

Spatio-temporal Variations and Trends of Aerosol Optical Depth over Guinea, Guinea-Bissau, and Senegal Based on VIIRS Satellite Validated with AERONET (2012–2024)

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ABSTRACT

This study aimed at using Visible Infrared Imaging Radiometer (VIIR) to investigating the spatial and temporal variation of aerosols over West African sub-region and its deriving factors play a vital role for assessing the impacts of aerosols on air quality, health and environment. Aerosol optical depth is a key variable and important indicator as it measures the aerosol loading in the atmosphere. This study examined the spatiotemporal variations and trends in aerosol optical depth (AOD) at 550nm wavelength over West African sub-region Guinea (GU), Guinea Bissau (GB) and Senegal (SE) from 2012 to 2024. The daily AOD data were retrieved from Visible Infrared Imaging radiometer (VIIR) satellite to evaluate monthly, seasonal, annual spatiotemporal variation and aerosol modal characteristics and the AERONET data were used for validation. The results shows that, GU, GB and SE has the highest AOD value in spring (0.54) (0.55) (0.56) and the least in autumn (0.30) (0.31) (0.33) respectively. The Annual mean AOD fluctuate considerably with the higher AOD value are (0.47) & (0.45) in 2015 and (0.48) in 2017, the least AOD value are (0.36) (0.37) and (0.38) in 2013 for GU, SE and GB respectively. Additionally, month of June exhibit a higher AOD value of (0.84) and least in January (0.25) for SE, February (0.58) and August (0.25) for GU and January (0.67) and October (0.27) for GB respectively. Scatter plot of AOD and AE were used to characterized the aerosols modal, Biomass burning (BB), Sea salt (SS), Saharan dust (SD) and Vehicular emission (VE). GU (fine mode: 1.2-1.8, coarse mode: 0.51-1.2, Mixed mode: 0-0.51), GB (fine mode: 1.1-1.8, coarse mode: 0-0.5, Mixed mode: 0.5-1.1), and SE ((fine mode: 1.0-1.8, coarse mode: 0.3-1.0, Mixed mode: 0-0.3). These findings underscore the need for rigorous air quality regulations and emission control measures in West Africa coastal region.

1. INTRODUCTION

Aerosols are solid or liquid particles suspended in the air, which directly or indirectly affect the climate including smoke, haze and dust particles (Kaufman et al., 2002). Moreover, their accumulation near the ground can cause a reduction in atmospheric visibility and deterioration of air quality, which can seriously affect the normal life of human beings and even endanger their health (Shuhui et al., 2023). The increased in urbanization and industrialization in these regions have led to higher emissions of aerosol concentration (pollutants), which have effect to human health and the climate system. Higher population density, economic growth and vehicular emissions in urban areas result in excessive emissions of pollutants

such as nitrogen oxides and particulate matter (PM). These emissions lead to severe health issues, such as respiratory and cardiovascular diseases, and significantly impact the climate system (Torabi et al. 2024)

Ground-based monitoring stations provide accurate and periodic monitoring of air pollution, with intervals ranging from a few minutes to several hours. Ground based measurements (sun photometers) such as AEROSOL ROBOTIC NETWORK (AERONET) provide multispectral aerosol optical properties (Holben et al., 1998) having high temporal resolution and accuracy, these instruments are limited to a particular location. To overcome this limitation, various satellites were launched for measurement of aerosol optical depth

(AOD) at different altitudes of spatial and temporal resolution (Payra et al., 2023). AOD is defined as a measure of light extinction caused by aerosols with the atmospheric column from sensors to the Earth's surface (Van Donkelaar et al., 2010). Recent initiatives to enhance Satellite and ground-based observations of aerosols have significantly improved our understanding of their impact on climate systems and regional air quality (Torabi et.al. 2024). Satellite aerosol retrieval methods, such as those used by NASA's Terra and Aqua satellites with the Moderate Resolution Imaging Spectroradiometer (MODIS), and Visible Infrared Imaging Radiometer (VIIR) provide accurate data. The key parameters used in the analysis of aerosols include AOD, single-scattering albedo, Angstrom exponent, complex refractive index, aerosol extinction coefficient, and aerosol layer height (Bencherif et al., 2022, Caïdo et al., 2022, Chau et al., 2021, Ettehadî et al., 2022, Gouda et al., 2022). Aerosol retrieval algorithms have been developed for global distribution of aerosol optical depth (AOD) using various satellite observations, like the Moderate-Resolution Imaging Spectroradiometer (MODIS) (Levy et al., 2010), Multi-angle Imaging Spectro Radiometer (MISR) (Kahn et al., 2009), Ozone-Monitoring Instrument (OMI) (Torres et al., 2007), Advanced Very-High-Resolution Radiometer (AVHRR)(Gao et al., 2016) and Visible Infrared Imaging Radiometer Suite (VIIR)(Payra et al., 2023). Atmospheric aerosols such as volcanic dust or haze can prevent sunlight through absorption or scattering. Aerosol optical depth measures the extent to which direct sunlight is prevented from reaching the ground. This dimensionless quantity correlates with aerosol concentrations in the vertical atmospheric column, with values typically ranging from 0.01 (clean atmosphere) to over 1 (associated with dust and sandstorms) (Tarobi et al., 2024).

