Journal of Chemical, Environmental and Biological Engineering
2026, Vol. 10, No. 2, pp. 57–66
https://doi.org/10.11648/j.jcebe.20261002.13

Review Article

The Influence of Changes in Land Use on the Concentration of Carbon Monoxide (CO) as an Indicator of Climate Change in Bugesera District

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Abstract

In this comprehensive study, researcher investigate the complex interplay between land use changes, vegetation health as measured by NDVI, and carbon monoxide (CO) concentration in the Bugesera District from 2019 to 2022 using Google Earth Engine. The introduction sets the context by highlighting the environmental significance of understanding this relationship in a region marked by rapid urbanization and shifting land use patterns. A thorough literature review underscores the global relevance of this topic, discussing the impact of urban development, transportation, and industrialization on both vegetation health and air quality. The methodology section outlines data collection methods and analytical techniques, emphasizing the use of remote sensing technology and GIS for spatial analysis accompanied by Machine Learning in Google Earth Engine. The results demonstrate a clear inverse correlation between NDVI and CO concentration, particularly in areas with high urbanization and infrastructural development, validating the negative impact of human activities on vegetation and air quality. The discussion delves into the implications of these findings, emphasizing the need for sustainable urban planning and environmental conservation efforts. Finally, the conclusion summarizes the study's significance, offering actionable recommendations for policymakers and urban planners to promote healthier, more resilient ecosystems and improved air quality in the Bugesera District and similar rapidly evolving regions.

Keywords

Correlation, NDVI, Carbon Monoxide (CO), Land Use Change and Urbanization

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Received: 25 May 2026; **Accepted:** 3 June 2026; **Published:** 6 November 2026

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1. Introduction

Air pollution has emerged as a major and pressing issue for humanity in recent decades, causing adverse effects on both human health and the natural environment [1]. It is described as the pollution of either indoor or outdoor air due to the presence of a variety of gaseous pollutants and solid particles. The World Health Organization (WHO) reported that in 2022, a significant portion of premature deaths associated with outdoor air pollution could be attributed to specific health conditions. Approximately 37% of these deaths resulted from ischaemic heart disease and stroke, while 18% were linked to chronic obstructive pulmonary disease, and another 23% were attributed to acute lower respiratory infections. Additionally, around 11% of these premature deaths were associated with cancer within the respiratory tract [2]. Air pollution is recognized as the fourth or fifth largest global risk factor for mortality [3]. In 2016, it was estimated that approximately 4.2 million global fatalities could be linked to outdoor air pollution. Pollutants found in the air, such as carbon monoxide (CO), sulfur dioxide (SO_2), particulate matter (PM_{10}, $PM_{2.5}$), nitrogen dioxide (NO_2), and ozone (O_3), have the potential to contribute to a range of chronic illnesses, including lung cancer, cardiovascular conditions, and various respiratory diseases [4].

Land use and climate change are intimately intertwined, with each exerting a profound influence on the other across varying temporal and spatial scales [5, 6]. At its core, improper land use practices represent a primary causal factor driving climate change [7]. Rwanda, much like many other developing countries, has witnessed significant changes in land use across its cities, towns, and centers [8]. Unfortunately, these changes have often occurred in an unplanned and haphazard manner, resulting in detrimental consequences for the local living conditions and overall air quality [9]. Bugesera District serves as a prime example of this rapid urbanization trend, where the expansion of urban areas has been accompanied by various impacts, including the increased emission of global warming gases [10]. As these emissions rise, the quality of the air we breathe becomes increasingly endangered, presenting a pressing concern for both environmental and public health reasons [11].

In our analysis, carbon monoxide (CO) is recognized as a crucial atmospheric trace gas, particularly in understanding tropospheric chemistry and its role as a major urban pollutant in certain areas [12, 13]. Its primary sources include fossil fuel combustion, biomass burning, and the oxidation of methane and hydrocarbons [14]. While fossil fuel combustion dominates at northern mid-latitudes, the tropics are influenced by isoprene oxidation and biomass burning [15]. The TROPOMI instrument on the Sentinel 5 Precursor satellite observes global CO concentrations using clear-sky and cloudy-sky Earth radiance measurements in the 2.3 μm spectral range [16, 17]. Clear-sky observations provide sensitivity to CO total columns within the tropospheric boundary layer, while for cloudy atmospheres, the sensitivity varies with the light path [18, 19]. This technology helps researchers monitor and better understand CO dynamics, aiding in pollution mitigation and climate-related studies.

