DETERMINATION OF THE CONTRIBUTION OF DUST AND SEA SALT TRANSPORT TO THE PARTICULATE MATTER 10 LEVELS RECORDED IN THE MUĞLA PROVINCE

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ABSTRACT

DETERMINATION OF THE CONTRIBUTION OF DUST AND SEA SALT TRANSPORT TO THE PARTICULATE MATTER 10 LEVELS RECORDED IN THE MUĞLA PROVINCE

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In Türkiye and southern Europe, compliance with PM_{10} standards is not easy due to influence of North African dust and Arabian, Middle Eastern and Asian crustal dusts. Additional non-anthropogenic factors such as sea salt aerosols, forest fires and volcanic activities also contribute. A better understanding of the natural contribution is essential for better management of air quality in Türkiye. In this study, contribution of the natural dust sources, mainly African dust and sea salt aerosols, to the PM_{10} levels in the Muğla province was quantified for 2014-2018. The analysis was performed according to the relevant Guidance of the European Commission, with the utilization of air quality monitoring stations' data including rural data (PM_{10} and elemental concentrations) from Marmaris, satelite products, aerosol models and backtrajectories. Altitude differences and data gaps were of concern and different statistical methods were tried. Forest fires were found responsible for exceedance of daily limit of the CAFÉ Directive on two dates. Daily volcanic activity contribution reached 4.6 ug/m3. The non-African arid regions were found to contribute on 122

days within 1404 dates. The average combined natural contributions were calculated for only 32 dates possessing all necessary data, and the highest was found as 17% annual contribution at a coastal station. The main uses of the results are expected to be, firstly, a better understanding of natural dust contribution to Muğla province and analysis tools, and secondly, the use of such data within the framework of the CAFÉ Directive and for deriving air quality measures pertinent to the remaining emissions.

Keywords: North Africa, Particulate Matter, Backtrajectory, Satellite, Volcano

ÖZ

MUĞLA İLİNDE KAYDEDİLEN PARTİKÜL MADDE 10 SEVİYELERİNE TOZ VE DENİZ TUZU TAŞINIMI KATKILARININ BELİRLENMESİ

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Türkiye ve güney Avrupa ülkelerinde PM_{10} standartlarının sağlanması, bu ülkelerin Kuzey Afrika kaynaklı tozun, ayrıca Arap yarımadası ve Ortadoğu ile Asya'dan gelen karasal tozların etkisi nedeniyle, kolay olmamaktadır. Deniz tuzu, orman yangınları ve volkanlar gibi, insan kaynaklı olmayan ilave etkenlerin de katkısı bulunmaktadır. Doğal kaynaklı katkıların daha iyi anlaşılması, Türkiye'de hava kalitesinin daha iyi yönetilebilmesi için büyük öneme sahiptir. Bu çalışmada, Muğla ilindeki PM_{10} düzeylerine Afrika tozu ve deniz tuzu başta olmak üzere doğal toz kaynaklarının katkı miktarı 2014-2018 dönemi için hesaplanmıştır. Avrupa Komisyonu'nun ilgili rehberi doğrultusunda, Marmaris'te yer alan bir kırsal istasyonun verileri (PM10 ve element derişimleri) de dahil olarak hava kalitesi izleme istasyonlarının verileri ve uydu ürünleri, aerosol modelleri ile geriyörüngeler kullanılarak bir analiz gerçekleştirilmiştir. Yükseklik farkları ve veri eksikleri dikkate alınmış ve farklı istatistiksel yöntemler denenmiştir. Orman yangınlarının, iki günde CAFÉ Direktifi günlük sınır değerinin aşılmasından sorumlu olduğu tespit

edilmiştir. Günlük volkanik aktivite katkısı 4.6 ug/m3 düzeyine varmıştır. 1404 gün içerisinde 122 günde; Afrika dışı karasal toz alanlarının katkıda bulunduğu anlaşılmıştır. Sadece tüm gerekli verilere sahip olan 32 günde, ortalama birleşik doğal katkılar hesaplanmış ve en yükseği bir kıyı istasyonunda %17 yıllık katkı bulunmuştur. Bu çalışmanın beklenen yararları; ilk olarak, Muğla ilindeki doğal toz katkısının ve analiz araçlarının daha iyi anlaşılması ve ikinci olarak, bu tür verilerin CAFÉ Direktifi çerçevesinde ve ayrıca kalan emisyonlar için hava kalitesi tedbirleri geliştirilmesi amacıyla kullanılmasıdır.

Anahtar Kelimeler: Kuzey Afrika, Partikül Madde, Geriyörünge, Uydu, Volkan

To my never-giving-up very dear friend Ağcagül

To dear Nurhan, for whom this graduation matters like hers, and to all beautiful souls.

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Lastly, thanks are truly deserved by the operators and builders of open access tools and data. Some data were retrieved from the Multi-model, where dust data and images were provided by the WMO Barcelona Dust Regional Center and the partners of the Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) for Northern Africa, the Middle East and Europe. The other freely available, useful tools used were TRAJSTAT model and Google Earth Engine (GEE). VIIRS and MODIS data distributed from NASA FIRMS as well as other NASA images were also freely used.

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LIST OF ABBREVIATIONS

AOD	Aerosol Optical Depth
AE	Angstrom Exponent
CAMS	Copernicus Atmosphere Monitoring Service
EFFIS	European Forest Fires Information System
FIRMS	Fire Information System for Resource Management System
GEE	Google Earth Engine
Guidance	The guidance created in line with the CAFE Directive in 2011
HKDYY	Hava Kalitesi Değerlendirme ve Yönetimi Yönetmeliği
HYSPLIT	Hybrid Single-Particle Lagrangian Integrated Trajectory model
TUBITAK	Türkiye Bilimsel ve Teknolojik Araştırma Kurumu
MAIAC	Multi-Angle Implementation of Atmospheric Correction
MODIS	Moderate-resolution Imaging Spectroradiometer
SLP	Sea Level Pressure
CAFÉ	Clean Air For Europe Directive
UHKİA	Ulusal Hava Kalitesi İzleme Ağı
the Ministry	Ministry of Environment, Urbanisation and Climate Change
PMF	Positive Matrix Factorization

CHAPTER 1

INTRODUCTION

As is known, the particulate matter in the air that is smaller than 10 μm diameter (hereafter referred to as "PM_{10} ") is an important indicator of air quality. PM_{10} mainly originates from industrial combustion, residences, agriculture, forests, dust transport, etc., which can be named natural or anthropogenic sources or a combination. From an environmental point of view, this is important, especially since it causes cancer, heart and respiratory health problems, inter alia various other damages. Meanwhile, natural PM_{10} emissions constitute an important contribution to the overall PM_{10} levels. With these in mind, below is information on the legal background and basis for calculating the natural contributions to the overall PM_{10} levels.

In the case of the EU, the Clean Air For Europe Directive numbered 2008/50/EC, in other words, Ambient Air Quality and Cleaner Air for Europe (CAFÉ) Directive (hereafter referred to as "CAFÉ Directive") is the major tool for regulating emission limits. The consolidated text of the said directive was also made available (European Parliament and the Council, 2015). The directive includes the following daily limit: 50 μg/m^3, which shall not be exceeded by more than 35 days in a calendar year. The daily limit is imposed in addition to the annual limit of 40 μg/m^3. Meanwhile, an amendment to the directive is proposed. In this framework (European Commission, 2022), among the limit values for protecting human health to be attained by 1 January 2030, the PM_{10} daily and annual limit values are proposed to be changed as 45 μg/m^3 and 20 μg/m^3 respectively. The annual limit proposed is also already proposed by World Health Organization(WHO, 2005). The proposed amendments are not certain to be enacted, but consultation processes must be consulted.

In the Directive and similarly in the amendment proposal of the European Commis-

sion (2022), "contributions from natural sources" is defined as

> emissions of pollutants not caused directly or indirectly by human activities, including natural events such as volcanic eruptions, seismic activities, geothermal activities, wild-land fires, high-wind events, sea sprays, or the atmospheric resuspension or transport of natural particles from dry regions.

According to the proposal of the European Commission (2022) for revision on the CAFÉ Directive, the rules on deducting natural source contributions to exceedances of air quality standards are foreseen to be extended to cover exceedances of average exposure reduction obligations (no such obligations would be deemed necessary in the cases of exceedances due to natural source contributions). It was further mentioned in the legal proposal that air pollution from natural sources such as Saharan dust cannot be influenced by air quality management, because of which air quality exceedances resulting from these sources will not count as non-compliance with air quality standards, including average exposure reduction obligations, and not require air quality plans.

In Türkiye, the By-Law on Evaluation and Management of Air Pollution ("Hava Kalitesi Değerlendirme ve Yönetimi Yönetmeliği" in Turkish, hereafter referred to as "HKKY") is the most relevant legal tool. It provides air quality limit values in Annex I. The limit values are the same as the abovementioned limits of the CAFÉ Directive.

Compliance with these PM_{10} standards is a serious issue in most Türkiye. This problem is not specific to Türkiye but is valid for the Mediterranean basin, which is affected by the strong dust transport originating from the Sahara and Sahel regions. Some other parts of the north of the African continent (North Africa) are also contributing. Such dust transport is a major type of "natural" contribution to the PM_{10} levels.

According to the Guidance prepared by European Commission (2011) in line with CAFÉ Directive, "natural contribution" (contributions to PM_{10},$\mathrm{PM}_{2.5}$, SO_2, CO) term is used for not the emissions originating from natural sources in a generic sense, but is rather specified such that;

- cannot be created by human action/negligence,
- hence, also, it cannot be decreased in amount or otherwise totally prevented by human action.

According to these criteria, the following pollution factors are automatically out of context: land use (considering the effects of agriculture as an anthropogenic activity) and controllable forest fires. The rest of the pollution factors need some proof that they are natural.

CAFÉ Directive allows the countries to subtract the PM_{10} values which are proved to correspond to such "natural contribution" from their PM_{10} levels to demonstrate their harmony with the emission limits of the Directive. In line with this, in the above-mentioned Guidance of the European Commission (2011), methods for subtraction of "natural contribution" from the PM_{10} levels are suggested, but not strictly. Along with all the principles and advice about the subtraction procedure, it is also reminded that subtraction and demonstration should not be the ultimate aim but that precautions shall be taken regarding the exposure to PM_{10}.

The major natural sources mentioned in the abovementioned 2011 Guidance are the transport of particles from dry regions, sea spray (sea salt, marine salt), volcanoes and seismic activities, and wild-land fires.

Regarding particle transport from dry regions (i.e., arid region dust transport), Figure 1.1 shows the major arid areas of concern that can be recognized with light colors. The largest dust regions of the world lie within the global dust belt, which includes deserts such as the Sahara in the North of Africa, the deserts in the Arabian Peninsula and Oman, Gobi and Taklimakan in China (Formenti et al., 2011 cited in Calvo et al., 2013).

Arid regions of Africa are known as major mineral aerosol sources in Mediterranean countries. Approximately half of the dust suspended in the atmosphere is estimated to have originated from North Africa due to the abundance of dust sources and the region's position under the subtropical jet stream, which carries dust worldwide. The rest of the dust suspended in the atmosphere is thought to come from a few other well-known dust-producing regions, including the Taklimakan (alternatively named

Figure 1.1: Arid Regions of Concern

"The Taklamakan") Desert in China, some arid regions of Arabia, Iran, the shore of the Caspian Sea, the Lake Eyre Basin in Australia, and the area around Utah's Great Salt Lake in the USA.[1]

Taklamakan desert is a vast area known as the world's second-largest shifting sand desert, lying in Xinjiang ("Sincan" or "Şincan" in Turkish) state of China[2]. With much sand and little vegetation or moisture, dust storms are a regular occurrence, particularly in the spring, when strong surface winds can sometimes lift dust up to 10 kilometers altitude, by which it can be transported by higher-altitude winds that send them across China and the Pacific[3]. March is also among the active months for dust storms in the Gobi and Taklimakan deserts[4].

Additionally, the Karakum Desert and Aralkum are among the important arid regions. Karakum desert covers approximately seventy percent of Turkmenistan. Aralkum desert is the desert produced by the Aral Sea as an environmental catastrophe. The Aral Sea was formerly the fourth-largest lake in the world and began shrinking after the rivers that fed it were diverted by Soviet irrigation projects. The eastern basin of the Aral Sea had completely dried up, now called the Aralkum Desert.

According to the European Commission (2011) Guidance, whether or not a given arid

[1] https://www.nesdis.noaa.gov/news/its-dusty-world-noaa-satellites-help-us-keep-track-of-it
[2] https://www.chinadiscovery.com/china-deserts/taklamakan.html
[3] https://earthobservatory.nasa.gov/images/87969/the-taklimakan-desert-a-factory-for-dust-storms
[4] https://earthobservatory.nasa.gov/images/89889/gray-plume-over-the-sea-of-japan

region can be counted as an eligible source of natural dust is linked to the following considerations, which make it difficult to assess:

1. Long-term anthropogenic developments have contributed to the current state of land use; therefore, the contribution has been influenced by human action;
2. The re-suspension process itself might be caused by human action.

It is further mentioned that particles directly re-suspended by agricultural activities or originating from the agricultural fields (e.g., ploughed fields) should be considered as formed by the interaction of nature with anthropogenic activities and shall not be considered eligible for deduction. The sandy-soiled areas of the Danube–Tisza Interfluve and the Great Hungarian Plain are given as eligible arid regions within the EU.

Lightning is among the causes of forest fires, which could be considered natural (wild) fires. The map below taken from the website World Lightning Strikes Map[5] shows the average yearly counts of lightning flashes per square kilometer based on data collected by NASA's Lightning Imaging Sensor on the Tropical Rainfall Measuring Mission satellite between 1995 and 2002. Places where less than one flash occurred (on average) each year are gray or light purple. The places with the most lightning strikes are deep red, grading to black. These maps belong to older times than the study period and do not give information on a smaller scale, i.e., details on the locations, such as whether or not it is forest land. Their main deduction could be that many lightning strikes occur in points scattered throughout Türkiye, including the study region Muğla. Another map is provided by Vaisala at Interactive Global Lightning Density Map[6] for the period 2016-2023. As seen in the map, while some parts of Muğla are shown with a frequency of lightning as 8 flashes of lightning/km^2-year, the majority of Muğla is seen with 4 flashes of lightning/km^2-year in 2016-2023. When considered at a larger scale covering the whole of Türkiye, Muğla is seen to have one of the few highest (8 lightning/km^2-year) lightning frequencies in the country per the 8-year period. All of these maps are shown together in below Figures 1.2, 1.3, 1.4.

Regarding volcanoes, Figure 1.5 below demonstrates the active volcanoes around

[5] hhttps://geology.com/articles/lightning-map.shtml
[6] https://interactive-lightning-map.vaisala.com/

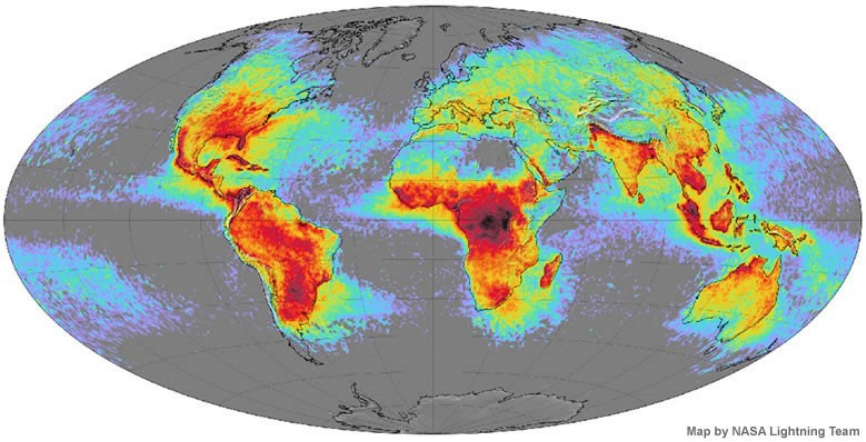

Figure 1.2: Lightning Density-Source: NASA

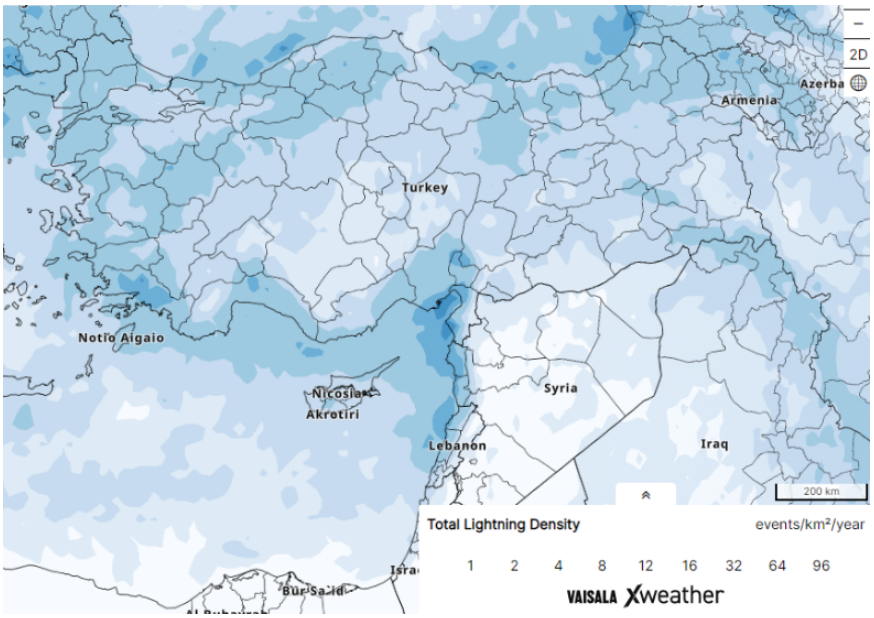

Figure 1.3: Lightning Density(Larger Scale)-Source: VAISALA

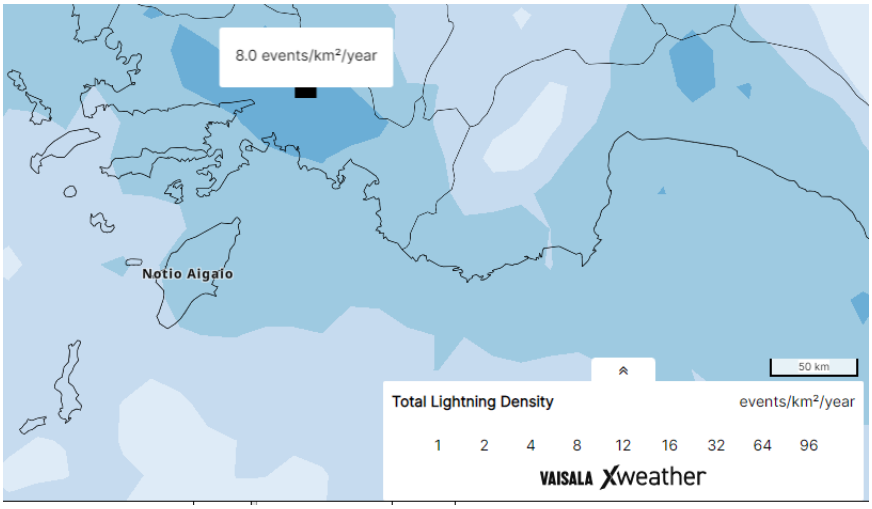

Figure 1.4: Lightning Density-Source: VAISALA

Türkiye, which is derived from a database available accessible at Interactive Map of Active Volcanoes and recent Earthquakes worldwide[7]. They include the volcanoes that are “eruptive” and the volcanoes that are shown with “warning / minor activity.” Türkiye does not have any active volcanoes.