In many studies, the retrieval of aerosol optical depth from satellite data has been emphasized such as MODIS and other sensors have been widely used (Qi et al. 2013). For instance, Payra et al. (2023) utilized MODIS and VIIR aerosols to evaluate their performance over the Indian subcontinent from 2014 to 2020. They reported that, the spatial comparison exhibits the same AOD pattern seasonally as well as annually having a minimum bias from -0.3 to +0.3 between MODIS and VIIRS. Tarobi et al. (2024) utilized MODIS to assess monthly, seasonal, and annual spatiotemporal variations and long-term trends during 2020-2022. Kumar et al. (2014) utilized MODIS aerosol products to analyze long-term climatological trends and variations in aerosol optical parameters over three stations in South Africa during 2003–2013. They reported a decadal decrease in mean annual AOD with high values being observed in spring due to the existence of aerosols from frequent biomass burning in this season. A recent study by Nyasulu et al. (2020) analyzed seasonal climatology and the relationship between AOD and cloud properties

derived from MODIS during 2008–2017 over Malawi and observed a general increasing trend in AOD patterns except during the spring season (SON) which was characterized by a decreasing trend. Furthermore, several countries in West Africa, along the Gulf of Guinea Coast, were reported to experience decreasing AOD trends according to Aklesso et al. (2018). Some of the studies have used both satellite and ground-based data, such as, Boiyo et al. (2017, 2018a, 2018b, 2019) and de Graaf et al. (2010), over East Africa, with large spatio-temporal heterogeneity in aerosol concentrations resulting from the presence of fine and coarse-mode aerosols due to natural and anthropogenic sources. Sa'adu et al. 2025 also utilized MODIS AOD to analyze spatiotemporal variability over six geo-political zones of Nigeria from 2004 to 2023. They observed the spatial variability in the north west and south west region is large and the least is north east and south-south.

The aim of this study is to evaluate the spatiotemporal variability and trends of aerosol optical depth (AOD) using satellite sensors VIIRS and investigate their spatial distribution monthly, annually as well as seasonally over West African sub-region. The entire study has been carried out over the time period of 12 years (2012–2024). The AOD product of the satellites is compared with ground-observed AOD data from one station, namely, Dakar AERONET. The study compares VIIRS and AERONET AOD over a West African sub-region known for its complex aerosol properties and high air pollution levels, making it a region of notable environmental concern. This is the first study to determine how VIIRS AOD performs across West African region (Guinea, Guinea-Bissau and Senegal). This is particularly important because AOD measurements play a key role in observing and understanding air quality and climate change.

2. MATERIALS AND METHODS

2.1 Methodology

The figure 1 below comprehensively describes the methodology used in this study. This study concentrated on Guinea, Guinea-Bissau and Senegal in coastal region West Africa, using two distinct datasets. The Visible Infrared Imaging Radiometer Suite (VIIRS) NASA standard Level-3 (L3) daily Deep Blue aerosol products from the Suomi National Polar-orbiting Partnership (SNPP) instrument provide satellite-derived measurements of Aerosol Optical Thickness (AOT) and their properties over land and ocean as gridded aggregates, on a daily basis, globally. This daily aggregated product (Short-name: AERDB_D3_VIIRS_SNPP) is derived from the Version-2.0 (V2.0) L2 6-minute swath-based products (AERDB_L2_VIIRS_SNPP) is obtained from the Level-1 and Atmosphere Archive & Distribution System (LAADS) Distributed Active Archive Center

(DAAC) (<https://ladsweb.modapa.eosdis.nasa.gov/search/>) and is provided in a 1 x 1 degree horizontal resolution grid. The VIIRS/SNPP Deep Blue (DB) aerosol product collection version 2_level1, Atmosphere, land (“Aerosol_Optical_Thickness_550_Land_Ocean_Mean”) were acquired from the VIIRS satellites. These satellite-derived data provide valuable insights into the distribution of Aerosol optical depth. Additionally, AEROSOL REBOTIC NETWORK AOD were used to validate

the satellite data, the finer-resolution AOD data were aggregated by calculating average values in each grid cell. Various visualization techniques were employed to analyze their spatiotemporal patterns and characteristics, including spatial maps, histograms, time-series graphs for AOD. Furthermore, relationships between satellite AOD and ground based measurements were explored by plotting them together and calculating the Pearson correlation coefficient as well as scattered plot with AE to classify aerosol types.

