Assessment of air quality during worst wildfires in Turkey

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Abstract

Recently, a worse and large-scale forest fire broke out across Turkey, which adversely affected the country's air quality level and caused a tremendous loss. Mugla and Antalya cities were the hot spot areas of this fire that experience adverse effects. In this paper, we examined and compare the air pollution scenario before and during the forest fire episode i.e., from 27 July to 10 August 2021 in Antalya and Mugla. The results show that before the fire accusation, i.e., on 27 July, the daily mean aerosol optical depth (AOD), was 0.1 indicates a clear sky. However, as the fire breakouts on 28 July, this daily mean AOD value increased too rapidly and reached 0.52 on 6 August, indicating intense air pollution. The highest AOD was 2.2 over northern Marmaris, Ula, southeastern Milas, Mugla Merkez on 5 August 2021. The results show that peak fire activity occurred during 4–8 August. Meanwhile, the highest NO_2 concentration was $167 \mu\text{mol}/\text{m}^2$ over mid-east Merkez and Köycegiz. The peak HCHO load was $750 \mu\text{mol}/\text{m}^2$ over southern Mugla city. Moreover, Mugla and central Antalya cities experienced the highest O_3 concentrations of $0.14 \mu\text{mol}/\text{m}^2$. Similarly, at the Junction of Dalaman, Köycegiz, and Ortaca, peak CO ($0.08 \text{ mol}/\text{m}^2$) and AI (3.5) had been observed. The high-altitude smoke was over Mugla city. Whereas, over Antalya, mixed aerosols had dominant, followed by smoke, dust, non-smoke fine mode, and fine dominated aerosols.

1. Introduction

For estimation of the concentration of particulate matter (PM) in the atmospheric column, AOD (aerosol optical depth) is a surrogate index (Wei et al., 2021). AOD can utilize for human health, air quality, navigation management, ecosystem, climatological, and meteorological assessment (Sowden et al., 2018). Various wildfire events in the Turkey (Elvan et al., 2021), United States (US), Australia, and Brazil have gained greater concentration due to their impacts on air quality and human health (Butt et al., 2020; H. et al., 2020). Forest fire is a significant source of trace gases and PM in the atmosphere that degrades the regional air quality and severely affects public health (Butt et al., 2020). Both land use and climate change influence the fires in the tropics (Heald & Spracklen, 2015). About 90% of global fine particulate matter ($\text{PM}_{2.5}$) fire emissions cause due to the fires in sub-tropical and tropical regions (Van Der Werf et al., 2017; Wiedinmyer et al., 2011). Fires are the primary cause of PM pollution in tropics and sub-tropical regions (Johnston et al., 2012; Lelieveld et al., 2015). Forest degradation and deforestation (Morgan et al., 2019) cause fragmented forest landscapes, which result in being rapidly prone to fire (Alencar et al., 2015; Cano-Crespo et al., 2015). Additionally, deforestation raises the local temperature (Baker & Spracklen, 2019), affects regional climate and rainfall (Spracklen et al., 2012; Spracklen & Garcia-Carreras, 2015). Interaction of smoke from fires with radiation and clouds further decreases rainfall (Cheng et al., n.d.; Kolusu et al., 2015).

Forest vegetation and climatic condition in Turkey make it vulnerable to forest fires (Elvan et al., 2021). During the last 20 years, about 2000 forest fires had observed every year in Turkey, among them 48% caused by humans (Atasoy & Geçen, 2014; Elvan et al., 2021). However, when the fires rate of unknown

causes is incorporated, this percentage rises to 71% (Elvan et al., 2021). Open neighborhoods in Turkey can spread the forest fire rapidly and burn the burnable materials, e.g., bushes, grasses, leaves, thick or thin branches, and tress. Forest fires in Turkey not only affect Turkey. However, neighboring regions are also influences (Atasoy & Geen, 2014). There is a lack of researches that analyzes the air pollution scenario during forest fire events using remote sensing techniques over Turkey. Therefore, in this study, we have analyzed the role of Turkish forest fire in air pollution levels.