The eruptive volcanoes are in Africa and Italy. All are 6 volcanoes; their details are tabulated below in Table 1.1. The closest ones are Etna and Stromboli in Italy. Stromboli is primarily linked to the "stromboli" kind of eruption, from which the volcano derives its name. This type of eruption is characterized by a relatively weak form of explosion.

Sea salt aerosols are also a significant natural source of PM_{10} in Türkiye. Due to its geographical location, several provinces are impacted by sea salt aerosols as they are surrounded by three oceans. Information about tornadoes is available at European Severe Weather Database[8], which may be useful for the study of sea salt aerosols.

[7] https://earthquakes.volcanodiscovery.com

[9] Please see Footnote 7

[8] https://eswd.eu/cgi-bin/eswd.cgi

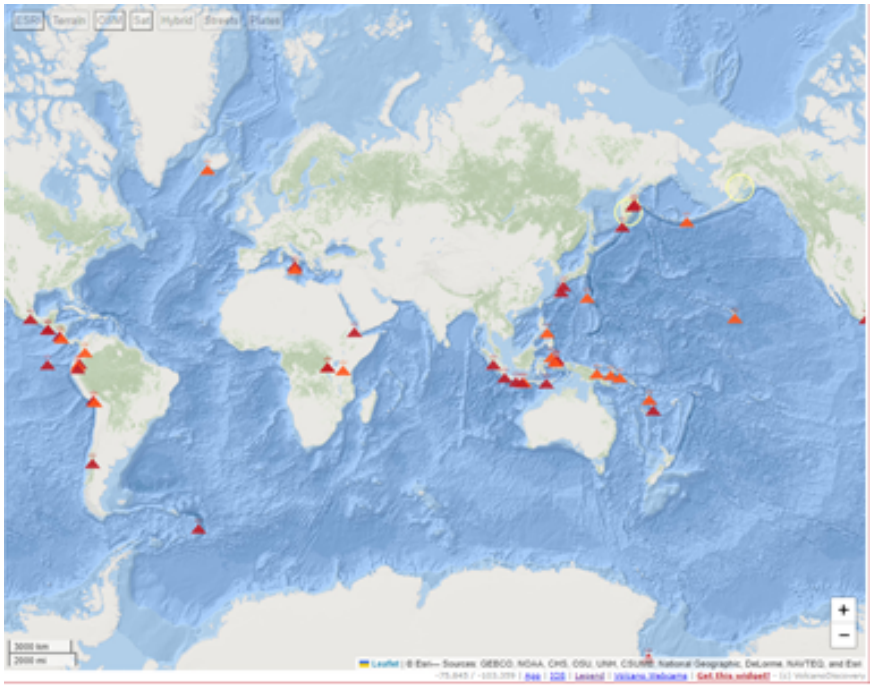

Figure 1.5: Volcanoes of Concern - Source: Interactive Map of Active Volcanoes[9]

Table 1.1: Volcanoes of concern

Volcano	**Country**	**Approximate Distance to Muğla (km)**
Reykjanes	Iceland	4500
Etna	Italy	1180
Stromboli	Italy	1170
Nyiragongo	DRC*	4275
Erta Ale	Ethiopia	2870
Ol Doinyo Lengai	Tanzania	4480

*the Democratic Republic of Congo

1.1 Research Questions and Approach

Within this framework, the aim of the study is to demonstrate the character and impact of natural contributions, mainly arid region dust transport and sea salt aerosols, also including volcanoes and forest fires, to PM_{10} levels for the selected province Muğla. To this end, the study focused on the following natural contribution sources: arid region crustal dust transport, volcanoes, forest fires, and sea salt aerosols. More specifically, the following question was aimed to be handled during the research conducted for the thesis:

> How do natural sources, specifically arid region dust transport and sea salt aerosols, along with volcanoes and forest fires, contribute to PM_{10} levels in the province of Muğla, and what is the impact of these natural contributions on compliance with air quality standards as outlined in the CAFÉ Directive and Türkiye's HKKY?

To accomplish this goal, a Research Approach was adopted as described below.

Literature Review and Legal Framework Analysis:

- Review relevant literature on natural PM_{10} sources, their identification and impacts.
- Analyze the CAFÉ Directive and Türkiye's HKKY to understand legal limits and provisions for natural source contributions.

Data Collection:

- Gather PM_{10} data for Muğla.
- Collect data on potential natural sources such as dust transport from arid regions and sea salt aerosols.
- Obtain meteorological, geological, and satellite data to correlate PM_{10} levels with natural events (e.g., dust storms, sea sprays, volcanoes, forest fires, etc).

Source Identification and Attribution:

- Use satellite data and models to identify and track dust transport from arid regions to Muğla.
- Assess contributions from sea salt aerosols by considering elemental data and meteorological records.
- Identify other potential natural sources, such as volcanic activity and forest fires, using geological, historical, and satellite data.

Quantitative Analysis and Impact Assessment:

- Quantify the contributions of natural sources to PM_{10} levels using statistical techniques.
- Apply the methods suggested by the European Commission's Guidance (2011) to subtract natural contributions from overall PM_{10} levels to obtain anthropogenic contributions.

Results Interpretation and Policy Recommendations:

- Interpret the results in the context of current and proposed air quality standards.

- Provide recommendations for policymakers on managing and reporting natural contributions to PM_{10} levels to ensure compliance with air quality standards.
- Provide recommendations to future researchers in relation to their technical studies within this field of policy

This approach will comprehensively address the research question by combining legal analysis, data collection, statistical computations analyses of results, and policy evaluation.

1.2 Structure of the Thesis

This study is presented in five chapters, with four chapters following this introduction chapter.

In **Chapter 2, Literature Review**, the literature, including relevant studies and associated data on the identification and impacts of natural sources, are explained concerning PM_{10} levels.

In **Chapter 3, Methodology**, the data obtained for the thesis (including the data derived from related previous studies), the subsequent studies performed with the data, including statistical and qualitative analyses, identification of the dates with natural source contribution to PM_{10} levels and quantification of their impact are explained.

In **Chapter 4, Results and Discussion**, the results related to characteristics of data, identification of the dates with natural source contribution to PM_{10} levels and quantification of their impact, and the recognized relationships of some data or results with each other, are presented. These results are demonstrated via text, tables, graphics, and other figures and discussed throughout the chapter.

In both of the third and fourth chapters, the text is divided into four subchapters based on the type of natural PM_{10} source studied:

- arid region dust,
- volcanoes,
- forest fires and

- sea salt aerosol

In harmony with the differing extent of the analyses for different natural contribution sources, among the abovementioned natural sources, the arid region dust was given higher emphasis than the others in both the second and third chapters.

Finally, the last chapter, **Chapter 5**, is devoted to **Conclusions** where the main outcomes of this study are summarized along with recommendations for further research and some notes on the foreseen policy changes.

CHAPTER 2

LITERATURE REVIEW

Within the framework of African dust, there are extensive studies to demonstrate the Saharan or Sahel-originating dust's effect on Mediterranean particulate matter (PM) levels. North African dust is generally considered a major contributor overall. It is known that 1–1.5 billion tons of dust are thrown from the Saharan desert and scattered into the atmosphere yearly. Besides closer continents such as Europe and Asia, Saharan desert dust affects transatlantic regions, primarily the Caribbean and America, including the USA and beyond. Satellite observations have revealed that there is frequent transport of Saharan dust as pulses in various directions, including Türkiye, and regional studies have confirmed that the main path of the dust-carrying winds has a westerly (%87) or southwesterly (%61) component (i.e., from North Africa). Studies performed in the east of the Mediterranean have confirmed that 20 million tons of Saharan and other African dust are transported to Anatolia each year(Kubilay and Saydam, 1995; Kubilay et al., 2000 and Koçak et al., 2007, all cited in Doganay et al., 2009). Similarly, as cited in Güllü et al. (1996), the arid regions of Africa and Asia are believed to be the major mineral aerosol sources in the atmosphere.

Generally, satellite images, HYSPLIT model to calculate backtrajectories, DREAM or similar 3-D aerosol forecast models are used in the studies aiming at demonstrating the African natural dust's effect on the PM levels in different parts of the Mediterranean region, in addition to the aerosol monitoring results at urban and rural stations. The TRAJSTAT model is a practical alternative to the HYSPLIT model (using the same algorithm, freely available like HYSPLIT) since it enables users to calculate backtrajectories for durations of up to one month at a time. The DREAM model is an aerosol model which foresees the 3-D tropospheric dust distribution. Multi-

model is the model that is used to analyze the combined results of other models (e.g., DREAM), where the results are generated as combined results of the other models' numerical outputs, which are presented on the website of the World Meteorological Organization (WMO) Barcelona Dust Regional Center. Images and other outputs from satellites are tools that can be used to understand the real case, together with the monitoring results, in combination with the predicted model results. However, clouds and rain may undermine such observations, and in such cases, the dust may seem not to have arrived.

One of the most widely used methods to detect Saharan or other North African dust transport is the observation of aerosol optical depth (AOD) levels based on satellite AOD outputs. -NASA MODIS satellites (Terra and Aqua) have their own AOD outputs andNASA MODIS MAIAC outputs are served as the combination of them.

NASA[10] mentioned that the AOD value 0.01 corresponds to an extremely clean atmosphere, while 0.4 corresponds to a very hazy condition. AOD at 550 nm wavelength is termed "Green band aerosol optical depth," and AOD at 470 nm wavelength is termed "Blue band aerosol optical depth."

In some studies, such as in the study of Achilleos et al. (2020), which will be mentioned again shortly, instead of the total AOD at 550 nm (AOD_{550}), "dust-AOD" data which is valid at 550 nm wavelength is used. The Mediterranean region was mentioned by Papadimas et al. (2008) as confirmed through AOD findings to be one of the most heavily aerosol-polluted areas of the world. On the other hand, it was mentioned by Ettehadi Osgouei et al. (2022) in agreement with several authors that although MAIAC accounts for the contribution of dust particles from the Sahara and the Middle East in the region, it primarily represents an arid climate with a larger coarse fraction which seems might be inappropriate for a site dominated by fine-mode anthropogenic urban/industry aerosols, mixed with marine aerosols from the Mediterranean Sea.

Several articles mention examples of AOD_{550} levels corresponding to arid region dust, specific to the Meditteranean region or parts of it, as described below. Meanwhile, it was mentioned in General Directorate of Meteorology (2023) report that

[10]https://svs.gsfc.nasa.gov/12302

elevated levels of AOD, together with low levels of Angstrom Exponent (AE), can be considered an indication of an abundance of PM particles with crustal origin in the atmosphere.

In the study of Papadimas et al. (2008), AOD values between 0.12 and 0.45 and a mean regional value of 0.22 (with ± 0.07 standard deviation) were reported for the region. At the regional scale, values up to 0.5 were reported in areas dominated by aerosols of desert origin. The mean seasonal, regional AOD_{550} values ± standard deviations were found as 0.15 ± 0.03, 0.27 ± 0.03, 0.27 ± 0.03, 0.20 ± 0.03, for the winter (December to February), spring (March to May), summer (June to August), and autumn (September to November) seasons, respectively. High AOD_{550} values (0.3–0.4) were found in areas with intense anthropogenic activity, such as the industrial region of the Po Valley in Northern Italy and the megacity of Cairo.

It was mentioned that even on an annual mean basis, regions like North Africa, southeast Spain, the central Mediterranean, the Middle East, and the Anatolian plateau in central Türkiye are strongly influenced by aerosols as indicated by AOD_{550} values exceeding 0.27. Meanwhile, the 21-day moving averages computed in the study for the whole region are seen to be descending in the period 2000-2006, starting with approximately 0.25 and reaching approximately 0.2. This reduction is also seen from the graphics presented, through part of the data specific to Muğla or many other parts of Türkiye.

In the study of Schroedter-Homscheidt et al. (2010), it was mentioned by the authors that during dust outbreaks, values between 0.2 and 0.5 were observed in the study in Italy and Greece, while values up to 0.27 and 0.13 were observed in stations like Leipzig or Kühlungsborn in Germany, respectively.

AOD_{550} data for the years 2000-2005 over Athens was studied by Kaskaoutis et al. (2007). The AOD value 0.2 corresponding to clear conditions was chosen as the usual upper limit for maritime AOD_{550} (the reason for this was the known overestimation of MODIS for AODs in land-ocean surfaces according to this article, while according to the user guide for MAIAC by Lyapustin and Wang (2022), this problem was later overcome when compared to previous MODIS AOD products. The AOD_{550} threshold for desert dust was set as 0.3. Between them was another portion of AOD defined as

"mixed type." At the end of the study, the mean AOD ± standard deviation value for desert dust contribution during the entire period was found to be 0.52 ± 0.19, which was distributed to seasons as follows: 0.57 ± 0.31, 0.60±0.24, 0.46 ± 0.12 and 0.45 ± 0.10 for the winter, spring, summer and autumn seasons, respectively.

Dust-AOD at 550 nm data obtained from the Copernicus Atmosphere Monitoring Service (CAMS) global reanalysis was analyzed by Achilleos et al. (2020) and found to be at the levels of 0.16 ± 0.15, 0.27 ± 0.17 and 0.21 ± 0.16 for the dust storm events in three locations lying in Crete (Finokalia background station), Cyprus (Ayia-Marina Xyliatos background station), and Israel (Beer Sheva urban station) respectively, for 2006-2017. The following values were determined by the authors for desert dust events with Saharan, Middle-Eastern, and combined origin, respectively: 0.18 ± 0.15 (Saharan), 0.13 ± 0.14 (Middle-Eastern), and 0.19 ± 0.15 (combined) at the Cyprus site and 0.23 ± 0.16 (Saharan), 0.19 ± 0.16 (Middle-Eastern) and 0.20 ± 0.15 (combined) at the Israeli site.

According to Fluck and Raveh-Rubin (2023), who used the term dust optical depth (DOD) at 550 nm in relation to the DOD product obtained from CAMS and studied the period 2003–2018 in North Africa, generally, minimal DOD levels were found for November, December, and January, the highest values were seen to be dominating from March to June. While January, February, and March events were seen to have comparable duration and size, the mean and maximum DOD in March was almost double the DOD in January and February.

It was reported by the General Directorate of Meteorology (2023) for the period 2003-2022 that the AOD spatial averages are seen to have an increasing trend in all regions of Türkiye starting with 2007, the reverse starting with 2012, then another increasing trend starting from 2018 and afterward another decreasing trend.

Regarding monthly spatial average AOD values, the highest values were recognized in spring months (the combined average of March, April, and May) for Türkiye on a seasonal basis, where, according to the results provided, the highest values are recorded in the months of April-August. It has been observed that, on average, the AOD values tend to rise from February, reach their highest point in May, and then gradually decrease until they reach their lowest levels in December.

The data clearly indicates that in Türkiye, the months following spring are July and August, based on the average AOD values. The average AOD value for the whole country of Türkiye from 2003 to 2022 was determined to be 0.19. During the period of 2014 to 2018, the AOD values varied between 0.18 (0.1764) and 0.20 (0.2014), with the highest value of 0.20 occurring in 2018. It is important to note that only data from January 2018 is included in this thesis. The range for 2014-2017 is between 0.18 (0.1764) and 0.19 (0.1901).

There have been many academic studies in the literature that have examined the dates and contributions of dust episodes in arid regions. Some of them are regarded as highly informative due to the extensive range of dates and/or multiple Mediterranean locations that were studied. Examples are illustrated below.

In a recent article by Baltaci (2021) on meteorological conditions in Türkiye, it was mentioned that the study highlighted the occurrence of "dust storm event days" (DEDs) in the country. According to the records from 2014, the scores for each season were as follows: winter - 0, spring - 11, summer - 9, and autumn - 10. These scores added up to a total of 30. For the same seasons in 2015, the scores added up to 49, with individual scores of 10, 10, 11, and 18. 2016, the winter, spring, summer, and autumn scores were 7, 13, 15, and 11, respectively. These scores added up to a total of 46. The scores for the four seasons in 2017 were 10, 8, 1, and 5, adding up to a total of 24. In 2018, the scores for winter, spring, summer, and autumn were 5, 15, 1, and 0, respectively, adding up to a total of 21.

Furthermore, an analysis was carried out on the year 2019. Across different seasons, the frequencies of the 189 DEDs varied. According to the data, there were 66 days with DEDs in the spring, 47 in the fall, 40 in winter, and 36 in summer. Upon examining the geographical regions of Türkiye, it is seen that Saharan dust storms exhibit a higher frequency in the western section of the country during the spring season. The occurrence of Sharav cyclones moving throughout Italy and the Balkan Peninsula results in an appearance of strong south and southwesterly winds. The winds enable the movement of natural dust particles from Northern Africa to cross through the Mediterranean Sea.

The mean PM_{10} concentration values for the Aegean Region for DEDs are as fol-

lows: 104, 112, 34, and 0 micrograms per cubic meter (µg/m^3) for winter, spring, and summer, respectively. Unfortunately, there is no data available for the autumn season. The PM_{10} concentration levels for the Marmara region during winter, spring, and summer are 140, 107, and 40 µg/m^3, respectively. These values are lower in comparison. Once again, the data for fall is also unavailable for the Marmara region.

To partially explain the difference, it was observed that the mean altitude of the inversion layer in the Marmara Region during dust storms at 00:00 UTC (as determined by radiosonde measurements in Istanbul) is 273 m, whereas in the Aegean region (as determined by radiosonde observations in Izmir), the inversion level was found to be 594 m. According to the given statistics, spring has the highest number of DEDs with a frequency of 13, followed by winter with 5 occurrences, and summer with 1 case. In contrast, autumn has no documented cases of "dust storm event days" (DED).

Fluck and Raveh-Rubin (2023) conducted a study on 325 dust-dry intrusion (DI) events that occurred between 2003 and 2018. According to Browning (1997), DI is a region of air that descends from near the tropopause level. According to the study, an event called a dust-DI event was identified when DI and dust objects matched for a minimum of 12 hours. Dust objects were determined based on high DOD levels.

It was discovered that the events primarily occurred between November and April, reaching their highest point in February and March. In February and March, it was observed that the events had the longest duration, lasting 1-4 days. They also covered the largest area and showed the highest intensity compared to dust events not associated with DIs in those months. It was discovered that winter events tend to be larger in size and have a longer duration, in contrast to summer events.

Upon analysis of the dust optical depth from CAMS at a wavelength of 550 nm, it was observed that the levels tended to be higher in the presence of dry intrusions (DIs). It was observed that the occurrence of dust objects is highest during the summer months, with a frequency of over %95 from April to August. However, this frequency drops significantly to %20 in December, only to rise again to %80 in March. It was discovered that a specific mechanism was responsible for the events that occurred in March. This mechanism involved a shift in the northward jet over the North Atlantic, followed by the breaking of anticyclonic Rossby waves about 4-5 days before the

events.

As a result, the lower troposphere experienced dry and cold conditions in northwest Africa. At the same time, the DI airstream started to flow out, initially guided by the upper trough. This eventually led to higher dust concentrations near the surface in tropical west Africa and northeast Africa. In addition, the dust was carried to the Mediterranean due to the presence of a Mediterranean cyclone.

According to the information, the highest concentration of large dust particles is at the front of a relatively cold and dry DI outflow. This outflow is usually limited to the lower troposphere and is commonly observed in tropical West Africa. Based on studies by Flaounas et al. (2015), Kalkstein et al. (2020), Flaounas et al. (2022), it has been established that the dust is carried northward in connection with Mediterranean cyclones. Given the information provided, it was noted that DI analysis could identify precursors for significant dust emission and transport up to 5 days in advance. This could potentially allow DI diagnostics from observations to offer an extra warning signal to operators at meteorological services and early warning centers.

Nissenbaum et al. (2023) conducted another research that specifically examined the concept of DI. A climatological set of extreme dust events in Israel between 2003 and 2020 was created using PM_{10} measurements, ERA5 (ECMWF Reanalysis v5), CAMS reanalysis atmospheric data, and an automated unsupervised machine learning method.