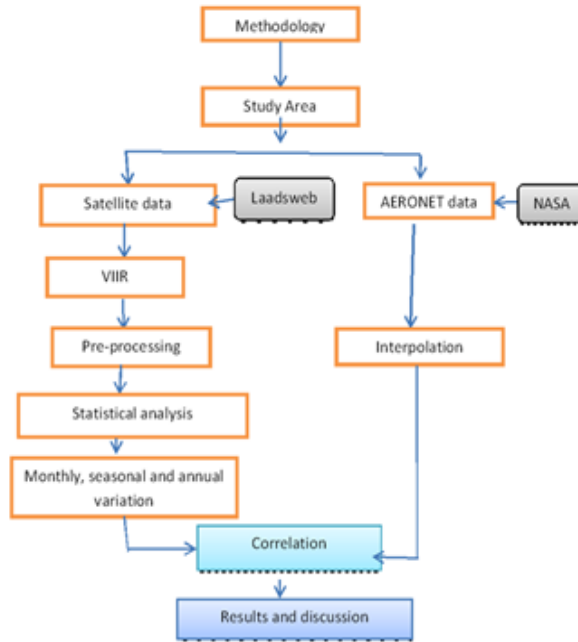


Figure 1: Flowchart

2.1 Overview of the Study Area

The study examined the spatio-temporal variations of aerosols over the West African region: Guinea (GU), Guinea-Bissau (GB) and Senegal (SE) located in Atlantic coast of West Africa. The region is situated geographically bounded approximately within the latitude of 7°N-17°N and longitude of -7°W-18°W. The region is characterized by diverse climatic conditions ranging from humid tropical in the south to semi-arid Sahelian in the north and notably influenced by Western African Monsoon (WAM) and the Harmattan winds which has a vital role in spatial and temporal variability of aerosols in the region. Natural sources (Saharan desert and biomass burning) and Anthropogenic (vehicular emission and urbanization) contributes to the higher level of aerosol loading in the region which makes them particularly relevant for investigating the spatiotemporal variation and distribution of aerosol optical depth (AOD).

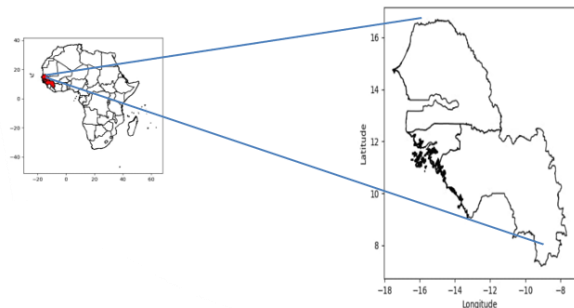


Figure 2: Map of the study area

2.2 Data Description and Processing

2.2.1 Visible Infrared Imaging Radiometer (VIIR)

VIIRS is an instrument on board under the joint mission of NASA and NOAA Soumi NPP (Zhou et al., 2016). It was launched into space on 28 October 2011 to revolve around the Earth in a sun synchronous, polar orbit (Xiong et al., 2013). A total of 22 spectral channels

were used by the VIIRS sensor ranging from 0.412 μm to 12 μm (Moyer et al., 2018)). Spatial resolution of VIIRS varies from 375 m to 750 m and covers the entire globe twice a day (Oudrari et al., 2014) Soumi NPP crosses the equator at 1:30 am (nighttime overpass) and 1:30 pm (daytime overpass) at the same local time (Miller et al., 2012). VIIRS also works on dark target (DT) and deep blue (DB) algorithms for AOD retrieval. A detailed explanation of VIIRS AOD retrieval is illustrated in (& Wang et al., 2017; Payra et al., 2023).

2.2.2 Ground based observation AERONET

The AERONET (AErosol RObotic NETwork) sun photometer (model CE318) is a measure the optical and microphysical properties of vertically integrated aerosols in the atmosphere (e.g., optical depth). Measurements are taken at 15 min intervals under cloud free and daytime conditions at wavelengths of 340, 380, 440, 500, 670, 870, 940, and 1020 nm. Column water abundance is measured using the 940 nm channel. Under cloud free conditions, the uncertainty in AOD measurements was estimated to be ~ 0.01 in the visible and near-IR and increasing to ~ 0.02 in the ultraviolet (340 and 380 nm) (Eck et al., 1999, Bibi et al., 2015). The Angstrom exponent (AE) is a parameter of atmospheric turbidity (Angstrom 1964) and expresses the spectral dependence of aerosol optical depth with the wavelength; tions, validation was carried out over one station (Mongu). The data was obtained from the AERONET website <http://aeronet.gsfc.nasa.gov/>. More details about data accuracy and instrumentation have been reported by several authors (Holben et al., 1998; Kumar et al. 2013; Bibi et al., 2015; Hersey et al. 2015; Boiyo et al., 2017).

