

Aerosol Composition and Source Characteristics Across Coastal and Inland Nigerian Cities: A MERRA-2 Assessment of Carbonaceous, Sulfate, Dust, and Sea-Salt Aerosols.

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Abstract

Atmospheric aerosols play a critical role in climate regulation, air quality degradation, and radiative forcing, yet comprehensive assessments of aerosol composition across Nigerian urban environments remain limited. This study investigated the composition, seasonal variability, and interrelationships of major aerosol species over Lagos, Abuja, and Kano using MERRA-2 aerosol reanalysis data for the period 2014–2018. Daily aerosol optical depth components, including dust aerosol extinction optical depth (DUEXTTAU), sulfate aerosol extinction optical depth (SUEXTTAU), black carbon aerosol extinction optical depth (BCEXTTAU), organic carbon aerosol extinction optical depth (OCEXTTAU), sea-salt aerosol extinction optical depth (SSEXTTAU), and total aerosol optical depth (TOTEXTTAU), were analyzed. Aerosol composition analysis revealed that dust aerosols dominated Kano, contributing 42.80% of total aerosol loading, compared with 33.35% in Abuja and 27.24% in Lagos. Sulfate aerosol contributions increased progressively from Kano (21.42%) to Abuja (24.95%) and Lagos (27.21%), indicating stronger anthropogenic and coastal influences in southern Nigeria. Lagos also recorded the highest contributions of black carbon (13.61%), organic carbon (22.87%), and sea-salt aerosols (9.07%). Seasonal analysis showed that sulfate aerosols peaked during April–May, reaching approximately 0.154 in Lagos, 0.125 in Kano, and 0.109 in Abuja, followed by declines during the rainy season due to enhanced wet deposition. Time-series analysis further revealed a gradual increase in sulfate loading across all cities between 2014 and 2018, reflecting increasing urbanization and anthropogenic activities. Correlation analysis showed strong relationships between sulfate aerosols and total aerosol loading ($r = 0.88$), black carbon ($r = 0.86$), organic carbon ($r = 0.86$), and sea-salt aerosols ($r = 0.86$), whereas dust aerosols exhibited weaker correlations ($r = 0.40$ – 0.41) with other aerosol species, indicating a distinct source regime. The results demonstrate clear spatial contrasts in aerosol composition between coastal and inland Nigeria and highlight the combined influence of natural and anthropogenic aerosol sources on regional atmospheric conditions.

Keywords: Aerosol composition; Sulfate aerosols; MERRA-2; Urban air quality;

1. Introduction

Atmospheric aerosols play a fundamental role in the Earth's climate system through their influence on radiative transfer, cloud formation, atmospheric chemistry, and air quality. Aerosol particles originate from both natural and anthropogenic sources and exhibit substantial spatial and temporal variability depending on emission intensity, meteorological conditions, and atmospheric transport processes (Seinfeld, & Pandis, 2016). Major aerosol species include mineral dust, sulfate aerosols, black carbon, organic carbon, and sea-salt particles, each of which possesses distinct physical and chemical properties that determine its climatic and environmental impacts (IPCC., 2021).

In tropical and subtropical regions, aerosols exert considerable influence on regional climate through direct and indirect radiative effects. While scattering aerosols such as sulfate and sea salt generally cool the atmosphere by reflecting incoming solar radiation, absorbing aerosols such as black carbon contribute to atmospheric warming by absorbing shortwave radiation (Bond, et al., 2013). Mineral dust, one of the most abundant aerosol species globally, influences radiation balance, cloud microphysics, nutrient transport, and visibility, particularly in regions affected by desert dust outbreaks (Ginoux, et al., 2012). Consequently, understanding the composition and variability of atmospheric aerosols is essential for assessing their impacts on climate, air quality, and environmental sustainability.

Nigeria represents an important region for aerosol studies due to its diverse climatic zones and rapidly expanding urban centers. The country experiences strong influences from both natural and anthropogenic aerosol sources. Northern Nigeria is frequently affected by Saharan dust transport associated with the Harmattan circulation, whereas southern coastal regions experience the combined influence of urban emissions, industrial activities, maritime transport, biomass burning, and marine aerosols (Knippertz, P., & Todd, 2012). The spatial variability of these sources creates substantial differences in aerosol composition between coastal and inland environments. However, despite increasing concerns regarding air quality and climate change in West Africa, comprehensive assessments of aerosol composition and source characteristics across Nigerian cities remain relatively limited.

