

SPATIAL DISTRIBUTION OF CARBON DIOXIDE CONCENTRATION FROM INDISCRIMINATE DUMPSITES IN STUDENT RESIDENTIAL AREA OF KWARA STATE UNIVERSITY, MALETE

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Abstract

The increasing prevalence of indiscriminate solid waste disposal sites is an alarming environmental concern in peri-urban and developing student residential communities across Nigeria, particularly because of their contribution to greenhouse gas emissions. Yet, there are limited studies with explicit and spatial evidence based on the variability of carbon dioxide (CO₂) concentration levels from these disposal sites. The study measured CO₂ concentrations at indiscriminate waste disposal sites from the Kwara State University (Kwasu) student residential area to assess spatial variability and distribution using field-based measurement. CO₂ concentrations were measured at 74 identified indiscriminate waste disposal locations in the study area using handheld Crowcon Gasman gas detector and benchmarked against 400 ppm. The values ranged from 301 to 789 ppm and a mean of 541.7. The data were georeferenced and analysed using Kriging interpolation, focal point and Getis-Ord Gi hotspot analysis techniques to determine spatial variation. The result reveals distinctive spatial variability in the distribution of measured CO₂ concentrations; areas such as Tarmac and Westend were identified as hotspots of elevated CO₂ concentrations with statistically significant clusters of a 95% and four 90% confidence levels, respectively. The Getis-Ord Gi* analysis map indicates that elevated concentration levels are not exclusively from decomposition or burning from disposal sites but are influenced by anthropogenic activities, and GIS-based analysis can effectively identify locations requiring prioritised environmental management intervention. The study recommends frequent awareness, strategic positioning of waste collection infrastructures and GIS-based monitoring for early detection to enhance environmental sustainability.*

Keywords: CO₂ concentration, indiscriminate waste disposal, student residential area, hotspot.

Introduction

Carbon dioxide (CO₂) is an atmospheric component that occurs naturally in quantities that are recycled through natural processes (Talaie et al., 2026). Human-induced CO₂ emissions occur at rates faster than the environment can recycle and play a significant role in the global carbon cycle

and climate change. These continuous exchanges of CO₂ between the natural and anthropogenic sources alter its concentration and spatial distribution. Natural sources include decomposition of organic matter, ocean-atmosphere interaction, wildfire, wetland release, volcanic activity, and soil and plant respiration (Kumar et al., 2020; Möller et al., 2019). While anthropogenic sources include combustion from fossil fuel engines, industrial activities, land use change and deforestation, improper waste management, biomass combustion and waste burning (Yoro & Daramola, 2020; Nunes, 2023). According to the World Meteorological Organization (WMO, 2025), the global mean CO₂ concentration was 423.9 ± 0.2 ppm in 2024, which is 52% higher than the pre-industrial era. The rapid increase in atmospheric CO₂ reflect a continuous and persistent emission from anthropogenic sources such as fossil fuel combustion, change in land use, and the declining capacity of terrestrial and oceanic environments to serve as carbon sinks (WMO, 2025). However, at the local level, CO₂ concentrations might differ from those at global or regional scale depending on the proximity, density and spatial distribution of emission sources.

Emission from solid waste constitute an important anthropogenic carbon distribution source. Deposited organic material in disposal sites undergoes biological decomposition, resulting in the production of carbon compounds such as CO₂ and methane (CH₄) (Lou & Nair, 2009). The magnitude and rate of emissions released are strongly influenced by the composition and quantity of organic waste, temperature, moisture, oxygen and the management practices employed at the disposal site (Nanda & Berruti, 2021). Despite the advances in technology, biodegradable waste is still recognised as an important source of greenhouse gases in conventional landfilling systems (Yesil et al., 2025), while inadequate management practices such as poor compaction and the absence of, or damaged to, landfill gas collection systems are contributing factors (Idowu et al., 2019; Kamaruddin et al., 2022). Accordingly, indiscriminate disposal sites might contribute largely to local emission of CO₂, particularly when a significant proportion of the waste contains accumulated biodegradable materials and undergo continuous decomposition. Another major source of CO₂ release into the atmosphere is open waste burning (Reyna-Bensusan, 2018). The density and proximity of indiscriminate waste disposal sites and management practices employed influence local CO₂ concentration and spatial distribution in a particular area.