2.2.3 Validation of the Data

Validation of satellite AOD is the first method to perform (Ichoku et al., 2002; Liu et al., 2014; Ogunjobi & Awolaye, 2029) using several steps for data collocation and correlation estimation. By considering Satellite retrieved AOD data at each tile of each day falling within the boundary of the study area, are used for processing. Pre-processing also used such as outliers and removing null values were performed over satellite AOD as per requirement. These satellite-acquired AODs are validated with the average AERONET sun photometer daily data (2012–2024). This work aimed to find the spatiotemporal pattern of AOD to have good correlation and number of match-up points. Statistical analysis is made to find the matching values of VIIR in order to perform the temporal and spatial variations. As AERONET does not provide AOD at 550 nm, therefore, the AOD value at 550 nm is obtained from the sun photometer data (AERONET) by using the Angstrom exponential formula. Using AOD data at wavelengths closer to 550 nm, typically 440 nm and

870 nm, the AOD at 550 nm was calculated for the sun photometer data (Zhengnan et al., 2023), according to Angstrom’s formula.

$$AOD_{550} = \beta \times 500^{-\alpha} \tag{1}$$

$$\alpha = -\frac{\ln\left(\frac{AOD_{500}}{AOD_{550}}\right)}{\ln\frac{500}{550}} \tag{2}$$

$$\beta = \frac{AOD_{550}}{500^{-\alpha}} \tag{3}$$

where α is the Angstrom index (440-870nm), estimated from the slope of the spectral AOD plots in logarithmic scales, β is the turbidity coefficient, AOD_{500} means AOD at 550 nm, and AOD_{675} means AOD at 675 nm

$$x = \frac{1}{n} \sum_{i=1}^n x_i \tag{4}$$

$$\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2} \tag{5}$$

Where \bar{x} is the arithmetic mean of VIIR AOD, and x_i is the i^{th} AOD sample value with n number of samples.

$$R = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2 \times (y_i - \bar{y})^2}} \tag{6}$$

R is the correlation between the variable x and the variable y; x_i is the AOD for a year i; y_i is the value of another AOD variable in year i; x is the average AOD over the study period; y is the average of the other variables over the study period.

It was found that the Angstrom exponent varies with wavelength because of deviations that occur due to power law size distribution of aerosols (Kaufman, 1993; Sorek-Hamer et al., 2020)

2.2.4 Pre-processing of the Data

Pre-processing is the initial step in obtaining reliable AOD data analysis. This cleaning process ensures a consistency of the data and addresses potential issues. Daily AOD data were obtained from Laadsweb, and aggregated to monthly, annually and seasonally. The missing values and outliers were discarded during pre-processing to ensure datasets integrity. The AOD measurements that significantly deviated from a dataset’s expected range of values due to some issues is known as outliers. Because AOD data have a fine resolution, we aggregated them to match the AERONET data by calculating the average AOD values in each grid cell. This step ensured that the spatial

resolution of AOD data aligned with that of AERONET data, enabling accurate comparisons and analysis. The retrieved VIIR AOD data were averaged to present a comprehensive view of air quality across monthly, seasonal, and annual scale.

3 Results and Discussions

This section presents the results and related discussions regarding the correlation of the satellite and AERONET data, monthly, seasonal and annual spatial distributions, temporal variations in Aerosol Optical Depth (AOD) and aerosols type during the study period from 2012 to 2024 across West African sub-region.

3.1 Comparison of the VIIR and AERONET data

The VIIR AOD is compared with the AERONET AOD observation over the prominent stations (Dakar) as shown in Figure 3. demonstrates a poor consistency between VIIR AOD and AERONET AOD measurements was found, with a correlation coefficient (R^2) of 0.1286 for Senegal. In addition, figure 4 demonstrate a relationship between the satellite AOD and ground-based AOD over the study period, the highest AOD value for VIIR was observed in the years 2015& 2018 (5.0) and the less in 2013(1.4) & 2020(1.8) while the AERONET has the highest AOD value in the year 2017(2.4) and the least in 2020(1.3).

