SOKOTO JOURNAL OF GEOGRAPHICAL STUDIES (SJGS) *E-ISSN: 3115-5812, PRINT ISSN: 3043-551X*

© DEPARTMENT OF GEOGRAPHY, SOKOTO STATE UNIVERSITY, SOKOTO

Volume 4, Issue 2, August 2026 Edition

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

Saheed Mohammed ISHAQ[1] Aishat Oluwadamilola ABDULKADIR[2] Emmanuellah Odunayo DARAMOLA[3] Noimot Ibitola ILORI[4] Hannah Wuraola AYENI[5] Opeyemi Rofiat AMOSU[6] Oluwaferanmi Victoria OLOPADE[7] Alamin Adedeji ADENEKAN[8] Alexander Terdoo AKIGHIRGA[9]

[1-7]Department of Environmental Management and Toxicology, Faculty of Pure and Applied Sciences, Kwara State University Malete, Nigeria
[8]Centre of Excellence in Agricultural Development and Sustainable Environment, Federal University of Agriculture Abeokuta, Nigeria.
[9]Department of Forestry and Environmental Technology, Hussain Adamu Federal Polytechnic, Kazure, Jigawa State.

[1]ORCID: 0000-0001-7290-2458

Corresponding Author's Email: saheed.ishaq@kwasu.edu.ng

Abstract **https://doi.org/10.65760/sjgs.v4.i2.13**

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 (CO_2) concentration levels from these disposal sites. The study measured CO_2 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. CO_2 concentrations were measured at 74 identified indiscriminate waste disposal locations in the study area using handheld Crowcon Gasman gas detector and benchmarked against 400 pm. 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 CO_2 concentrations; areas such as Tarmac and Westend were identified as hotspots of elevated CO_2 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: *CO_2 concentration, indiscriminate waste disposal, student residential area, hotspot.*

Introduction

Carbon dioxide (CO_2) is an atmospheric component that occurs naturally in quantities that are recycled through natural processes (Talaie et al., 2026). Human-induced CO_2 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 CO_2 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 CO_2 concentration was 423.9 ± 0.2 ppm in 2024, which is 52% higher than the pre-industrial era. The rapid increase in atmospheric CO_2 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, CO_2 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 CO_2 and methane (CH_4) (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 CO_2, particularly when a significant proportion of the waste contains accumulated biodegradable materials and undergo continuous decomposition. Another major source of CO_2 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 CO_2 concentration and spatial distribution in a particular area.

The study and interpretation of ambient CO_2 concentrations necessitate the distinction between atmospheric concentration, emission and exposure. A measured concentration represent amount of CO_2 per unit e 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 concentration levels

https://doi.org/10.65760/sjgs.v4.i2.13

ranging from 420 to 1,254 ppm, while Ede and Edokpa (2015) reported CO_2 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 CO_2 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 CO_2 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 CO_2 concentration at sampling locations and evaluating their relationship with surrounding environment. GIS-based analytical techniques can identify areas of elevated CO_2 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 CO_2 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 CO_2 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 CO_2.

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 CO_2

https://doi.org/10.65760/sjgs.v4.i2.13

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 CO_2 concentration in the study area, while Hot Spot Analysis (Getis-Ord Gi*) was used to identify clusters of low or high concentrations.