Six distinct categories were identified, which correspond to events controlled by i and ii) cyclones moving eastward over the Mediterranean Sea (Shallow and Deep Mediterranean cyclones) i)observed most frequently during autumn-winter and lasting approximately one day in Israel, ii) observed most frequently during late winter and lasting around 2-4 days in Israel), iii) certain extreme cases resulting from a significant difference in sea level pressure (SLP) known as the Mediterranean Dipole, which carries dust across North Africa before dry intrusions (observed during winter and lasting approximately 2 days in Israel), iv) the Sharav Thermal Low events in Israel can be attributed to three main factors, each with its own seasonal pattern.

Firstly, during spring, there is a unique phenomenon where a thermal low in North

Africa propagates eastward, leading to the development of low events that typically last for 1-3 days. Secondly, in winter and early spring, the Arabian Anticyclones, characterized by anticyclonic conditions, transport dust from easterly sources, resulting in low events that typically last around 3 days. Lastly, local factors come into play during summer, causing low events that typically last a few hours.

These factors exhibit distinct seasonalities. Dry intrusions significantly influence all situations except for the local Summer type. They are characterized by increased surface winds and elevated amounts of dust. The study revealed that the slantwise-descending dry intrusions are an important precursor dynamic characteristic shared by three clusters with the highest PM_{10} concentrations. Dry intrusions are known to increase the amount of dust by creating dry winds at the surface. The use of the machine learning technique was suggested to facilitate an objective assessment of the patterns of dry intrusion occurrence and their impact on the intensification of dust events in the region.

The research stated above documented a total of 356 episodes of desert dust episodes. These episodes were identified based on a threshold of 2 standard deviations above the background level at various locations. The threshold level was specifically set at 65.3 μg/m^3. During these episodes, the PM_{10} levels reached the following values: i) PM_{10} peak levels of 80–100 μg/m^3 in Israel, ii) PM_{10} peak levels of 160 μg/m^3 in Israel but higher in Balkans, iii) PM_{10} peak levels of 80–200 μg/m^3 in Israel, iv) PM_{10} peak levels of 160 μg/m^3 in Israel again, v) average PM_{10} levels of 80–120 μg/m^3 in Israel, and vi) average PM_{10} levels of 70-80 μg/m^3 in Israel.

Gallisai (2016) studied 153 dust events that occurred between 2000 and 2007. The study found that the modeled dust deposition during this period was highest in late autumn and winter in the Central and Eastern Mediterranean. However, the overall annual variability was lower compared to the Northern-Northwestern Mediterranean. In the latter region, there was a spatially high deposition close to Africa, with a decreasing gradient from South to North of the Mediterranean basin. Large dust deposition episodes exhibit significant variety in terms of the area impacted within a certain time frame.

The Eastern Mediterranean has the highest level of impact during winter, followed

by the Central Mediterranean in fall and the Western Mediterranean in spring. Out of all the instances of significant dust deposition, 31 were classified as very significant dust deposition occurrences. These events were not evenly distributed throughout seasons, with 12 occurring in winter, 5 in spring, and 14 in fall. There were a total of 7 significant dust deposition occurrences observed in the Western Mediterranean, 13 in the Central Mediterranean, and 11 in the Eastern Mediterranean. Dust deposition onto surface waters was found to be greater in the Eastern Mediterranean than in the Western Mediterranean.

The studies previously conducted for the Marmaris rural station are deemed to provide valuable information for this thesis. Studies of E. S. Uzunpınar et al. (2022), S. Uzunpınar et al. (2023), Uzunpinar et al. (2023) and the project associated by TÜBİTAK (2019) are among such studies. According to Uzunpinar et al. (2023), the Saharan dust episodes were found to be most frequent during the spring period in two stations, one being the Marmaris station. Dust transport from the Middle East was not recognized as frequent enough to discuss its monthly distribution. At the Marmaris station, non-dust episodes were found to be most frequent during the winter season due to the arrival of sea salt. (Uzunpinar et al. (2023))

Specific information on arid region dust plumes arriving at possibly Muğla is given in Table 2.1, as compiled from the literature. The identified dates include part of 06-11.09.2015 and 01-03.02.2015. These dates are depicted as intense dust episode dates.

There were also remarks made regarding heights in the literature. To exemplify, the layers from ground level to 4.5 km, from ground level to 5.5 km, 2.5 km to 7.5 km, and from approximately ground level to about 3 km were found to be composed mainly of Saharan dust based on measurements for 17.02.2014, 24.02.2017, 01.02.2018 and 18.02.2019 respectively at Sofia, according to the study of Deleva et al. (2021). The differences in vertical profiles based on these measurements (smooth profile shapes, sublayers, centered at and around the upper boundary of the atmospheric boundary layer or high above it, well separated, etc.) were mainly attributed to differences in whether the lidar measurements were conducted in the initial or middle phase of the dust load event. In the study of Soupiona et al. (2020), the dust layers were detected

between approximately 1.6 and 5 km altitudes.

Regarding levels of PM_{10} reported, the PM_{10} time series from background monitoring stations in seven countries were analyzed by Gómez-Losada and Pires (2020) from 2015 to 2018. The average characteristic contributions of arid region dust to PM_{10} were estimated as 11.6 ± 10.3 μg/m^3 (Bosnia and Herzegovina), 8.8 ± 7.5 μg/m^3 (Spain), 7.0 ± 6.2 μg/m ^{3} (France), 8.1 ± 5.9 μg/m^3 (Croatia), 7.5 ± 5.5 μg/m^3 (Italy), 8.1 ± 7.0 μg/m^3 (Portugal), and 17.0 ± 9.8 μg/m^3 (Türkiye) based on European Environment Agency (EEA) data.

Exceedance of PM_{10} daily average concentration of 150 μg/m^3 was set as a threshold, as this had been detected as the maximum level in Southern Europe during dust outbreaks in the literature (Goudie (2014) and Querol et al. (2019)). For dust episode dates, the numbers of dates with such exceedance from Turkish background station were found to be 21, 19, 24 and 14 for 2015-2018 in the order of years.

These exceedance dates were separated into dust and non-dust dates. For dust dates, minimum, median and maximum PM_{10} values were found to be 167.0, 261.6 and 444.9 μg/m^3, 263.7, 267.2 and 338.4 μg/m^3, 152.6, 232.0 and 334.3 μg/m^3 and 180.9, 192.3 and 208.7 μg/m^3 for 2015-2018, again in the order of years. The same information was provided for non-dust exceedance dates as 7.0, 31.3 and 125.3 μg/m^3, 4.5, 21.4 and 105.9 μg/m^3, 7.5, 27.4 and 113.1 μg/m^3 and 5.4, 21.1 and 110.0 μg/m^3 in the same order.

Average severe contributions of desert dust were quantified as 66.4 ± 42.8 μg/m^3 (Bosnia and Herzegovina), 33.2 ± 25.4 μg/m^3 (Spain), 22.5 ± 14.5 μg/m^3 (France), 28.1 ± 16.7 μg/m^3 (Croatia), 28.4 ± 17.6 μg/m^3 (Italy), 28.1 ± 21.2 μg/m^3 (Portugal), and 73.1 ± 69.8 μg/m^3 (Türkiye), whereby Bosnia and Herzegovina and Türkiye are seen to have the highest levels. Pollution profiles were determined by excluding outlier data, meaning 1.5 times below and higher than the 25th and 75th percentile in distributions, where Türkiye was determined as the country with the highest pollution profile for PM_{10} among the 7 countries.

Türkiye was mentioned to receive a higher dust load than the others, especially for the year 2015, and mainly Spain, among the remaining 6 countries, was mentioned to

Table 2.1: Information on arid region dust plumes arriving (possibly) at Muğla

Date	**Source of information**	**Confirmed arrival to Muğla?**	**Notes/Phrases**
Date(s) within the period 06-11.09.2015	Source[11]	Not specified.	"From the 6th until the 11th of September, the storm swept through Iraq, Syria, Lebanon, Israel, the Palestinian territories, Jordan, Egypt, and even parts of Turkey and Cyprus."
Date(s) within the period 06-09.09.2015	Source[7]	No. It was mentioned that the plume had reached "part of Turkey's Mediterranean coast."	"Dust first emerged in [MODIS] satellite imagery in Syria on September 6, 2015. By September 7, a thick plume swept across Syria, the Mafraq region of Jordan, and part of Turkey's Mediterranean coast. By September 8, the dust had enveloped all of Lebanon, Israel, Jordan, Cyprus, and the Palestinian Territories. By September 9, it had moved southwest and spread over northeastern Egypt and the Gulf of Suez." "In Jerusalem, pollution levels were 173 times higher than average."
01-03.02.2015	Source[12] Source[13] Source[14]	Yes for 01.02.2015. Not specified for the rest.	"Turkey was buffeted by strong southwesterly winds known locally as lodos.[...]They also helped bring ashore a cloud of dust that originated in Africa's Sahara Desert." "the dust [...] moved from North Africa, swept northeast over the Mediterranean Sea, and blanketed the atmosphere over Turkey and Greece. According to media reports, the dusty winds turned the sky orange in Istanbul (north of this image)." It was further mentioned that the timing was very unusual for such a dust event.
01.02.2015	Çapraz and Deniz (2022)	No (İstanbul) but linked to the episode above	"emergency attendances for acute bronchitis significantly increased on the episode day."

have a similar situation as a country typically suffering from desert PM contributions.

218 Saharan dust events were studied by Varga (2020) in the Carpathian Basin lying in Central Europe for the period from 1979 to 2018, for which different synoptic meteorological patterns occurring mostly in spring and summer were found responsible. It was mentioned that several intense wintertime dust deposition events have been recorded in Central Europe since 2014, which were between the end of October and February, although the main period of dust transport to Europe is the spring and summer.

All of these winter events were characterized by severe washout of mineral dust material and were found to be related to very similar synoptic meteorological situations. Within the 90 Saharan dust events with a total of 2.1 g/m^2 dust deposition studied for the 2009-2018 period, 16 events (%18.8 of number of events) with 0.5 g/m^2 deposition (%24.9 of weight), 26 events (%30.6 of number of events) with 0.8 g/m^2 deposition (%40.0 of weight), 30 events (%35.3 of number of events) with 0.3 g/m^2 deposition (%15.0 of weight) and 13 events (%15.3 of number of events) with 0.4 g/m^2 deposition (%20.0 of weight) were detected for the groups of months December-January-February, March-April-May, June-July-August, and September-October-December respectively.

It was mentioned that an increase in the annual occurrences in the 2009-2018 period (the total number of Saharan dust events as 90 for the said period were reported as 48, 27, and 53 for 1979–1988, 1989–1998, and 1999–2008 respectively) as well as changes in seasonal distribution of deposition in the last quarter were recognized where almost %25 of the Saharan dust deposition occurred during winter. A warning made by the authors that the general increasing trend of numbers of SDEs and the increasing wintertime amount of deposited dust material shall not be directly interpreted as the increasing intensity of dust events where there are grain-size-related uncertainties.

During some intense deposition episodes, deposited mineral dust particles of medium (6.25–20.00 μm) and coarse silt-sized (20.00–62.50 μm) sizes were detected, and it was mentioned that such bigger particles are usually not accounted for in model simulations. A major finding presented is the clearly changing characteristics of re-

cent wintertime Saharan dust-deposition episodes together with enhanced warming of high latitudes of the Northern hemisphere during severe winter dust events of the 2009-2018 period.

For the period between 2006 and 2017, desert dust storm events in three Eastern Mediterranean sites in Crete (Finokalia background station), Cyprus (Ayia-Marina Xyliatos background station), and Israel (Beer Sheva urban station) were studied by Achilleos et al. (2020). 810 (Cyprus), 451 (Crete), and 633 (Israel) events were identified, and 91 events originating from Saharan or Middle Eastern deserts or a combination of them were common in all. While for Crete, the Saharan desert was determined via backtrajectories as almost totally the source of dust, for Cyprus and Israel, Daily PM_{10} concentration above 35 μg/m^3 and 28 μg/m^3 were found to be a significant indicator of these storms for the background sites of Cyprus and Crete respectively.

Higher thresholds were found for Israel depending on the season (fall and spring: 70 μg/m^3, winter and summer: 90 μg/m^3). %15, %51, and %14 of events for Cyprus, Crete, and Israel, respectively, were found to have occurred at not ground level but higher altitudes.

It was mentioned that the years with the highest frequency of these storms were not the years with the most intense episodes (the highest dust frequency was observed in 2010 at all three locations, but the highest annual median dust-PM_{10} level was observed in 2012 in Crete (55.8 μg/m^3) and Israel (137.4 μg/m^3), and in 2010 in Cyprus (45.3 μg/m^3). The highest concentrations observed during these storms were reported as 705.7 μg/m^3 and 1254.6 μg/m^3, respectively, for Crete and Cyprus (the same Saharan dust storm event in 2006), and 3210.9 μg/m^3 for Israel (a three-day Saharan dust storm event in 2010).

With the selection of two-year periods, the mean PM_{10} ± standard deviation found for event days in the selected years 2011 and 2014 together was 45.8±35.0 μg/m^3 in Cyprus and 42.3±26.4 μg/m^3 in Crete, the same for Israel in the selected years 2011 and 2017 together was 89.0±72.0 μg/m^3.

The peaks of events' characteristics such as daily PM_{10}, AOD, hourly and daily PM_{10} maxima, seasonality were found to be observed in different years, mainly due to

the inter-annual variability of local, regional and global climatic conditions. It was mentioned that trend analysis results for event characteristics differ across studies, locations, and time periods.

An interesting finding is that even though the Cyprus site had the highest number of identified DDS, only %33 of them exceeded the EU PM_{10} daily limit of 50 μg/m^3, probably due to the frequency of low-intensity events or since dust aerosol was traveling in the upper atmospheric levels above Cyprus in several of these events.

In Crete and Israel sites, %41 and %91 of the total events identified were found to be exceeding the EU PM_{10} daily limit, respectively. From the results tabulated therein, it is seen that the following number of events were detected at each site for 2014, 2015, 2016, and 2017, respectively: 49, 48, 35, 48 in Cyprus; 43, 37, 49, 29 in Crete, 46, 49, 53, 45 in Israel (the numbers tabulated in the study as findings of automated and manual analyses were summed here to obtain the total numbers per years).

In the same study, 546 events were identified for 2000-2017 in Cyprus with the inclusion of an urban station (Nicosia) together with the rural background station, where for more than half of events (n = 391) PM_{10} levels were found to exceed the daily EU limit of 50 μg/m^3 at the urban station and the annual incidence range in Cyprus was found as 20–34 events per year. It was mentioned that no statistically significant trend was observed from 2000 to 2017, and no statistically significant trend in seasonal variability of DDS frequency and intensity was detected in Cyprus.

In Cyprus, the dust PM_{10} annual median was reported to range from 41.2 μg/m^3 (2011) to 100.6 μg/m^3 (2008) μg/m^3 at the Nicosia urban site and from 30.1 μg/m^3 (2012) to 79.3 μg/m^3 (2008) μg/m^3 at the rural area. The highest daily maximum dust PM_{10} level was observed in 2006 (urban: 1498.2 μg/m^3, rural: 1307.4 μg/m^3), and the lowest in 2016 (urban: 94.3 μg/m^3) and 2011 (rural: 113.6 μg/m^3) in Cyprus. It was mentioned that the driest year in the last 18 years was also the year with the highest frequency of events exceeding the EU daily limit and the highest annual dust PM_{10} concentration for the urban area of Nicosia.

Most of the literature on the contribution of arid region dust to PM_{10} levels in Turkiye is relevant to African air masses. However, other arid regions may also contribute;

where one example is the study of Karaca et al. (2009) on İstanbul for the year 2008 with backtrajectories computed at 500 m, 1000 m, and 1500 m above ground level (a.g.l.). It was found by the authors that air masses arriving in İstanbul include air pollution originating in European and Black Sea countries during winter and mineral dust-loaded air originating in the northern Mediterranean and Arabian countries during spring. An Asian region, eastern Turkmenistan, was found to be an important source region for autumn. Flores et al. (2017) is another example of the studies including non-African arid regions' contribution to Turkiye, again specifically İstanbul, where backtrajectories were analyzed for the period 2007-2014. It was found that through cluster analysis of yearly trajectories that the five mean air mass trajectories arriving at Istanbul are from (1) northerly direction from Europe (2-%29), Ukraine-Finland-Black Sea (%10-40), and Russia-Asian Desert-Black Sea (%6-35) and (2) southerly direction from the western Mediterranean Region (%14-24), African desert (%7-21), and short trajectories from the Greece-Aegean Sea (%21-40). Over the whole study period, the main trajectories arriving at İstanbul at 500 m were found to have northeastern trajectories (%42 frequency) that may be associated with desert dust transport from the Asian desert and Arabian Peninsula at 1000-1500 m through the Black Sea. The northern trajectories with the highest frequencies were found to be associated with particulate matter transported from the Asian desert, Arabian Peninsula, Russia, and Ukraine.

Regarding forest fires, according to the General Directorate of Meteorology (2018), the period of forest fires is the 6-month period between May 1 and October 31, although forest fires can also occur at other times, even in winter. It is further mentioned that %92 of forest fires in Türkiye are anthropogenic, whereas % 8-10 have natural causes such as lightning or effects of tornadoes on energy lines.

According to the past 10 years' data analyzed in General Directorate of Forestry (OGM) Forest District in Muğla (2023) report, and according to this report, %36 of forest fires originate from lightning strikes. Furthermore, yearly numeric data for the Muğla region is given in Table 6 of the said report, from which the yearly percentages can be calculated by simple division as %39.4, %30.7, %29.8, %30.0, and even %50.1, for the years 2014-2018 respectively in the order of years, and an overall percentage can be calculated as %36.7 for the said period with the data of forest fires.

According to Çamalan and Çamalan (2023), annually, one big forest fire was found to have occurred during the years 2005-2022. 245 big forest fires occurred (covering a minimum of 100 hectares each), leading to a total forest land damage of 235.535 hectares. In the big forest fires, %67 of the number and %85 of the burnt land surface area occurred in the forests under the jurisdiction of Muğla, Antalya, İzmir Kahramanmaraş, Adana, and Mersin Forest Districts.

It was also mentioned in Çamalan and Çamalan (2023) that the European Forest Fires Information System (EFFIS) provides accurate information about forest fires to which Türkiye is a party. According to the article, EFFIS utilizes the active forest fire data of NASA's Fire Information System for Resource Management System (FIRMS), which are data acquired based on thermal anomalies, being monitored with the tools of MODIS as well as NASA SNPP and NOAA-20 VIIRS satellites. VIIRS is mentioned to be more effective than MODIS in detecting relatively small forest fires that can be ignored by MODIS and in identifying the borders of the continuing major fires.

Based on this article, the FIRMS database Active Fire Data[15] was thought of as a valuable resource for forest fires. It is seen that MODIS C6.1 data are available in the database from November 2000 (for Terra) and from July 2002 (for Aqua) to present, and VIIRS 375 m (S-NPP) data are available from 20 January 2012 to present. The other data do not match the time range studied in this thesis.

The study by Demirel and Türk (2023) mentions that Muğla is among the 5 provinces with the highest number of forest fires in the eight years 2015-2022. The number of forest fires in Muğla for 2015, 2016, and 2017 are 214, 303, and 190, respectively. Furthermore, the percentage distribution of causes of forest fires in Türkiye for the said period is given separately for causes such as "natural," "anthropogenic," and "unknown." Percentages for the causes marked as "ignorance" and "accident" are also given, which could be among the cases that are counted as anthropogenic, according to European Commission (2011) Guidance.