NDVI (Normalized Difference Vegetation Index) and CO (carbon monoxide) can be correlated in environmental monitoring. NDVI, derived from remote sensing data, measures the health and density of vegetation [20]. High NDVI values indicate lush, healthy vegetation, while low values suggest sparse or stressed vegetation [21]. The correlation between NDVI and CO levels can reveal insights into ecosystem health and land use changes [22, 23]. For instance, increased CO concentrations from sources like deforestation or wildfires may correspond to decreased NDVI values, indicating reduced vegetation cover and overall environmental degradation [24]. Conversely, a decrease in CO concentrations might correlate with higher NDVI values, suggesting improved vegetation health due to conservation efforts or natural regrowth.

In Bugesera, a district in Rwanda characterized by rapid urbanization and various land use changes, the correlation between NDVI (Normalized Difference Vegetation Index) and CO (carbon monoxide) levels becomes particularly relevant. Monitoring NDVI in Bugesera helps to assess changes in vegetation cover, which might be influenced by urban expansion, deforestation, or agricultural practices [25]. These changes in land use can, in turn, impact CO levels due to emissions from construction, transportation, and other human activities [26]. Studying the correlation between NDVI and CO in Bugesera can provide valuable insights into how urbanization and land use changes are affecting the local environment, air quality, and overall sustainability of the region.

2. Study Area Description

Bugesera District is located in the Eastern Province of Rwanda and encompasses an area of approximately 1,290.57 square kilometers [27]. This region, characterized by its diverse landscape, includes urban centers, rural communities, wetlands, and agricultural areas [28]. Bugesera is known for its rapid urbanization and development, with the district serving as a significant transportation hub due to its proximity to Kigali, the capital city [29]. It features a dynamic mix of land uses, including urban expansion, agriculture, and wetland conservation, which contribute to its unique socio-economic and environmental challenges and opportunities [30, 31]. Studying the relationship between land use and carbon monoxide (CO) concentration in regions like Bugesera District is essential due to its direct relevance to climate change, local environmental impact, interdisciplinary nature, data availability, sustainability, and policy implications [32]. This research informs strategies for mitigating CO emissions, improving air quality, and fostering sustainable urban development, addressing pressing global challenges while benefiting both ecosystems and human populations in rapidly evolving regions [33].