2. Materials And Methods

2.1. Study Area

Turkey is located partly in Europe and Asia at 36°–42° N and 26°–45°E, with 83.15 million population and 81 cities. Turkish territory is 1660 km long from east to west and covers 780043 km² of area. Four different types of climate prevail in Turkey, i.e., Mediterranean, Black Sea, Continental, and Marmara climate. Ankara, the capital of modern Turkey. Antalya and Mugla cities are the southwestern city of Turkey having a Mediterranean climate which is warm and rainy in winters and dry and hot in summer. Tourism and agriculture are the leading sectors of these cities. The vegetation in Antalya and Mugla cities is composed of Anatolian black pine, Calabrian pine, stone pine, cedar, oak, Turkish sweetgum, eucalyptus, fir, cypress, juniper, sycamore, maple tree, and rambutans. Besides these, ukurova orchid, sunflower, ukurova violet are the unique plants of this region. Moreover, thyme, bayleaf, herba sideritis, carop, mushrooms, myrtishrub, folium, and moss have economic value for this region. In the European continent, Turkey hosts almost 75% of the total flora species. Among them, 533 endemic taxons are within Antalya (Kaman & Yavař, 2014). All the risk factors that cause forest fire can be found together in these areas (Sevinc et al., 2020). In Turkey, during the last 10 years, the highest number of wildfires occurred in this region. From 2008 to 2018, about 3231 wildfires were seen in this region with a burned area of 4343 hectares (Sevinc et al., 2020). Antalya and Mugla cities were selected as the study area because of the worse wildfire damages in these regions during the recent wildfire activity.

2.2. MAIAC AOD

High resolution aerosol optical depth (AOD) dataset had acquired from MAIAC (Multi-Angle Implementation of Atmospheric Correction) algorithm of MODIS (Moderate Resolution Imaging Spectroradiometer) (A. Lyapustin et al., 2011; Alexei Lyapustin et al., 2011). MAIAC comprised both Aqua and Terra satellites in the afternoon and morning. MODIS has a broader swath width of 2330 km with minimal gaps over the tropics. It collects data within 36 spectral bands starting from the visible to the infrared spectrum, seven of these bands spanning 0.47 to 2.13 µm utilize for the aerosol retrievals. For this study, we used MAIAC AOD having a 1km spatial resolution from 27 July to 10 August 2021.

2.3. TROPOMI Sentinel-5P

On October 13, 2017, the ESA (European Space Agency) launched a Sentinel-5 Precursor satellite that carrying TROPOMI (TROPOspheric Monitoring Instrument) sensor to monitor air pollution (Veefkind et al.,

2012). In this study, air quality datasets had acquired from TROPOMI. The datasets included offline tropospheric NO₂ column number density, tropospheric Formaldehyde (HCHO) column number density, O₃ column number density, CO column number density in the unit of mol/m², and UV Aerosol Index (AI).

2.4. Suomi NPP/VIIRS and Active fire

The aerosol type data had obtained from Suomi National Polar-orbiting Partnership/Visible Infrared Imaging Radiometer Suit (Suomi NPP/VIIRS). The Deep Blue and Satellite Ocean Aerosol Retrieval algorithms are employed over land and ocean to identify atmospheric aerosol-type. A deep blue aerosol-type layer of VIIRS gives information regarding the aerosol composition over the ocean and land. The combined Aerosol-type over the ocean and land obtained from such pixels that pass high-quality assurance tests. Aerosol-type classification based on the AOD, Ångström exponent (Ozdemir et al., 2020; Tariq et al., 2016), brightness temperature, and Lambert Equivalent Reflectivity. Additionally, MODIS-derived active fire data had utilized to determine active fire locations over the study area.

2.5. HYSPLIT model

Air Resources Laboratory of NOAA (National Oceanic and Atmospheric Administration) developed HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) model (<https://www.arl.noaa.gov/ready/index.php>). This model frequently utilizes in atmospheric sciences to computing the direction and path of the air masses (Bagheri et al., 2019; Qu et al., 2018; Rao et al., 2018; Wu et al., 2015). This model provides backward (Tariq et al., 2016; Zielinski et al., 2016) and forward wind trajectories (Bagheri et al., 2019). HYSPLIT model runs four types of trajectories, i.e., normal, matrix, ensemble, and frequency. Frequency trajectory initiates a trajectory from a single height and location after every six hours. Afterward, add the frequency that the trajectories pass across a grid cell. Then, normalize them either by using the total number of endpoint or trajectories. In this study, we utilized a frequency-forward trajectory at the height of 500m to determine the particles' distribution direction and path.

3. Results And Discussion

3.1. Active fire activity

Figure 1 shows MODIS-derived active fire regions of Turkey from 28 July to 10 August 2021. Most of the forest fire activities have occurred over southwestern regions included Antalya and Mugla cities. Therefore, in this research, we selected these two cities as our study area. Within these cities, intense fire activities were observed in Gündoğmus, Manavgat, Köyceğiz, Kavaklıdere, Marmaris, Mugla Merkez, Bodrumand, and Milas districts.

