi-gas monitor for CO, NO_2, SO_2, VOC, NH_3, $PM_{2.5}$, and PM_{10}.

Kestrel 4500 NV portable meteorological station for temperature, humidity, and oxygen levels.

Boscean T-Z01 multimeter for NO, O_3, and formaldehyde (HCHO).

GHG concentrations (CH_4, CO_2) were analyzed using data processing and statistical analyses, including correlation heat maps to evaluate relationships between meteorological variables and pollutant emissions, were conducted in R software (version 4.3.1).

III. Result and Discussion

The findings from this study reveal significant correlations between atmospheric conditions, greenhouse gases (GHGs), criteria air pollutants (CAPs), and other assessed air pollutants at selected dumpsites in southwestern Nigeria. These relationships highlight the complex interplay between meteorological factors and gas emissions in open dumping environments, consistent with prior research conducted globally and within Sub Saharan Africa.

One of the most striking observations from this study is the strong positive correlation between temperature and methane ($r = 0.99$) during both dry and wet seasons. This finding aligns with earlier studies that emphasize the sensitivity of methane emissions to temperature variations, particularly in anaerobic environments such as landfills [14]. Methane production, a byproduct of organic matter decomposition under anaerobic conditions, intensifies with rising ambient temperatures due to enhanced microbial activity. Similarly, carbon dioxide also exhibits a robust positive correlation with temperature ($r = 0.65$ in the dry season and $r = 0.81$ in the wet season), corroborating the role of microbial respiration and organic decay processes in landfill gas dynamics [7]. These results underscore the importance of thermal conditions in regulating GHG emissions, which has been observed in studies across Sub-Saharan Africa, where urban waste management systems often lack adequate infrastructure to mitigate such emissions [15].

Relative humidity demonstrates a significant positive correlation with carbon dioxide ($r = 0.65$), suggesting that higher moisture levels may enhance microbial activity and organic waste degradation. This relationship is consistent with findings from Adebayo et al. (2019), who reported increased decomposition rates in humid tropical climates. Furthermore, ammonia displays strong correlations with methane ($r = 0.88$) and carbon dioxide ($r = 0.87$), indicating shared emission pathways linked to the anaerobic decomposition of nitrogen rich organic waste. These findings resonate with observations from similar studies in Nigeria, where nitrogen transformation processes within waste matrices contribute significantly to ammonia and nitric oxide emissions [16].

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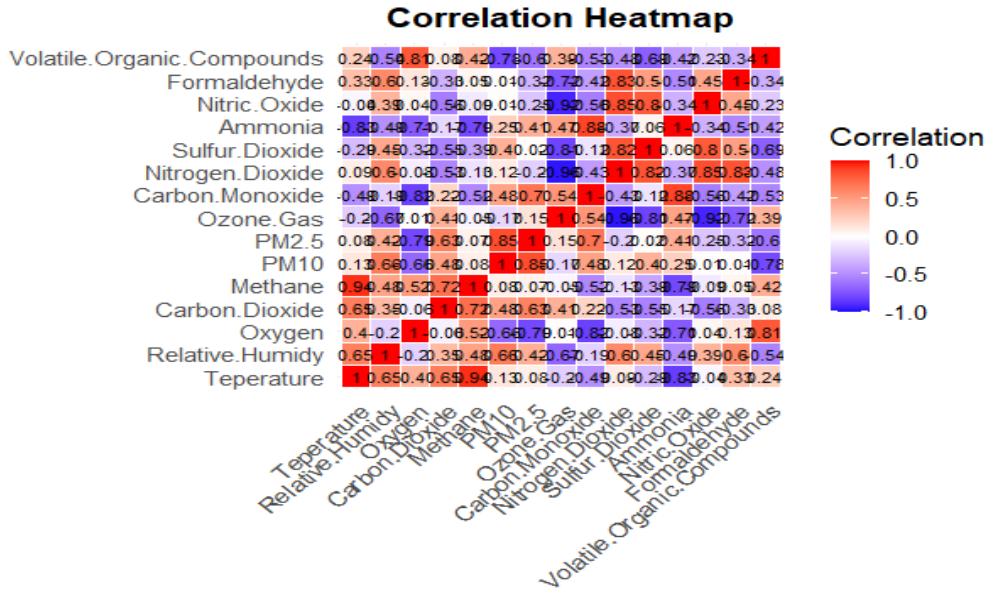


Fig.1: Plot showing Correlation Heat map of Parameters in dry season

Nitric oxide shows a strong positive correlation with methane (r = 0.83), highlighting the interconnected nature of nitrogen and carbon cycling in decomposing waste. While nitric oxide is traditionally associated with combustion sources, its presence in open dumps suggests that anaerobic microbial activity can also influence its formation under specific environmental conditions. This phenomenon has been documented in studies examining landfill emissions in Ghana and Kenya, where nitrogen based compounds play a critical role in pollutant profiles [17]. Additionally, the perfect positive correlation between nitric oxide, nitrogen dioxide, and sulfur dioxide (r = 1.00) indicates their common origin from high temperature processes, such as waste combustion or chemical reactions.