Previous studies have largely focused on total aerosol optical depth, desert dust transport, biomass-burning emissions, or individual aerosol species (Prospero, et al., 2002) (Ramanathan & Carmichael, 2008). Although these investigations have improved understanding of aerosol behavior over West Africa, fewer studies have examined the relative contributions of major aerosol species within contrasting Nigerian urban environments. Quantifying the contributions of sulfate, dust, black carbon, organic carbon, and sea-salt aerosols is important for identifying dominant sources of atmospheric pollution and evaluating their potential climatic effects. Such information is particularly relevant for rapidly urbanizing regions where anthropogenic emissions continue to increase alongside population growth and industrial development (Lioussé, et al., 2014).

The Modern-Era Retrospective Analysis for Research and Applications Version 2 (MERRA-2) provides a valuable framework for investigating aerosol composition because it separately represents major aerosol species and their contributions to total atmospheric aerosol loading (Gelaro, et al., 2017) (Randles, et al., 2017). By integrating satellite observations with atmospheric modeling and data assimilation techniques, MERRA-2 offers long-term, spatially consistent aerosol datasets suitable for regional climate and air-quality studies.

Therefore, the present study investigates aerosol composition and source characteristics across three major Nigerian cities representing distinct geographical settings: Lagos (coastal), Abuja (central inland), and Kano (northern inland). Using MERRA-2 aerosol reanalysis data from 2014 to 2018, the study examines the relative contributions of sulfate, dust, black carbon, organic carbon, and sea-salt aerosols, evaluates their seasonal variability, and assesses relationships among aerosol species. The findings provide new insights into the dominant aerosol sources affecting Nigerian urban environments and contribute to a better understanding of aerosol-related environmental and climatic processes across West Africa.

2. Materials and Methods

2.1 Study Area

This study was conducted over three major Nigerian cities representing distinct geographical and climatic environments: Lagos, Abuja, and Kano. Lagos (6.52°N, 3.38°E) is located along the Gulf of Guinea and serves as Nigeria's principal coastal megacity. The city is characterized by high population density, intense vehicular traffic, industrial activities, maritime transport, and coastal influences. These factors contribute significantly to anthropogenic aerosol emissions and make Lagos one of the most important urban aerosol hotspots in West Africa.

Abuja (9.08°N, 7.40°E), situated within the central region of Nigeria, represents an inland urban environment characterized by rapid urban expansion, transportation activities, and administrative functions. Owing to its location within the Guinea Savannah ecological zone, Abuja experiences both northern and southern air-mass influences, making it an important transitional environment for aerosol studies.

Kano (12.00°N, 8.52°E) is located within the semi-arid region of northern Nigeria and is one of the largest commercial centers in West Africa. The city is frequently influenced by Harmattan dust transport originating from the Sahara Desert and therefore experiences substantial mineral dust loading, particularly during the dry season. In addition to natural dust sources, Kano is also affected by urban emissions associated with transportation, domestic fuel combustion, and industrial activities.

The selection of these three cities provides an opportunity to investigate aerosol composition across contrasting coastal and inland environments and to evaluate the relative influence of natural and anthropogenic aerosol sources in different climatic regions of Nigeria.

2.2 MERRA-2 Aerosol Dataset

Aerosol data were obtained from the Modern-Era Retrospective Analysis for Research and Applications Version 2 (MERRA-2), developed by the National Aeronautics and Space Administration (NASA) Global Modeling and Assimilation Office (GMAO) (Kaufman, et al., 2002)(Remer, et al., 2005). MERRA-2 combines satellite observations, ground-based measurements, and numerical atmospheric modeling through a data assimilation framework to produce consistent long-term atmospheric reanalysis products.

Daily aerosol optical depth components at 550 nm were extracted for Lagos, Abuja, and Kano for the period January 2014 to December 2018. The aerosol species analyzed in this study included sulfate aerosol extinction optical depth (SUEXTTAU), dust aerosol extinction

optical depth (DUEXTTAU), black carbon aerosol extinction optical depth (BCEXTTAU), organic carbon aerosol extinction optical depth (OCEXTTAU), sea-salt aerosol extinction optical depth (SSEXTTAU), and total aerosol extinction optical depth (TOTEXTTAU). These variables collectively represent the major aerosol components contributing to atmospheric aerosol loading over the study region.