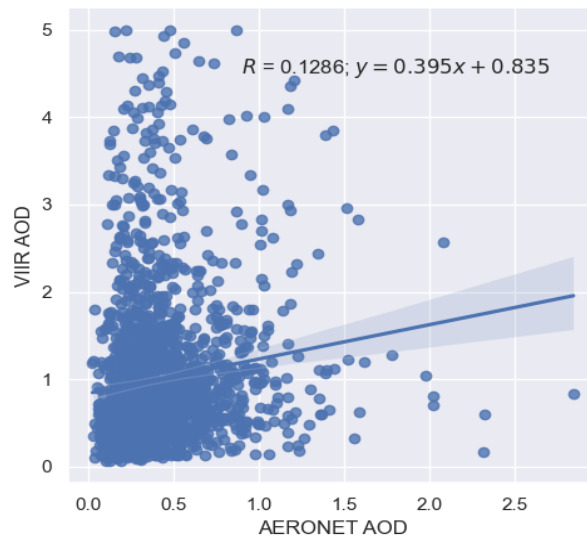


Figure 3: Comparison of VIIR and AERONET AOD for Dakar Station

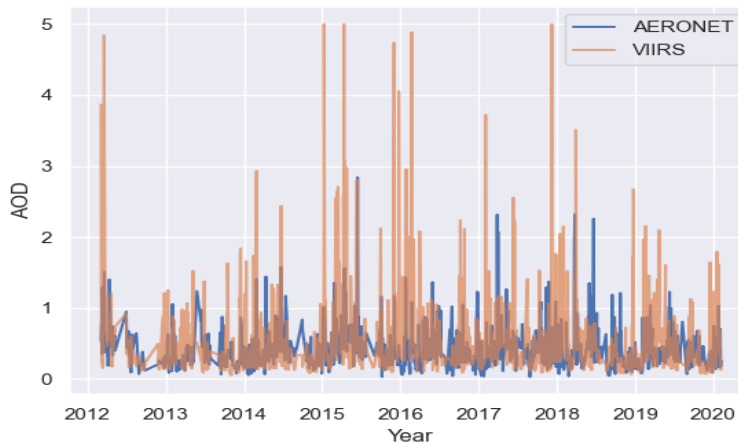


Figure 4: Comparison of VIIR and AERONET AOD for Dakar

3.2 Spatial and annual pattern of AOD

The spatial distribution pattern of the monthly average AOD across the region is depicted in Figure 5(a), (b) & (c) revealing a distinct pattern with concentrations of

high AOD values exceeding 0.45, 0.38 & 0.34 in Guinea, Guinea-Bissau and Senegal respectively. The hazy conditions in the countries were observed in the month of April and May for Guinea, April and September for Guinea-Bissau and February and March

for Senegal. Various factors, including anthropogenic activities which increase the level of AOD and meteorological factors such as irregular rainfall, increase in temperatures, and humidity in the regions, possibly affected this spatial variability. The inter-annual spatial distribution reveals significant variability over the study period from 2012 to 2024. The annual average AOD values in figure 6(a), (b) & (c), highlighting fluctuations that reflect the influence of natural and human activities and high AOD concentrations were observed in 2023 and 2024 for

Senegal but similar pattern throughout the years for Guinea and Guinea-Bissau with little changes. The seasonal spatial distributions of the AOD is also deficit in figure 7(a),(b) & (c), The results illustrate a consistent pattern in the countries, with autumn and spring showing the highest average AOD values for Guinea and Guinea-Bissau, Senegal respectively. Notably, high concentration of mixed particles is dominated for Guinea and fine particle for Guinea-Bissau while coarse particle is dominated for Senegal due to the Saharan dust transport over the area.

