
Spatiotemporal Variability of Black Carbon Aerosol Optical Depth and its Contribution to Total Aerosol Loading in Lagos and Kano, Nigeria.

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Abstract

Black carbon (BC) is an important atmospheric aerosol that influences climate, air quality, and human health through its strong absorption of solar radiation. This study investigated the spatiotemporal variability of Black Carbon Aerosol Optical Depth (BCEXTTAU) and its contribution to total aerosol loading (TOTEXTTAU) over Lagos and Kano, Nigeria, during 2014–2018 using MERRA-2 reanalysis data. Annual trends, seasonal variability, Black Carbon Contribution Ratio (BCR), annual growth rates, and the Urban Black Carbon Enhancement Factor (UBEF) were evaluated. Results showed a steady increase in BCEXTTAU in both cities, rising from 0.0398 to 0.0554 in Kano and from 0.0569 to 0.0764 in Lagos between 2014 and 2018. Lagos consistently recorded higher BCEXTTAU values, reflecting stronger anthropogenic emissions. Seasonal analysis revealed maximum BCEXTTAU during April–May and minimum values during September–October due to enhanced wet scavenging during the rainy season. The BCR remained relatively stable, averaging approximately 10.7–10.8% in Kano and 13.5–13.7% in Lagos, indicating a greater contribution of combustion-derived aerosols in Lagos. UBEF values greater than unity further confirmed persistent black carbon enhancement in Lagos relative to Kano. The results demonstrate increasing black carbon loading in Nigerian urban environments and highlight the importance of emission-control strategies for improving air quality and mitigating climate impacts.

Keywords: Black Carbon Aerosols; Aerosol Optical Depth; MERRA-2; Urban Air Pollution; Nigeria

1. Introduction

Atmospheric aerosols play a crucial role in the Earth's climate system through their interactions with solar radiation, clouds, and atmospheric chemistry. Among the various aerosol species, black carbon (BC) is of particular scientific interest because of its strong light-absorbing properties and its significant influence on climate, air quality, and human health. Unlike scattering aerosols that predominantly reflect incoming solar radiation, black carbon absorbs solar energy and contributes to atmospheric warming, thereby altering the regional and global radiation balance (Bond, et al., 2013). In addition to its climatic impacts, black carbon is recognized as an important air pollutant due to its association with respiratory and cardiovascular diseases arising from prolonged exposure to fine particulate matter (Janssen, et al., 2011).

Black carbon is generated primarily through the incomplete combustion of fossil fuels, biomass, and biofuels. Major anthropogenic sources include transportation emissions, industrial processes, power generation, residential fuel combustion, and open biomass burning. Rapid urbanization and increasing energy demand in developing countries have led to a substantial rise in black carbon emissions, making urban centers important hotspots of atmospheric pollution (Ramanathan, & Carmichael, 2008). The distribution and concentration of black carbon aerosols are therefore strongly influenced by human activities, population density, industrial development, and prevailing meteorological conditions.

Nigeria has experienced rapid urban expansion over the past few decades, accompanied by increasing industrial activities, transportation demand, and energy consumption. Lagos, located along the Gulf of Guinea, is one of Africa's largest coastal megacities and is characterized by intense vehicular traffic, industrial operations, maritime activities, and high population density. Kano, situated in northern Nigeria, is a major commercial and industrial center that experiences additional atmospheric influences from the seasonal Harmattan circulation. These contrasting geographical and climatic settings provide an ideal framework for investigating spatial and temporal variations in black carbon aerosols across Nigerian urban environments.

Despite growing concerns regarding air quality degradation and climate change in West Africa, long-term investigations of black carbon aerosol variability in Nigerian cities remain limited. Previous studies in the region have focused largely on total aerosol optical depth, desert dust transport, and regional aerosol distributions derived from satellite observations and atmospheric reanalysis products (Prospero, et al., 2002) (Knippertz, P., & Todd, 2012). Comparatively few studies have examined the contribution of black carbon aerosols to the total atmospheric aerosol burden, particularly within rapidly growing urban centers. Understanding the relative importance of black carbon within total aerosol loading is essential for assessing its environmental impacts, climate implications, and potential mitigation strategies.