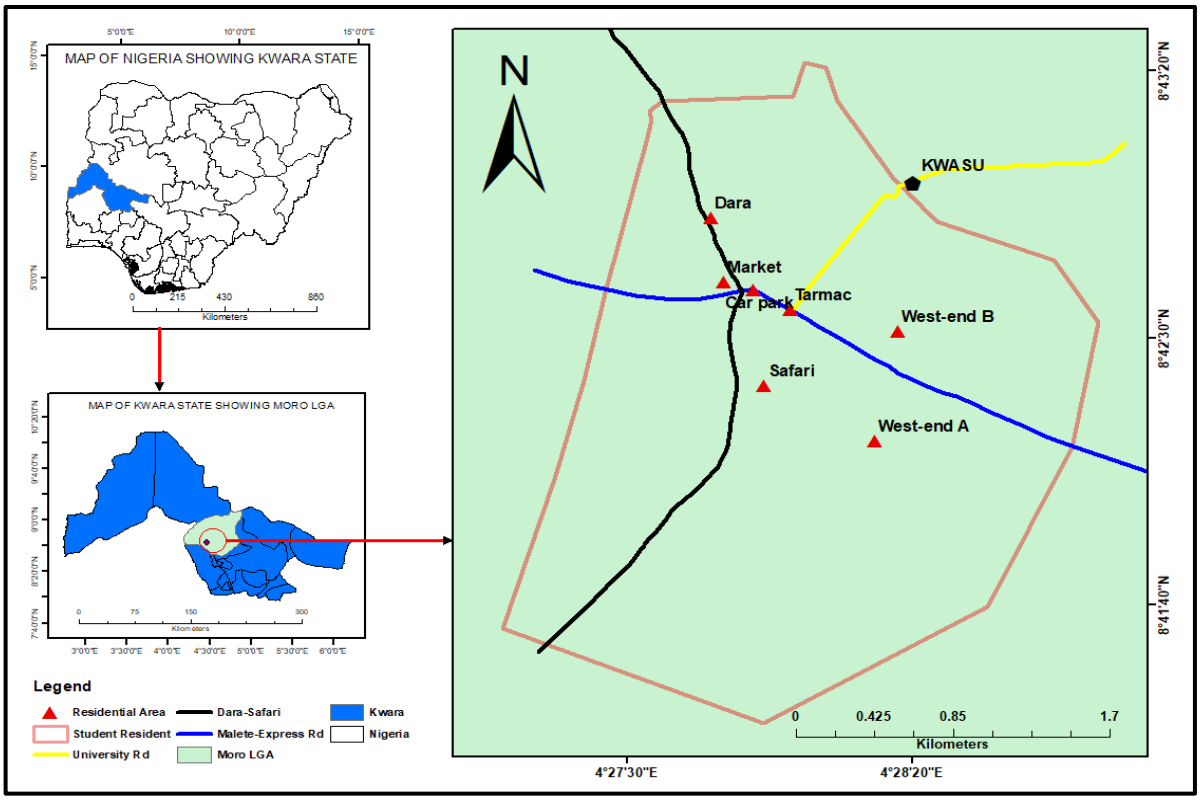

Figure 1: Map of Study Area
Source: GIS Laboratory, Dept. EMT, KWASU (2026)

Sample and Sampling Procedure

A handheld Crowcon Gasman CO_2 gas was used to measure CO_2 concentration at the 74 identified sites. The instrument has CO_2 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 CO_2 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 CO_2 from the reviewed literatures. Accordingly, a reference value of 400 ppm was adopted for comparison with the measured CO_2 concentrations, based on the literature reviewed.

https://doi.org/10.65760/sjgs.v4.i2.13

© DEPARTMENT OF GEOGRAPHY, SOKOTO STATE UNIVERSITY, SOKOTO

Volume 4, Issue 2, August 2026 Edition

Data Processing and Analysis

CO_2 concentration data collected from the 74 sampling points were imported into Microsoft Excel 2023. A table containing columns for latitudes, longitudes, CO_2 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 CO_2 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 CO_2 concentration across the study area from the 74 collected sampled points. The interpolated CO_2 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 CO_2 concentrations. A reference value of 400 ppm was adopted as comparison based on previous studies.