3.2. Spatial-temporal variations in AOD

Forest fire activity may also cause to enhance the aerosol burden (AOD value) over the affected region. The spatial-temporal distribution of AOD over the Antalya and Mugla cities of Turkey on 27 July (before

the fire event) and from 28 July to 10 August 2021 (during the fire activity) has shown in Fig. 2. The daily average AOD value before the fire accusation, i.e., on 27 July, was 0.1 shows a clear sky with no aerosol load. However, as the fire breakouts on 28 July, this daily average AOD value increased too rapidly and reached 0.52 on 6 August, indicating intense air pollution. Initially, on 29 July, only southern Manavgat and southwestern Alanya had perceived the highest aerosol load. Afterward, it spread over the whole study region till 6 August. During the study period, the highest spatial distribution of AOD was on 6 August with a peak of 2.0 over mid-north Mugla Merkez. However, the highest AOD was found to be 2.2 over northern Marmaris, Ula, southeastern Milas, Mugla Merkez on 5 August 2021. The peak fire activity were from 4–8 August due to the highest AOD values these days, demonstrating the intense air pollution. However, after 6 August, AOD values declined gradually shows a decreasing trend.

From 30 July to 3 August, the maximum AOD, i.e., greater than 2.1 was over the southern Manavgat, southwestern Gündoğmuş, and Alanya district. However, later on, from 4 August, this maximum value appearing over central Mugla city. Mid-east Köyceğiz, mid-north Mugla Merkez, southern junction of Milas and Mugla Merkez, Ola and Marmaris, Ortaca and Köyceğiz, southern Manavgat, Gündoğmuş, and Alanya were the highly affected areas.

3.3. Air quality indicators

TROPOMI-derived spatial distribution of air quality parameters, i.e., (NO_2 , O_3 , HCHO, CO, and aerosol index) on 7 August have shown in Fig. 3. From Fig. 3. the consistency found among the AOD, AI (El-Nadry et al., 2019), NO_2 , and CO, suggesting these air quality parameters can be the AOD indicators or vice versa. Descriptive statistics of AOD, NO_2 , O_3 , HCHO, CO, and AI provide in Table 1. The results show mid-east Mugla Merkez and Köyceğiz had experienced the highest $167 \mu\text{mol}/\text{m}^2$ concentration of NO_2 .

This followed by Yatagan, Milas, Marmaris, Fethiye, and Dalaman districts of Mugla and Merkez of Antalya city. The highest HCHO concentration of $750 \mu\text{mol}/\text{m}^2$ was observed over southern Mugla city. Moreover, the peak O_3 concentration, such as $0.14 \mu\text{mol}/\text{m}^2$, was mainly distributed over the Mugla and central Antalya cities. At the Junction of Dalaman, Köyceğiz, and Ortaca, peak CO ($0.08 \text{ mol}/\text{m}^2$) and AI (3.5) had observed.

Table 1
Descriptive statistics of air quality parameters.

Air pollutant	Min	Max	Mean	Standard deviation
AOD	0.01	1.3	0.34	0.2
CO (mol/m ²)	0.02	0.08	0.04	0.01
O ₃ (μmol/m ²)	0.130	0.144	0.139	0.002
NO ₂ (μmol/m ²)	1.4	167	30.1	13.6
HCHO (μmol/m ²)	0.004	752	181	116
AI	-1.16	3.4	-0.09	0.57

3.4. Aerosol classification

Satellite Ocean Aerosol Retrieval and Deep Blue algorithms had utilized for atmospheric aerosol-type classification. Based on the AOD, Ångström exponent, brightness temperature, and Lambert Equivalent Reflectivity, aerosols had classified into different classes, i.e., fine dominated, mixed, non-smoke fine dominated, high altitude smoke, dust, smoke, background, and No data. Figure 4 demonstrates the spatiotemporal distribution of aerosol-type. On 27 July (before the fire breakouts), background aerosols had frequently distributed over the study area. However, during the fire activity, i.e., on 5 August, high altitude smoke has become dominant over the Mugla city, but its northwestern regions had covered with mixed aerosol. On this day, over western Antalya, the smoke dominated. However, mixed aerosols had observed over eastern Antalya with a combination of dust, background particles, non-smoke fine mode, and fine dominated aerosols. By 6 August, the smoke had seen over Mugla city. Whereas, over Antalya, mixed aerosols had dominant, followed by smoke, dust, non-smoke fine mode, and fine dominated aerosols, indicating intense air pollution in this region during this fire event.