2.3 Data Processing and Aerosol Composition Analysis

Daily aerosol data were processed using Python statistical routines to evaluate temporal variability, seasonal characteristics, and aerosol composition across the study cities. Annual means, monthly climatologies, and temporal trends were computed for each aerosol species. To quantify the relative importance of individual aerosol components, the percentage contribution of each aerosol species to the total aerosol loading was calculated using:

$$\text{Contribution}_i(\%) = \frac{\text{Aerosol}_i}{\text{TOTEXTTAU}} \times 100, \quad (1)$$

where (Aerosol_i) represents the aerosol extinction optical depth of a specific aerosol species (DUEXTTAU, SUEXTTAU, BCEXTTAU, OCEXTTAU, or SSEXTTAU), and (TOTEXTTAU) denotes the total aerosol extinction optical depth. This calculation was used to determine the relative contributions of dust, sulfate, black carbon, organic carbon, and sea-salt aerosols to atmospheric aerosol loading over Abuja, Kano, and Lagos.

Monthly climatologies were obtained by averaging daily observations for each calendar month over the entire study period. This approach enabled the identification of seasonal patterns and recurring aerosol cycles associated with meteorological conditions, emission variability, and atmospheric transport processes. Temporal variability was further examined using daily time-series analyses spanning the period from 2014 to 2018.

To investigate relationships among aerosol species and identify potential similarities in source characteristics, Pearson correlation coefficients were computed among the major aerosol components. The Pearson correlation coefficient was calculated as:

$$r = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^n (y_i - \bar{y})^2}} \quad (2)$$

where (x_i) and (y_i) represent paired aerosol observations, ($\bar{x}$) and ($\bar{y}$) denote their respective means, and (n) is the total number of observations. Correlation coefficients approaching +1 indicate strong positive relationships, whereas values approaching 0 indicate weak or no linear association. The resulting correlation matrix was used to evaluate interactions among total aerosol loading, sulfate, dust, black carbon, organic carbon, and sea-salt aerosols and to provide insight into dominant aerosol source characteristics across the study region.

3. Results and Discussion

3.1 Aerosol Composition and Source Characteristics

Figure 1 presents the relative contributions of the major aerosol species to atmospheric aerosol loading over Abuja, Kano, and Lagos during the period 2014–2018, while the corresponding numerical values are summarized in Table 1. Distinct differences in aerosol composition are evident among the three cities, reflecting the influence of geographical location, climatic conditions, and dominant emission sources. Overall, mineral dust (DUEXTTAU) constituted the largest aerosol component in all cities, although its contribution varied substantially between coastal and inland environments.

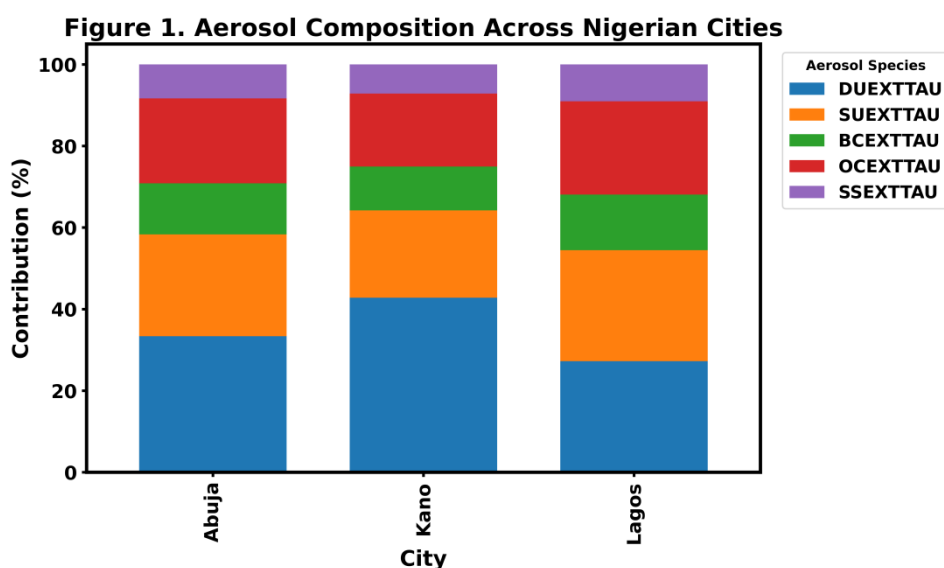


Figure 1. Relative contribution of major aerosol species (DUEXTTAU, SUEXTTAU, BCEXTTAU, OCEXTTAU, and SSEXTTAU) to total aerosol loading over Abuja, Kano, and Lagos during 2014–2018.