The study and interpretation of ambient CO₂ concentrations necessitate the distinction between atmospheric concentration, emission and exposure. A measured concentration represent amount of CO₂ per unit volume of air sampled at a particular location and time, while 'emission' refers to the amount released from a point source over a particular period of time. Local ambient CO₂ concentrations are influenced by the interaction between the amount released from these sources, their proximity to one another and prevailing environmental conditions. In addition to waste decomposition and poor management practices, such as open burning, other anthropogenic sources, including emission from vehicles, generators, and industrial fuel combustion, can contribute to local CO₂ concentrations (Yoro and Daramola, 2020). This is distinction is particularly in developing peri-urban communities where indiscriminate waste disposal sites are frequently situated in close proximity to roads, residential buildings, markets and other commercial establishments.

Studies have established the spatial variability of CO₂ concentrations across a plethora of anthropogenic environments. According to Gautam and Agrawal (2020), over 50% of global municipal solid waste (MSW) is poorly managed, open burning contributing to 5% of earth greenhouse gas emissions. Poor waste management practices contribute approximately one billion tonnes of CO₂ annually (Salvador & Doong, 2024), and over 50% of MSW in developing countries is composed of organic decomposable waste (Koliyabandara et al., 2024). In a study to determine the carbon footprint across dumpsites in Uyo, Nigeria, Edet et al. (2026) found CO₂ concentration levels ranging from 420 to 1,254 ppm, while Ede and Edokpa (2015) reported CO₂ concentration ranging

from 400 to 45 ppm in Buguma, Port Harcourt, Nigeria. Despite this growing body of knowledge on the relationship between greenhouse gases and waste management, limited research focuses on the CO₂ concentrations from indiscriminate disposal sites located within densely populated student residential areas. Existing studies focus mainly on individual waste management facilities, regional air quality or general emission sources, while presenting limited spatial evidence on how CO₂ concentrations vary within residential settlements.

Geospatial techniques present an effective means of developing a spatially orientated framework for the evaluation of complex environmental phenomena (Ishaq, et al., 2026; Sowmiya Narayanan & Manimaran, 2024). GIS-based approaches support the analysis CO₂ concentration at sampling locations and evaluating their relationship with surrounding environment. GIS-based analytical techniques can identify areas of elevated CO₂ concentrations, spatial distribution patterns and detect statistically significant clustering that might not be apparent from field measurements alone. Geospatial analysis, such as Kriging, provide spatial representation of measured values, while the Getis-Ord Gi* statistic identifies cluster areas that are statistically significant hot spots and cold spots, respectively (Xie et al., 2024) of. Integrating these approaches provides a framework for examining the spatial distribution and concentration of CO₂ across the sampled indiscriminate waste disposal sites and identifying areas with statistically significant clusters of elevated concentrations.

The research is important for student residential areas rapidly developing institutional settings where continuous increase in consumption, population concentration and inadequate solid waste management system contribute to the proliferation of indiscriminate disposal sites. These sites are frequently beside student hostels and uncompleted buildings, along walkways or streets, major roads, and near commercial centres and student activity centres in small or medium-sized. The proximity of these indiscriminate waste disposal sites to other anthropogenic emission sources may result in complex pattern of CO₂ concentrations that conventional descriptive statistics cannot adequately characterise.

Material and Methods

Study Area

This study was conducted in the Kwara State University (KWASU) student residential areas, Malete, in Moro Local Government Area (LGA) of Kwara State, Nigeria. The study area is lies geographically between latitude 8°42'00" N to 8°43'00" N and longitude 4°27'20" E to 4°28'40" E (Figure 1). The study covered five major student residential locations in Malete, namely Tarmac, Dara, Market, Safari, and Westend. These locations were characterised by indiscriminate waste disposal sites of solid waste containing household wastes, food waste, paper, plastic sachets and bottled-water containers, and other biodegradable and burning of combustible waste materials which contribute to the emission of greenhouse gases such as CO₂.

Data Collection

A reconnaissance survey of the study area was conducted to identify indiscriminate waste disposal sites and examine the activities of residents with the KWASU student residential area. Thus, the study defined indiscriminate waste disposal sites operationally as any location within the study area where solid waste is disposed of or/and burnt. A total of 74 sites were identified and sampled. All sampled dumpsites geographic coordinates were recorded in decimal degrees, and site was assigned a unique identification code. The samplings were conducted to measure the concentration of CO₂ from the identified dumpsites across the student residential area. Each dumpsite was treated as an

individual sampling unit rather than as a fixed monitoring station maintained throughout the study period. Google Earth Pro version 7.3.3 was employed to create road networks, which saved as Keyhole Markup Language (KML) and imported to ArcGIS 10.3 using a conversion tool. Kriging interpolation and focal analysis were used to determine spatial distribution of CO₂ concentration in the study area, while Hot Spot Analysis (Getis-Ord Gi*) was used to identify clusters of low or high concentrations.