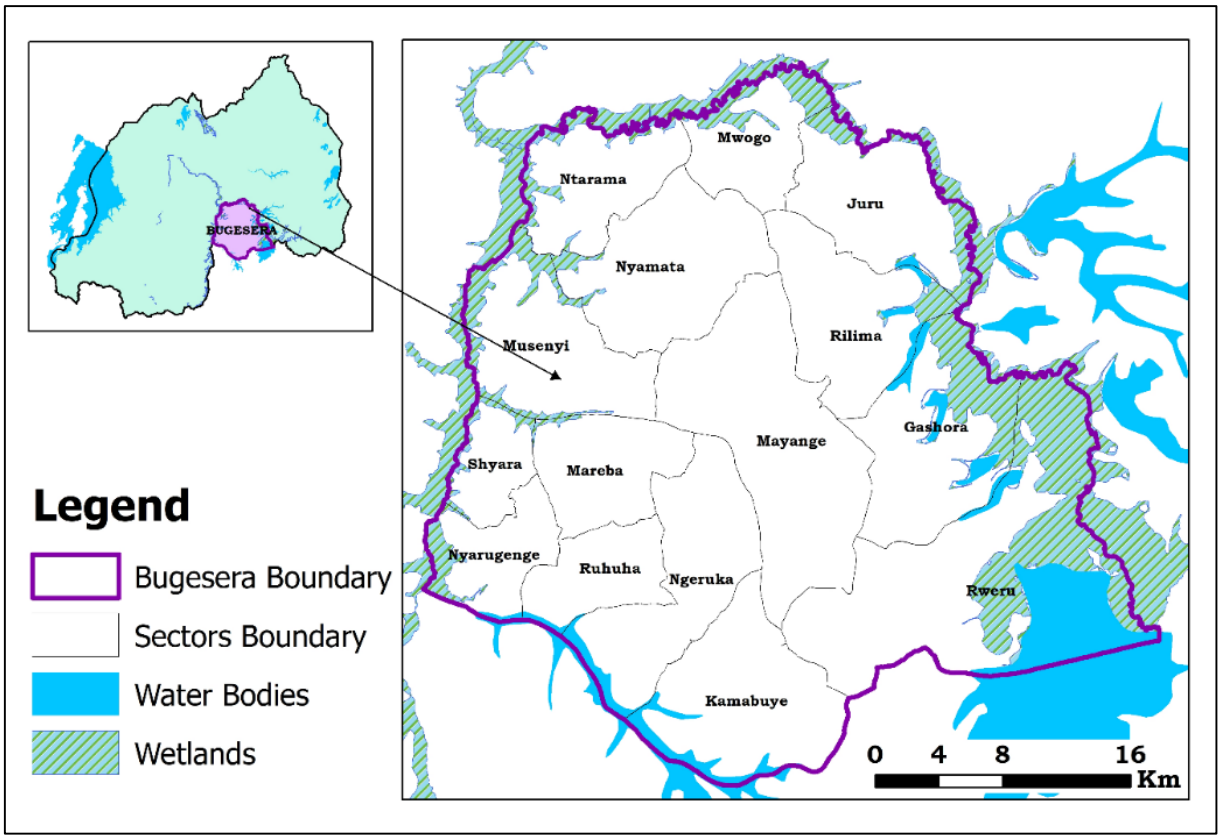


Figure 1. *Bugesera study area map located in Eastern Province.*

3. Data Description and Analysis

The Sentinel-5P OFFL CO dataset includes two key measurements: CO column number density, measured in mol/m^2, with values ranging from -34.43 to 5.71, and a spatial resolution of 7.0 x 7.0 km [34]. This data quantifies the concentration of carbon monoxide (CO) in the atmosphere. Additionally, the Sentinel-2 MSI dataset provides Normalized Difference Vegetation Index (NDVI) values, which have no units, ranging from -1 to 1, and offer a much finer spatial resolution of 10 x 10 meters [35]. NDVI is a critical indicator of vegetation health and density, making it useful for monitoring land use and ecosystem dynamics in detail [36]. These data parameters are essential for understanding the relationship between atmospheric CO levels and vegetation health at varying scales.

Table 1. *Data Description and source.*

Data Name	Measurement	Dataset Availability	Resolution	Source
CO column number density	mol/m^2	2018-06-28 to 2023-10-03	7.0 x 7.0 Km	Sentinel-5P OFFL CO
NDVI	No Unit range From -1 to +1	2017-03-28 to 2023-10-06	10 x 10 m	Sentinel-2 MSI

4. Results

a. Carbon monoxide (CO) Trend Analysis

The findings below reveal a significant relationship between carbon monoxide (CO) concentration and seasonal variation. The data clearly indicate that CO levels are highest during the dry season and lowest during the rainy season, as shown in the table below where maximum record found in February of 2021 with 0.044 mol/m^2.

Table 2. *Monthly Carbon monoxide Trend Analysis from 2019-2022.*

Month	CO column number density (2019) in mol/m^2	CO column number density (2020) in mol/m^2	CO column number density (2021) in mol/m^2	CO column number density (2022) in mol/m^2
Jan	0.035	0.037	0.036	0.037
Feb	0.034	0.035	0.044	0.035
Mar	0.032	0.035	0.033	0.035
Apr	0.029	0.03	0.026	0.03
May	0.026	0.027	0.028	0.027
Jun	0.039	0.033	0.032	0.033
Jul	0.038	0.038	0.039	0.038
Aug	0.037	0.041	0.04	0.041
Sep	0.037	0.038	0.037	0.038
Oct	0.031	0.037	0.035	0.037
Nov	0.03	0.031	0.034	0.031
Dec	0.031	0.032	0.031	0.032

This graph succinctly portrays the annual distribution of Carbon Monoxide (CO) concentrations in Bugesera's atmosphere from 2019 to 2022. It effectively captures the fluctuating patterns, offering a concise overview of the region's atmospheric composition and contributing to a better understanding of air quality dynamics.