To address this knowledge gap, the present study investigates the spatiotemporal variability of Black Carbon Aerosol Optical Depth (BCEXTTAU) and its contribution to Total Aerosol Optical Depth (TOTEXTTAU) over Lagos and Kano, Nigeria, during the period 2014–2018. Monthly aerosol reanalysis data obtained from the Modern-Era Retrospective Analysis for Research and Applications Version 2 (MERRA-2) were analyzed to evaluate interannual trends, seasonal variability, and the relative contribution of black carbon to total aerosol loading. Furthermore, the Black Carbon Contribution Ratio (BCR), Annual Growth Rate

(GR), and Urban Black Carbon Enhancement Factor (UBE_F) were computed to quantify the significance of black carbon aerosols within the atmospheric environment of the two cities. The findings contribute to a better understanding of urban aerosol characteristics in Nigeria and provide valuable information for climate studies, air-quality management, and environmental policy development in West Africa.

2. Materials and Methods

2.1 Study Area

This study was conducted over two major Nigerian urban centers, Lagos and Kano, which represent contrasting geographical, climatic, and socio-economic environments. Lagos is located in southwestern Nigeria along the Gulf of Guinea between approximately 6.45°N and 3.39°E. As the largest city in Nigeria and one of the fastest-growing metropolitan areas in Africa, Lagos is characterized by intense industrial activities, dense transportation networks, maritime operations, and a rapidly increasing population. The city experiences a tropical wet climate with relatively high humidity and annual rainfall exceeding 1,500 mm. These meteorological conditions influence aerosol transport, dispersion, and removal processes, particularly through wet deposition mechanisms.

Kano is located in northern Nigeria at approximately 12.00°N and 8.52°E and serves as one of the country's principal commercial and industrial centers. Unlike Lagos, Kano experiences a semi-arid climate characterized by lower annual rainfall, higher temperatures, and seasonal Harmattan conditions. During the Harmattan season, dry northeasterly winds transport aerosols and particulate matter from the Sahara Desert across northern Nigeria, thereby influencing regional atmospheric composition and air quality. The contrasting climatic conditions between Lagos and Kano provide a suitable framework for investigating spatial differences in black carbon aerosol loading and its contribution to the total atmospheric aerosol burden.

2.2 Data Source

Monthly aerosol reanalysis data spanning January 2014 to December 2018 were obtained from the Modern-Era Retrospective Analysis for Research and Applications Version 2 (MERRA-2), developed by the Global Modeling and Assimilation Office (GMAO) of the National Aeronautics and Space Administration (NASA) (Gelaro, et al., 2017). MERRA-2 integrates satellite observations, ground-based measurements, and atmospheric model simulations through a data assimilation framework to provide globally consistent atmospheric aerosol products (Randles, et al., 2017).

Two aerosol parameters were utilized in this study: Black Carbon Aerosol Optical Depth (BC_{EXTTAU}) and Total Aerosol Optical Depth (TOT_{EXTTAU}). BC_{EXTTAU} represents the column-integrated optical depth associated with black carbon particles, while TOT_{EXTTAU} represents the total aerosol optical depth contributed by all aerosol species within the atmospheric column. Monthly mean values were extracted for Lagos and Kano for the period 2014–2018 and subsequently subjected to statistical and temporal analyses.

2.3 Data Processing and Statistical Analysis

The downloaded aerosol datasets were organized and processed using Python programming language. Monthly records were converted into a standardized time-series format, and annual mean values were computed to assess interannual variability in black carbon aerosol loading. Monthly climatological averages were also calculated to examine seasonal variations and recurring patterns in aerosol behavior.

To quantify the contribution of black carbon aerosols to the total atmospheric aerosol burden, the Black Carbon Contribution Ratio (BCR) was calculated as:

$$BCR(\%) = \frac{BC_{EXTTAU}}{TOT_{EXTTAU}} \times 100\% \quad (1)$$

where (BC_{EXTTAU}) represents Black Carbon Aerosol Optical Depth and (TOT_{EXTTAU}) represents Total Aerosol Optical Depth. The BCR provides the percentage contribution of black carbon to the total aerosol loading and serves as an indicator of the relative importance of anthropogenic combustion-related aerosols within the atmospheric column.

To evaluate temporal changes in black carbon aerosol loading, the Annual Growth Rate (GR) was computed using:

$$GR(\%) = \frac{BC_t - BC_{t-1}}{BC_{t-1}} \times 100\% \quad (2)$$

where BC_t and BC_{t-1} represent annual mean BC_{EXTTAU} values for the current and preceding years, respectively. Positive growth rates indicate increasing black carbon concentrations, while negative values signify declining aerosol loading.