According to Gayır and Arslan (2018), Muğla Forest District has "1st Degree Fire Sensitivity". It is further mentioned that lightning is the cause of 126 out of 320 forest fires in Muğla in 2014 and 78 out of 254 in 2015, corresponding to % 39.4 and

[15] https://firms.modaps.eosdis.nasa.gov/active_fire/

% 30.7, respectively. These ratios are excessively higher than the rest of the figures (for the whole Türkiye) provided in the literature. Furthermore, the number of forest fires in Muğla in 2015 differs from the study results of Demirel and Türk (2023).

According to Mateos et al. (2019), who studied forest fires that occurred during a 2.5-year period in Cordoba City (Argentina), levels of Fe, Ca, and K were significantly higher in fire periods than in the nonfire periods, suggesting that these elements can be reliable forest fire markers. It was mentioned by Popovicheva et al. (2017)that the concentration of the potassium ion K+ in smoke aerosols was between 0.2 and 2.8 μg/m^3, with an average of 1.1 μg/m^3, which is an order of magnitude higher than the background value.

According to the supplementary material given for Calvo et al. (2013) the mean concentration of K at 12 different sites where wildfires had occurred is seen to be in the range between 0.84-14 for $PM_{2.5}$ and 0.79-22 for $PM_{2.5}$-PM_{10}. According to Cheng et al. (2013), the $PM_{2.5}$ scale K concentration during biomass burning episode in summer at Beijing was at the level of 5.81±2.75 ug/m^3. Several other studies mentioned K levels as indicators for biomass combustion or forest fires. K data in those studies was generally used in combination with additional data on organic carbon (OC), elemental carbon (EC), and levoglucosan levels, which are absent in the rural station in this study.

Meanwhile, K is related not only to forest fires but also to volcanoes. Particulate K compounds are found in Mountain Etna emissions. However, the decrease in K concentrations before the eruption was mentioned by Quisefit et al. (1988). According to the findings of Allen et al. (2006), K is a major part of the coarse aerosols from Etna, as the second most abundant (following sulfate) part of the coarse aerosols in the Northeast crater of Etna, according to the measurements conducted from 28 July to 5 August 2004. K concentration at different stages relevant to Etna was also studied by Martin et al. (2008).

Further, regarding volcanoes, Etna and Stromboli are the closest ones, so a literature search was focused on them. However, as Stromboli was previously mentioned to be associated with strombolian volcanic activity, after which it was named, Etna was considered the most relevant volcano. Etna was mentioned to be continuing emission

to air on 21- 26.5.2016 according to the Chamber of Geological Engineers (2017) report. Ash emissions were reported from Etna on 12.12.2015 in the report of Natural Disasters Working Group (2016). There are various additional activity records found on two websites dedicated to volcanoes, namely Etna Volcano Profile[16] and Interactive Map of Active Volcanoes and recent Earthquakes worldwide[17].

One case of intersecting reports is for December 2015. It is mentioned in the study of Aloisi et al. (2017b) that during the first days of December 2015, there were four paroxysmal events at the "Voragine" crater on Mount Etna, which were among the most violent observed during the preceding two decades. The ash emissions are reported to have started in August 2015 and occurred intensely on 3-11.12.2015. The website Etna Volcano Eruption Update[18] has similar records.

Volcanoes are known to emit PM_{10} and SO_2, among other substances. SO_2 emissions from the volcano Nabro in Eritrea were analyzed by Liu et al. (2019). It was mentioned that the average time to convert SO_2 to sulfate was found to be 27 days, and the residence time of volcanic SO_2 in low latitudes was the longest, where daily concentration was continuously higher than the background value of about 3 months after the eruption. Meanwhile, the figures given therein are seen to include altitudes higher than 10 km for the detection of sulfate. On the other hand, the average residence times of SO_2at the volcano site in Montserrat island, North America, were analyzed in another study and found to be in the order of only minutes L. A. Rodríguez et al. (2008).

Regarding sea salt aerosols, to be able to estimate the sea-salt contribution by observing elemental concentration observations, the chemical composition of sea salt was tabulated in Guidance of European Commission (2011) and illustrated below as Table 2.2.

In this case, the sea salt contribution amount equals the summed ion concentrations. The following simpler formula was also included in the Guidance, directly derived from this Table 2.2:

$$[\text{Sea salt aerosol}] = 3.27 \times [\text{Na}] \tag{2.1}$$

[16] https://volcano.si.edu/volcano.cfm?vn=211060

[17] Please see Footnote 7

[18] https://www.volcanodiscovery.com/etna/current-activity-part-9.html

Table 2.2: Chemical Composition of Sea Salt - European Commission (2011)

Chemical ion	Valence	Concentration (mg/kg)	% Weight	Molecular Weight	Concentration (µmol/kg)
Chloride Cl	−1	19 345	55.03	35.453	546
Sodium Na	1	10 752	30.59	22.990	468
Sulphate SO_4	−2	2701	7.68	96.062	28.1
Magnesium Mg	2	1295	3.68	24.305	53.3
Calcium Ca	2	416	1.18	40.078	10.4
Potassium K	1	390	1.11	39.098	9.97
Bicarbonate HCO_3	−1	145	0.41	61.016	2.34
Bromide Br	−1	66	0.19	79.904	0.83
Borate BO_3	−3	27	0.08	58.808	0.46
Strontium Sr	2	13	0.04	87.620	0.091
Fluoride F	−1	1	0.003	18.998	0.068

While here the assumption is the completely marine origin for the whole Na concentration, sea salt aerosol concentration was calculated by Diapouli et al. (2017) with several elements, using only the "sea salt related" concentration portion within Na concentration data. The non-sea salt-related concentration portion of Na concentration was segregated through a calculation with the crustal Na/Al ratio -0.35 (to be more accurate, 0.348) - as done by Calzolai et al. (2015). The study is based on results from Lampedusa Island (Italy), and the elemental ratios for the crustal part were taken via calculation from the amounts given in the Book of Mason (1966). It was mentioned in Mason (1952)'s Book that while the amounts mentioned for Na, Al (along with other various elements) present the data on the abundances of the elements, most of these figures are based on determinations in igneous rocks but can reasonably be considered as representing abundances in the crust as a whole.

Several studies were conducted per the European Commission (2011) Guidance. According to Malta's Environment and Resources Authority (2020), the annual average of PM_{10} at one site in Malta (Msida) was reduced from 41.3 µg/m^3 to 38.2 µg/m^3 following subtraction of the African dust events contribution to PM_{10} levels. Percentage PM_{10} reduction figures are also provided in some studies after this subtraction. This

is relevant to various natural sources, mainly arid region dust. The summarized results are below in Table 2.3.

Table 2.3: Summarized results from literature with percentage PM_{10} reduction figures

Study	**Place**	**Period**	**Calculation method**	**Contribution to PM_{10} (%)**	**Natural PM_{10} source**	**Notes/Phrases**
Scerri et al. (2016)	Gharb-Malta	from March 2012 to May 2013	positive matrix factorization (PMF)	At rural background station, 39. Dust mentioned as "Saharan dust"	Sea salt aerosol	"This value is in the upper part of the range derived from previous studies, for natural contributions to PM_{10} in Europe (%0.5-%58)."

Table 2.3 – *Continued from previous page*

Study	**Place**	**Period**	**Calculation method**	**Contribution to PM_{10} (%)**	**Natural PM_{10} source**	**Notes/Phrases**
Compilation given for past studies by Scerri et al. (2016)(Pio et al. (1996), Querol et al. (2019), S. Rodríguez et al. (2002),Yin et al. (2005), Marenco et al. (2006),Beuck et al. (2011), Gianini et al. (2012),Masiol et al. (2012), Minguillón et al. (2012), Öztürk et al. (2012))	Areao / Portugal, Bemantes-Monagrega / Spain, Monagrega / Spain, Galway / Ireland, Cimone / Italy, Eifel / Germany, Payerne-Magadino / Switzerland, Venice / Italy, Payerne / Switzerland and Antalya / Türkiye	N/A	N/A	In the range %0.5-%58	Natural contribution	-

Table 2.3 – *Continued from previous page*

Study	**Place**	**Period**	**Calculation method**	**Contribution to PM_{10} (%)**	**Natural PM_{10} source**	**Notes/Phrases**
Diapouli et al. (2017)	Porto / Portugal, Barcelona / Spain, Milan / Italy, Florence / Italy, and Athens / Greece	from January 2013 to February 2014	In general: 30-day moving averages (corresponding to 40 percentile) of the previous and next 15 days of the regional background concentrations, excluding days with potential African dust transport. In Milan and Athens, it is in the 50 percentile instead of the average. In Florence: additionally, PMF analysis	2.2±0.1, 2.2±0.0, 2.2±0.0, 5.2±0.7, and 21.4±2.8 for the cities Porto, Barcelona, Milan, Florence and Athens respectively	Dust mentioned as "African dust"	"The mean annual relative contributions of African dust to the PM_{10} concentrations decreased from east to west: %21 in Athens, %5 in Florence, and %2 in Milan, Barcelona and Porto." "The African dust inputs were highest during spring and lowest during summer in Athens and Florence." "Except for Porto, results are in good agreement with Moulin et al. (1997), who reported that the annual cycle of African dust transport over the Mediterranean region starts during springtime in the eastern part, while during summer, there is maximum transport in the western part."
			Calculation with several elements based on sea-salt composition. Non-sea salt-related Na concentration was excluded based on the crustal Na/Al ratio.	12.3±1.2, 6.6±0.8, 1.3±0.1, 3.3±0.3, 8.1±0.7 for the cities Porto, Barcelona, Milan, Florence, and Athens respectively	Sea salt aerosol	"lower levels of sea salt at the inland Italian cities (Florence and Milan) and higher at the Mediterranean coastal sites, with the highest contribution observed at the Atlantic site (Porto)."
Diapouli et al. (2017)	Porto / Portugal	from late August to September 2013.	PMF	1.4±0.1	"Wildfires"	The cause being natural or anthropogenic (including neglect) not mentioned.

Table 2.3 – *Continued from previous page*

Study	**Place**	**Period**	**Calculation method**	**Contribution to PM_{10} (%)**	**Natural PM_{10} source**	**Notes/Phrases**
Calzolai et al. (2015)	Lampedusa island / Italy	2007–2008	Calculation from elemental concentration data and additionally PMF	According to the calculation, sea salt and mineral dust contribute to PM_{10} at levels of 26 and %18. PMF analysis gives higher ratios. It was concluded that "mineral dust" contribution is around %25, while "sea salt" constitutes about %40 (dry sea salt: %26, water: %14) of the PM_{10}.	Dust mentioned as "Mineral dust"	Improvements to this source apportionment mentioned to possible by considering the future carbonaceous fraction.
					Sea salt aerosol	-

Table 2.3 – *Continued from previous page*

Study	**Place**	**Period**	**Calculation method**	**Contribution to PM_{10} (%)**	**Natural PM_{10} source**	**Notes/Phrases**
Clemente et al. (2023)	Elche city and Mt. Aitana / Spain (Urban station at 12 km distance from the coast, regional background station at 1558 m a.s.l altitude and 16 km distance from the coast)	February 2019 and July 2019.	PMF	At urban site, 3 for February and 16 for July 2019. At the background site, 22 for February and 37 for July 2019.	Dust mentioned as "Saharan dust"	The average contribution of Saharan dust to PM_{10} levels was much larger at the mountain site (%33) than at the urban location (%9) due to the absence of significant anthropogenic emission sources in the vicinity of the regional background sampling station.
				At urban site, 12 for February and 17 for July 2019. At the background site, 16 will be for February, and 28 will be for July 2019.	Sea salt aerosol mentioned as "fresh sea salt" and "aged sea salt"	-
Maenhaut et al. (2016)	Four urban background sites in Flanders / Belgium (Antwerpen, Gent, Brugge, and Oostende)	From 30 June 2011 to 2 July 2012	PMF	9.7	Mentioned as "crustal matter"	Local and transboundary sources not differentiated

Table 2.3 – *Continued from previous page*

Study	**Place**	**Period**	**Calculation method**	**Contribution to PM_{10} (%)**	**Natural PM_{10} source**	**Notes/Phrases**
			PMF	29.2	Sea salt aerosol mentioned as "fresh sea salt" and "aged sea salt"	"It should be noted that our aged sea-salt factor also contained a substantial amount of secondary nitrate and sulfate"

Table 2.3 – *Continued from previous page*

Study	**Place**	**Period**	**Calculation method**	**Contribution to PM_{10} (%)**	**Natural PM_{10} source**	**Notes/Phrases**
Cuspilici et al. (2017)	Three stations in Sicily / Italy (Partinico, Enna, Misterbianco)	from 2013 to 2015		Calculated in terms of not PM_{10} but a number of exceedances of 50 µg/m^3 daily limit value as 3/4, 12/20, 8/9 total exceedances in the years 2013,2014,2015 respectively in Partinico station; 1/4, 1/9, 5/6 total exceedances in the years 2013,2014, 2015 respectively in Enna station; 3/4, 9/16, 2/5 total exceedances in the years 2013,2014,2015 respectively in Misterbianco station	mentioned as "Saharan dust"	There seems to be no separation between the Saharan contributions and other natural contributions such as sea salt aerosol for the identified dates.

CHAPTER 3

METHODOLOGY

The methodology is explained in this Chapter in the order of the types of natural contribution sources included in the study. Thus, with the addition of a section devoted to the retrieval and preliminary analysis of air quality data to enable the examination of all these contributions, the chapter comprises the following parts:

The methodology is mainly comprised of the following parts:

- Air Quality Data Retrieval and Preliminary Analysis
- Dust Transport from Arid Regions
- Volcanoes
- Forest Fires
- Sea Salt Aerosols
- Sea Sprays

Each of the following sections first involves information on the method to identify the relevant dates for the said contributions and then quantify their impacts on the PM_{10} levels measured at the nearby stations.

3.1 Air Quality Data Retrieval and Preliminary Analysis

The rural air quality station utilized in this study was operated with the support of TUBITAK in the project numbered 115Y252. The station was located at the Doppler radar and operated by the General Directorate of Meteorology, affiliated with the Ministry. The radar is located approximately 8 km to the northeast of the Marmaris province of Mugla on the Taurus Mountains, within a pine forest, at 936 m altitude

above sea level (a.s.l.). No industrial activity or settlement is reported for the vicinity of the station. The closest road was mentioned to be 5 km away, the Marmaris – Muğla road. Thus, it was mentioned that the station is completely rural type in the TÜBİTAK (2019).

In the TÜBİTAK (2019), automated laser spectrometer measurements were conducted in Marmaris and Ankara for PM_{10}, among other sizes of particulate matter, for the period April 2017 – October 2018.

PM_{10}, $PM_{2.5}$, and PM1 mass concentrations and number size distributions were measured using GRIMM Model EDM 164 laser spectrometer at the Marmaris site (TÜBİTAK, 2019; Uzunpinar et al., 2023; E. S. Uzunpınar et al., 2022; S. Uzunpınar et al., 2023. Particle number concentrations in 31 size bins between 0.265 µm and 34.0 µm particle diameters were measured with this laser spectrometer (TÜBİTAK, 2019; Uzunpinar et al., 2023; E. S. Uzunpınar et al., 2022; S. Uzunpınar et al., 2023. Elemental (Al, As, Ca, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, S, Si, Ti, V, Zn) concentrations were also determined for the same period with the following procedure explained by S. Uzunpınar et al. (2023): The filters were placed in Petri dishes and sent to analysis. Fifteen elements, including Al, Si, Ca, Na, Mg, K, Ti, V, Mn, Ni, As, Cu, Pb, S, and Zn, were determined in collected samples using Oxford, ED-2000 energy dispersive X-Ray Fluorescence Spectrometer at Turkish Atomic Energy Agency, Sarayköy Nuclear Research and Training Center. Elements were excited with an X-ray tube with 1000 µamp maximum current and 50 kV maximum voltage. The first excitation conditions were used to excite light elements Mg, Al, Si, Na, and S; the second condition was to excite K and Ca; the third condition for Ti, V, and Mn; the fourth for the remaining elements measured in this study, namely As, Ni, Cu, Zn, and Pb. The excitation conditions are tabulated below in Table3.1. The total analysis time was 17 minutes for each filter. This time also included removing analyzed samples from the turret and loading fresh filters. The total irradiation time was 7.5 min. A turret with 7 cassettes was used in the autosampler, and thus, batches of 7 samples were analyzed without changing samples.

For quality control concerns, the laser spectrometers used in these two cities were initially operated side to side for quality control. Blind sample and parallel sample

Table 3.1: Different measurement conditions used in the spectrometer during the analysis of a sample

Parameter	**Condition 1**	**Condition 2**	**Condition 3**	**Condition 4**
Tube Voltage (keV)	2.5	10	15	22.6
Tube Current (mA)	900	900	1000	494
Analysis Time (s)	150	100	100	100
Energy Range Analyzed	Na - K	K – Cr	Cr – Fe	Fe – Mo

analyses were performed. Blind samples were the samples prepared by merely placing and quickly removing the filters in the laser spectrometer device at the site, going through exactly the same steps as the normal samples otherwise. Parallel samples were the samples on which measurements were performed more than once to check data quality by sending them to the relevant laboratory within different sets of samples at different times without notifying the laboratory. The laser spectrometer measurement PM results conducted in Ankara were also compared with the PM data from air quality monitoring stations operated by the Ministry in Ankara, found to be of satisfactory quality: the average ± standard deviations, as well as the times of peaks, were found to be similar. On the other hand, the R^2 values obtained from the comparison of the background station's and Ministry stations' data were found to be quite low, only slightly higher than 0.10 (0.0121 for comparison with Demetevler station PM_{10} data and 0.0166 for comparison with Dikmen station PM_{10} data). However, it was mentioned that considering the huge datasets used in the comparison (14,000 PM_{10} and 14,000 $PM_{2.5}$), even such R^2 values were considered to mean a correlation with a confidence level higher than %95.

The rest of the air quality stations utilized in this study (all lying in the vicinity of the rural station, hereafter named as "nearby stations") are operated by the Ministry of Environment, Urbanisation and Climate Change (hereafter referred to as "the Ministry"). Data was downloaded in this study from the Ministry's server at Ulusal Hava Kalitesi İzleme Ağı(UHKİA)[19] open to public access for the period 30.03.2014-31.1.2018 and for the cities located around the Marmaris rural station. Table 3.2 lists

[19] http://sim.csb.gov.tr

the names and types of the stations used in this thesis study.