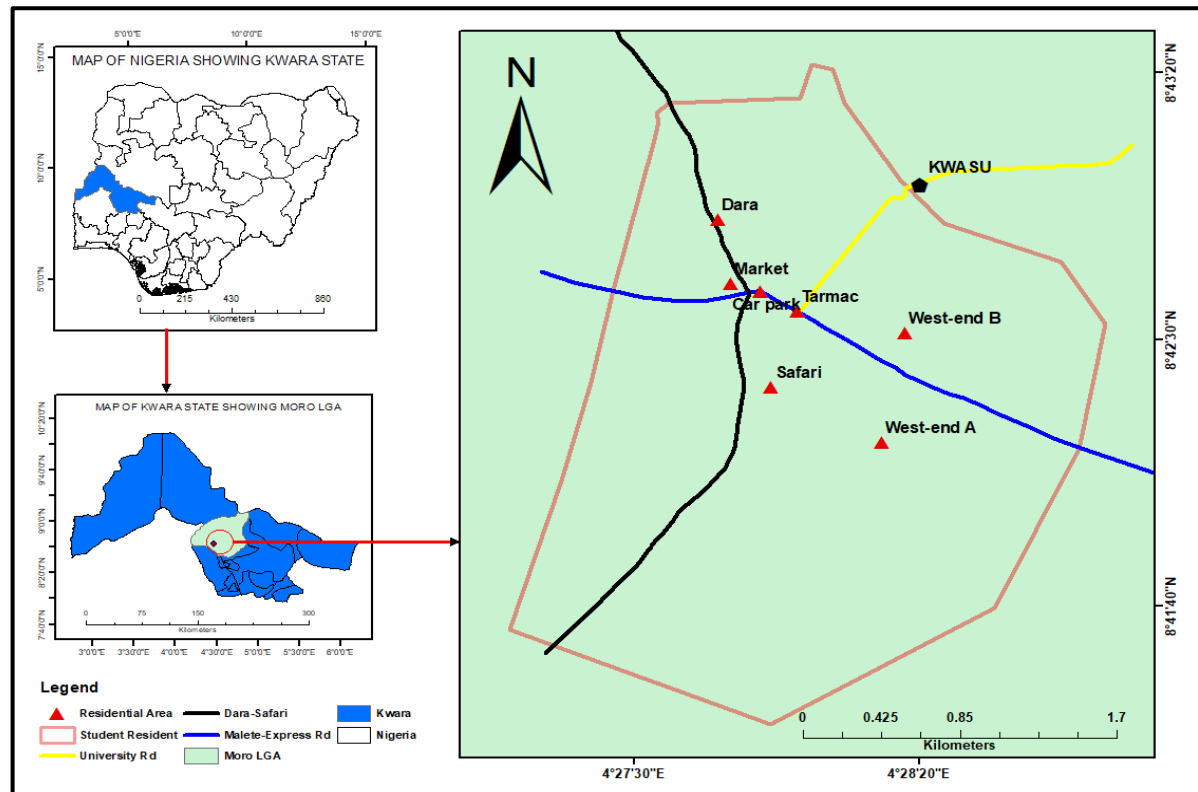


Figure 1: Map of Study Area

Source: GIS Laboratory, Dept. EMT, KWASU (2026)

Sample and Sampling Procedure

A handheld Crowcon Gasman CO₂ gas was used to measure CO₂ concentration at the 74 identified sites. The instrument has CO₂ measurement ability range of 0-50,000 ppm. The measurements were recorded in parts per million (ppm), the unit used to express instrument readings. The instrument readings were treated as CO₂ concentration rather than emission fluxes. The same procedure was applied consistently across all the identified indiscriminate dumpsites to ensure comparability among measurement. Prior to data collection, the instrument was calibrated in accordance with the manufacturer's guidelines. At each sampling point, the instrument was positioned at the designated waste disposal and allowed to provide a stable reading for 10 to 20 seconds before the readings were recorded. The geographic coordinates and description of the sampled dumpsite were entered into a predesigned field data sheet to support spatial identification and interpretation of results. No clearly established regulatory limit for ambient CO₂ from the reviewed literatures. Accordingly, a reference value of 400 ppm was adopted for comparison with the measured CO₂ concentrations, based on the literature reviewed.