Kano exhibited the highest dust contribution, accounting for 42.80% of total aerosol loading (Table 1). This dominance is consistent with the city's proximity to the Sahara Desert and its frequent exposure to Harmattan dust outbreaks, which transport large quantities of mineral particles across northern Nigeria during the dry season. Similar observations have been reported throughout the Sahel and West African regions, where desert dust represents the dominant aerosol component and strongly influences regional atmospheric conditions (Kok, et al.,2017). The large dust fraction observed in Kano therefore reflects the strong influence of natural aerosol sources relative to anthropogenic emissions.

In contrast, Lagos displayed the lowest dust contribution (27.24%) but recorded the highest sulfate (27.21%), black carbon (13.61%), organic carbon (22.87%), and sea-salt (9.07%) fractions among the three cities. The elevated sulfate contribution suggests a stronger influence of anthropogenic emissions associated with industrial activities, fossil-fuel combustion, maritime transportation, and urban energy consumption. Lagos is Nigeria's largest commercial and industrial center and hosts one of the busiest seaports in West Africa; consequently, sulfate formation from sulfur-containing emissions is expected to be more pronounced than in inland cities (Haywood, & Boucher, 2000). The relatively large sea-salt

fraction further reflects the influence of marine aerosols generated over the adjacent Atlantic Ocean and transported inland through coastal circulation processes (O'Dowd, & de Leeuw, 2007).

Abuja exhibited an intermediate aerosol composition characterized by dust (33.35%), sulfate (24.95%), organic carbon (20.84%), black carbon (12.52%), and sea salt (8.34%). The mixed aerosol signature observed in Abuja reflects its location within Nigeria's transitional climatic zone, where both northern dust transport and southern anthropogenic influences contribute to atmospheric aerosol loading. The comparable contributions of sulfate and carbonaceous aerosols suggest the coexistence of natural and urban emission sources within the region.

A comparison of sulfate contributions among the three cities reveals a gradual increase from Kano (21.42%) to Abuja (24.95%) and Lagos (27.21%). This spatial pattern highlights the increasing importance of anthropogenic and coastal influences toward southern Nigeria. Conversely, the dust contribution decreases from Kano to Lagos, indicating a reduction in Saharan dust dominance with increasing distance from major desert source regions. These results demonstrate that aerosol composition across Nigeria is strongly controlled by regional geography and source characteristics, with inland cities dominated by mineral dust and coastal cities exhibiting a more diverse mixture of sulfate, carbonaceous, and marine aerosols.

Table 1. Mean percentage contribution aerosol species to atmospheric aerosol loading

City	DUEXTTAU	SUEXTTAU	BCEXTTAU	OCEXTTAU	SSEXTTAU
Abuja	33.35	24.95	12.52	20.84	8.34
Kano	42.8	21.42	10.72	17.91	7.15
Lagos	27.24	27.21	13.61	22.87	9.07

Table 1 further confirms the contrasting aerosol environments represented by the three cities. While Kano is characterized by a predominantly dust-driven aerosol regime, Lagos exhibits a more balanced aerosol mixture in which sulfate, organic carbon, and black carbon contribute substantially to total aerosol loading. Abuja occupies an intermediate position between these two extremes, reinforcing its role as a transition zone between northern and southern aerosol regimes. The observed aerosol composition patterns have important implications for regional climate forcing, atmospheric visibility, and air-quality management across Nigeria (Carslaw, et al., 2010).

3.2 Seasonal Dynamics of Sulfate Aerosols

Figure 2 illustrates the seasonal cycle of monthly mean sulfate aerosol optical depth (SUEXTTAU) over Abuja, Kano, and Lagos during the study period. A pronounced seasonal pattern is evident in all three cities, characterized by increasing sulfate concentrations from January to May, followed by a gradual decline from June to October before a slight recovery toward December. This common pattern suggests that sulfate aerosols across Nigeria are influenced by regional meteorological conditions and seasonal emission processes.