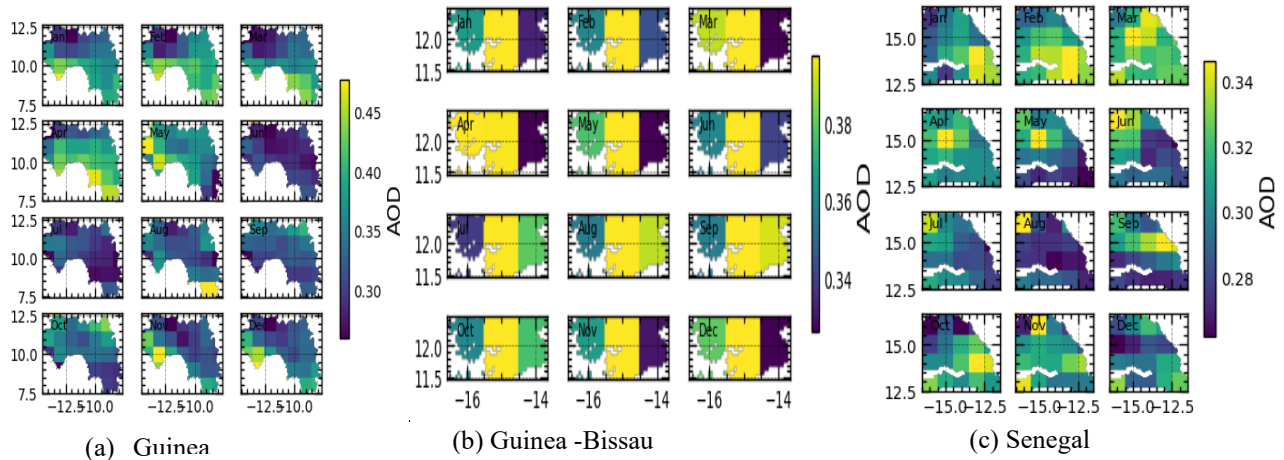


Figure 5: Monthly spatial distribution of VIIR AOD over the region

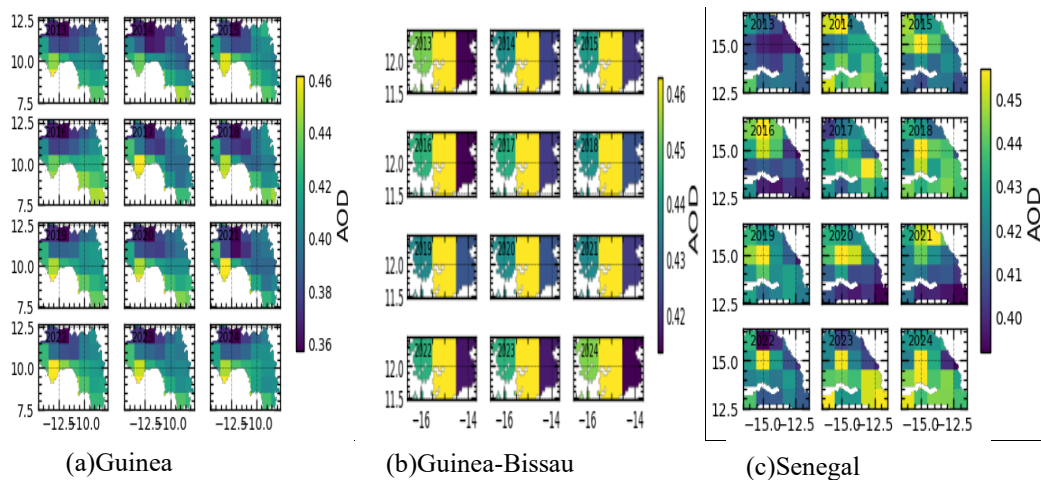


Figure 6: Annual spatial distribution of VIIR AOD over the study region

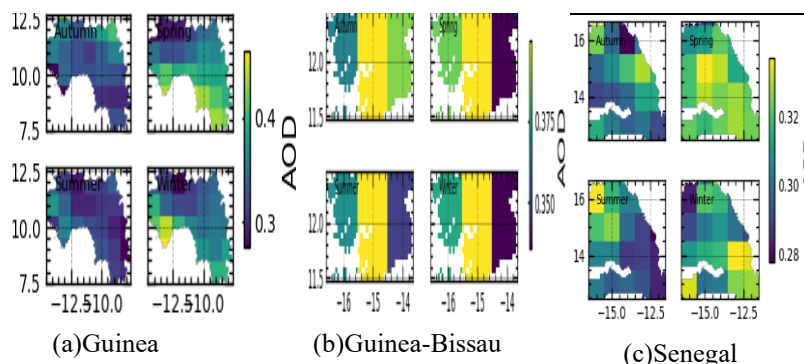


Figure 7: Seasonal spatial distribution of VIIR AOD over the region

3.3 Aerosols Classification

The figure below revealed a distinct aerosol type known to significantly affect the investigation of the spatial and temporal of AOD over the region, although satellite-derived AODs have been documented. Angstrom Exponent (AE) derived from AERONET is used to investigate the size and aerosol types, as shown in the figure below for the satellites VIIR (a-c) over the three regions. $AE < 0.6$ is classified as the Coarse mode (dark blue), $0.6 < AE < 1.2$ is considered as mixed-mode aerosol (green), and $AE > 1.2$ is classified as the fine mode (Cyan) (Lgoghetis et al., 2020; Ali et al., 2020)

Fine-mode aerosols are smaller in size and more abundant in urban and industrial areas, tend to scatter and absorb light more efficiently at shorter wavelengths in the visible spectrum (Yang et al., 2009). Mixed-mode aerosols are those that combined fine- and coarse mode particles in their size distribution. These aerosols can have a significant impact on satellite-derived AOD estimates due to their complex optical properties and size distribution (levy et al., 2007). As a result, the presence of fine- and mixed-mode aerosols can cause satellite-retrieved AOD values in the visible spectrum to be underestimated (Payra. et al., 2023).