Data Processing and Analysis

CO₂ concentration data collected from the 74 sampling points were imported into Microsoft Excel 2023. A table containing columns for latitudes, longitudes, CO₂ concentration values and sampling point descriptions was saved in CSV comma-delimited format for operational ease in ArcGIS 10.3 after data cleaning and validation of geographic coordinates (Figure 2). To estimate the CO₂ concentration of unsampled locations in the study area, Kriging technique was used due to its ability to autocorrelated un measured values. The technique was used to estimate continuous spatial distribution of CO₂ concentration across the study area from the 74 collected sampled points. The interpolated CO₂ concentration map was presented thematically using a colour gradient from green to red to represent low and elevated concentrations, respectively. HotSpot Analysis (Getis-Ord Gi*) was also conducted to identify statistically significant clusters of low and elevated CO₂ concentrations. A reference value of 400 ppm was adopted as comparison based on previous studies.

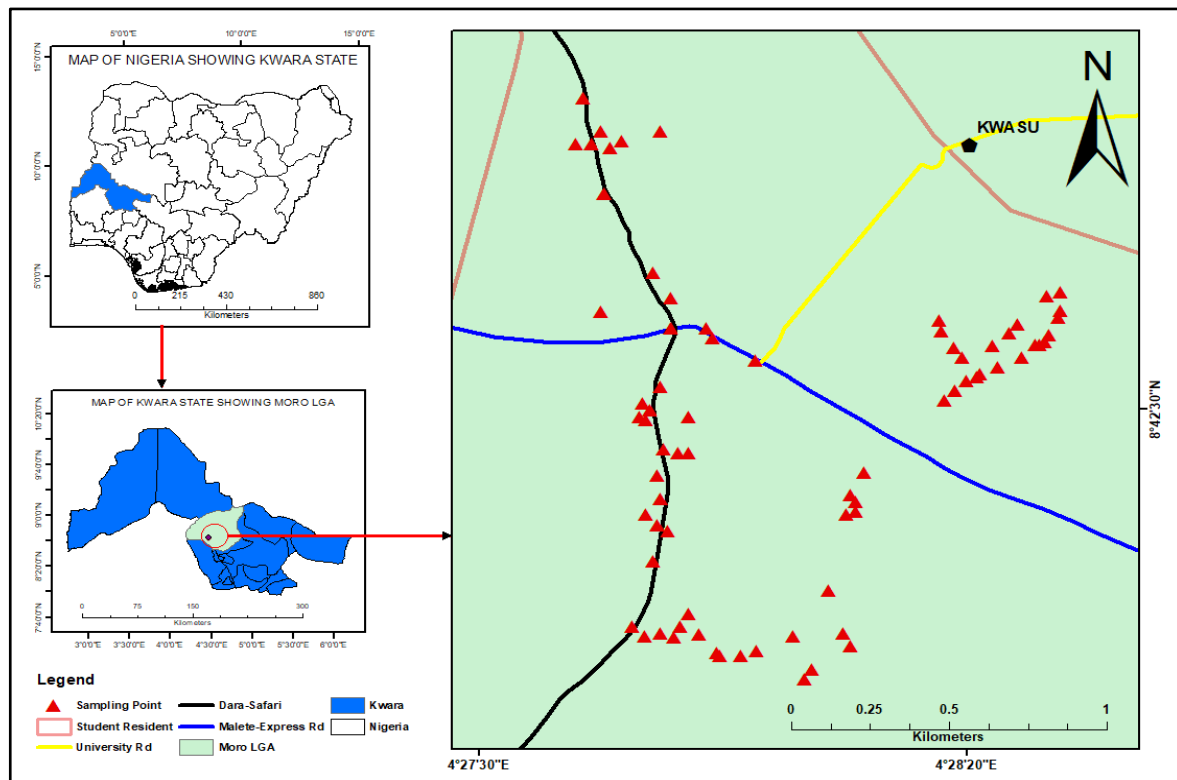


Figure 2: Sampling Map

Source: GIS Laboratory, Dept. EMT, KWASU (2026)

Result and Discussions

The measured CO₂ concentrations across the 74 indiscriminate disposal sites demonstrated spatial variability among the studied dumpsites. CO₂ concentrations ranged from 301 to 789 ppm, with a mean concentration of 541.7 ppm. Relative to the adopted 400 ppm reference value, the mean concentration was 35.43% higher, while the maximum concentration was 97.25% higher. In contrast, the minimum concentration was 24.75% below the reference value (Figure 3). The observed variation indicates spatial heterogeneity in CO₂ concentrations among the considered sampled dumpsites in the KWASU student residential area.