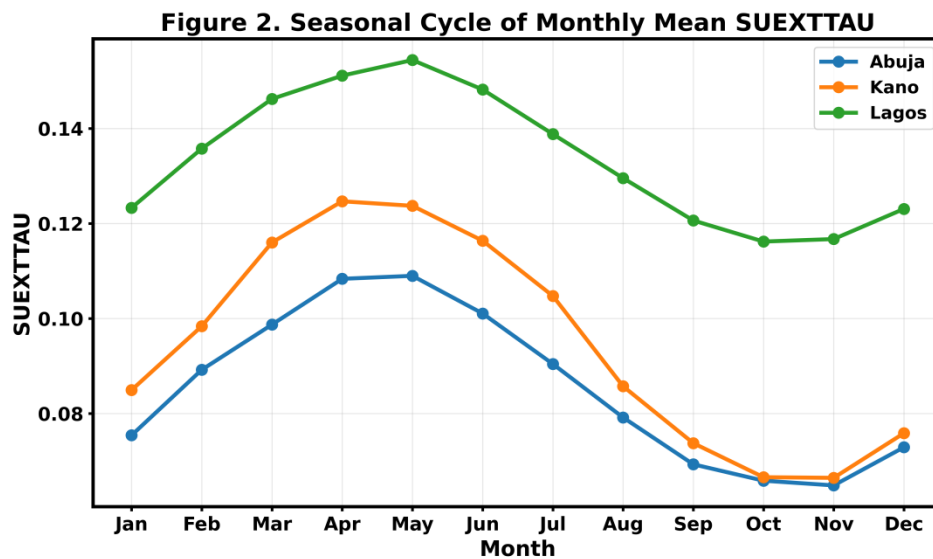


Figure 2. Seasonal cycle of monthly mean sulfate aerosol optical depth (SUEXTTAU) over Abuja, Kano, and Lagos during 2014–2018.

Lagos consistently recorded the highest monthly sulfate concentrations throughout the year, with values increasing from approximately 0.123 in January to a maximum of 0.154 in May before declining to about 0.116 in October. The elevated sulfate levels observed in Lagos are consistent with the city's intensive industrial activities, dense transportation network, maritime operations, and fossil-fuel combustion sources. As a major coastal and commercial center, Lagos experiences continuous emissions of sulfur-containing precursors that promote sulfate aerosol formation through atmospheric oxidation processes (Colarco, et al., 2010)(Andreae, & Rosenfeld, 2008).

Kano exhibited intermediate sulfate concentrations, increasing from approximately 0.085 in January to 0.125 in April before declining to about 0.067 during October and November. Although Kano is strongly influenced by desert dust transport, the seasonal sulfate pattern indicates that secondary aerosol formation and regional transport processes also contribute substantially to aerosol loading over northern Nigeria. The increase observed during the late dry season and early wet season may be associated with enhanced photochemical activity and favorable atmospheric conditions for sulfate production (Lelieveld, et al., 2015).

Abuja displayed the lowest sulfate concentrations among the three cities, ranging from approximately 0.066–0.109 throughout the year. Nevertheless, the city exhibited a seasonal evolution similar to that observed in Kano and Lagos, with peak values occurring during April–May and minimum concentrations during October–November. This similarity suggests that large-scale meteorological controls influence sulfate variability across different climatic regions of Nigeria.

An important feature of Figure 2 is the occurrence of maximum sulfate concentrations during April and May in all three cities. Lagos reached approximately 0.154 in May, Kano 0.125 in April, and Abuja 0.109 in May. These peak values coincide with the transition period between the dry and wet seasons, when increased atmospheric moisture and enhanced photochemical reactions can promote the conversion of sulfur dioxide into sulfate aerosols. Similar seasonal enhancements of sulfate aerosols have been reported in tropical and

subtropical environments where atmospheric oxidation processes are strongly influenced by temperature, humidity, and solar radiation (Charlson, et al., 1992). Following the seasonal peak, sulfate concentrations decreased progressively from June to October. This decline is likely associated with increased wet scavenging and precipitation during the rainy season, which efficiently removes sulfate particles from the atmosphere. Wet deposition represents one of the primary removal mechanisms for sulfate aerosols and often leads to reductions in atmospheric concentrations during periods of enhanced rainfall (Textor, et al., 2006).