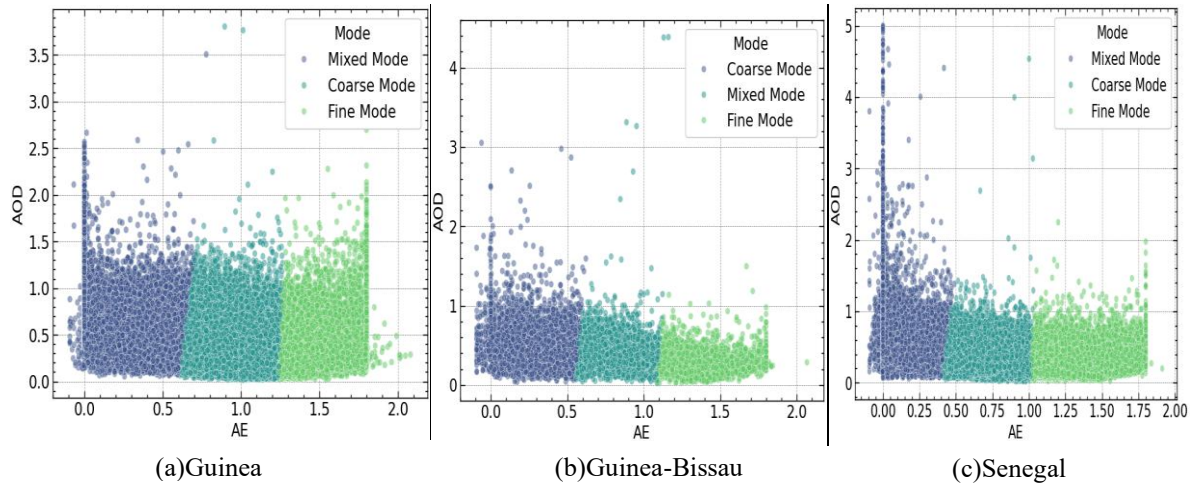


Figure8: Scatter plot of AE (440-870) against Satellite AOD at 550nm for VIIR (a-c)

To account for the regional differences, Figure 9 indicates the statistical distribution of seasonal and mean AOD values in different country. The annual mean AOD values ranged from 0.21 to 0.69 in the study area. GU and GB showed similar seasonal variations, while the SE showed distinct seasonal variations. The AOD in GU and GB followed the order spring>summer>winter>autumn while for SE, summer>spring>autumn>winter and the higher value in

spring may be attributed due to coarse dust particles transported from the north over long distances which adversely affect the air quality in the region. The spatial variability of AOD in the GU and GB regions is large while SE has less spatial variability in the two major areas had the highest AOD values in spring, while only the SE area had the highest AOD values in summer. Such differences might be attributed to different driving forces.

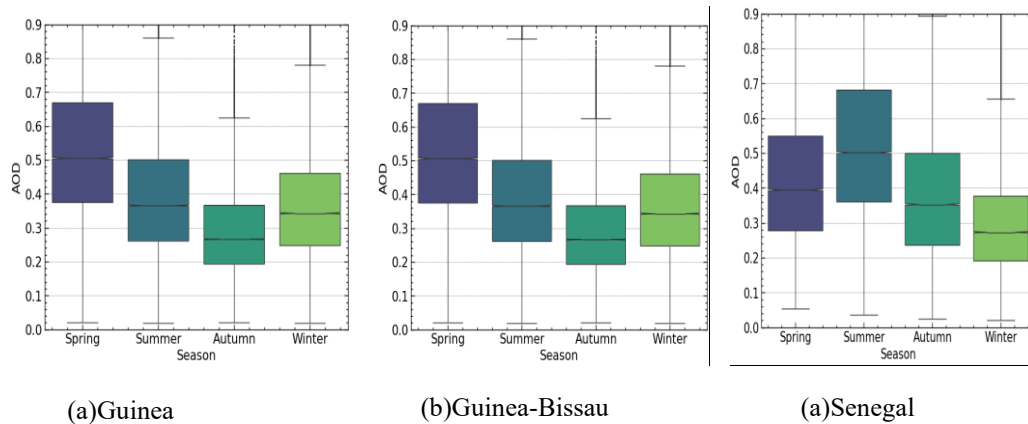


Figure 9: Statistics of seasonal and annual average AOD values in different country.

3.3 Temporal Analysis of the Aerosol Optical Depth (AOD)

The analysis of monthly, annual and seasonal AOD over Guinea, Guinea-Bissau and Senegal reveals distinct temporal variations that reflect the influence of Saharan dust, biomass burning, and rainfall season. Guinea and Guinea-Bissau shows pronounced higher value of AOD in February (0.57), (0.52) respectively while Senegal exhibit relatively higher AOD value in June (0.84). The higher value of the AOD in Guinea and Guinea Bissau in the month of February which is among the month of winter is due to the dust transported from the Saharan and the higher value in June for Senegal is among the month of summer is due to the increase of sea salt from Atlantic Ocean. The annual variations of AOD indicates similar value for Guinea and Guinea-Bissau in 2015(0.49) and Senegal in 2016(0.55). The highest mean AOD values for both countries observed during spring and the least mean AOD value was recorded in autumn. The spring maximum is particularly significant, corresponding to the onset of the West African biomass burning season, especially during fire peak and reflecting the combined influence of Saharan dust outbreaks and coastal meteorology.