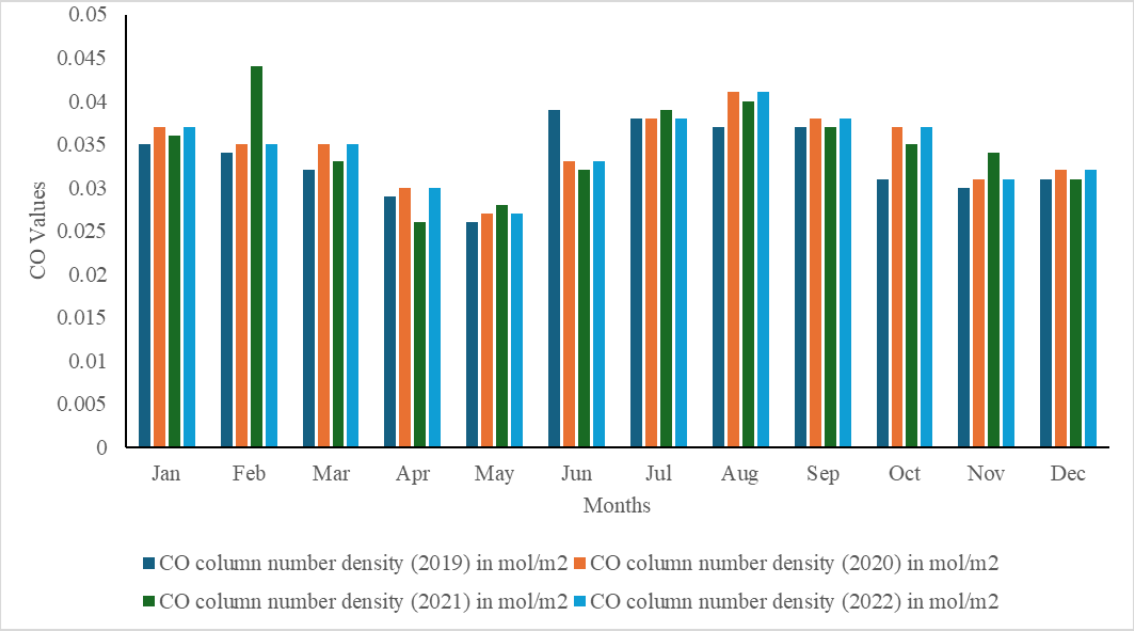


Figure 2. *Carbon monoxide distribution 2019-2022.*

b. Spatio-temporal analysis of Carbon monoxide from 2019-2022

Carbon monoxide (CO) spanning from 2019 to 2022 offers a comprehensive understanding of how CO concentrations have evolved over this period. The dynamic interplay of CO levels across different locations and timeframes has not only shed light on the seasonal and annual variations in CO concentration but also identify specific trends, hotspots, and potential contributing factors. Such insights are crucial for assessing air quality, understanding the impact of land use

changes, and formulating effective strategies for mitigating CO emissions and their implications for both the environment and public health [37]. In this region, areas with a high concentration of carbon monoxide (CO) are typically characterized by a lack of vegetation cover. Vegetation acts as a natural absorber of carbon emissions, making it more effective than other factors in reducing CO levels. A comprehensive study analyzing these patterns revealed that in 2019, CO concentrations were relatively lower compared to the following years. However, in 2020, CO levels decreased significantly compared to the subsequent two years. This decline was confirmed to be linked to the COVID-19 lockdown measures, during which various emissions sources were temporarily inactive, leading to improved air quality.