Overall, the seasonal cycle demonstrates that sulfate aerosols are influenced by both emission intensity and meteorological conditions. While Lagos maintained the highest sulfate concentrations throughout the year due to stronger anthropogenic and coastal influences, Abuja and Kano exhibited lower concentrations but followed similar seasonal patterns. The observed consistency among the three cities suggests that regional atmospheric processes play an important role in regulating sulfate aerosol variability across Nigeria.

3.3 Temporal Evolution of Sulfate Aerosols (2014–2018)

Figure 3 presents the temporal evolution of sulfate aerosol optical depth (SUEXTTAU) over Abuja, Kano, and Lagos from 2014 to 2018. The time series reveals substantial day-to-day variability superimposed upon a clear seasonal cycle and a gradual long-term increase in sulfate aerosol loading across all three cities. Despite differences in magnitude, the temporal patterns exhibit remarkable similarity, suggesting that regional-scale atmospheric processes exert considerable control on sulfate aerosol variability throughout Nigeria.

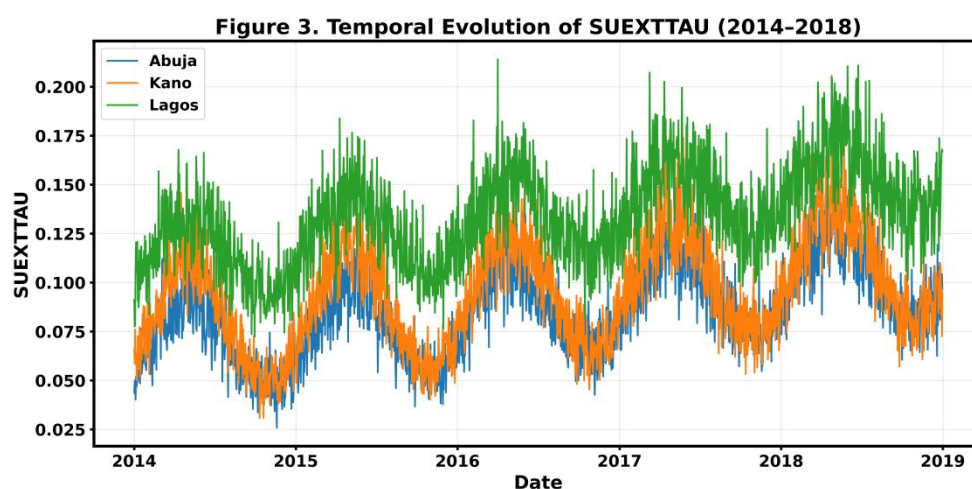


Figure 3. Temporal evolution of sulfate aerosol optical depth (SUEXTTAU) over Abuja, Kano, and Lagos during the period 2014–2018.

Throughout the study period, Lagos consistently recorded the highest sulfate concentrations, followed by Kano and Abuja. Daily sulfate values in Lagos frequently exceeded 0.150 and occasionally approached 0.200, whereas peak values in Kano generally remained below 0.170 and those in Abuja below approximately 0.140. The elevated sulfate burden observed in Lagos is consistent with the city's role as Nigeria's largest industrial and commercial center, where emissions from transportation, industrial activities, power generation, petroleum-related operations, and maritime shipping provide continuous sources of sulfur-containing precursor gases (Chin, Ginoux, & Malm, 2007). The persistent separation between

the Lagos time series and those of Abuja and Kano further indicates the importance of local anthropogenic emissions in enhancing sulfate aerosol formation within coastal urban environments.

A notable feature of Figure 3 is the recurring annual oscillation evident in all three cities. Sulfate concentrations generally increased during the early part of each year, reached maximum values during the late dry season and early wet season, and subsequently declined during the peak rainy months before increasing again toward the following dry season. This behavior is consistent with the seasonal climatology presented in Figure 2 and confirms that sulfate aerosol variability is strongly influenced by meteorological controls. Enhanced atmospheric oxidation during periods of increased solar radiation and favorable humidity conditions promotes sulfate formation, whereas rainfall acts as an efficient removal mechanism through wet deposition (Holben, et al., 1998).

The figure also indicates a gradual increase in sulfate loading between 2014 and 2018. In Lagos, the baseline sulfate concentration increased noticeably from approximately 0.11–0.13 during 2014 to approximately 0.14–0.18 during 2018. Similar upward tendencies are observed in Kano and Abuja, although with smaller magnitudes. This long-term increase may reflect growing urbanization, expanding industrial activities, increased energy consumption, and rising transportation emissions across Nigeria during the study period. Population growth and economic development have been identified as major drivers of increasing anthropogenic aerosol emissions in many rapidly developing African cities (Eck, et al., 1999).