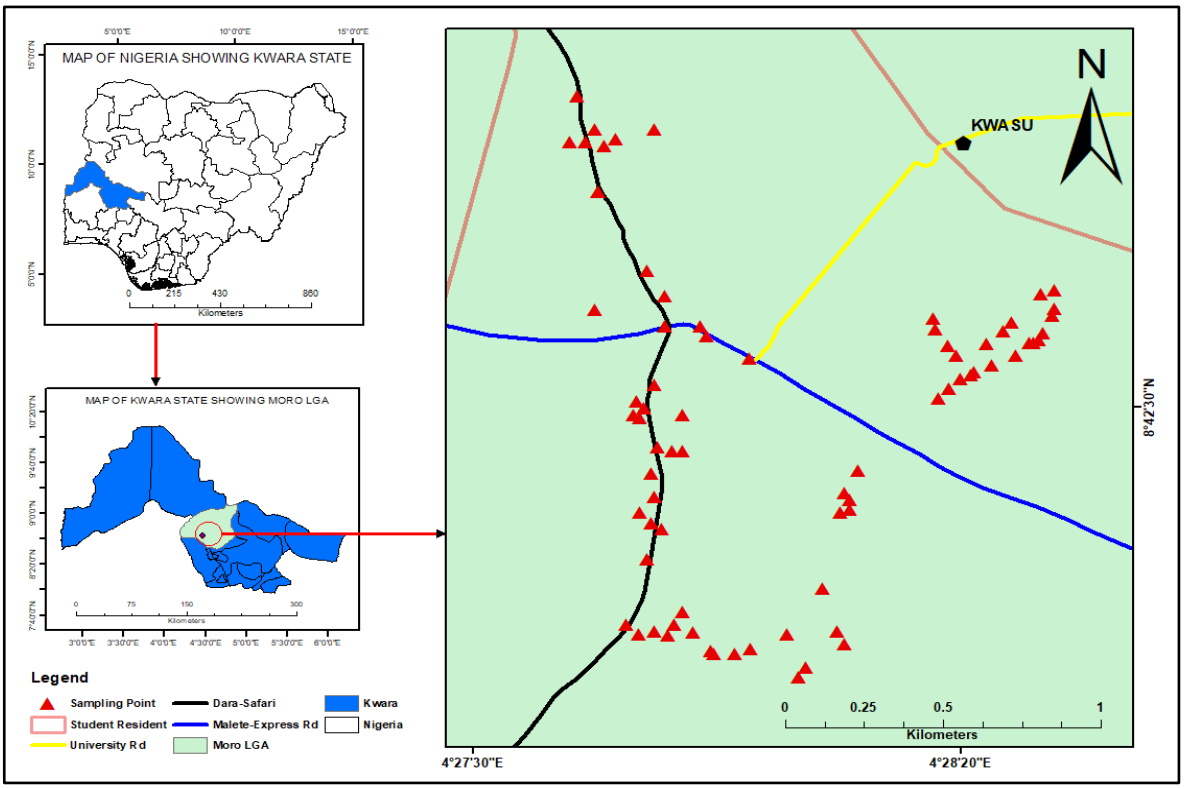

Figure 2: Sampling Map
Source: GIS Laboratory, Dept. EMT, KWASU (2026)

Result and Discussions

The measured CO_2 concentrations across the 74 indiscriminate disposal sites demonstrated spatial variability among the studied dumpsites. CO_2 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 CO_2 concentrations among the considered sampled dumpsites in the KWASU student residential area.