Table 3.2: Air Quality Stations Included in the Study

Station	**Type**
D0 – Marmaris_Muğla	rural background station
D1 - Milas Ören_Muğla	low-density-settlement/coastal station
D2 - Musluhittin_Muğla	urban station
D3 - Trafik_Muğla	urban station
D4- Fethiye_Muğla	urban/coastal station

Sampling in the rural station was conducted in linked studies by other researchers (S. Uzunpınar et al. (2023), E. S. Uzunpınar et al. (2022),Uzunpinar et al. (2023))

The locations of the stations can be seen in the Figures below 3.1,3.2, where population densities can also be seen. There are three thermal power plants close to these stations, i.e., Yatağan, Yeniköy, and Yatağan, which are all located in Muğla. On the other hand, Figure 3.3 demonstrates the thermal power plants and their coal mines near these air quality stations. The approximate distances to air quality monitoring stations are also given below Table 3.3[20]

Figure 3.1: The locations and population densities of the stations

After these specific pieces of information, the information on data availability across

[20]Figure 3.3 and the information tabulated in Table 3.3 are given by courtesy of Kutay Dişbudak

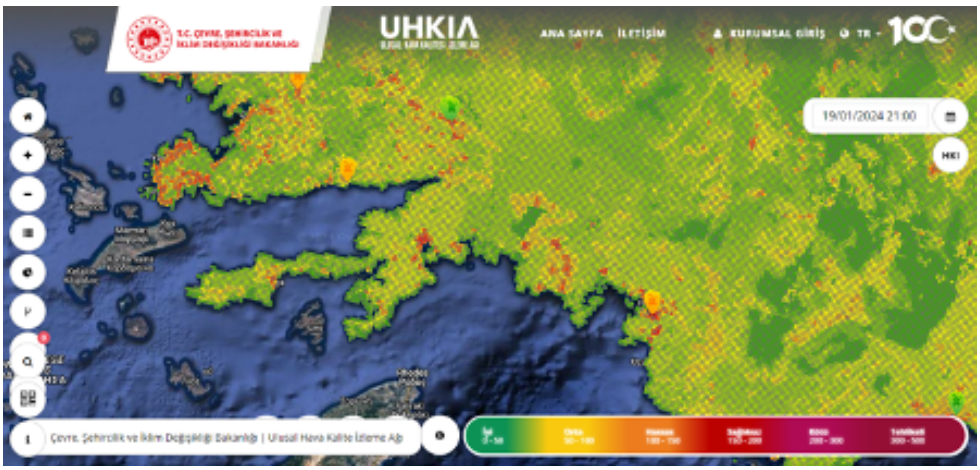

Figure 3.2: The locations and population densities of the stations

Figure 3.3: Thermal power plants and their coal mines close to air quality stations

Table 3.3: The approximate distances to air quality monitoring stations

Air Quality Stations	**Distance (km)**
Kemerköy – Milas Oren	6.33
Kemerköy – Marmaris	41.95
Kemerköy – Musluhittin	45.01
Yeniköy – Milas Oren	15.06
Yeniköy – Marmaris	49.85
Yeniköy – Musluhittin	43.65
Yatağan – Milas Oren	35.28
Yatağan – Marmaris	53.41
Yatağan – Musluhittin	25.60

different data categories can be seen below in Table 3.4

The time range given above specifies only the months in a broad sense. Yet, it should be remembered that there are daily gaps within the specified months. As is seen, also on the overall scale, there are big data gaps in the air quality monitoring data. Musluhittin station, among the Ministry's stations, provides data with the longest time range relevant to the study. On the other hand, if rural air quality monitoring data were almost the only type of data to rely on, the year 2017 would yield the most accurate results. Yet all of the data categories above are important, and they all serve as valuable tools. There are several uncertainty factors regarding various data categories, as described elsewhere in this thesis.

Daily PM_{10} values are unavailable for the Trafik station due to the very low number of hourly data per day from that station. On the other hand, the limited duration of available hourly PM_{10} data can be seen from the table as February and May- July 2018. In fact, there are also hourly PM_{10} data for January 2018. However, they seem to be erroneous, as the PM_{10} level 47.52 µg/m^3 is repeated on several days without any other value in between. Thus, the supplementary data to be used -if necessary- from Trafik station starts in February 2018.

Table 3.5 shows the main characteristics of available air quality monitoring station

Table 3.4: Time ranges of available data

CATEGORY	RELEVANT DATA TYPE	AVAILABLE TIME RANGE (within January 2014 – December 2018)
1. Air quality monitoring station data	1.1 Rural station data - Marmaris: PM_{10} and elemental composition (operated with the support of TUBITAK project numbered 115Y252, coordinates: 36.886944, 28.333889, distance to the Mediterranean Sea: approximately 6 km, altitude: 936 m above sea level (a.s.l.))	March – May 2014, August – September, November - December 2015, January – February, August – October 2016, January – December 2017, January 2018
	1.2 Urban station data – Musluhittin: PM_{10}, SO_2 (operated by the Ministry, coordinates: 37.2170, 28.3535, altitude: 647 m a.s.l.)	PM_{10}: End of March 2014 – January 2018 SO_2: End of March 2014 – January 2018 with few data in May 2015
	1.3 Urban station data – Trafik: PM_{10} (operated by the Ministry, coordinates: 37.2122, 28.3665, altitude: 652 m a.s.l.)	None (daily). Some hourly PM_{10} data for; February 2018, May – July 2018
	1.4 Low-density-settlement/Coastal station data - Milas Ören: PM_{10}, SO_2 (operated by the Ministry, coordinates: 37.0309, 27.9716, altitude: 3 m a.s.l.)	PM_{10}: July – December 2016, December 2017 – February 2018, SO_2: July – December 2016, December 2017 – June 2018 with only 3 data after April 2018
	1.5 Urban/Coastal station data - Fethiye: PM_{10}, SO_2 (operated by the Ministry, coordinates 36.6262, 29.1292, altitude: 11 m a.s.l.)	PM_{10}: January – February 2018, SO_2: January – August 2018
2. Backtrajectories	Previously[a] calculated TRAJSTAT backtrajectories for 100, 500, 1000 m agl (1036, 1436, 2436 m asl)	End of March 2014 – January 2018
3. Satellite photographs	MODIS Aqua and Terra photographs via NASA Worldview	End of March 2014 – January 2018
4. Aerosol Optical Depth (AOD)	MODIS MAIAC's AOD	End of March 2014 – January 2018
5. Aerosol model	Multi-model and DREAM8-CAMS – surface concentration	End of March 2014 – January 2018

[a]The TRAJSTAT backtrajectories had been previously calculated in another study: TÜBİTAK project no. 118R072 on determination of dust transport routes and natural dust contribution in Southern parts of Türkiye

data. Again, the statistical values tabulated for different data categories belong to their own periods of data availability within the interval from January 2014 to December 2018, as shown in the abovementioned table.

It is seen that the dates with a low number of hourly data were not considered by the Ministry for daily average calculations. This approach is adopted in this thesis, and the daily datasets published by the Ministry are utilized without direct computation from hourly data. However, amendments were described below in Table 3.6: There are negative hourly PM_{10} and SO_2 values at Milas Ören station, as tabulated. The table demonstrates the dates with many negative or missing hourly data for which daily values do not exist (excluded by the Ministry from daily average calculations). Furthermore, it is seen from the Ministry's hourly dataset that the dates with many negative hourly SO_2 values and only some, or no, negative hourly PM_{10} values were still excluded from not only the daily SO_2 values dataset but also the daily PM_{10} values dataset. This might be due to possible error factors affecting both. It was seen in this thesis that the date 23.08.16 could be additionally excluded from the dataset in the same manner since it has 6 hours of negative hourly SO_2 values. The negative values range between -0.01 and -0.54 for that date, all very close to 0. Yet in this thesis, the daily datasets published by the Ministry are used by excluding some more dates, including the specified date. Especially the dates 21, 24-26.08.2016, 04.09.2016, 19-20.09.2016, and 11.10.2016 have records of low or very low negative hourly PM_{10} values, and the date 27.08.2016 has records of low negative hourly SO_2 values. The negative values can be as low as -29.4 µg/m³.

Furthermore, the date 25.1.2018, for which the daily average exists, was seen to have excessive missing hourly data for PM_{10} and SO_2. Thus, this date was also excluded from the daily dataset regarding Muslihittin station.

It should be noted that the following seasonal grouping was used in the thesis: winter (December-January-February), spring (March-April-May), summer (June-July-August), and autumn (September-October-November).

Table 3.5: Data characteristics

RELEVANT DATA TYPE	mean	median	[min-max]	Notes
1.1.1. Rural station data - Marmaris: PM_{10} (µg/m³)	14.6	8.5	0.1 - 174.0	
1.1.2. Rural station data - Marmaris: Al (ng/m³)	90.2	48.0	0.0 – 971.2	
1.1.3. Rural station data - Marmaris: Fe (ng/m³)	1387.4	1717.3	2.6 - 4749.4	
1.1.4. Rural station data - Marmaris: Si (ng/m³)	243.0	136.4	1.4 – 2427.1	
1.2.1. Urban station data – Musluhittin: PM_{10} (µg/m³)	76.6	66.7	16.3 – 327.3	
1.2.2. Urban station data – Musluhittin: SO_2 (µg/m³)	24.0	16.0	0.6 – 179.5	
1.3.1. Urban station data – Trafik: PM_{10} (µg/m³)	N/A	N/A	N/A	There are excessive gaps in the hourly dataset, and thus no daily dataset exists. Kept in the dataset only as a supplementary (hourly) information source for PM_{10} to be checked where necessary.
1.4.1. Low-density-settlement/Coastal station data - Milas Ören: PM_{10} (µg/m³)	37.4	34.7	11.6 – 87.8	Negative hourly PM_{10} or SO_2 values seen on the dates given in the following table. Those dates are to be handled cautiously.
1.4.2. Low-density-settlement/Coastal station data - Milas Ören: SO_2 (µg/m³)	17.7	11.2	0.4 – 145.0	
1.5.1. Urban/Coastal station data - Fethiye: PM_{10}, SO_2 (µg/m³)	69.0	76.3	17.5 – 106.5	Data exists only for 2 months, again with gaps
1.5.2. Urban/Coastal station data - Fethiye: SO_2 (µg/m³)	4.1	2.3	1.0 – 40.2	

Table 3.6: Dates which yielded negative hourly PM_{10} or SO_2 values at Milas Ören station

Dates with Negative Hourly PM_{10} Values	**Dates with Negative Hourly SO_2 Values**
13.07.2016 - already excluded	12-31.07.16 – already excluded
20.07.2016 - already excluded	01-20.08.2016 - already excluded
24-25.07.2016 - already excluded	
03-05.08.2016 - already excluded	
07.08.2016 - already excluded	
11-13.08.2016 - already excluded	
15.08.2016 - already excluded	
20.08.2016 – already excluded	
(Other dates between 13.07.2016 and 20.08.2016 – already excluded)	
The additional dates excluded daily in this study:	The additional dates excluded daily in this study:
21.08.2016 (1 negative hourly value, -4.4 µg/m^3, excluded by the Ministry)	21.08.16 (1 negative hourly value, -0.2 µg/m^3, excluded by the Ministry
	22.08.16 (1 very minor negative hourly value, -0.0 (-0.01) µg/m^3, excluded by the Ministry)
	23.08.16 (6 negative hourly values excluded by the Ministry from -0.01 to -0.54 µg/m^3)
24-26.08.2016 (Negative hourly values per day excluded by the Ministry, -29.4, -13.8 and -11.7 µg/m^3)	24.08.16 (1 negative hourly value, -0.2 µg/m^3, excluded by the Ministry)
	25.08.16 (1 very minor negative hourly value, -0.0 (-0.02) µg/m^3, excluded by the Ministry)
	27.08.16 (2 negative hourly values excluded by the Ministry, -0.8 and -1.0 µg/m^3)
04.09.2016 (1 negative hourly value, -23.0 µg/m^3, excluded by the Ministry)	
19-20.09.2016 (Negative hourly values per day excluded by the Ministry, -7.0 and -3.7 µg/m^3)	
11.10.2016 (1 negative hourly value, -8.7 µg/m^3, excluded by the Ministry)	

3.2 Dust Transport from Arid Regions

The method regarding the contribution of dust transport from arid regions was based on the Guidance document of European Commission (2011) in general, which in turn was focused on the analysis procedure suggested in the study of Escudero et al. (2005). The TÜBİTAK (2019) study was a major reference, where several adjustments were made to the procedure as shown below in Table 3.7, either for practicality or for being safe while establishing a method. S. Uzunpınar et al. (2023)'s study was also among the major references.

The analysis consisted of mainly rural and nearby stations' data, aerosol model (Multi-model), satellite outputs (AOD and photographs), and TRAJSTAT model. While the nearby stations' data were analyzed based on their own medians, the nearby stations' data were analyzed based on the medians of the following data:

Multi-model outputs and satellite photographs were visually inspected. There were eight outputs as 3-hourly forecasts, considered for each day. When the dust arrival was confirmed by one, the score 1 was given for the whole day. The score -1 was given when none of these forecasts confirmed the arrival. 0.5 was given when dust was seen to reach close points. The same scoring approach was applied to the daily satellite photographs. The satellite images were obtained from NASA's website for the MODIS Terra satellite. The analysis included evaluating a date combined with consecutive dates where necessary in case factors interfere with satellite photographs.

The TRAJSTAT computations were previously made in another study, the TUBITAK study numbered 118R072, on determining dust transport routes and natural dust contribution in Southern parts of Türkiye. They were computed as 5-day backtrajectories as proposed in the Guidance (European Commission, 2011) and at altitudes approximate to those proposed therein, as follows: 1036, 1436, and 2436 m a.s.l.corresponding to 750, 1500, and 2500 m a.s.l. for the rural station with 936 m a.s.l. With respect to TRAJSTAT, this thesis study involved only analysing these outputs. With "analysis," not only scoring the dates according to TRAJSTAT with respect to the indication of arid region dust transport is meant, but also recording the arid regions shown by TRAJTAT as the origin of air masses for each date.

MODIS MAIAC AOD product was used for Aerosol Optical Depth at 550 nm. Its data for a selected rectangular area covering all stations was automatically retrieved with the aid of Google Earth Engine, GEE. It was downloaded in numerical form (the code available on the web was adapted to the context of this study (some of the errors encountered were handled independently, and some were handled with the aid of Selda Güngör via AI tools)). As the scale is mentioned as 0.001 in the MAIAC user guide by Lyapustin and Wang (2022), the values acquired were then divided into 1000 to bring them to comparable levels with MAIAC AOD values given on the NASA EOSDIS website. The AOD levels were analyzed differently based on their own statistics, as described in Section 4.2.

In each of the analyses, the score 1 was used to indicate confirmation of arid region dust contribution on the date of concern, -1 to indicate rejection (the selected analysis showed no arid region dust contribution on the date of concern), 0 to indicate uncertainty (e.g. cloudiness over or just near the selected region on the date of concern, which prevents an understanding of confirmation or rejection status by satellite photograph analysis), and 0.5 to indicate probable arid region dust contribution (e.g. at least one of the Multi-model three-hourly outputs for the date of concern demonstrating dust not exactly over but very close to the selected region).

Table 3.7: Comparison of Study Methods

Analysis	**TUBITAK (2019)**	**Uzunpınar et. al (2023a)**	**Thesis**
Study period	April 2017 – October 2018	April 2014 – January 2018*	End of March 2014 – January 2018 (no rural data was available for the thesis after January 2018)
PM size	PM_{10}, $PM_{2.5}$ and PM1 data	PM_{10} and $PM_{2.5}$ data	PM_{10} data
Nearby stations' data	X (but done for another rural station in Ankara covered in the study - PM_{10}, $PM_{2.5}$, and SO_2 data)	X*	✓(2 nearby stations with PM_{10}, 3 nearby stations with SO_2 data)
Backtrajectories	✓	✓	✓
MODIS AOD and AI values, visuals	✓	X	MODIS MAIAC AOD data (AI data was considered unsatisfactory resolution). Retrieved numerically, as a difference.
Aerosol model	✓(DREAM model)	✓(DREAM model)	✓(Multi-model)
Satellite pictures	X (instead, MODIS AOD visuals were used)	✓	✓(to check for dust and cloud mask)
Elemental data from Marmaris station	✓(Al, Si – size not mentioned)	✓(Al, Si – size not mentioned)	✓(Al, Fe, Si – PM_{10} size)

*However, the same is the case for TÜBİTAK (2019) in the associated articles, E. S. Uzunpınar et al. (2022) and Uzunpinar et al. (2023)

The method differs from the method of S. Uzunpınar et al. (2023). PM_{10} data was the main PM data used in this study. The nearby stations were also taken into account together with rural station data, to allow for an integrated evaluation. AOD data was used. The multi-model aerosol model was preferred to the DREAM aerosol model. Among the elemental rural data, Fe data was initially also taken into account exactly in the same manner with Al and Si data. Other than these, the method is similar, utilizing satellite photograph and backtrajectory analyses, aerosol model analysis (although different models), and rural data from the very same station.

In the studies of S. Uzunpınar et al. (2023) and Uzunpinar et al. (2023), as well as in the TÜBİTAK (2019)study, Fe data was not made use of. It was mentioned in the study of Uzunpinar et al. (2023) that Al and Si were preferred as markers of crustal contribution because they are commonly used as crustal markers in numerous studies and other crustal elements such as K, Fe, Ti, and Ca are highly correlated with them (p[r,n] values ranging from <0.01 to <0.05).

The quantities for the selected dates were estimated using different statistical indicators (average as the most practical one) as advised in the European Commission (2011) Guidance. The method presented is mainly based on the quantification method validated and proposed by Escudero et al. (2005). To estimate North African dust load, two kinds of statistical indicators proposed in the said Guidance, which are as follows:

1. For the days with identified North African influence, in regional background, natural dust load can be estimated based on **the moving percentile 40 registered during 15 days before and 15 days after** the analyzed dust outbreak episode excluding the days with the identified episode. This is shown below:

$$\begin{aligned}[\text{natural dust load}]_{\text{(any stations)}} = {} & [\text{daily } PM_{10}]_{\text{(rural station)}} \\ & - [\text{monthly moving percentile 40 of daily } PM_{10} \text{ values}]_{\text{(rural station)}}\end{aligned} \tag{3.1}$$

For this first case, it is mentioned in the Guidance of the European Commission (2011) that the moving 40 percentile of 30 days with the evaluated days being in position 15 is reproducing well in the Iberian Peninsula, the regional background levels without North African dust contributions.

2. A more conservative indicator, e.g., **the average of the PM_{10} concentrations registered during 15 days before and 15 days after** the analyzed dust outbreak episode excluding the days with the identified episode, or **the moving 50 percentile of 30 days**. Hence, the natural dust load can be estimated as follows;

$$[\text{daily } PM_{10}]_{\text{(nearby stations)}} - [\text{the alternative indicator}] \tag{3.2}$$

In both methods, the assumption is that the natural dust load that contributes to the PM_{10} levels at the rural station also contributes to the PM_{10} levels at the nearby stations in the same amount. Different computation methods (moving 30, 40, and 50 percentiles, moving average, and computation with nearby stations' PM_{10} instead of rural station PM_{10} data) were employed. As written in the European Commission (2011) Guidance, one approach for accuracy check could be the validation with computation of arid region dust contribution amount from elemental values. However, as a difference from the European Commission (2011), the elemental data already being utilized in the date identification step, to prevent any biases related to the double account of the elemental data, the step of validation with elemental data was omitted.

Overall, this study, with an attempt to comply with the criteria set out by the European Commission (2011) at the largest possible extent within the framework of the time-related and budgetary constraints and with a pursuit for a good level of conformity with the conditions peculiar to Türkiye, a methodology that is partially different from the one proposed by the European Commission (2011) is used regarding the transport of dust for arid regions:

- Backtrajectories leading to not only the Sahara/Sahel region or other arid parts of the North African region but also Middle Eastern and Asian arid regions are considered as much as possible.
- Backtrajectories already available were also used, with different altitudes.
- SO_2 data are also used after retrieval from the very same urban network database: Among the episodes, the times at which simultaneous peaks were observed for SO_2 and PM_{10} were identified through the same dataset. S data was used similarly, as derived from the rural station dataset.
- Due to the availability of chemical elemental data at the rural station and wherever the corresponding PM_{10} was unavailable, these data are used as an earlier step than its rank in the European Commission (2011) (analysis rather than validation).

- For this study, a Multi-model model is used, which is among the list of the suggested aerosol models (SKIRON, BSC-DREAM, NAAPs). This model is a combination of several models.
- For reasons of practicality, the HIRLAM model was not applied.
- AOD data was automatically downloaded in numerical form.
- As advised in the European Commission (2011) Guidance, considering that the statistical method established for the Iberian Peninsula is not necessarily valid for Türkiye, the more conservative statistical method proposed in the EU Guidance is used as the major one, with the addition of several other computations.