Another important characteristic of the time series is the occurrence of short-term sulfate enhancement events, particularly in Lagos and Kano. These episodic peaks may be associated with periods of intensified industrial activity, regional transport of polluted air masses, biomass-burning emissions, or favorable meteorological conditions that promote aerosol accumulation. Such events contribute significantly to the overall aerosol burden and demonstrate the dynamic nature of atmospheric sulfate concentrations within the study region.

Overall, Figure 3 demonstrates that sulfate aerosol variability across Nigeria is governed by the combined effects of emission sources, seasonal meteorological conditions, and long-term socioeconomic development. While all three cities exhibit comparable seasonal behavior, Lagos consistently experiences substantially higher sulfate concentrations, highlighting the dominant influence of coastal urban emissions on sulfate aerosol loading. The observed temporal evolution further suggests that anthropogenic activities are becoming increasingly important contributors to atmospheric sulfate concentrations across Nigeria.

3.4 Relationships Among Aerosol Species

Figure 4 presents the Pearson correlation matrix among the major aerosol species and total aerosol optical depth over the study region. The analysis provides insight into the degree of association among aerosol components and helps identify potential similarities in source characteristics, atmospheric transport pathways, and removal processes. Overall, the correlation matrix reveals two distinct aerosol groupings: a dust-dominated component and a closely linked sulfate–carbonaceous–marine aerosol component.

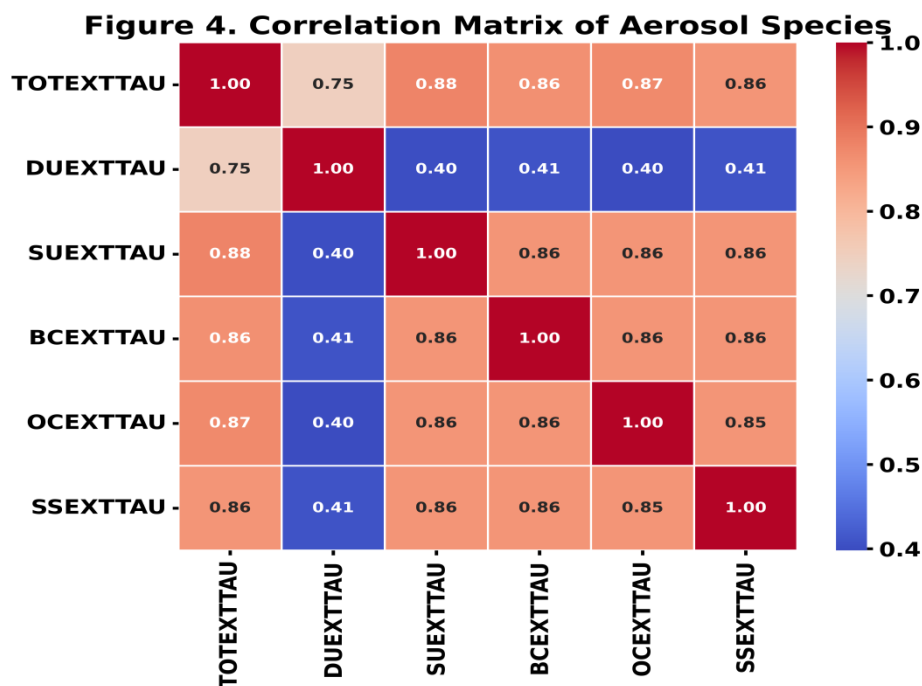


Figure 4. Pearson correlation matrix showing relationships among total aerosol optical depth (TOTEXTTAU), dust aerosols (DUEXTTAU), sulfate aerosols (SUEXTTAU), black carbon aerosols (BCEXTTAU), organic carbon aerosols (OCEXTTAU), and sea-salt aerosols (SSEXTTAU) over Abuja, Kano, and Lagos during 2014–2018.

The strongest relationship involving total aerosol loading (TOTEXTTAU) was observed with sulfate aerosols (SUEXTTAU), which exhibited a correlation coefficient of $r = 0.88$. Similarly strong positive correlations were found between TOTEXTTAU and black carbon ($r = 0.86$), organic carbon ($r = 0.87$), and sea-salt aerosols ($r = 0.86$). These results indicate that variations in total aerosol loading across the study region are strongly influenced by fluctuations in sulfate and carbonaceous aerosols. The strong association suggests that these aerosol species frequently coexist and may respond similarly to regional meteorological conditions and anthropogenic emission patterns (Myhre, et al.,2013).