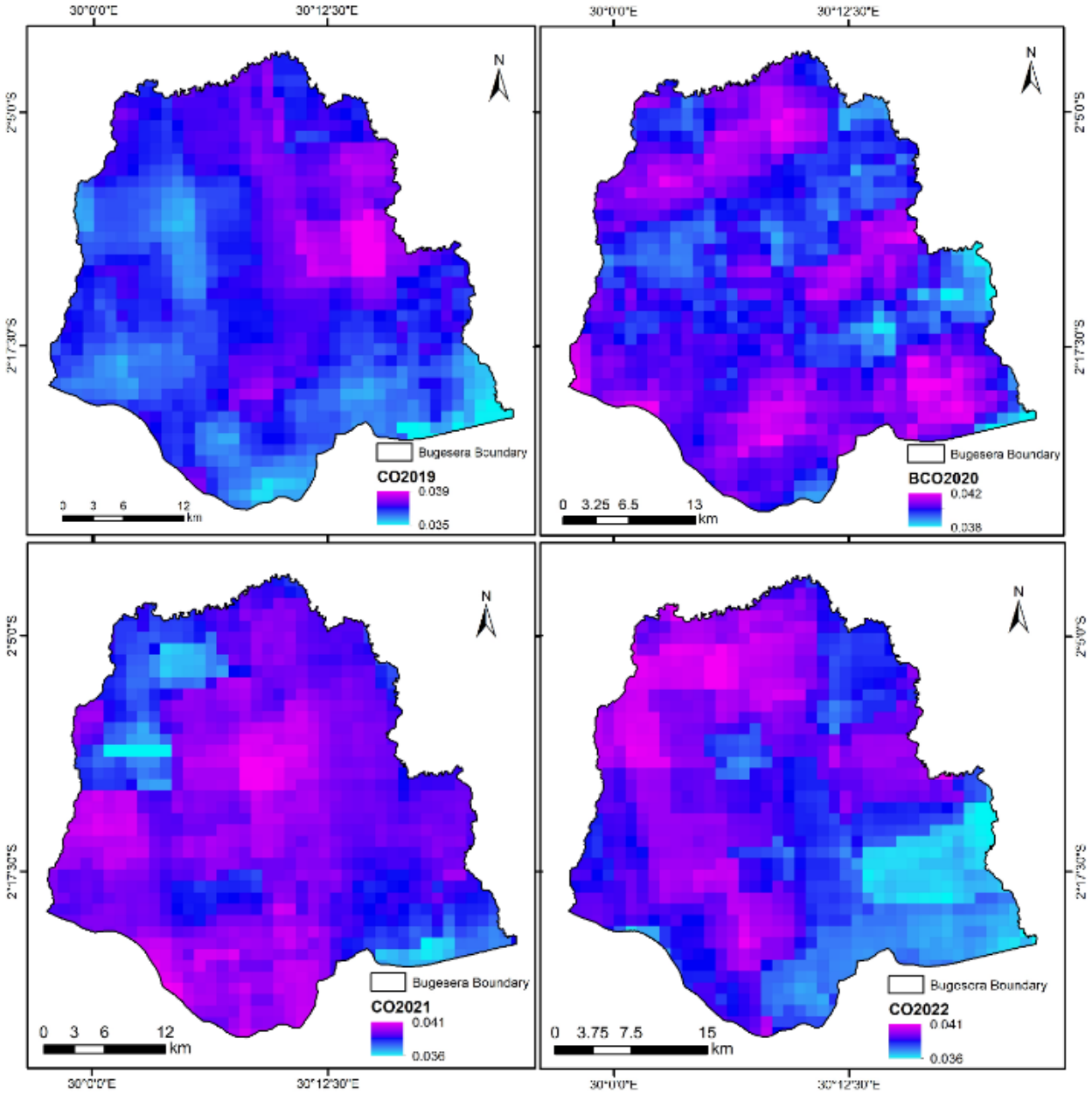


Figure 3. *Spatio-temporal analysis of Carbon monoxide from 2019-2022 where A, B, C and D represent Carbon monoxide concentration in the study area from 2019, 2020, 2021, and 2022 respectively.*

c. NDVI Trend Analysis

The analysis of NDVI trends from 2019 to 2022 has revealed a noticeable decline in vegetation health, particularly in Bugesera District, which experiences relatively low rainfall. This reduction in vegetation health is strongly correlated with seasonal variations, with the dry seasons showing more pronounced impacts than rainy seasons. Rwanda experiences two primary seasons: a rainy season and a dry season. The long rainy season typically spans from March to May, characterized by heavy rainfall and lush vegetation. The shorter rainy

season occurs from October to December. In contrast, the dry season falls between June and September, featuring drier conditions with occasional light rains. These distinct seasons play a vital role in agriculture and impact on the country's landscapes, with the dry season often coinciding with lower vegetation cover and the rainy season supporting extensive greenery and agricultural activities and influence the distribution of Carbon monoxide gases in atmosphere.