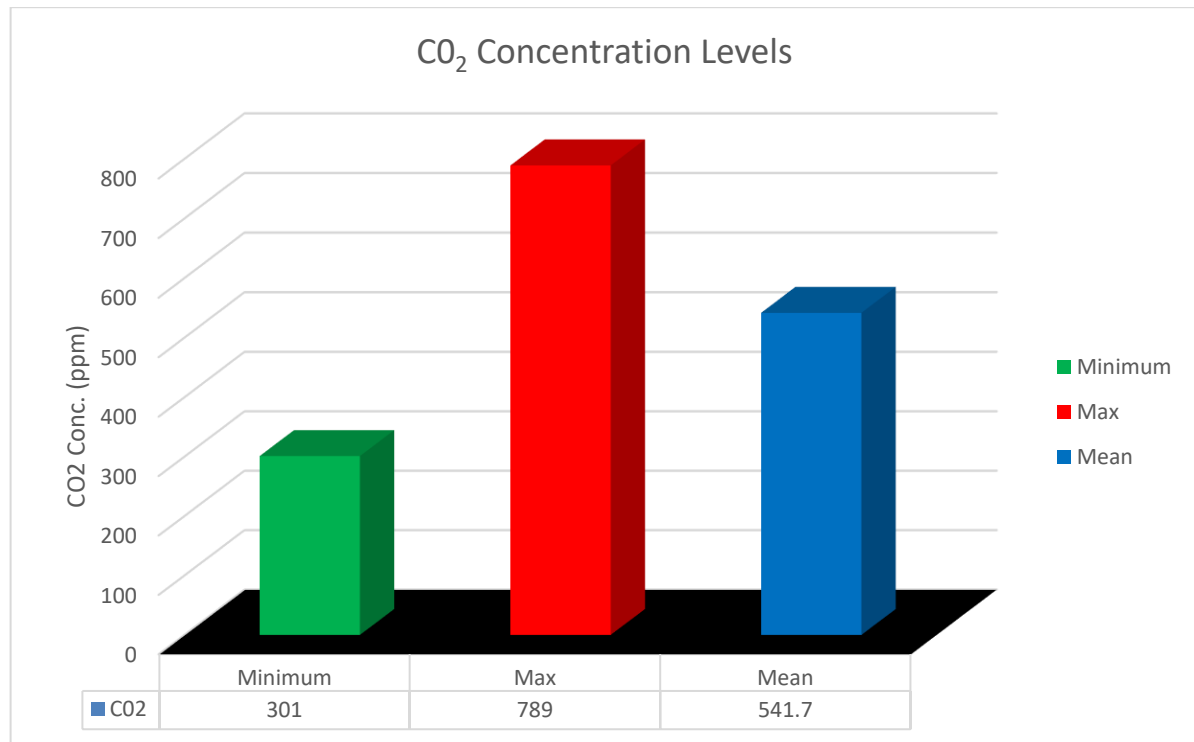
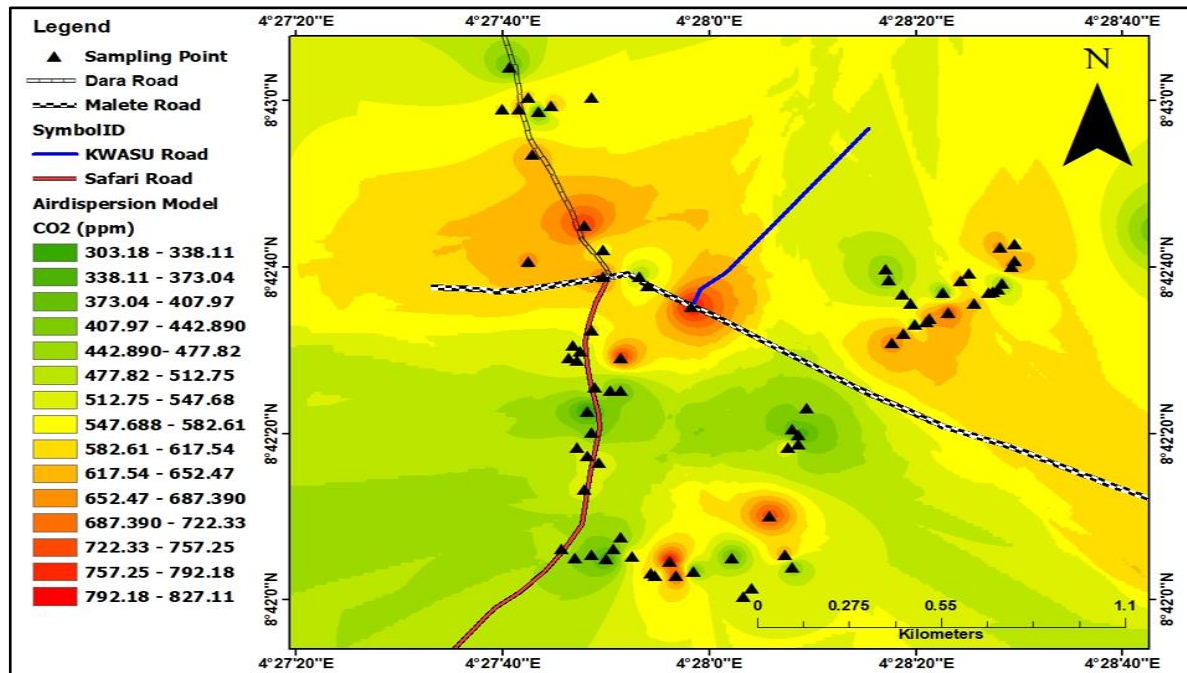