Sulfate aerosols also exhibited remarkably strong positive correlations with black carbon ($r = 0.86$), organic carbon ($r = 0.86$), and sea-salt aerosols ($r = 0.86$). Such relationships suggest that these aerosol components are often influenced by common atmospheric processes despite originating from different primary sources. Sulfate aerosols are formed through secondary chemical reactions involving sulfur-containing precursor gases, while black carbon and organic carbon are primarily emitted through combustion processes. Their strong correlations therefore imply that urban emissions, industrial activities, transportation, and regional atmospheric transport collectively contribute to aerosol variability across the study area (Mahowald,et al., 2009).

In contrast, dust aerosols exhibited substantially weaker correlations with the remaining aerosol species. Correlation coefficients between DUEXTTAU and sulfate, black carbon, organic carbon, and sea salt ranged only from **0.40 to 0.41**, indicating relatively independent behavior. These weaker relationships reflect the fundamentally different origin of mineral dust, which is primarily associated with natural processes such as desert dust mobilization and long-range transport from the Sahara. Unlike sulfate and carbonaceous aerosols, dust

variability is strongly controlled by surface wind conditions, soil characteristics, and regional circulation patterns (Forster, et al., 2007).

The correlation between total aerosol loading and dust aerosols ($r = 0.75$) remained positive but was noticeably lower than correlations involving sulfate and carbonaceous aerosols. This finding suggests that although dust contributes significantly to atmospheric aerosol loading, particularly in northern Nigeria, it is not the sole driver of total aerosol variability. Instead, total aerosol loading appears to be influenced by a combination of natural and anthropogenic aerosol sources.

An important implication of Figure 4 is the apparent separation between dust-dominated and anthropogenic/coastal aerosol regimes. The strong intercorrelations among sulfate, black carbon, organic carbon, and sea-salt aerosols indicate that these species often vary together across the study region, whereas dust behaves more independently. This pattern is consistent with the aerosol composition analysis presented in Figure 1, which showed that coastal Lagos is characterized by enhanced sulfate, carbonaceous, and marine aerosol contributions, while inland Kano remains more strongly influenced by mineral dust.

Overall, the correlation analysis demonstrates that sulfate aerosols play a central role within the Nigerian aerosol system, exhibiting the strongest relationships with total aerosol loading and other major aerosol components. The results further indicate that anthropogenic emissions and coastal influences contribute substantially to aerosol variability across Nigeria, while mineral dust remains an important but comparatively independent aerosol source. These findings reinforce the importance of considering both natural and human-induced emissions when evaluating aerosol-climate interactions and air-quality conditions across West Africa (Koren, et al., 2005).

4. Conclusions

This study investigated aerosol composition, seasonal variability, and source characteristics across Lagos, Abuja, and Kano using MERRA-2 aerosol reanalysis data from 2014 to 2018. The results revealed significant spatial differences in aerosol composition, with dust aerosols dominating Kano (42.80%), while Lagos exhibited the highest contributions of sulfate (27.21%), black carbon (13.61%), organic carbon (22.87%), and sea-salt aerosols (9.07%), reflecting stronger anthropogenic and coastal influences. Sulfate aerosols displayed a consistent seasonal cycle across all cities, reaching peak concentrations during April–May and declining during the rainy season due to enhanced wet deposition. Temporal analysis indicated a gradual increase in sulfate loading over the study period, suggesting growing urban and industrial emissions. Correlation analysis further demonstrated strong associations between sulfate aerosols and total aerosol loading ($r = 0.88$), black carbon ($r = 0.86$), organic carbon ($r = 0.86$), and sea-salt aerosols ($r = 0.86$), whereas dust aerosols exhibited comparatively weaker correlations ($r = 0.40$ – 0.41), highlighting their distinct source characteristics. Overall, the findings identify two dominant aerosol regimes across Nigeria: a dust-dominated inland regime and a sulfate–carbonaceous–marine regime associated with coastal urban environments. These results improve understanding of aerosol variability in West Africa and provide valuable information for climate studies, air-quality assessment, and environmental management strategies.

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