A comparative assessment between Lagos and Kano was performed using the Urban Black Carbon Enhancement Factor (UBEF), defined as:

$$UBE = \frac{BC_{Lagos}}{BC_{Kano}} \quad (3)$$

where (BC_{Lagos}) and (BC_{Kano}) denote the annual mean BC_{EXTTAU} values for Lagos and Kano, respectively. Values greater than unity indicate higher black carbon loading in Lagos relative to Kano, whereas values below unity suggest stronger black carbon influence in Kano.

The processed data were subsequently visualized using time-series plots, annual trend analyses, seasonal climatological plots, and Black Carbon Contribution Ratio diagrams. Descriptive statistical analyses were employed to evaluate temporal variability and spatial differences between the two urban environments.

3. Results and Discussion

3.1 Interannual Variability of BCEXTTAU in Lagos and Kano

Figure 1 illustrates the interannual variation of annual mean Black Carbon Aerosol Optical Depth (BCEXTTAU) over Kano and Lagos from 2014 to 2018. A clear increasing trend is evident in both cities throughout the study period, indicating a progressive rise in atmospheric black carbon loading. Lagos consistently recorded higher BCEXTTAU values than Kano, suggesting stronger anthropogenic emissions associated with its larger population, higher traffic density, industrial activities, and port operations. The annual mean BCEXTTAU in Lagos increased from 0.0568 in 2014 to 0.0763 in 2018, representing an overall increase of approximately 34.3%. Similarly, Kano exhibited a rise from 0.0397 in 2014 to 0.0554 in 2018, corresponding to an increase of about 39.5%.

Figure 1. Interannual Variability of Annual Mean BCEXTTAU

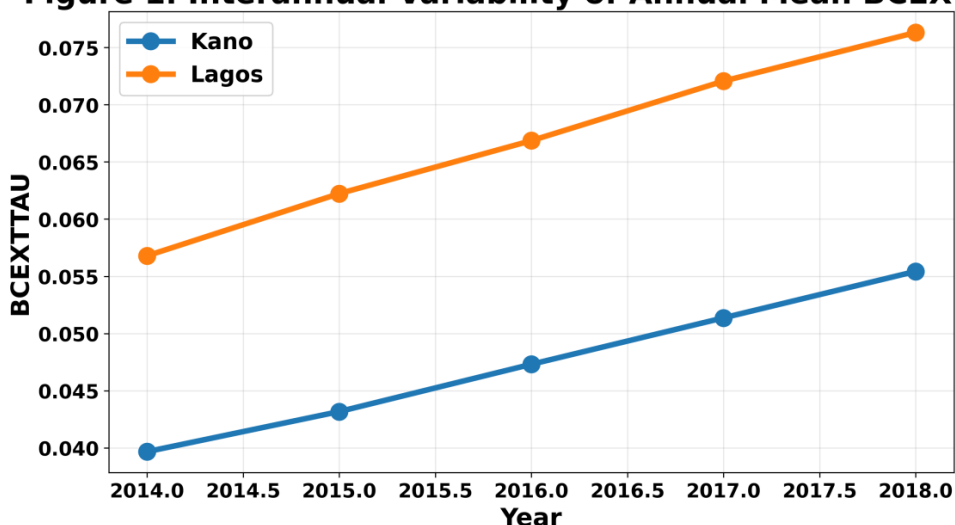


Figure 1. Interannual variability of annual mean Black Carbon Aerosol Optical Depth (BCEXTTAU) over Kano and Lagos, Nigeria, during the period 2014–2018.

The increasing BCEXTTAU observed in both cities is consistent with the rapid urbanization, increasing vehicular emissions, industrial expansion, and growing energy demand that characterize many developing urban centers in Africa (Lioussé, et al., 2014)(Adon, et al., 2010). Although Lagos maintained higher BCEXTTAU values throughout the study period, Kano exhibited a slightly larger relative growth rate, suggesting that black carbon emissions are increasing rapidly in northern Nigeria. This trend may reflect increasing commercial activities, transportation demand, biomass fuel consumption, and industrial development within the Kano metropolitan region.