3.5. Latitudinal and longitudinal transport of aerosols

The Hovemollar diagram also plays a significant role in understanding the spatial-temporal distribution of AOD (Tariq et al., 2016). The longitude and latitude-average Hovemollar diagram in Fig. 5 demonstrated the AOD spatial distribution at 550nm for 26.5°-33.5°E and 33.5°-37.5°N area from 27 July to 10 August 2021. It shows daily AOD variations regarding longitude and latitude. The longitude-average Hovemollar diagram presents low AODs, i.e., less than 0.1, on 27 July 2021 (before fire breakouts). Afterward, a rising trend was found in AOD values, with the highest AOD values between 35.5° N to 36.7°N around 7 August 2021, indicating high air pollution. In the longitude-average Hovemollar diagram two hotspots (having an AOD value above 0.5) had found, 1st between 33.5 °-35° N from 29–30 July 2021 and Second, from 6–8 August. However, in the latitude-average Hovemollar diagram, the AOD value has been found below 0.7 before 5 August except for around 31.5°E on 29 July 2021. Afterward, a higher

aerosol load, i.e., greater than 0.7 AOD values found on 5–7 August 2021 between 27.5°–30°E. The increase in AOD had caused by the transport of particulate matter from the burning area. Latitude-average diagram presents two hotspots, first around 31.5°E on 29 July indicates intense air pollution over Manavgat.

Second, between 27.5°–30°E, during 5–7 August demonstrating high aerosol load that caused worse air quality over eastern Mugla and western Antalya cities.. Figure 6 demonstrated the HYSPLIT model (Bagheri et al., 2019; Bera et al., 2021; Draxler et al., 1998; Tariq et al., 2016) forward trajectories at the height of 500m from the ground. The results demonstrate that the forward trajectories follow the south and southeastern direction from their source at the height of 500 m from the ground.

4. Conclusions

In this paper, we examined the air pollution scenario in the Antalya and Mugla cities of Turkey before and during the forest fire episode, i.e., for the period 27 July to 10 August 2021. The highest MAOD was found to be 2.2 over northern Marmaris, Ula, southeastern Milas, Mugla Merkez on 5 August 2021, indicating worse air pollution over these regions. The daily average AOD value before the fire accusation, i.e., on 27 July, was 0.1 shows a clear sky with no aerosol load. However, as the fire breakouts on 28 July, this daily average AOD value increased too rapidly and reached 0.52 on 6 August, indicating intense air pollution. MODIS active fire data suggests that the intense fire activities have occurred in Gündogmus, Manavgat, Köycegiz, Kavaklıdere, Marmaris, Mugla Merkez, Bodrum and, and Milas districts. Mid-east Merkez and Köycegiz had experienced the highest $167 \mu\text{mol}/\text{m}^2 \text{NO}_2$ concentration. This followed by Yatagan, Milas, Marmaris, Fethiye, and Dalaman districts of Mugla and Merkez of Antalya city. The highest HCHO concentration was to be $750 \mu\text{mol}/\text{m}^2$ over southern Mugla city. Moreover, the peak $0.14 \mu\text{mol}/\text{m}^2 \text{O}_3$ concentration was observed over the Mugla and central Antalya cities. At the Junction of Dalaman, Köycegiz, and Ortaca, peak CO ($0.08 \text{ mol}/\text{m}^2$) and AI (3.5) had observed. The high-altitude smoke had seen over Mugla city. Whereas, over Antalya, mixed aerosols had dominant, followed by smoke, dust, non-smoke fine mode, and fine dominated aerosols. Mid-east Köycegiz, mid-north Mugla Merkez, southern junction of Milas and Mugla Merkez, Ula and Marmaris, Ortaca and Köycegiz, southern Manavgat, Gündogmus, and Alanya were the highly affected areas. HYSPLIT model forward trajectories suggest the south and southeastern wind direction from their source at the height of 500 m from the ground.

Declarations

Data Availability

Data used in this study can be downloaded from the Giovanni website (<http://giovanni.gsfc.nasa.gov>).

Ethical Approval

Not required

Consent to Publish

Not Applicable

Consent to Participate

All authors participate in this research.

Authors Contributions

Salman Tariq conceptualizes the work and wrote the manuscript. Fazzal Qayyum make maps and wrote the description. Usman Mehmood conducted analysis. Zia ul-Haq wrote the manuscript.

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Competing Interests

Not Required

Availability of data and materials

Not required

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Figures

Figure 1

MODIS-derived active fire location from 28 July to 10 August 2021.

Figure 2

Spatial-temporal distribution of AOD before (27 July 2021) and during (28-10 August 2021) the forest fire episode over Mugla and Antalya city of Turkey.

Figure 3

Spatial distribution of TROPOMI-derived AI, CO (mol/m²), O₃ µmol/m²), NO₂ (µmol/m²), and HCHO (µmol/m²).

Figure 4

Aerosol classification on 27 July (before) and 5-6 August 2021 (during forest fire event) over Antalya and Mugla cities.

Figure 5

Longitude (left) and latitude-averaged (right) Hovemollar diagram from 27 July to 10 August 2021.

Figure 6

HYSPLIT model forward trajectory demonstrating particles distribution direction path.

Supplementary Files

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