https://doi.org/10.65760/sjgs.v4.i2.13

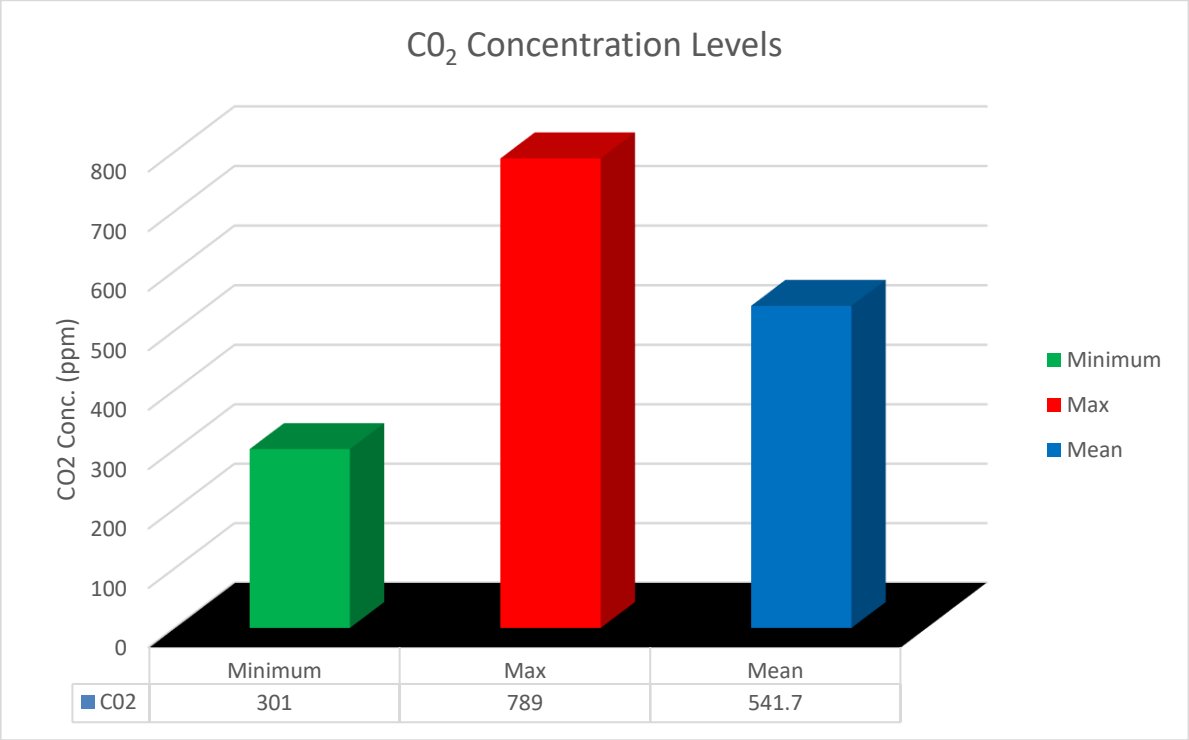

Figure 3: CO_2 Concentration Levels Across the Study Area

The assessment of CO_2 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 CO_2 concentration was 35.43% above the adopted reference value of 400 ppm, indicating that CO_2 concentrations across the KWASU exceed reference value. The minimum concentration of 301 ppm further demonstrate variation of CO_2 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 CO_2 concentrations are elevated to 97.25% above the adopted reference value, indicating a significant elevation in specific dumpsites.

The Kriging interpolation CO_2 map of the KWASU study area further indicated that the highest elevated CO_2 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 CO_2 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 CO_2 concentrations recorded in TARMAC, Malete car park and Malete market may reflect the combined influence of the activities.

https://doi.org/10.65760/sjgs.v4.i2.13

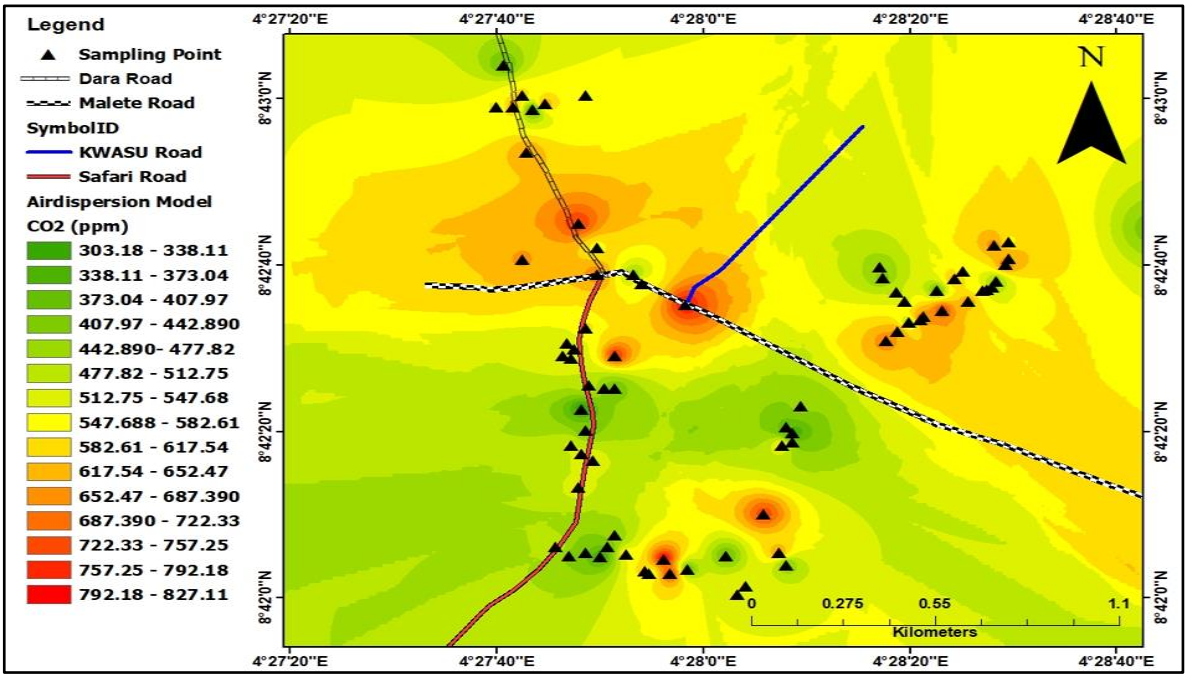

Figure 4: CO_2 Dispersion
Source: Dept. EMT GIS Lab, KWASU (2026)