Table 3. *The monthly NDVI trend from 2019-2022.*

Month	NDVI Value (2019)	NDVI Value (2020)	NDVI Value (2021)	NDVI Value (2022)
Jan	0.656	0.614	0.588	0.557
Feb	0.606	0.565	0.539	0.484
Mar	0.592	0.551	0.521	0.486
Apr	0.633	0.587	0.572	0.523
May	0.658	0.622	0.571	0.543
Jun	0.603	0.549	0.503	0.457
Jul	0.483	0.436	0.39	0.335
Aug	0.387	0.345	0.302	0.274
Sep	0.352	0.317	0.282	0.241
Oct	0.413	0.356	0.328	0.271
Nov	0.512	0.521	0.426	0.365
Dec	0.637	0.597	0.526	0.509

This concise graph illustrates the annual variations in Vegetation Values, specifically the Normalized Difference Vegetation Index (NDVI), across Bugesera's landscape from 2019 to 2022. It effectively conveys the dynamic patterns, providing a brief overview of the region's vegetation health. This contributes to a deeper understanding of the dynamics shaping the quality of vegetation health in the Bugesera area.

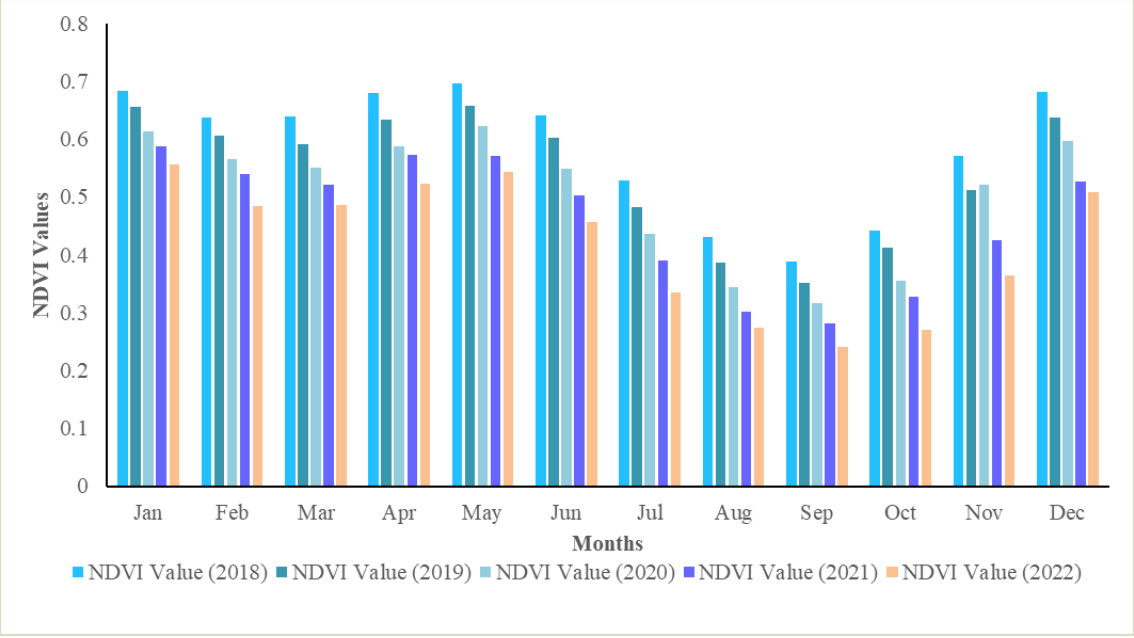


Figure 4. *NDVI Values distribution in Bugesera Landscape.*

d. Spatio-Temporal Analysis NDVI from 2019-2022

Bugesera, characterized as a drained area, features various regions with persistent flooded vegetation cover over extended periods. However, the district is currently witnessing rapid urbanization, leading to significant changes in land use patterns. This urbanization trend has a direct impact on the greenery and overall health of vegetation, as it often involves the replacement of natural landscapes with buildings and infrastructure. Consequently, this transformation contributes to an unconditional increase in carbon monoxide levels, as urban development and associated activities release higher concentrations of this pollutant into the atmosphere.