The results of each analysis were recorded in the form of scores and some additional details. The most confirming cases were scored 1, and the opposite was given -1. For cases such as unavailable satellite photographs (for satellite photograph analysis) or contradictory results such as different elements with high and low concentrations (for satellite photograph analysis), the score 0 was given. When confirmation was not certain due to several factors (e.g., uncertain dust-like appearance in the satellite photograph with nearby cloudiness, if not confirmable from the remaining parts of or consecutive dates of the analysis), a score of 0.5 was given. An important step in the process was the selection of dates as episode dates based on various results. Differing results were compared and analyzed to check their validity, as discussed in more detail in Section 4.2

Finally, a set of dates considered to correspond to dust transport from arid regions was selected, with the following criteria: having at least 2 scores of "1" from different analyses. Afterward, quantification was done as described above. The important point is that the rural PM_{10} of each day was used in calculations after the subtraction of the daily sea salt aerosol contribution calculated per Section 3.5.

3.3 Volcanoes

The rural air quality station data was utilized for PM_{10} and S data together. The dates when a combined PM_{10} and S episode occurred at the rural site were considered potential dates for volcanic activity contribution. To confirm those days, satellite

lower tropospheric (0-2.5 km) SO_2 data was analyzed with TRAJSTAT. This means no automatic rejection by TRAJSTAT even when TRAJSTAT backtrajectory was seen to end before reaching a volcano site. It was considered satisfactory and relevant, where TRAJSTAT backtrajectory was seen to arrive at the SO_2 plume originating from a volcano. The volcanic activity records were also checked from sources such as Global Volcanism Program[21] and Interactive Map of Active Volcanoes[22] as well as other literature.

After identifying the dates, the quantification was made with 30-day averages with the volcanic activity contribution dates in position 15. As the European Commission (2011) Guidance mentioned, alternative computation methods with other statistical indicators can also be employed if justified. There were trials, as described in Section 4.3.

3.4 Forest Fires

To retrieve the list of forest fires in the region, the FIRMS database was used for downloading data from MODIS and VIIRS satellites as .csv files for the rectangular region used in Section 3.2. Additions were made to the list through a search on newspaper news for the relevant time range.

The quantification method mentioned by European Commission (2011) involves the following step: "The average of the PM_{10} concentrations registered in the 15 days before and in the 15 days after the episode in the reference time series is used as the background concentration. The difference between the concentrations measured during the episode and the above-mentioned 30 days (episode days excluded) should be considered a contribution of the wild-land fire episodes. In case the duration of the event is significant compared to 30 days, a more elaborate scheme may be necessary to estimate the concentration levels without the wildland fire contribution adequately. Other statistical indicators of the levels excluding the natural contribution at the site/area can be used if properly justified." Thus the duration of the fire is to be evaluated to decide on the statistical indicator to be utilized. Again, the rural PM_{10}

[21] https://volcano.si.edu/volcano.cfm?vn=211060

[22] https://earthquakes.volcanodiscovery.com/

concentration data was used by excluding the specific dates identified, this time the dates of the forest fires.

The number of forest fires was determined in two alternative ways. One was accepting all forest fires as a natural source of PM_{10} pollution, and the second was to point at only the portion with known natural origin. This is further discussed in Section 4.3.

3.5 Sea Salt Aerosols

Regarding sea salt aerosol contribution, the essential parts of the method given in the 2009 EU Guidance can be summarized as follows;

- Assumption: Na is entirely sea-salt-originated
- Assumption check with backtrajectory
- For dates when the assumption is valid, contribution to PM_{10} levels:

$$[\text{Sea salt aerosol}] = 3.27 \times [\text{Na}] \tag{3.3}$$

The coefficient 3.27 was taken from the Guidance of European Commission (2011), but it was not directly applied to the Na data from the rural station. To strengthen the assumption of full marine origin, the Na concentration used was chosen as follows in line with Calzolai et al. (2015) and Diapouli et al. (2017) and based on the generic crustal Na to crustal Al ratio of 0.348Mason (1966):

$$\text{Na for calculations} = \text{Na} - \text{Na}_{\text{crustal}} = \text{Na} - 0.348 \times \text{Al} \tag{3.4}$$

Muğla is a coastal province, and with the observation of almost all of the backtrajectories already passing through the sea, these steps were followed without the backtrajectory check. Additionally, the rural station with many Na concentration data gaps is close to the sea but at a high altitude (936 m a.s.l. altitude), while the Ministry-operated station in Milas Ören is, in fact, a coastal station (3 m a.s.l. altitude). For this reason, it was considered whether Milas Ören station could give more information on sea salt, except for the fact that it does not have records of Na concentration.

Thus, the applicability of PM_{10} levels in Milas Ören station and Na levels in the rural station was collectively investigated for the sea salt aerosol contribution calculations, as discussed in Section 4.5

The dates with tornadoes were given special concern. Such dates were determined from the website of the European Severe Weather Database[23] and literature involving mainly newspaper news.

3.6 The Anthropogenic Part of PM_{10}

The anthropogenic portion of the PM_{10} levels was determined by subtracting the amounts found in the previous sections from the daily PM_{10} levels. After this subtraction, the remaining levels are considered the anthropogenic PM_{10}levels. This subtraction was done separately for each air quality station. For the arid region dust contribution, where the natural contribution essentially means the natural dust load, it can be shown as;

$$[\text{remaining daily PM}_{10}]_{\text{(nearby station)}} = [\text{daily PM}_{10}]_{\text{(nearby station)}} - [\text{natural contribution}]_{\text{(rural station)}} \tag{3.5}$$

It can be understood that there is an exceedance due to natural contribution in the selected urban monitoring station if;

$$[\text{daily PM}_{10}]_{\text{(nearby station)}} > 50\,\mu\text{g/m}^3 \tag{3.6}$$

AND

$$[\text{remaining daily PM}_{10}]_{\text{(nearby station)}} < 50\,\mu\text{g/m}^3 \tag{3.7}$$

[23] https://eswd.eu/cgi-bin/eswd.cgi

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Preliminary Data Analysis

Tables 4.1 and 4.2 summarise the main statistics for PM_{10} data at sampling sites during the whole study period regarding PM_{10} and chemical composition. Minimum and maximum values, averages, and standard deviations (SD) are included in Table 4.1. The detection limits, too, were determined in the TÜBİTAK (2019) study but with the ng/cm^2 unit and only for the period April 2017 – October 2018.

The average PM_{10} concentration at the rural site (14.27 ± 22.06 µg/m^3) was found to be very close to that found in the station in Mount Aitana (14.3 ± 9.9 µg/m^3) in one month in winter and one month in summer, 2019, and again quite close to the average PM_{10} concentration (13.3 ± 12.1 µg/m^3; Galindo et al. (2018) cited in Clemente et al. (2023) registered at the Aitana station in March 2014 - September 2015. Due to the great resemblance of the values to those reported in Clemente et al. (2023), just like for the station in Mount Aitana specified in the study mentioned, the PM_{10} values were of the same order with those reported for a remote site northern France (13.0 µg/m^3; Weber et al. (2019), but significantly lower than the concentration measured at a high-mountain site (29.2 ± 17.3 µg/m^3) located in the Middle Atlas Mountains (2100 m a.s.l.; Deabji et al. (2021) (attributable to the high contribution of mineral dust (17.7 ± 7.4 µg/m^3) due to the close proximity of this station to the Sahara Desert (300 km), as mentioned by Clemente et al. (2023). When the PM_{10} level is compared to those reported by Gómez-Losada and Pires (2020), it is seen to be in general within the range of median PM_{10} values regarding non-dust periods in background stations from 6 countries of Europe (10.8-20.6 µg/m^3 but with most of the median values being

close to 14.27 μg/m^3) for 2015-2018. However, again, according to Gómez-Losada and Pires (2020), the median PM_{10} values regarding non-dust periods in background stations from Türkiye were seen to be quite higher, i.e., 21.1-31.3 μg/m^3 for 2015-2018. The fact that the average obtained for rural stations is similar to the median for non-dust days reported in Gómez-Losada and Pires (2020) can be explained by the low number of dust dates with a significant contribution of dust to the overall PM levels.

Table 4.1: Summary of the concentrations of PM_{10} and chemical species at Marmaris rural station

	Min (μg/m^3)	**Max** (μg/m^3)	**Average** (μg/m^3)	**Std Deviation** (μg/m^3)
PM_{10}	0.09	174.02	14.27	22.06
Al	0.00	971.25	90.75	122.59
Cu	0.06	56.33	5.45	5.82 6
Fe	2.61	4749.42	1401.16	1086.56
K	0.17	363.35	52.91	62.47
Mg	0.08	585.72	42.52	55.30
Mn	0.28	623.43	92.07	143.46
Na	0.57	1184.49	100.92	133.49
Ni	0.03	92.90	19.33	21.62
Pb	0.07	18.95	4.43	4.12
S	0.41	341.83	52.72	54.37
Si	1.41	2427.06	244.74	331.51
Ti	0.05	79.66	8.22	10.65
V	0.02	5.20	1.03	0.83
Zn	0.38	1061.26	66.14	89.14

According to Horálek et al. (2022) among the publications of the European Environment Agency (EEA), Muğla is seen to have average PM_{10} concentrations within the range of 20-40 μg/m^3 for the year 2017. The numbers above for Milas Ören station fall into this range, whereas the numbers for Muslihittin station are quite higher. Muslihittin station is an urban station in the city center, thus with a higher anthropogenic contribution to PM_{10} levels than the other stations in Muğla, such as Milas Ören or Fethiye (although there is no available PM_{10} data from Fethiye).

Table 4.2: Summary of the concentrations of PM_{10} and SO_2 at nearby stations.

Station	PM_{10} **Avg.±STD**	**Min-Max**	**SO_2 Avg.±STD**	**Min-Max**
Muslihittin	75.64 ± 38.13	16.27–250.49	20.31 ± 19.76	0.62–179.51
Milas Ören	36.61 ± 15.76	11.64–87.78	18.79 ± 20.47	0.82–145.02
Fethiye	N/A	N/A	11.79 ± 2.73	7.49–14.56

The mean PM_{10} values from all stations (the rural station and nearby stations) are higher than the respective median PM_{10} levels. These distributions are right-skewed (positively skewed). The right skew is actually what is expected in this dataset. As the median number points to the 50 percentile, the mean being higher than the median shall be understood as such that the majority of the data lies below the mean level. This can be due to several outliers, each with a remarkable magnitude in the dataset. This situation can be expected if high episodal peaks are likely. Fethiye station was not included in the statistics for PM_{10} because it has only 8 dates with such data.

As expected, due to the absence of urban pollutants, rural PM_{10} levels recorded in Marmaris are, in general, lower than the PM_{10} levels recorded in the Ministry's stations. This situation is valid for the station in Marmaris when compared to the low-density-settlement/coastal station, Milas Ören, too. Furthermore, as expected from this character (if considered alone), Milas Ören PM_{10} levels rank the lowest among the rest of the nearby stations. It should be added that this is seen to be the case even despite the existence of the thermal power station Kemerköy close to the Milas Ören station.

The SO_2 data was initially considered to be used mainly to evaluate the PM_{10} levels in the same station to indicate anthropogenic pollution. It can also be of use to confirm the regional distribution of SO_2 swept forward until the stations by African or other dust transport plumes. It can also be considered possible that cold weather conditions had suddenly affected the region or a holiday season had ended, causing a low emission period cessation. In those cases, higher heating or traffic-related combustions could also be reasons for higher SO_2 levels in the whole region. Meanwhile, it should be kept in mind that the stations are near thermal power plants generating PM_{10} and

SO_2. Not the other two power plants, but the power plant in Yatağan is associated with an air quality monitoring station at Yatağan, from which hourly data can be accessed through the Ministry's server. Volcanic activity is another source of SO_2 combined with PM_{10}. However, considering the distance of Muğla to the nearest volcanoes, Etna and Stromboli, it is uncertain if the SO_2 emitted could still be measured as SO_2, and the rural S could be a better indication in that sense.

Utilizing the nearby air quality stations data here is summarized information about daily exceedances of the 50 µg/m^3 limit value: There are 948 daily exceedances in solely Muslihittin station, 2 in solely Milas Ören station, and 40 in both. The cases where both show exceedances are mainly in summer (31 out of 39 days), followed by autumn and winter months (4 days out of 39 each), with none in spring. The details are given in the table below. The number of exceedances is much lower in Milas Ören than in Muslihittin, as can also be derived from the above information. The months with the highest number of exceedances are August and March (both with 103 dates) for Muslihittin and July and August (with 17 and 16 dates, respectively) for Milas Ören, which is a station with a much lower number of data than Muslihittin and same time not an urban station, unlike Muslihittin station.

After compiling these pieces of overall information, the data was analyzed first before marking the dates as dates with or without natural contribution based on the coming sections. For the preliminary data analysis, the statistical analyses of Mood's Median Test and Multiple Range Tests (with 95,0 percent Least Significant Difference method) were applied to the rural data. Firstly, monthly variation was investigated. For this purpose, the months of different years were considered collectively. Naturally, the analysis is weaker for March and January, which are the months not fully covered at the rural station in 2014 and 2018, respectively.

According to these analyses, the statistical characteristics of the rural station data are given in the following Table 4.5 and Figure 4.1 generated by the program for the elemental data of Al.

Since the P-value for the chi-square test found by the Mood's median test is less than 0,05, it can be understood that the medians of the samples are significantly different at the %95,0 confidence level. This demonstrates that the concentration of Al varies

Table 4.4: Monthly Exceedances for the PM_{10} Limit 50 μg/m^3 at Nearby Stations

Month	**Number of daily exceedances at Muslihittin station**	**Number of daily exceedances at Milas Ören station**
January	88	3
February	65	0
March	103	0
April	80	0
May	54	0
June	60	0
July	94	17
August	103	16
September	73	2
October	85	0
November	95	2
December	88	2
TOTAL	988	42

Table 4.5: Summarized Statistics for Al (ng/m^3)

Month	**Count**	**Average (ng/m^3)**	**Std deviation (ng/m^3)**	**Median (ng/m^3)**	**Minimum (ng/m^3)**	**Maximum (ng/m^3)**
Jan	25	15.8553	22.9646	7.96844	0.349997	91.4194
Feb	22	58.1755	74.7777	26.206	3.88422	237.869
Mar	13	64.0333	62.5924	45.8788	10.9382	246.083
Apr	23	73.3357	77.7445	46.3717	7.72798	288.119
May	9	163.834	144.602	104.613	17.862	485.811
Jun	25	84.0677	65.2734	77.736	13.9439	349.345
Jul	26	180.179	133.701	136.015	31.3028	577.136
Aug	32	121.706	110.923	75.2709	9.15047	433.756
Sep	38	135.12	168.649	69.3662	3.13589	890.293
Oct	42	94.3628	118.658	48.0033	2.54805	580.474
Nov	20	101.373	216.882	22.5363	1.88593	971.247
Dec	37	22.6342	33.6431	7.12297	0.00262679	152.248
Total	312	90.7487	122.788		0.00262679	971.247

significantly on a monthly basis. Based on this statistically significant relationship with months, the box-and-whisker plot is illustrated in 4.1. The presence of far outside points in the plot, as the case for this dataset, may indicate outliers or a highly skewed distribution. The highest Al concentrations were observed during the months of May and July, probably due to the resuspension of soil dust, combustion activities, and partly long-range dust transport.

The same analysis procedure was also applied to Fe and Si. The results are tabulated below similarly, in Tables 4.6 and 4.7. According to Mood's median test, the P-value for the chi-square test is greater than or equal to 0,05, meaning that the medians of the samples are not significantly different at the %95,0 confidence level. As the P-value for the chi-square test in the Mood's median test is less than 0,05, the medians of the samples are significantly different at the %95,0 confidence level. As a result, unlike Fe data, the Si also varies significantly on a monthly basis, as was the case for the Al data.

The box-and-whisker plot is included below Figure 4.2 based on the monthly varia-

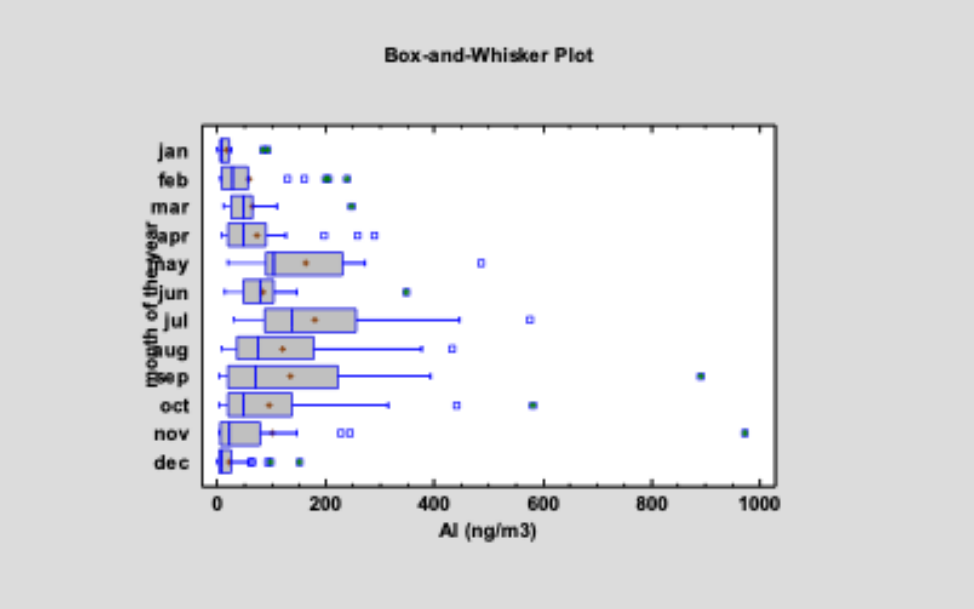

Figure 4.1: Box and Whisker Plot for Al

tion's statistical significance. This plot includes there are 11 outside points and 11 far outside points. The presence of far-outside points may indicate outliers or a highly skewed distribution.

The results given above, in general, are considered to demonstrate the monthly variation of Al and Si concentrations, and almost no such variation for Fe elemental data from the rural station. The monthly variation was expected -without certainty for arid region dust-related elements because arid region dust is also known to have monthly variation. There could be issues with the representativeness of a smaller dataset since 312 Al, 157 Fe, and 294 Si data were used in this thesis.

4.2 Dust Transport From Arid Regions

The analyses mentioned in Section 3.2 yielded a collection of results about dust transport from arid regions. The term "confirmation" below should be understood as a score of 1, and the term "rejection" below should be understood as a score of -1.