The generated maps from focal analysis and Getis-Ord Gi* hotspot analysis revealed spatial variation in CO_2 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 CO_2. The hot spot map showed that CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 value was spatially associated with neighbouring elevated observations. The occurrence of this hotspot is consistent with the focal-point analysis, which identified elevated CO_2 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 CO_2 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

https://doi.org/10.65760/sjgs.v4.i2.13

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 CO_2 concentrations and the co-occurrence of significant hotspots and coldspots reveals a noticeable spatial difference in CO_2 concentrations across Malete. Elevated CO_2 concentrations were concentrated mainly areas characterised by intensive human activities.

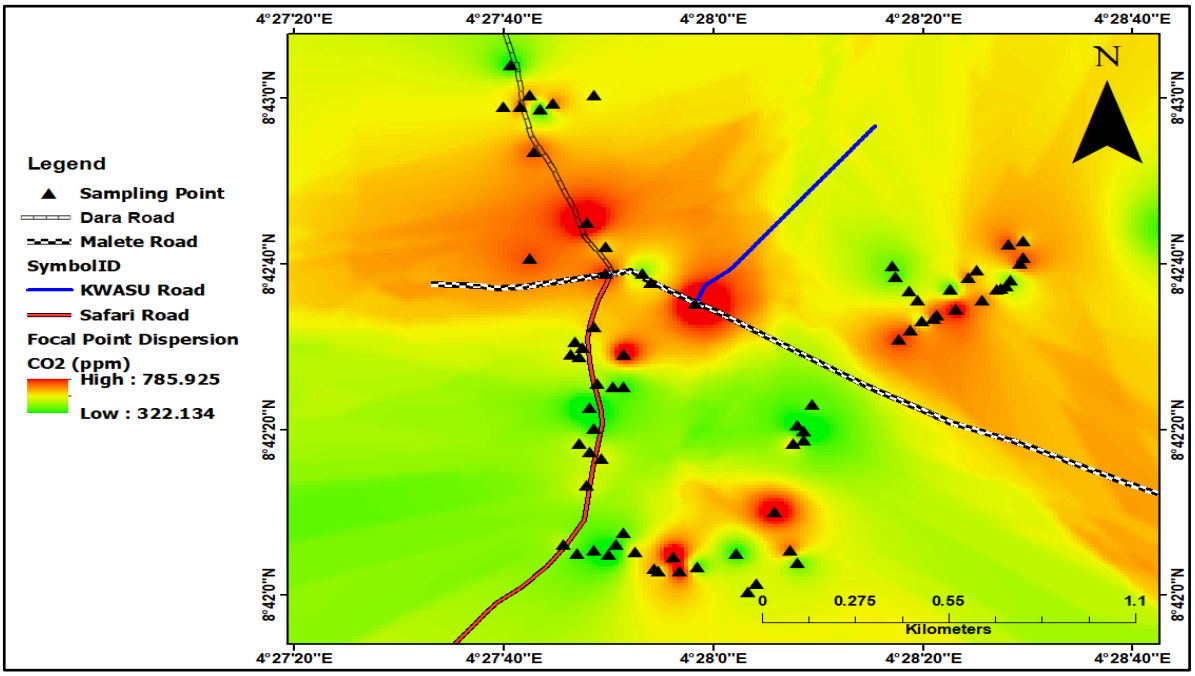

Figure 5: CO_2 Focal Point Dispersion
Source: Dept. EMT GIS Lab, KWASU (2026)