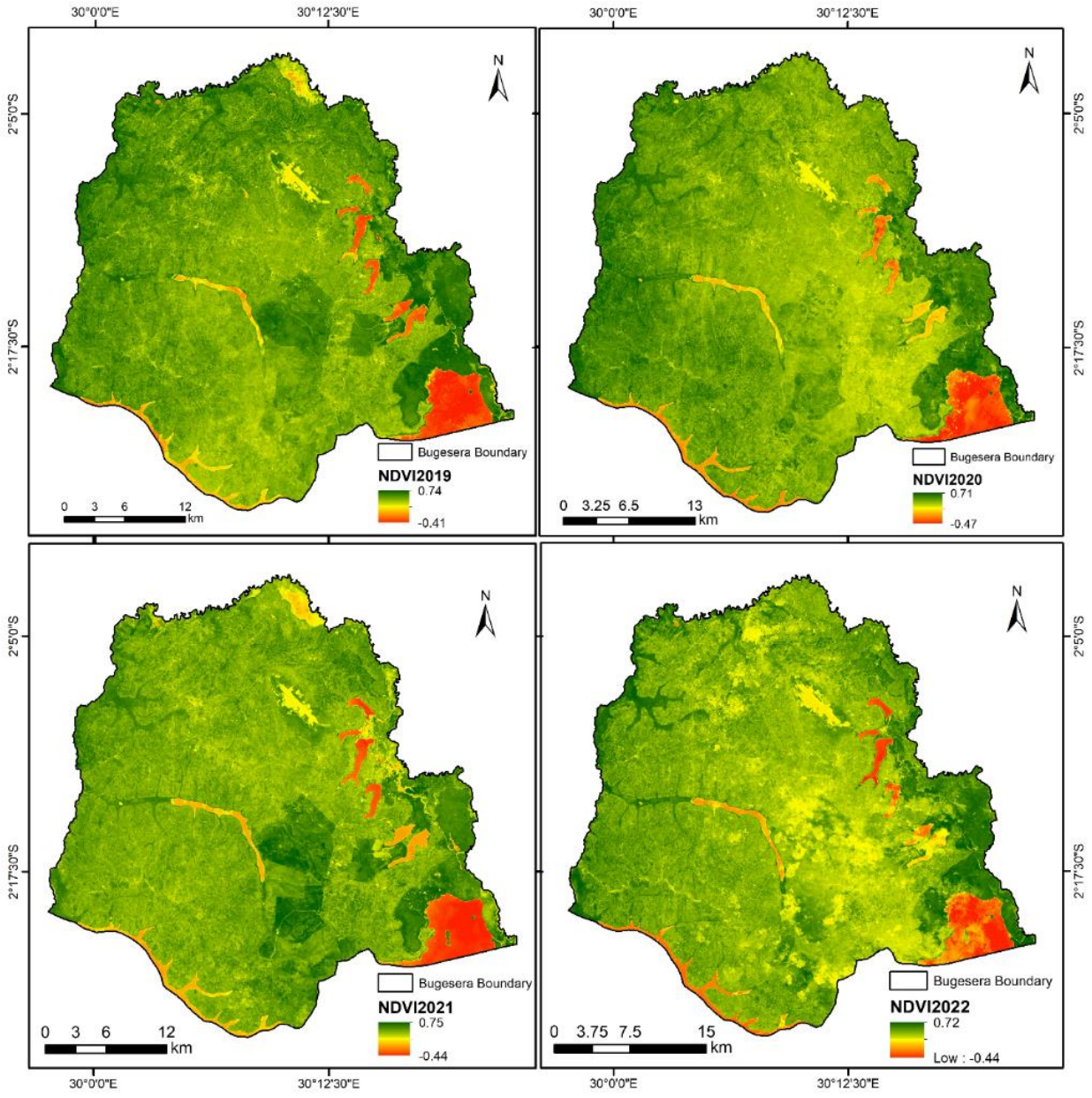


Figure 5. *Spatio-Temporal Analysis NDVI of study area region from 2019-2022, where A, B, C and D represent NDVI from 2019, 2020, 2021, and 2022 respectively.*

5. Discussion

In this context, the relationship between NDVI as an indicator of vegetation health and carbon monoxide (CO) concentration becomes evident. Areas affected by human activities, including urban development, infrastructure expansion [38] like highways, and industrial facilities, tend to exhibit lower NDVI values, signifying reduced vegetation cover due to construction

and land use changes [39]. This, in turn, contributes to elevated emissions of pollutants such as CO and particulate matter (PM) from increased traffic and industrial processes [40]. Conversely, regions with higher NDVI values typically indicate healthier vegetation and can correspond to lower CO concentrations due to the pollutant-absorbing capacity of thriving greenery. As shown in the graph, there is an inverse relationship between NDVI and CO concentration, highlighting how urbanization and land use impact both air quality and ecosystem health.