The persistent difference between the two cities highlights the influence of local emission sources and geographical setting on atmospheric aerosol loading. Lagos, as a coastal megacity, experiences substantial emissions from road transportation, industrial complexes, power generation, and maritime activities. In contrast, Kano represents an inland urban environment where anthropogenic emissions interact with regional atmospheric processes associated with the semi-arid climate of northern Nigeria. Previous studies have demonstrated that black carbon concentrations tend to increase in rapidly developing urban regions where

fossil fuel combustion and biomass burning remain dominant emission sources (Bond, et al., 2013). The observed upward trend therefore suggests an increasing contribution of combustion-derived aerosols to atmospheric pollution in both cities during the study period.

Table 1 provides the annual mean values of BCEXTTAU, TOTEXTTAU, and the Black Carbon Contribution Ratio (BCR) for Kano and Lagos during 2014–2018. The results indicate that both BCEXTTAU and TOTEXTTAU increased steadily in the two cities over the study period. In Kano, BCEXTTAU increased from 0.0397 in 2014 to 0.0554 in 2018, while TOTEXTTAU increased correspondingly, indicating a general rise in atmospheric aerosol loading.

Table 1. Annual mean BCEXTTAU, TOTEXTTAU, and Black Carbon Contribution Ratio (BCR) for Kano and Lagos during 2014–2018.

Year	Kano TOTEXTTAU	Lagos TOTEXTTAU	Kano BCR (%)	Lagos BCR (%)
2014	0.3687	0.4163	10.79	13.67
2015	0.4021	0.4491	10.82	13.63
2016	0.4356	0.4898	10.74	13.62
2017	0.4728	0.5285	10.77	13.59
2018	0.5147	0.5638	10.76	13.55

Lagos exhibited a similar pattern, with BCEXTTAU increasing from 0.0568 to 0.0763 and TOTEXTTAU showing a comparable upward trend. Despite the increase in both aerosol indicators, the BCR remained relatively stable, suggesting that black carbon and total aerosols increased proportionally over time. Lagos consistently exhibited higher BCR values than Kano, indicating a stronger contribution of combustion-related emissions to the total aerosol burden. Such elevated black carbon fractions are commonly associated with densely populated urban environments characterized by intensive transportation activities and industrial emissions (Bahino, et al., 2018).

3.2 Seasonal Cycle of Monthly Mean BCEXTTAU

Figure 2 illustrates the seasonal variation of monthly mean Black Carbon Aerosol Optical Depth (BCEXTTAU) in Kano and Lagos averaged over the 2014–2018 study period. A pronounced seasonal cycle is evident in both cities, characterized by increasing BCEXTTAU values from January to late spring, followed by a gradual decline toward the end of the year. Lagos consistently recorded higher BCEXTTAU values than Kano throughout all months, confirming the stronger influence of anthropogenic emission sources in the coastal megacity.

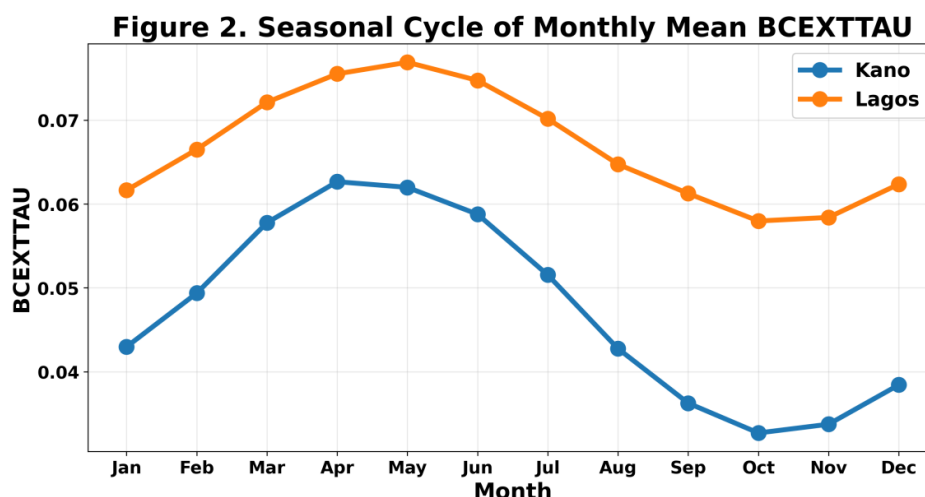


Figure 2. Seasonal cycle of monthly mean Black Carbon Aerosol Optical Depth (BCEXTTAU) over Kano and Lagos during the period 2014–2018.