Figure 3: CO₂ Concentration Levels Across the Study Area

The assessment of CO₂ concentrations across the 74 sampled indiscriminate waste disposal sites in the KWASU student residential area revealed substantial spatial variability, with concentrations ranging from 301 to 789 ppm and a mean concentration of 541.7 ppm (Figure 3). The mean CO₂ concentration was 35.43% above the adopted reference value of 400 ppm, indicating that CO₂ concentrations across the KWASU exceed reference value. The minimum concentration of 301 ppm further demonstrate variation of CO₂ concentration across the study area. Signifying possible differences in emission intensity, indiscriminate disposal site waste characteristics, decomposition conditions, and activities in close proximity among the sampling locations. The maximum concentration of 789 shows that CO₂ concentrations are elevated to 97.25% above the adopted reference value, indicating a significant elevation in specific dumpsites.

The Kriging interpolation CO₂ map of the KWASU study area further indicated that the highest elevated CO₂ concentrations were predominantly associated with dumpsites located around TARMAC, Malete Car Park, Malete Market and a few locations within the core student residential area (Figure 4). These locations are characterised by intensive anthropogenic activities and may therefore be influenced by CO₂ emissions from sources other than waste decomposition and open burning. TARMAC serves as the study area's central business district (CBD), characterised by relatively high traffic density and commercial activities, whereas Malete Car Park is associated primarily with vehicular movement and related combustion emissions. Malete Market, in contrast, is characterised by intensive commercial activities, diesel- and petrol-powered grinding machines, as well as substantial generation and accumulation organic waste and other heterogeneous solid waste. Therefore, the elevated CO₂ concentrations recorded in TARMAC, Malete car park and Malete market may reflect the combined influence of the activities.

**Figure 4: CO₂ Dispersion**

Source: Dept. EMT GIS Lab, KWASU (2026)

The generated maps from focal analysis and Getis-Ord Gi* hotspot analysis revealed spatial variation in CO₂ concentrations across the 74 sampled indiscriminate disposal sites in the KWASU student residential area (Figure 5 and Figure 6). The analysis identified statistically significant cluster of hot spot and cold spot concentrations of CO₂. The hot spot map showed that CO₂ concentrations exhibited spatial clustering across the study area, with statistically significant clusters of high and low concentrations occurring around locations such as TARMAC, Malete Car Park and Malete Market, rather than being uniformly distributed throughout the study area.