Furthermore, the observed seasonal fluctuations reinforce the strong linkage between climatic conditions, vegetation dynamics, and atmospheric pollution levels. During the dry season, reduced rainfall and declining vegetation cover limit the natural absorption capacity of ecosystems, thereby increasing the accumulation of CO in the atmosphere [41]. In contrast, rainy seasons promote vegetation regeneration and enhanced NDVI values, which contribute to improved air purification processes. These findings emphasize the importance of integrating environmental conservation strategies into regional development plans. Strengthening afforestation programs, protecting wetlands, and encouraging sustainable land management practices can significantly reduce pollution levels while enhancing ecological resilience and long-term environmental sustainability in rapidly urbanizing areas like Bugesera District.

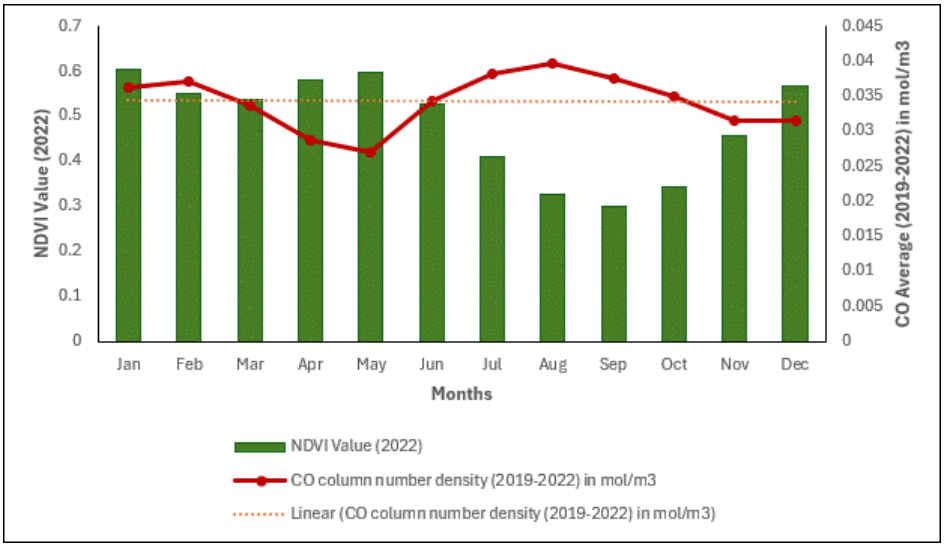


Figure 6. *Graph shows how NDVI and Carbon Monoxide are related from 2019-2022.*

6. Conclusion and Recommendation

The analysis of the inverse relationship between NDVI and carbon monoxide (CO) concentration underscores the critical importance of sustainable urban planning and environmental stewardship. To mitigate air pollution and safeguard ecosystem health, it is imperative to prioritize green spaces, vegetation preservation, and sustainable land use practices within urban development projects. Recommendations include the incorporation of green infrastructure, such as parks and green belts, into urban planning, the promotion of public transportation to reduce traffic emissions, and the enforcement of stricter emissions standards for industrial facilities. Moreover, continuous monitoring of air quality and vegetation health, coupled with informed policymaking, is essential for fostering healthier, more sustainable urban environments that benefit both residents and the ecosystem.

Abbreviations

NDVI	Normalized Difference Vegetation Index
CO	Carbon Monoxide
GIS	Geographic Information System
WHO	World Health Organization
SO_2	Sulfur Dioxide
PM_{10}	Particulate Matter with Diameter ≤ 10 Micrometers
$PM_{2.5}$	Particulate Matter with Diameter ≤ 2.5 Micrometers
NO_2	Nitrogen Dioxide
O_3	Ozone
TROPOMI	TROPOspheric Monitoring Instrument
MSI	MultiSpectral Instrument
Sentinel-5P	Sentinel-5 Precursor
COVID-19	Coronavirus Disease 2019
Km	Kilometer
M	Meter
mol/m^2	Moles Per Square Meter

Author Contributions

Joel Ndayisaba: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Resources, Supervision, Visualization, Writing – original draft

Theodore Nshimiyumuremyi: Data curation, Formal Analysis, Methodology

Mucyo Ndera Tuyizere: Data curation, Methodology & Visualization

Eric Ndagijwenimana: Data curation, Formal Analysis, Investigation, Methodology, Resources

Conflicts of Interest

There are no conflicts of interest.

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