In Kano, BCEXTTAU increased from approximately 0.043 in January to a peak value of about 0.063 in April before gradually declining to its annual minimum of approximately 0.033 in October. Lagos exhibited a similar seasonal pattern, with BCEXTTAU increasing from 0.062 in January to a maximum of approximately 0.077 in May and subsequently decreasing to around 0.058 in October. The seasonal amplitude was more pronounced in Kano than in Lagos, suggesting a stronger influence of regional meteorological processes on aerosol variability in northern Nigeria.

The elevated BCEXTTAU values observed during the March–May period may be associated with enhanced atmospheric stability, increased biomass burning activities, and the accumulation of combustion-derived aerosols before the onset of the peak rainy season. Similar seasonal maxima of absorbing aerosols have been reported in tropical and subtropical regions where reduced wet deposition and increased anthropogenic activities favor aerosol accumulation in the atmosphere (Liousse, Cachier, & Jennings, 1993)(Eck, et al., 1999). The gradual decrease in BCEXTTAU after May coincides with the progression of the rainy season, during which precipitation scavenging becomes an important aerosol removal mechanism.

The lower BCEXTTAU values observed during September and October in both cities can largely be attributed to enhanced wet deposition processes associated with the peak rainfall period. Rainfall efficiently removes atmospheric aerosols through in-cloud and below-cloud scavenging, thereby reducing aerosol optical depth and improving atmospheric visibility (Seinfeld, & Pandis, 2016). This effect appears particularly strong in Kano, where BCEXTTAU decreased from approximately 0.063 in April to 0.033 in October, representing a reduction of nearly 48%. Lagos also experienced a decline during the same period, although the reduction was comparatively smaller due to the continuous influence of urban and industrial emission sources.

Another notable feature is the persistence of relatively elevated BCEXTTAU values in Lagos throughout the year. Even during the wet season, when aerosol removal by precipitation is expected to be most effective, BCEXTTAU remained relatively high, varying between approximately 0.058 and 0.077. This indicates the continuous influence of anthropogenic

emission sources such as vehicular traffic, industrial activities, electricity generation, and maritime transport. The sustained aerosol loading despite seasonal rainfall suggests that emission rates in Lagos are sufficiently strong to offset a substantial portion of wet deposition effects. This finding is consistent with previous studies that identified urban combustion sources as major contributors to black carbon aerosols in rapidly developing coastal cities (Ramanathan, V., & Carmichael, 2008). The consistently higher monthly BCEXTTAU values in Lagos therefore reflect both stronger emission intensity and a greater anthropogenic influence compared with Kano..

Overall, the seasonal pattern demonstrates that black carbon aerosol loading in Nigerian urban environments is controlled by a combination of emission intensity and meteorological conditions. While anthropogenic emissions determine the overall magnitude of BCEXTTAU, seasonal rainfall and atmospheric circulation strongly influence its temporal distribution throughout the year.

3.3 Temporal Evolution of Monthly BCEXTTAU (2014–2018)

Figure 3 presents the temporal evolution of BCEXTTAU over Kano and Lagos from January 2014 to December 2018. The time series reveals substantial temporal variability superimposed on a long-term increasing trend in both cities. Throughout the study period, Lagos consistently maintained higher BCEXTTAU values than Kano, further confirming the greater influence of anthropogenic emission sources in the coastal urban environment. The observed variability reflects the combined effects of seasonal meteorological conditions, emission intensity, and atmospheric transport processes that influence black carbon concentrations over Nigeria.