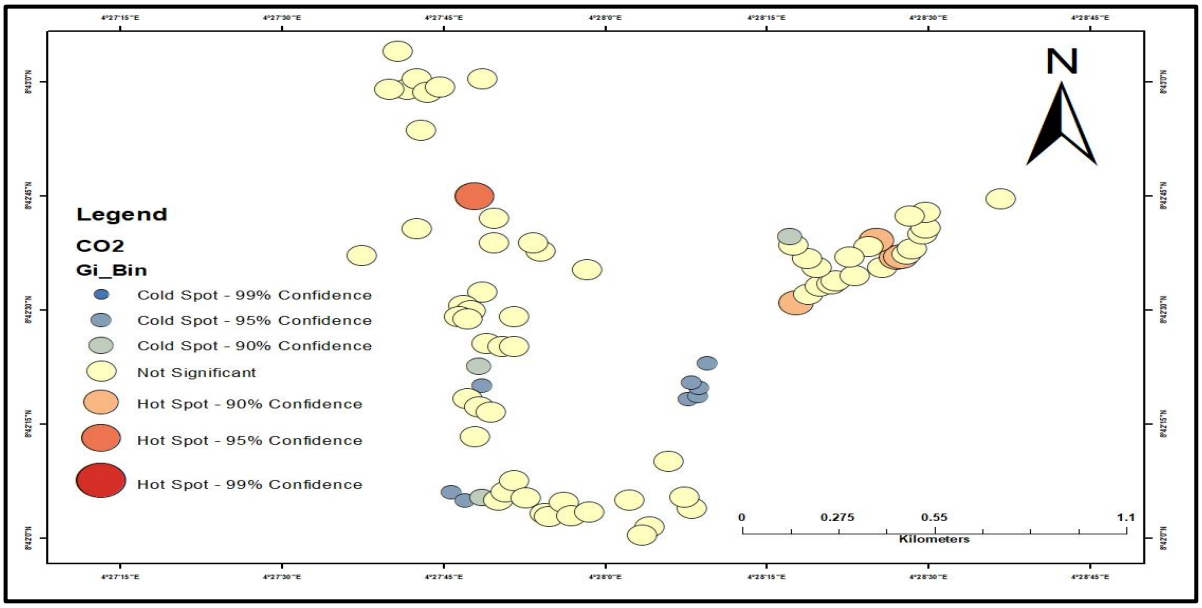

Figure 6: CO_2 Hotspot Distribution
Source: Dept. EMT GIS Lab, KWASU (2026)

https://doi.org/10.65760/sjgs.v4.i2.13

Conclusion

The methodological novelty of this study lies in integrating field-based CO_2 measurements, geospatial positioning and GIS-based hotspot analysis to determine the spatial variability of ambient CO_2 concentrations levels at undesignated waste disposal sites in Kwara State university student residential area, Malete, Kwara State. The approach transforms point-based CO_2 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 CO_2 monitoring and waste-management planning in data-limited peri-urban environments.

Recommendations

Based on the observed spatial variability and identified CO_2 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 CO_2 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.

References

Ede, P. N., & Edokpa, D. O. (2015). Regional air quality of the Nigeria's Niger Delta. *Open Journal of Air Pollution*, *4*(1), 7-15.https://doi.org/10.4236/ojap.2015.41002

Edet, E. O., Ambrose, I. S., Agbasi, O. E., Saturday, U. U., Etuk, S. E., Uwah, E. D., Ettah, O. I., & Osogi, M. A. (2026). Carbon footprint and air quality signature around an open Waste dumpsite in Uyo, Nigeria. *Environmental Pollution and Management*. 3, 200-310. https://doi.org/10.1016/j.epm.2026.05.001

Gautam, M., & Agrawal, M. (2020). Greenhouse gas emissions from municipal solid waste management: a review of global scenario. In: Muthu, S.S. (eds) *Carbon footprint case studies: municipal solid waste management, sustainable road transport and carbon sequestration*, 123-160. https://doi.org/10.1007/978-981-15-9577-6_5

Idowu, I. A., Atherton, W., Hashim, K., Kot, P., Alkhaddar, R., Alo, B. I., & Shaw, A. (2019). An analyses of the status of landfill classification systems in developing countries: Sub Saharan Africa landfill experiences. *Waste Management*, *87*, 761-771. https://doi.org/10.1016/j.wasman.2019.03.011

Ishaq, S. M., Adenekan, A. A., Dauda, A., Amoo, A. O., & Amoo, N. B. (2026). GIS- and remote sensing-based identification of suitable agricultural waste landfill sites for climate-smart agriculture in Ilorin, Nigeria. *Journal of Contemporary Social Research, 10*(2), 37-61. https://doi.org/10.5281/zenodo.23168429