Table1. Monthly mean AOD over the study area from 2012-2024

Month	Guinea AOD(mean)	Guinea Bissau AOD(mean)	Senegal AOD(mean)
Jan	0.4293	0.3501	0.2473
Feb	0.5682	0.5150	0.3465
Mar	0.5002	0.4433	0.4419
Apr	0.5027	0.4653	0.4819
May	0.4428	0.4976	0.6690
Jun	0.4399	0.5802	0.8437
Jul	0.3695	0.5120	0.7082
Aug	0.2894	0.3868	0.6597
Sep	0.3058	0.3461	0.4953
Oct	0.3297	0.3875	0.3983
Nov	0.2914	0.3311	0.2792
Dec	0.3521	0.3257	0.2784

Table2: Annual mean AOD over the study area from 2012-2024

Year	Guinea AOD(mean)	Guinea bissau AOD(mean)	Senegal AOD(mean)
2012	0.4675	0.4797	0.4931
2013	0.3524	0.3561	0.4142
2014	0.4055	0.4031	0.4565
2015	0.4888	0.4932	0.5314
2016	0.4246	0.4031	0.5535
2017	0.4672	0.4786	0.5417
2018	0.4503	0.4450	0.4833
2019	0.3895	0.3846	0.4738
2020	0.4318	0.4313	0.4887
2021	0.4303	0.4644	0.4863
2022	0.4344	0.4270	0.4800
2023	0.3866	0.3873	0.4832
2024	0.4379	0.4396	0.4896

Table 3: Seasonal mean AOD over the study area from 2012-2024

Season	Guinea AOD(mean)	Guinea-Bissau AOD(mean)	Senegal AOD(mean)
Autumn	0.2991	0.3058	0.3318
Spring	0.5367	0.5548	0.5582
Summer	0.3454	0.3538	0.4391
Winter	0.4418	0.4505	0.4232

4 Conclusions

This study conducted a comprehensive long-term analysis of spatio-temporal variations and trends in the aerosol optical depth AOD over West African sub-region from 2012 to 2024. This work involved validating the VIIRS AOD (550 nm) DB product with ground-observed AOD over the region. The findings revealed several key insights:

The findings revealed that, GU, GB and SE has the highest AOD value in spring (0.54) (0.55) (0.56), possibly due to the increased emissions from agricultural practices and bush burning during the season and the least in autumn (0.30) (0.31) (0.33) due to reduction of anthropogenic activities and wet deposition in the area respectively. The Annual mean AOD fluctuate considerably with the higher value of AOD(0.47) in 2015 and least AOD (0.36) in 2013 for GU, (0.48) in 2017 and (0.38) in 2013 for GB and (0.45) in 2015 and (0.37) in 2013 for SE. The spatial pattern of AOD indicated that, hazy conditions in the countries were observed in the month of April and May for Guinea, April and September for Guinea-Bissau and February and March for Senegal. Additionally, the month of June exhibit a higher AOD value (0.84) with least in January (0.25) for SE, February (0.58) and August (0.25) for GU and January (0.67) and October (0.27) for GB respectively. Scatter plot of AOD and AE were used to classify the aerosols modal, Biomass burning (BB),Sea salt(SS), Saharan dust (SD) and Vehicular emission(VE).GU recorded(fine mode: 1.2-1.8, coarse mode: 0.51-1.2, Mixed mode: 0-0.51), GB (fine mode: 1.1-1.8, coarse mode: 0-0.5, Mixed mode: 0.5-1.1), and SE ((fine mode: 1.0-1.8, coarse mode: 0.3-1.0, Mixed mode: 0-0.3). These findings underscore the need for rigorous air quality regulations and emission control measures in West Africa coastal region.

Approximately similar seasonal variations have been observed for GU and GB, while the SE showed distinct seasonal variations. The AOD in GU and GB followed the order spring>summer>winter>autumn while for SE, summer>spring>autumn>winter and the higher value in spring may be attributed due to coarse dust particles transported from the north over long distances which adversely affect the air quality in the region. The spatial variability of AOD in the GU and GB regions is large while SE has less spatial variability in the two major areas had the highest AOD values in spring, with only higher AOD recorded in summer for SE. Such differences might be attributed to different driving forces

These findings shows that, critical need for robust air quality regulations and effective emission control measures to reduce the impacts of air pollution on public health and the environment in the region.

Author Contribution

BS: data curation, conceptualization, writing original draft, preparations, interpretation, and reviewing; UM: visualization, reviewing, validation, editing and supervision. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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Conflicts of Interest: The authors declare no conflicts of interest.

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