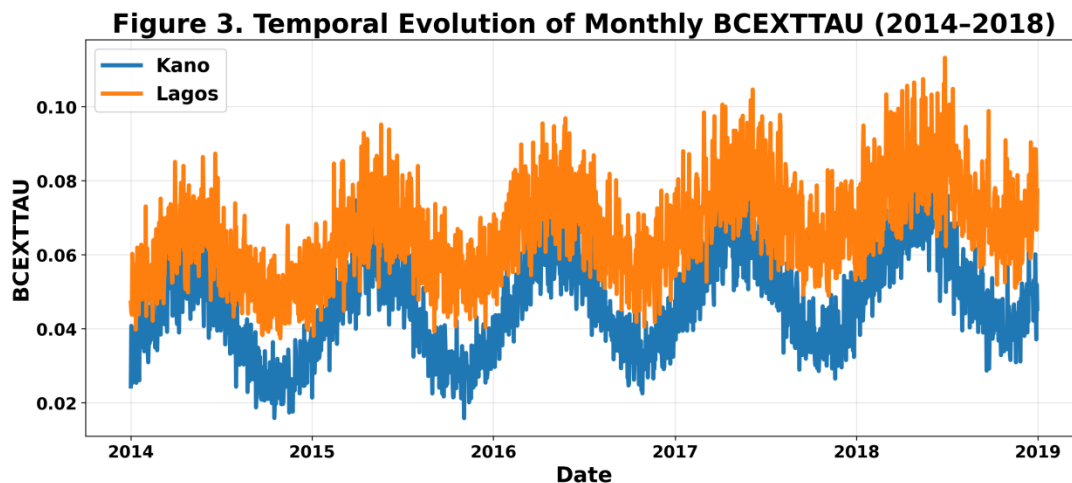


Figure 3. Temporal evolution of monthly Black Carbon Aerosol Optical Depth (BCEXTTAU) over Kano and Lagos during the period 2014–2018.

A notable characteristic of the time series is the recurring seasonal oscillation evident in both cities. BCEXTTAU values generally increased during the first half of each year, reached peak concentrations during the late dry season and early wet season, and subsequently declined during the latter part of the year. This pattern agrees with the seasonal climatology presented in Figure 2 and highlights the important role of rainfall scavenging in controlling atmospheric aerosol loading. The cyclical behavior observed over the five-year period

indicates that seasonal meteorological forcing remains a dominant control on black carbon variability despite the overall upward trend.

The long-term increase in BCEXTTAU is particularly evident when comparing the beginning and end of the study period. In Kano, monthly BCEXTTAU values generally ranged between approximately 0.02 and 0.06 during 2014 but increased to values frequently exceeding 0.07 by 2018. Similarly, Lagos exhibited monthly BCEXTTAU values largely between 0.04 and 0.08 during 2014, while values exceeding 0.10 became increasingly common during 2018. These observations suggest a progressive increase in combustion-derived aerosol emissions over both cities, likely associated with population growth, increased transportation demand, industrial development, and expanding energy consumption (Lioussé, et al., 2014) (Lamarque, et al., 2010).

The temporal evolution also reveals that short-term fluctuations are more pronounced in Lagos than in Kano. This behavior may be attributed to the greater diversity of emission sources present in Lagos, including vehicular traffic, industrial operations, power generation facilities, and maritime activities. Variations in these emission sources, combined with changing meteorological conditions, can contribute to substantial month-to-month changes in atmospheric black carbon loading. Similar temporal variability has been reported in other rapidly urbanizing regions where anthropogenic emissions dominate aerosol composition (Zhang, et al., 2009).

Another important observation is the absence of any prolonged period of declining BCEXTTAU in either city. Although seasonal decreases are clearly visible during wetter months, subsequent increases consistently return aerosol levels to values higher than those observed during the corresponding periods of previous years. This pattern indicates that the underlying growth in black carbon emissions outweighs the mitigating influence of seasonal atmospheric cleansing processes. Consequently, the results suggest a gradual deterioration in aerosol conditions over the study period, with potential implications for urban air quality, atmospheric visibility, and regional climate forcing (Bond, et al., 2013) (Ramanathan, & Carmichael, 2008). The findings reinforce the importance of continuous monitoring and emission-control measures aimed at mitigating the increasing contribution of black carbon to atmospheric pollution in Nigeria's rapidly growing urban centers.

3.4 Contribution of Black Carbon to Total Aerosol Loading

Figure 4 presents the interannual variation of the Black Carbon Contribution Ratio (BCR), which quantifies the percentage contribution of black carbon aerosol optical depth to total aerosol optical depth. In contrast to the increasing trends observed for BCEXTTAU and TOTEXTTAU (Figure 1), the BCR remained relatively stable throughout the study period in both cities. This suggests that increases in black carbon loading occurred simultaneously with increases in total aerosol loading, resulting in only minor changes in the relative contribution of black carbon to the overall atmospheric aerosol burden.