Table 4.6: Summarized Statistics for Fe (ng/m^3)

Month	Count	Average (ng/m^3)	Standard deviation (ng/m^3)	Median (ng/m^3)	Minimum (ng/m^3)	Maximum (ng/m^3)
Jan	10	954.715	966.544	914.656	2.61265	1961.29
Feb	10	2194.49	1753.42	1844.84	66.2071	4749.42
Mar	6	1156.64	1847.28	104.951	31.4758	4543.29
Apr	10	1404.98	945.293	1850.24	48.1401	2501.1
May	2	2180.59	624.056	2180.59	1739.32	2621.87
Jun	13	1590.7	1369.39	1758.36	6.51444	4196.17
Jul	18	1378.32	904.9	1863.89	3.62414	2399.21
Aug	17	1211.38	848.455	1401.56	10.4457	2288.64
Sep	22	914.934	1120.79	202.748	21.3957	4429.56
Oct	19	1436.01	743.528	1839.16	10.5698	2200.07
Nov	11	1431.91	1032.63	1607.64	48.0405	3649.14
Dec	19	1783.88	740.99	1847.21	65.698	4127.32
Total	157	1401.16	1090.04		2.61265	4749.42

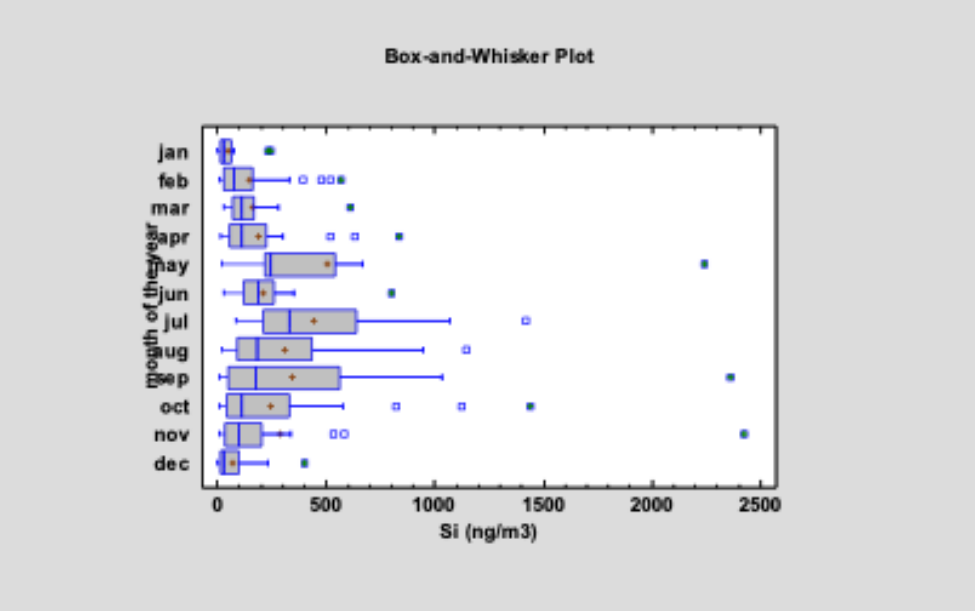

Figure 4.2: Box and Whisker Plot for Si

Table 4.7: Summarized Statistics for Si (ng/m^3)

Month	**Count**	**Average (ng/m^3)**	**Standard deviation (ng/m^3)**	**Median (ng/m^3)**	**Minimum (ng/m^3)**	**Maximum (ng/m^3)**
Jan	20	50.2244	67.575	27.3358	1.40653	243.998
Feb	22	149.295	180.473	77.2638	2.75426	569.302
Mar	13	161.05	157.007	109.969	26.4017	610.497
Apr	23	188.217	211.62	108.013	11.403	837.334
May	9	505.796	679.915	241.908	20.4398	2241.04
Jun	25	207.243	152.733	186.816	23.2135	801.459
Jul	26	439.854	326.23	332.169	79.5973	1417.52
Aug	32	308.767	287.136	183.314	22.4608	1145.19
Sep	38	346.252	441.659	174.78	2.0755	2362.25
Oct	42	243.802	306.407	112.982	2.79335	1443.12
Nov	17	286.753	579.15	99.6806	5.81343	2427.06
Dec	27	71.1226	92.9682	29.5258	1.44472	399.323
Total	294	244.741	332.079		1.40653	2427.06

There are also mid-scores between them based on the degree of certainty. The major results are summarized as follows:

- Rural station data yielded 41 confirmations and 116 rejections.
- TRAJSTAT yielded 439 confirmations and 875 rejections.
- Multi-model aerosol model yielded 782 confirmations and 539 rejections.
- AOD data -initially- yielded 672 confirmations and 656 rejections.
- Nearby stations' PM_{10} data yielded 52 confirmations and 45 rejections.
- Satellite photographs -initially- yielded 167 confirmations and 7 rejections.

In an ideal case, the sets per each analysis could be identical. This ideal world expectation is related to not only the number of dates but also the exact list of dates.

If this were the case, using multiple analysis methods would not be necessitated. However, multiple analyses are required, and there are two major aspects building up uncertainty for each analysis, cumulatively leading to different sets of dates confirmed or rejected.

The first aspect is the differing mechanisms related to the output production to be analyzed in each analysis. A second aspect that adds to the first one is the uncertainty in retrieving and analyzing these outputs. For MODIS MAIAC AOD data, this is mostly linked to the automatic retrieval process lacking human judgment (as discussed below), whereas, in the rest of the analyses, this is mostly linked to either technological limitations (e.g., a forecast model being only a technological representation of what could happen, rather than the reality) or the human involvement (this time as an error factor). To be more concise, the possible uncertainty factors relevant to various data categories and analyses are tabulated below in Table 4.8.

As is seen, no single data category or analysis is satisfactorily reliable by itself. It is generally similarly wrong to exclude one date from the list of African dust transport dates just judging by one of them. The analysis shall be based on a combination of all of them as the main mitigation measure while considering the uncertainty factors. The combination is considered without relying on any of them to include or exclude dates from the list of dust transport episode dates. These uncertainty factors can be considered as "risk"s for the analyses which might require pertinent additional

"mitigation measure"s to be able to reach accurate results.

Based on the first aspect and as expressed above, it is normal to have different sets of dates as analysis results. Still, the differences are expected to make sense based on the characteristics and limitations of each analysis and not to amount to excessive levels. Because of this, a quality check was performed on the analysis results.

Table 4.8: Uncertainty factors and relevant additional mitigation measures

Data Category/Analysis	**Uncertainty**	**Additional Mitigation Measure, if any**
Air Quality Monitoring Station Data – Rural Station Data	Gaps in data. Even a complete lack of data at the start of 2014 and the majority of 2018.	Whenever there is a lack of rural data, the analysis is conducted with only the other categories of data, taking note of this situation. Quantification needs to be done with a different method, such as the one mentioned as a possible solution to the *altitude difference problem below (the 5th item).*
	Possible measurement errors (at the station or in the lab).	The data is analyzed to detect discrepancies and bring solutions, including excluding some data when necessary. E.g. few elemental data were excluded as such.
	Intruding source of emission: burning of forests (could be anthropogenic or natural), other natural pollution sources such as volcanoes, etc.	This can be checked with other methods, such as satellite pictures and literature for other natural pollution sources.
	Intruding anthropogenic activity in rural areas.	No addition to a combined approach.

Table 4.8 – *Continued from previous page*

Data Category/Analysis	**Uncertainty**	**Additional Mitigation Measure, if any**
	Altitude (approx. 1 km) is higher than the other stations. Thus, the dust that has affected this station may not have been captured by the other stations' devices similarly (no episode or an episode having days with a lower rate of increase in PM_{10} levels). Vice versa, the sea salt that has affected the lower (e.g., coastal) stations may not have reached the rural station. It is seen that the European Commission (2011) Guideline also mentioned the elevation's effect on timing in relation to Atlantic advective flow.	This problem is valid mainly with the Milas Ören station (3 m a.s.l. altitude) but also valid for Muslihittin station (647 m a.s.l. altitude). The dust that created no episode in urban stations might be detected by their data, though within their own limitations of data availability. For the dust which created lower rates of increase in PM_{10} levels at nearby stations, as a problem for quantification of dust contribution to remaining PM_{10} levels at those stations, an alternative computation method is being tried in addition to the methods at hand: background PM_{10} calculations with not the rural but other stations' data (subtraction steps to be followed in the same manner as with the usual methods). Regarding the sea-salt episodes that occurred around the other stations but could not be detected by the rural station, this possibility is considered while analyzing the data. The problem is that elemental Na concentration data necessary to quantify sea-salt episodes exists only at the rural station. Thus, PM_{10} data was thought to be made use of. This is discussed in the coming parts.

Table 4.8 – *Continued from previous page*

Data Category/Analysis	Uncertainty	Additional Mitigation Measure, if any
Air Quality Monitoring Station Data – Urban Station Data	Gaps in data.	The current scoring framework was developed in such a way that even when one station lacks data, the other stations' data allows indication of a date as a "likely" episode day in this first data category
	Possible measurement errors (at the station)	The data is analyzed to detect discrepancies and bring solutions, including excluding some data when necessary. E.g., Muğla-Trafik station data was totally excluded from daily data.
	Cold weather conditions suddenly affecting the region or a holiday season ending, etc., which can be seen as additional factors influencing PM_{10} levels. In such cases, higher heating or traffic related combustions could cause higher levels in the whole region without natural pollution source contribution.	The regional increase could be evaluated taking all such issues into account. Meteorological data and the past holiday calendars may be useful tools to understand these. The specific site characteristics of the station could be a relevant aspect during this control. It should be reminded that while the holiday season might bring a decrease in SO_2 levels and PM_{10} levels in many places, it might also bring an increase in PM_{10} levels in the holiday-resort type of places.
Backtrajectory	Uncertainty of TRAJSTAT model's computations, also linked to the NOAA meteorological data files it utilizes	For this reason, the model is run for more than one elevation level (approx. 1000, 1500, 2500 m asl). It could be beneficial to run the model for even more altitudes, perhaps supported by the DREAM vertical profile levels to select altitudes.

Table 4.8 – *Continued from previous page*

Data Category/Analysis	**Uncertainty**	**Additional Mitigation Measure, if any**
Satellite Photographs	Clouds can mask the view.	Clouds, just to keep in mind that they covered the view on specific days, can be seen from the photographs. Whenever the real case cannot be depicted from consecutive dates or by viewing at a larger scale, the score 0 can be given.
	The dust seen (if any) could be at higher altitudes than the station level, possibly just passing through the region with no effect on PM_{10} levels.	Higher PM_{10} levels are already among the other criteria that need to be examined simultaneously. Thus, again, there is no addition to the combined approach.
	Satellites make measurements at differing hours of the day.	The possibility of differing views on differing hours is considered during the analysis. However, African dust episodes generally last longer than merely half a day. Thus, again, there is no addition to the combined approach.
MODIS MAIAC AOD	Clouds can hinder AOD measurements.	One approach could be to give the dates with cloud cover some evaluation scores higher than the scores the same days would be given unless there was such cloudiness. The problem with that is the already existing inner adjustment mechanism of AOD values with respect to cloud cover. Still, clouds, to keep in mind their cover of the view on specific days, can be seen from the photographs and noted.

Table 4.8 – *Continued from previous page*

Data Category/Analysis	**Uncertainty**	**Additional Mitigation Measure, if any**
	While AOD is relevant to the whole column, the concentrations are more relevant to the lower altitudes.	
	"Automatic" data retrieval in "numerical" form has some limitations	Comparison was made with satellite photographs.
	Satellites make measurements a few times a day.	The same as written above for *Satellite Photographs.*
DREAM as the aerosol model	Uncertainty of DREAM model's computations	No addition to combined approach
Quantification step for natural dust contribution	*Some issues and the alternative calculation method already mentioned above in relation to air quality monitoring stations. Gaps in data also affect quantification.*	
	The soil composition formula's (given in the Guideline) validity for Saharan dust	This can be investigated from literature (e.g., dust/soil composition literature). However, the validation step, which is based on the soil composition, was skipped in this thesis, as explained in relevant parts.

Firstly, the rejected dates according to one analysis were checked against the other analyses to determine the dates that were contrarily confirmed by any of them. Based on these results, further investigation was made to understand the reason for such discrepancies for specific dates. The evaluation is described further below.

In the absence of other confirming results, the absence of pollution at the rural sites but the existence of pollution at the sites of other stations might mean anthropogenic pollution. Thus, the dates rejected by rural station data but confirmed by one of the other stations' data were given a special concern. These dates were seen to have the

score -1 from the rural station, a PM_{10} concentration above the median from one other station, and the score 0 at maximum from all other analyses. There are 15 such dates. Only 1 of them has data in more than one nearby air quality station, with one below the median value for that second station, Milas Ören: 7.9.2016. The rest of them have data from only the Muslihittin station.

It is seen that all of these dates lie within the range of months September-March in different years. 6 of them are in November as the maximum number per month, 3 in January, and 2 in February. This monthly variation is in line with the assumption that the dates that were rejected by rural station data but confirmed through other stations' data belonged to anthropogenic pollution episodes, possibly due to residential combustion in winter. These dates were marked as probable anthropogenic pollution episode dates. They were left outside the subsequent steps of analysis.

Similarly, 5 dates were rejected by rural station data, with much lower concentrations than median levels, but confirmed by only AOD data. These dates were also left outside the subsequent analysis steps as possible anthropogenic pollution episode dates. Because it was considered that anthropogenic pollution can increase AOD too. An example of such cases is the existence of records of AOD values up to 0.4 for areas with strong anthropogenic activity (e.g., the Po Valley in Italy)Papadimas et al., 2008. Consequently, AOD levels alone cannot be taken as an indication of arid region dust contribution, as also the case for confirmation from any other single analysis.

There is an issue that should be noted about AOD analysis. Its data were downloaded in numerical form. The AOD values were evaluated according to their own characteristics. There are 103 dates in winter with AOD higher than 0.15, as one of the winter AOD levels mentioned in other studies. There are 292 dates in the other seasons with AOD higher than 0.2. These numbers were taken into account here indicatively with an inclusive approach because they can be considered as relatively low thresholds available from literature such as the study by Papadimas et al. (2008).

There was an interesting harmony between the results of TRAJSTAT and Multimodel, about their relationship with AOD. The dates rejected according to both of these models separately (whether or not confirmed by other analyses) cover AOD values until the exact same upper threshold: 0.48. For this reason, it may be possible

to accept 0.48 as the threshold above which the values would strongly indicate arid region dust contribution to Muğla for the specified period. This value is close to those AOD values found by Kaskaoutis et al. (2007). It should always be kept in mind that the threshold may be subject to change based on progressing years. Because AOD levels are mentioned to be changing with years (as can be seen in, e.g., the study by the General Directorate of Meteorology (2023).

It was initially assumed about the Multi-model aerosol model that, in general, it can yield a higher number of confirmations and a lower number of rejections than the rest of the analyses. The reason is that the light blue color, which corresponds to a slight increase in PM_{10} levels, was considered at an equal degree with the other colors. Such small contributions may, however, not be detected by the other analyses. The number of dates confirmed with Multi-model is seen to be truly higher than for the rest of the analyses.

Regarding the dates rejected by the rural station but confirmed by some other analyses, the Multi-model was regarded as a beneficial tool for clarification. The following hypothesis was adopted: although the North African dust plume arrived at Muğla, it did not arrive specifically at Marmaris. This may be the case for the dates marked with "partially" in the Multi-model analysis. There are 9 dates rejected by the rural station but confirmed by some other analyses and meanwhile marked with "partially" in Multi-model. Viewing the Multi-model to understand the included stations, the hypothesis was checked and confirmed for those dates. In none was Marmaris included within the coverage of the "partial" area where the dust plume was foreseen to arrive by the model.

MODIS MAIAC AOD and MODIS satellite photographs were expected to give similar results. They both depend on MODIS satellite data. However, there are 35 dates that were rejected by AOD analysis but confirmed by visual inspection of satellite photographs. Meanwhile, there are only 2 dates for the exact opposite case, which were confirmed by more than one analysis.

Regarding the dates that were rejected by AOD analysis but confirmed by visual inspection of satellite photographs, there are two aspects that might explain such differences: i) MAIAC AOD was retrieved through GEE through an automatic re-

trieval process and in quantified form, lacking human judgment, whereas the photographs were visually inspected. This can create differences where factors interfere with satellite operations, which can be solved in the case of visual inspection, which includes evaluating a date in combination with consecutive dates where necessary. Similarly, due to the same reason, the map was viewed at a larger scale where necessary, whereas the AOD data retrieval process was limited to a defined rectangular box of coordinates. Cloudiness, split of satellite photograph view, interference with the always-existing light mark, and blurred view are such interference factors. ii) MAIAC is a combination of Terra and Aqua satellites. It was mentioned by Ettehadi Osgouei et al. (2022) that Aqua performs better in MAIAC than Terra for rural/coastal regions. It was mentioned by Karslıoğlu et al. (2022) that, in the spring and summer seasons, urban locations at Aegean coasts were seen to have higher AOD values than other regions, and long-term average AOD values were lower from Aqua than from Terra. Nevertheless, it is understood that MAIAC AOD observation may not exactly match the satellite photographs served by only one of these satellites.

To test the first aspect, the satellite photographs were revisited. 25 out of 35 dates involved at least one of the abovementioned interference factors. The figure below includes an example of these factors. Please note that there is an always-existing light mark, which is, at times, close to Muğla.

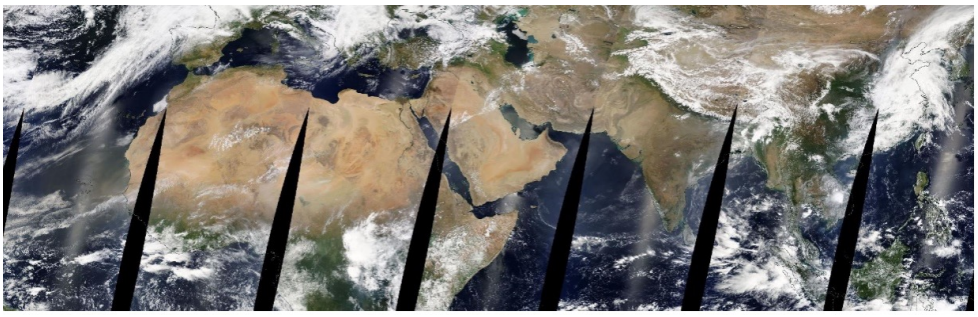

Figure 4.3: Example of factors interference with satellite photographs and AOD analysis

The remaining 10 dates among the 35 dates yielding such differences in results were also checked, testing the second aspect. It was seen that the results from Terra and Aqua satellites gave the same result. For this reason, the second aspect can be omitted for the dates that received -1 from AOD and 1 from Terra satellite photographs. This

check was not done to understand if the satellite photograph analysis score should be corrected (either Terra or Aqua, one yielding the score 1 would be enough already), but to understand if there is an indication that the lack of analysis with Aqua satellite might have created a problem which should be handled for satellite photograph analysis.

Afterwards, AOD data were checked in an alternative way. This time, the AOD values in the winter season were compared with not an overall median but the seasonal median for winter. Again, being higher than the median was seen as sufficient for the score 1. In this case, winter season AOD scores almost matched the satellite photographs scores. The majority of the differences for the winter season were owed to the abovementioned interference cases, satisfactorily indicating no significant problem. However, the total number of such discrepancies increased from 42 to 52. In the next trial, the AOD median was computed separately for each season, and AOD values were calculated with their own season's median for scoring. This time, the total number of such discrepancies was increased from 52 to 66. Hence, interestingly, seasonal comparison may not be regarded as beneficial. For all these cases, it should be remembered that the total number of dates amounts to 1434. Because of this, even the highest number of the discrepancy between the AOD and the satellite photographs, i.e., 66, does not exceed %5 of the total number of data 1404 (out of 1404, there are 84 dates with missing AOD scores, due to absence of AOD data, and 11 dates with missing satellite photograph scores, due to absence of satellite photographs, neither resulting in exceedance of 5

The AOD dates confirmed by AOD but rejected by satellite photographs were also counted. It was only 2 for all of the cases: for the case with an overall median, for the case with the median for winter, and the median for the rest, for the case with the medians for each season. These two dates were identical: 19.8.2015 and 20.7.2016 in all cases. It should be noted that these dates were also confirmed by some other analyses in support of AOD data, but one case (20.07.16) was not very supportive since it consisted of only AOD and nearby stations confirmation, as will be discussed in another paragraph shortly. When these satellite photographs were revisited in more detail, again also taking into account the consecutive dates, it was seen a score higher than -1 was actually possible, according to both Terra and Aqua

satellites, but it was more clear with Aqua in one of those dates. One date's satellite photograph score was changed to 0 and the other to even 1 (the date 20.07.16), from -1. Thus, the second aspect caused a minor change in results this time. Despite this change with respect to the dates which received the score 1 from AOD and -1 from satellite photographs, considering also the absence of any required change according to the very same second aspect with respect to the dates which received the score -1 from AOD and 1 from satellite photographs, it was considered not necessary to repeat the satellite photograph analysis of the whole set of dates with Aqua satellite. Rural station and satellite photographs each yielded a very low number of confirmations and rejections. The rest of the scores are 0 or 0.5. Rural station data has many gaps which lead to the score 0 in many cases. The majority of scores is 0 for the satellite photographs, due to the very same interference factors mentioned above.