Kamaruddin, M. A., Norashiddin, F. A., Yusoff, M. S., Hanif, M. H. M., Wang, L. K., & Wang, M.-H. S. (2021). Sanitary landfill operation and management. In L. K. Wang, M.-H. S. Wang, & Y.-T. Hung (Eds.), *Solid waste engineering and management* (Handbook of Environmental Engineering, Vol. 23, pp. 525–575). Springer. https://doi.org/10.1007/978-3-030-84180-5_8

Koliyabandara, P. A., Preethika, D. D. P., Cooray, A. T., Liyanage, S. S., Siriwardana, C., & Vithanage, M. (2024). The environmental pressure by open dumpsites and way forward. In A. Anouzla & S. Souabi (Eds.), *Technical landfills and waste management: Volume 1: Landfill impacts, characterization and valorisation* (Vol. 1, pp. 171–204). Springer. https://doi.org/10.1007/978-3-031-52633-6_7

Kumar, S. S., Mahale, A. G., & Patil, A. C. (2020). Mitigation of climate change through approached agriculture-soil carbon sequestration (a review). *Current Journal of Applied Science and Technology*, *39*(33), 47-64. https://doi.org/10.9734/CJAST/2020/v39i3331017

Lou, X. F., & Nair, J. (2009). The impact of landfilling and composting on greenhouse gas emissions: A review. *Bioresource Technology, 100*(16), 3792–3798. https://doi.org/10.1016/j.biortech.2008.12.006

Möller, D., Decker, M., Zosel, J., & Oelßner, W. (2019). Carbon dioxide in general. *Carbon Dioxide Sensing: Fundamentals, Principles, and Applications*, 7-44. https://doi.org/10.1002/9783527688302.ch2

Nanda, S., & Berruti, F. (2021). Municipal solid waste management and landfilling technologies: a review. *Environmental chemistry letters*, *19*(2), 1433-1456. https://doi.org/10.1007/s10311-020-01100-y

Nunes, L. J. (2023). The rising threat of atmospheric CO2: a review on the causes, impacts, and mitigation strategies. *Environments*, *10*(4), 66. https://doi.org/10.3390/environments10040066

Reyna-Bensusan, N., Wilson, D. C., & Smith, S. R. (2018). Uncontrolled burning of solid waste by households in Mexico is a significant contributor to climate change in the country. *Environmental research*, *163*, 280-288. https://doi.org/10.1016/j.envres.2018.01.042

Salvador, R. W., & Doong, R. A. (2024). Simultaneous achievement of energy recovery and carbon sequestration through municipal solid waste management: A review. *Chemosphere*, *361*, 142478. https://doi.org/10.1016/j.chemosphere.2024.142478

Sowmiya Narayanan, K. J., & Manimaran, A. (2024). Recent developments in geographic information systems across different application domains: a review. *Knowledge and Information Systems*, *66*(3), 1523-1547. https://doi.org/10.1007/s10115-023-01969-5

Talaie, A., Fulazzaky, M. A., Rezania, S., & Tamadon, A. (2026). A review of CO_2 removal technologies for a sustainable future. *Environmental Science and Pollution Research, 33*(26), 12970–13001. https://doi.org/10.1007/s11356-026-38104-0

World Meteorological Organization. (2025). *WMO greenhouse gas bulletin No. 21*. https://wmo.int/publication-series/greenhouse-gas-bulletin/greenhouse-gas-bulletin-no-21

Xie, W. F., Li, J. K., Peng, K., Zhang, K., & Ullah, Z. (2024). The application of local Moran's I and Getis–Ord G i* to identify spatial patterns and critical source areas of agricultural nonpoint source pollution. *Journal of Environmental Engineering*, *150*(5), 04024011. https://doi.org/10.1061/JOEEDU.EEENG-7585

Yesil, H., Tugtas, A. E., & Çalli, B. (2025). Beyond landfills: transforming biodegradable waste into climate solutions and valuable resources. *Reviews in Environmental Science and Bio/Technology*, *24*(3), 805-829. https://doi.org/10.1007/s11157-025-09739-1

Yoro, K. O., & Daramola, M. O. (2020). CO_2 emission sources, greenhouse gases, and the global warming effect. In *Advances in carbon capture* (pp. 3-28). Woodhead Publishing. https://doi.org/10.1016/B978-0-12-819657-1.00001-3