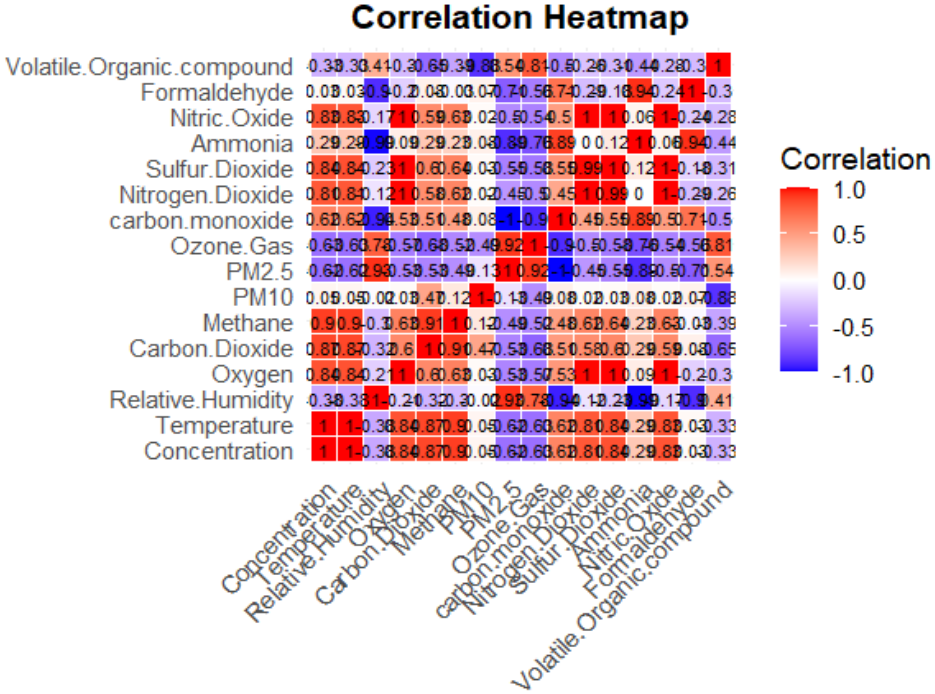


Fig. 2: Plot showing Correlation Heatmap of Parameters in wet season

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The strong positive correlation between ozone and formaldehyde (r = 0.83) underscores the secondary pollutant nature of formaldehyde, which forms through photochemical oxidation processes involving volatile organic compounds (VOCs). This observation aligns with global studies emphasizing the role of VOCs as precursors to secondary pollutants in urban environments [18]. Conversely, ozone exhibits a perfect negative correlation with carbon monoxide (r = 1.00) and nitric oxide (r = 1.00), reflecting the typical behavior of photochemical reactions where ozone precursors deplete ozone levels. Such trends have been extensively studied in metropolitan areas worldwide, including Lagos, Nigeria, where elevated traffic related emissions contribute to complex atmospheric chemistry [19].

The negative correlations between oxygen and both methane (r = 0.70) and ammonia (r = 0.79) validate the anaerobic conditions prevalent in decomposing waste. As oxygen levels decrease, microbial communities shift toward anaerobic metabolism, leading to methane and ammonia release. This trend has been widely reported in landfill studies across Sub Saharan Africa, where inadequate waste management practices exacerbate anaerobic conditions [20]. Similarly, the negative correlation between carbon monoxide and sulfur dioxide (r = 0.78) suggests divergent sources or competing reactions within waste combustion processes, further complicating emission profiles.

These findings are particularly relevant for southwestern Nigeria, where rapid urbanization and population growth have led to increased waste generation and improper disposal practices Implementing controlled landfill systems, promoting waste segregation, and adopting biogas recovery technologies could significantly reduce emissions while harnessing energy potential from organic waste [21].

IV. Conclusion

In conclusion, the results of this study provide valuable insights into the seasonal relationships between atmospheric conditions and gas emissions at dumpsites in southwestern Nigeria. By linking these findings to broader regional and global contexts, it becomes evident that addressing the challenges posed by open dumping requires integrated approaches encompassing policy reforms, technological interventions, and community engagement. Future research should focus on long term monitoring and modeling to better understand temporal variations and develop targeted mitigation strategies.

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