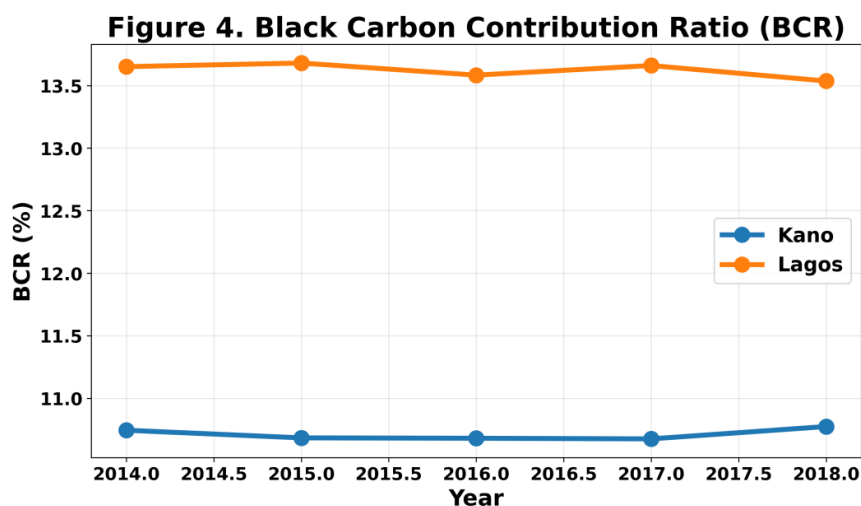


Figure 4. Interannual variation of the Black Carbon Contribution Ratio (BCR) over Kano and Lagos during the period 2014–2018.

As shown in Figure 4 and summarized numerically in Table 1, Lagos consistently exhibited higher BCR values than Kano throughout the study period. The BCR in Lagos varied between approximately 13.5% and 13.7%, whereas Kano recorded values ranging from about 10.7% to 10.8%. These results indicate that black carbon constitutes a larger fraction of the total aerosol burden in Lagos than in Kano. The higher contribution of black carbon in Lagos is consistent with the city's intense vehicular traffic, industrial activities, power generation, and maritime operations, all of which represent important sources of combustion-derived aerosols.

The relatively stable BCR values presented in Table 1 further indicate that black carbon and total aerosol loading increased proportionally between 2014 and 2018. Although BCEXTTAU increased substantially in both cities (Figure 1), its share of the total aerosol burden remained nearly constant. This behavior suggests that the growth of anthropogenic black carbon emissions was accompanied by corresponding increases in other aerosol species, resulting in a stable aerosol composition over time. Similar observations have been reported in rapidly developing urban environments where transportation, industrial activities, and energy production contribute simultaneously to multiple aerosol components (Lamarque, et al., 2010).

The persistent difference between Lagos and Kano also provides insight into the dominant aerosol sources affecting each city. Lagos maintained BCR values approximately three percentage points higher than Kano during all years of the study period. This finding indicates that combustion-related emissions exert a stronger influence on aerosol composition in Lagos. In contrast, the lower BCR values observed in Kano suggest a greater contribution from non-black-carbon aerosols, particularly mineral dust transported from the Sahara Desert and surrounding semi-arid regions. The influence of desert dust on northern Nigeria has been widely documented and is especially pronounced during the Harmattan season when dust transport substantially increases total aerosol loading (Knippertz, & Todd, 2012) (Ginoux, et al., 2012).

The values reported in Table 1 show that black carbon accounted for approximately one-seventh of the total aerosol optical depth in Lagos and about one-tenth in Kano. Although

these percentages may appear modest, black carbon is among the most radiatively active aerosol species and exerts a disproportionately large influence on atmospheric heating and climate forcing relative to its mass concentration. Consequently, the observed BCR values highlight the environmental significance of black carbon emissions in Nigerian urban environments and emphasize the need for mitigation strategies targeting transportation, industrial combustion, and fossil-fuel usage.

Overall, Figure 4 and Table 1 demonstrate that while aerosol loading increased steadily during 2014–2018, the relative contribution of black carbon remained remarkably stable. The consistently higher BCR values observed in Lagos confirm the stronger influence of anthropogenic combustion sources, whereas the lower values in Kano reflect the greater importance of natural and non-combustion aerosol sources in northern Nigeria.

3.5 Growth Trends and Urban Black Carbon Enhancement

Table 2 presents the annual growth rates of BCEXTTAU together with the Urban Black Carbon Enhancement Factor (UBEF) for Lagos and Kano during the study period. The results provide quantitative evidence of the progressive increase in black carbon aerosol loading observed in Figure 1 and further demonstrate the persistent enhancement of black carbon concentrations in Lagos relative to Kano.