An elevated hot spot cluster was identified in the eastern part of the study area, in the West-end student residential area, where several closely distributed indiscriminate dumpsites showed a statistically significant elevated CO₂ concentration. The cluster was predominantly characterised by hot spots significant at the 90% confidence level, with some locations exhibiting higher levels of statistical significance. The spatial continuity of these high-value observations indicates that elevated CO₂ concentrations were not confined to isolated sampling points but occurred as a localised cluster of relatively high values in the West-end. The Westend hot spot therefore represents a statistically significant cluster of elevated CO₂ values in the student residential area. A statistically significant hot spot, classified at the 95% confidence level, was identified in the central-western part of the study area around TARMAC. Although this hotspot was more spatially isolated feature in comparison to the Westend cluster, its statistical significance indicates that the observed high CO₂ value was spatially associated with neighbouring elevated observations. The occurrence of this hotspot is consistent with the focal-point analysis, which identified elevated CO₂ concentrations within the CBD of the study area (Figure 6). The spatial distribution of the hotspots aligns with areas categorized with relatively intensive human activities. concentration of statistically significant high values within these activity-intensive environments therefore reflects a localised pattern of CO₂ elevation associated with the combined characteristics of the dumpsites and their immediate environments. The map also identified student residential areas that are identified as statistically

significant cold spot clusters of 90% and 95% confidence levels at both West end and Safari student residential areas. Indicating areas with cluster of low CO₂ concentrations and the co-occurrence of significant hotspots and coldspots reveals a noticeable spatial difference in CO₂ concentrations across Malete. Elevated CO₂ concentrations were concentrated mainly areas characterised by intensive human activities.

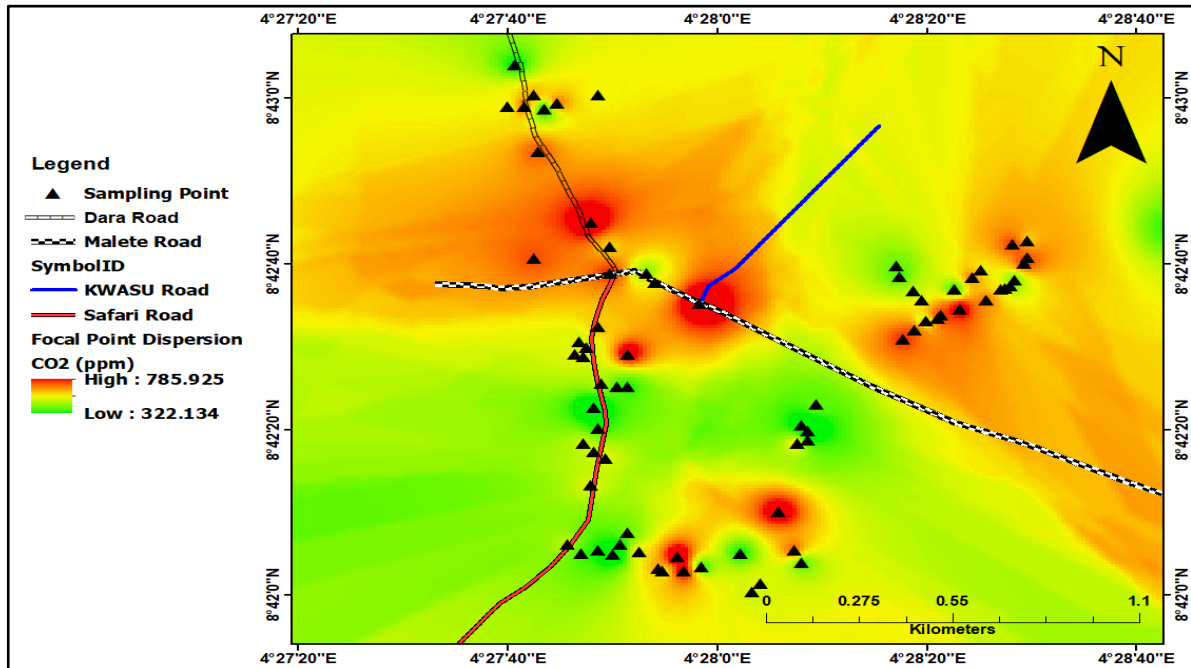


Figure 5: CO₂ Focal Point Dispersion

Source: Dept. EMT GIS Lab, KWASU (2026)