Table 2. Annual Growth Rate (GR) and Urban Black Carbon Enhancement Factor (UBEF) for Kano and Lagos during 2014–2018.

Year	GR Kano (%)	GR Lagos (%)	UBEF
2014	–	–	1.43
2015	9.30	7.56	1.41
2016	7.59	8.99	1.43
2017	8.76	7.65	1.41
2018	8.84	6.41	1.38

The annual growth rates indicate that BCEXTTAU increased consistently in both cities throughout the study period. Positive growth rates were observed in successive years, confirming a sustained increase in black carbon emissions between 2014 and 2018. Such increases are consistent with expanding urbanization, population growth, rising energy demand, increased transportation activities, and industrial development that characterize rapidly growing African cities (Andreae, M. O., & Gelencsér, 2006) ([IPCC].,” 2021). Previous studies have shown that black carbon emissions are closely linked to fossil-fuel combustion, biomass burning, diesel transportation, and inefficient energy systems, all of which remain important emission sources in many developing countries(Bond, & Bergstrom, 2006).

The Urban Black Carbon Enhancement Factor (UBEF) remained greater than unity throughout the study period, indicating that Lagos consistently experienced higher black carbon loading than Kano. This persistent enhancement reflects the stronger influence of anthropogenic emission sources in Lagos, including dense vehicular traffic, industrial complexes, port operations, and widespread use of fossil-fuel-powered electricity generation. The higher aerosol loading observed in Lagos agrees with previous studies that identified coastal megacities as major hotspots of combustion-derived aerosol emissions due to the concentration of economic and industrial activities (Jacobson, 2001).

Although Kano recorded lower BCEXTTAU values than Lagos, the positive growth rates indicate that black carbon emissions are also increasing in northern Nigeria. The growth of transportation networks, industrial activities, and commercial development within Kano may be contributing to this upward trend. Furthermore, interactions between locally emitted black carbon and regionally transported aerosols can influence atmospheric composition and enhance aerosol persistence within the lower atmosphere (Ginoux, et al., 2012). Consequently, the observed increases in Kano suggest that black carbon pollution is becoming an increasingly important environmental issue beyond Nigeria's coastal urban centers.

The UBEF values reported in Table 2 also provide insight into the spatial contrast between the two cities. While Lagos consistently maintained higher BCEXTTAU levels, the relatively stable UBEF values suggest that black carbon concentrations in both cities increased at comparable rates. This finding implies that the factors driving black carbon emissions operate across multiple urban regions of Nigeria, although their intensity remains greater in Lagos. Similar patterns have been reported in rapidly urbanizing regions where economic growth results in simultaneous increases in transportation emissions, industrial activities, and energy consumption across multiple urban centers (Koch, & Del Genio, 2010).

Overall, the results presented in Table 2 confirm that black carbon aerosol loading increased steadily between 2014 and 2018 in both Lagos and Kano. The positive growth rates demonstrate the continuing expansion of combustion-related emissions, while the UBEF analysis highlights the stronger anthropogenic influence in Lagos. These findings emphasize the need for effective emission-control policies aimed at reducing black carbon emissions from transportation, industrial activities, and energy production in order to improve air quality and mitigate climate impacts associated with absorbing aerosols (Lack, & Cappa, 2010).

4. Conclusion

This study assessed the spatiotemporal variability of BCEXTTAU and its contribution to total aerosol loading over Lagos and Kano, Nigeria, from 2014 to 2018 using MERRA-2 aerosol reanalysis data. Results showed a consistent increase in black carbon loading in both cities, with BCEXTTAU increasing from 0.0398 to 0.0554 in Kano and from 0.0569 to 0.0764 in Lagos during the study period. Lagos maintained higher BCEXTTAU and BCR values than Kano, indicating a stronger influence of anthropogenic combustion sources. Seasonal variability was characterized by peak BCEXTTAU during April–May and lower values during the rainy season due to enhanced aerosol removal by precipitation. The BCR remained relatively stable at approximately 10.7–10.8% in Kano and 13.5–13.7% in Lagos, while UBEF values consistently exceeded unity, confirming greater black carbon enrichment in Lagos. Overall, the findings reveal increasing black carbon emissions in both cities and emphasize the need for effective mitigation measures targeting transportation, industrial activities, and energy production to reduce air pollution and associated climate impacts.

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