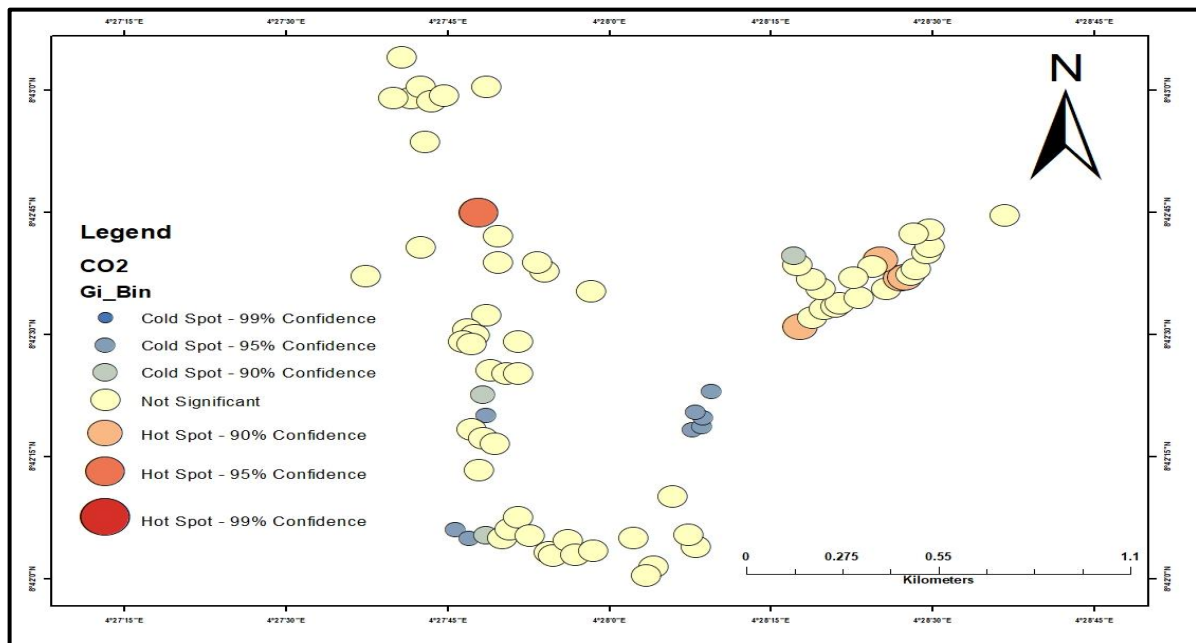


Figure 6: CO₂ Hotspot Distribution

Source: Dept. EMT GIS Lab, KWASU (2026)



Conclusion

The methodological novelty of this study lies in integrating field-based CO₂ measurements, geospatial positioning and GIS-based hotspot analysis to determine the spatial variability of ambient CO₂ concentrations levels at undesignated waste disposal sites in Kwara State university student residential area, Malete, Kwara State. The approach transforms point-based CO₂ concentration levels sampled from indiscriminate dumpsites into spatially explicit patterns that enable the identification of areas with elevated values for targeted environmental management. Importantly, the framework distinguishes spatial association from source attribution, recognising potential contributions from waste decomposition, traffic, combustion and atmospheric processes. This integrated approach provides a reproducible baseline for CO₂ monitoring and waste-management planning in data-limited peri-urban environments.

Recommendations

Based on the observed spatial variability and identified CO₂ hotspots from Getis-Ord Gi* analysis, a spatially influenced waste-management strategy should be adopted in KWASU student residential area, Malete;

- i. Identified indiscriminate disposal sites, particularly those within identified hotspot areas; Tarmac, Carpark, Westend and Malete market, should be systematically cleared, rehabilitated and monitored to prevent re-emergence in same or approximate locations by the Kwara State Environmental Protection Agency (KWEPA) and Moro Local Government Authority (LGA),
- ii. KWEPA should designate waste-collection points as practiced in the state's capital city, Ilorin, including appropriately locating roll-on-roll-off (RoRo) bins and reasonable distance, to deter informal waste disposal and open burning,
- iii. Malete market's waste management initiatives should be strengthened through frequent collection and routine inspection by the KWEPA the Moro LGA to ensure compliance;
- iv. KWEPA and the LGA should ensure GIS-based spatial monitoring of CO₂ concentrations levels throughout the year; and
- v. Finally, the KWEPA, LGA, KWASU, student union, and community should ensure frequent and continuous environmental awareness on the impact of indiscriminate dumpsites and waste burning involving all stakeholder's participation including residents, traders, community leaders, scavengers, private and government waste collection and relevant authorities in ensuring strict enforcement and compliance.

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