Based on these checks, the results were decided to be used without any further modification or exclusion beyond excluding the 15 probable anthropogenic pollution episode dates and 5 additional possible anthropogenic pollution episode dates.

Afterwards, arid region dust episodes were identified. The only exception is that, the dates confirmed by only AOD and nearby stations data were not counted. There are 11 such dates. Because it was thought that AOD could also rise due to anthropogenic pollution. It is considered that such anthropogenic pollution can occur (simultaneously in a group of stations together), for example, when the weather condition is suitable for inversion or the cold periods necessitating higher residential combustion.

The possibility of thermal power plants' influence was also considered. This can be eliminated for the Muslihittin station since almost none of the daily average of SO_2 values recorded at nearby stations for those dates are above their medians (except for only 1 date). However, the SO_2 data for the Milas Ören station is absent on all those dates. There are no available air quality data regarding Yeniköy and Kemerköy thermal power plants other than the nearby stations' data, but the Yatağan thermal power plant is close to another air quality station, the Yatağan station. When this station's PM_{10} and SO_2 values were checked for these dates, it was seen that the PM_{10} values were not high with respect to the PM_{10} average for 1.1.2014-31.12.2018, but SO_2 levels on 13.07.2016, 27-30.07.2016, 02.08.2016 -especially 27-29.07.2016- were

high when compared to the average for 1.1.2014-31.12.2018. When remembered that the peak PM_{10} concentrations were not observed in this network in another example case, the SO_2 data can also be regarded as informative. It should be noted that before changing the satellite photograph score of 20.07.16 as described above, the number of such dates was 12 and then reduced to 11. Before and after the said change in scoring, the set included the months of July, August, and September. The set of dates covers mostly July (8 dates after the change in scoring), then August (2 dates), and finally September (1 date). All of them are from the year 2016, in autumn and summer. These are not the months when anthropogenic pollution would be expected at maximum, such as cold winter days. They correspond to the period between 13.07.2016 and 06.09.2016 intermittently. It is seen that in this period, the rural data is absent (so it is possible that the rural data analysis confirmation could have been given without these data gaps), TRAJSTAT backtrajectories at all of the three altitudes show rejection (-1 score in all altitudes), Multi-model analysis yields rejection (-1 score), AOD according to all of three computation methods show confirmation (the score -1 in all methods) and satellite photograph analysis yields the score 0 (so it is possible that the satellite photograph analysis confirmation could have been given for some days with interference factors if they were absent). Furthermore, when the AOD and AE values reported for the period 2003-2022 by General Directorate of Meteorology (2023) are examined, it is seen that the month of July is the one with the fourth highest AOD levels and the 3rd lowest AE values in the whole Türkiye. Thus, July is generally a month with high AOD values resulting from natural dust pollution, and excluding these dates may be regarded as lying on the extremely cautious side. However, Yatağan's high SO_2 values on 6 of these 11 dates were seen as justification for not changing the exclusion status.

693 dates were identified based on the criteria of having at least 2 scores of 1 from the analyses. Again, the large number is owed to perhaps partly the extensive coverage of Multi-model confirmations with the light blue color. Thus, some of the 693 dates actually correspond to only incremental increases in PM_{10}. An example of an arid region (African) dust transport episode is given below, along with its analysis results. Firstly, rural station data (rural PM_{10} median = 8.54 μg/m^3, no elemental data) is given graphically in 4.4. Muslihittin PM_{10} and SO_2 data are given as the second

graphic namely 4.5. The satellite photograph follows, where dust can be seen despite the always-existing light mark shown in 4.6. The last items are Multi-model and AOD images, and the backtrajectory output is shown in Figures 4.7 and 4.8, 4.9:

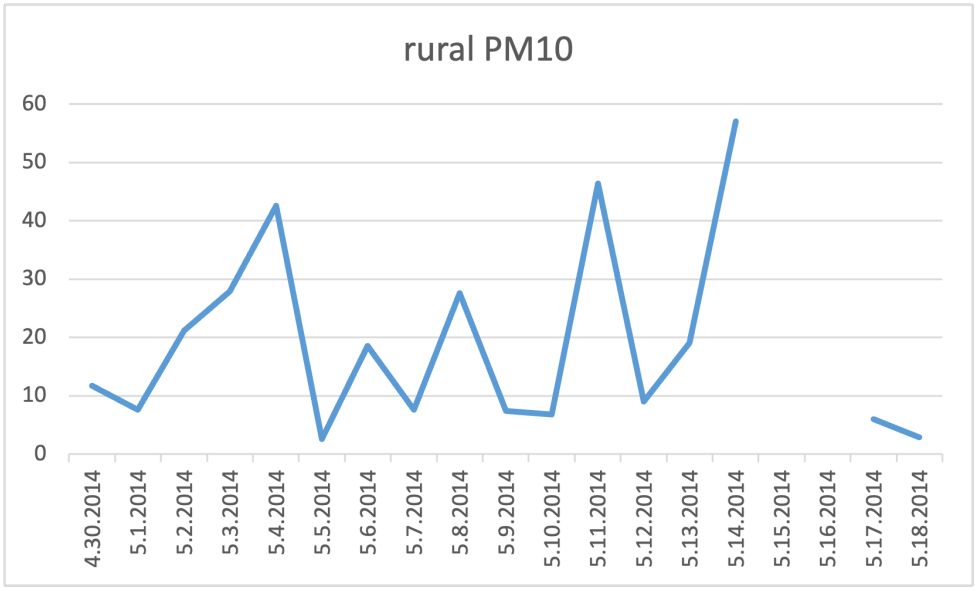

Figure 4.4: Rural Station Data

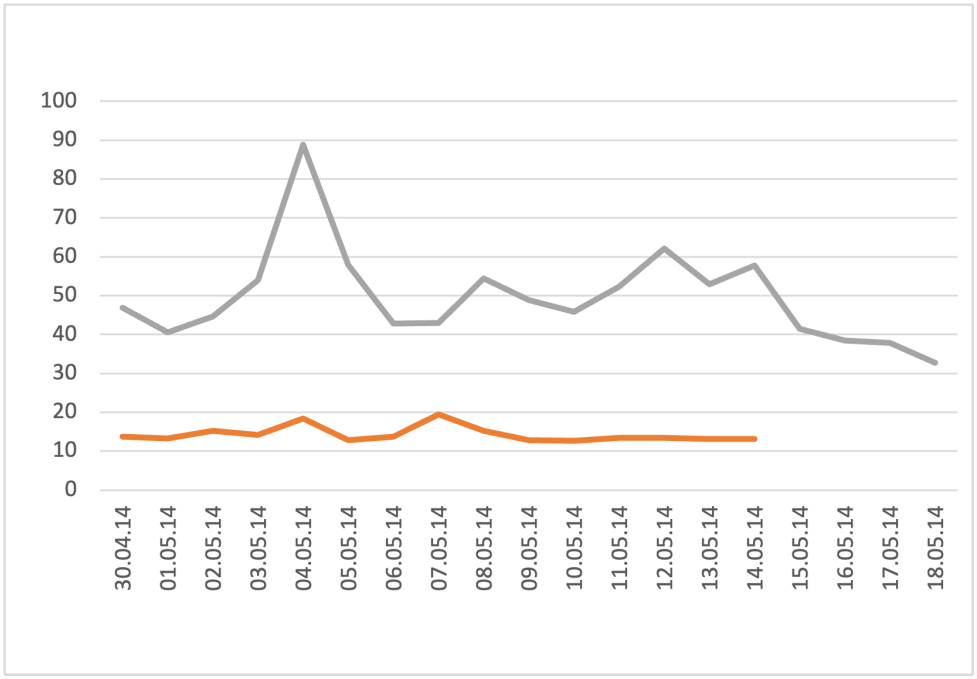

Figure 4.5: Muslihittin Station Data

The days that have been identified as arid region dust episode days were compared

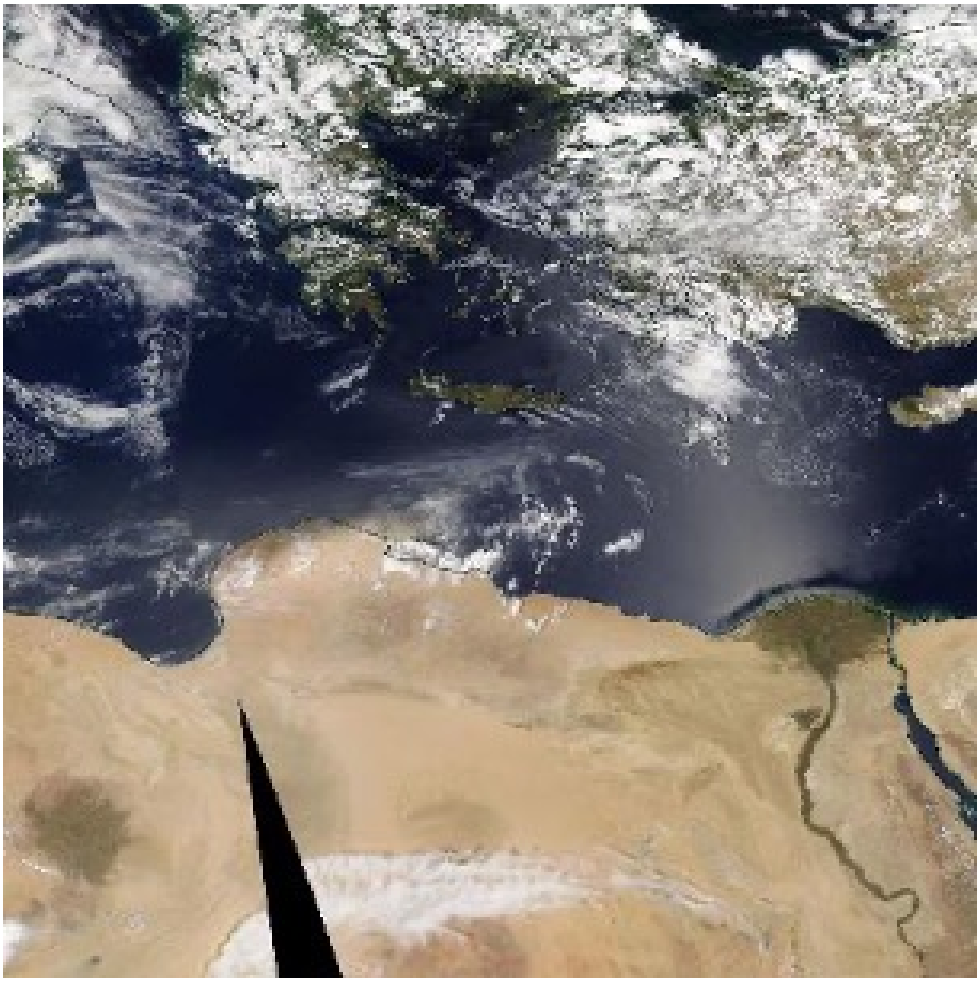

Figure 4.6: Satellite Photograph showing the indication of dust

with the dates of daily exceedance of PM_{10} limit value, 50 µg/m^3. They correspond to 493 daily exceedances of PM_{10} limit value in solely Muslihittin station, 1 in solely Milas Ören station, 16 in both, The total is 510 dates of nearby station daily exceedances of PM_{10} limit value, corresponding to the set of 693 dates with arid region dust contribution to PM_{10} levels. They correspond to 510 out of 984 exceedance dates, %52, in the Muslihittin station, and 17 out of 41 exceedance dates, %41, in the Milas Ören station. The cases where both stations show exceedances and when the date was identified as arid region dust episode day are mainly in summer (9 out of 16 days), followed by autumn and winter months (4 and 3 days out of 16, respectively), with none in spring.

As seen, the majority of the dates identified as arid region dust contribution dates

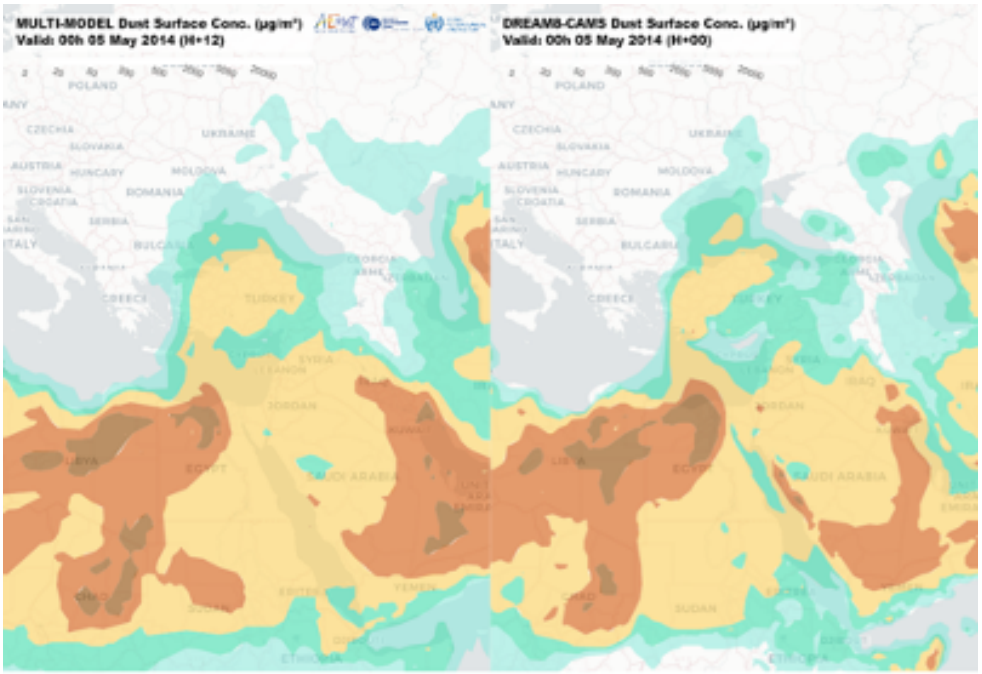

Figure 4.7: Multi-model

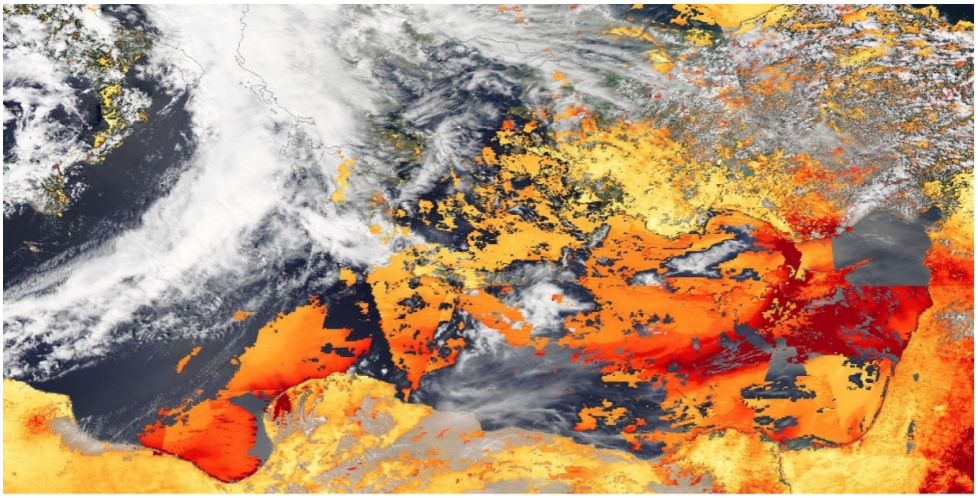

Figure 4.8: AOD Images

are among the dates when the daily limit value was exceeded in at least one nearby station. The fact that the latter is lower in number can again be explained with the inclusive scoring approach such as the one with Multi-model.

TRAJSTAT confirmations were given for 439 dates in total. 122 of these dates were found to have backtrajectories associated with Arabian or Asian arid regions for at

Figure 4.9: Analysis outputs relevant to the May 2014 episode

least one height among the three: 54 dates receiving the score 1 in analysis of the 100 m agl backtrajectory computation, 66 dates receiving the score 1 in analysis of the 500 m agl backtrajectory computation, 68 dates receiving the score 1 in analysis of the 1500 m agl backtrajectory computation were seen to have links to Arabian or Asian arid regions. There were intersections. Hence; only 1 date was seen to be confirmed by TRAJSTAT with a 100 m agl backtrajectory computation with such a link to Asian arid regions alone (21.1.2017),

- 9 dates were seen to be confirmed by TRAJSTAT with a 500 m agl backtrajectory computation with such a link to Asian and/or Arabian arid regions alone (18.7.2014, 28.10.2014, 29.10.2014, 30.10.2014, 24.11.2014, 19.1.2015, 7.3.2015, 22.3.2015 and 16.3.2017) and
- 35 dates were seen to be confirmed by TRAJSTAT with a 1500 m agl backtrajectory computation with such a link to Asian and/or Arabian arid regions alone (23.5.2014, 8-9.6.2014, 26.11.2014, 15-16.12.2014, 12-13.2.2015, 16.2.2015, 10.4.2015, 11.8.2015, 1.10.2015, 13.12.2015, 19-21.12.2015, 20.2.2016, 20.6.2016, 27.8.2016, 21-23.11.2016, 1.12.2016, 2.1.2017, 26.1.2017, 24.3.2017, 1.4.2017, 3.4.2017, 14.4.2017, 3.5.2017, 20.7.2017 and 26-29.1.2018).

In total, there were 45 dates with backtrajectories linked to Asian and/or Arabian arid regions alone. The remaining number of dates confirmed by TRAJSTAT analysis were seen to be associated with Africa.

When the months of the backtrajectories associated with Asian and Arabian arid regions alone are investigated (the 45 dates above), 9 of them are seen to lie in the autumn season. In the study by Karaca et al. (2009), it was mentioned that air masses arriving in Istanbul include air pollution originating in European and Black Sea countries during winter (including Eastern Russia, among others) and mineral dust-loaded air originating in the northern Mediterranean and Arabian countries during spring. While the winter mentioned seems to be related to the path between Asian countries and Türkiye, the spring season mentioned includes Arabian regions. These findings can also be compared with the findings in Flores et al. (2017), where there is no mention of Arabian arid regions, and it was found that %6-35 of the backtrajectories for İstanbul correspond to Russia-Asian Desert-Black Sea originated air masses. The abovementioned findings in this thesis about those regions indicate %27.79 of air masses with Arabian or Asian arid regions origin, i.e., 122/439. The fact that no backtrajectory was associated in the said study with the Arabian arid regions as differently from Marmaris can be thought to be related to the differences in location and meteorology. Meanwhile, %27.79 is seen to lie within the same range, %6-35.

The dates identified as arid region dust contribution days were statistically analyzed for the corresponding PM_{10} and elemental concentrations recorded at the rural site. The Multiple Range Tests (with 95,0 percent Least Significant Difference method) and Mood's Median Test were applied. The variation of general statistical characteristics of Al (ng/m^3) with the existence or absence of coinciding arid region dust contribution. Table 4.9, shows the results of the Multiple Range Tests associated with this variation. Tables 4.10, 4.11, 4.11,4.12, 4.13 are demonstrations of the same concepts for Fe and Si rather than Al.

These dates identified as arid region dust contribution days were statistically analyzed for the corresponding PM_{10} and elemental concentrations recorded at the rural site. The Multiple Range Tests (with 95,0 percent Least Significant Difference method) and Mood's Median Test were applied. The results are given below.

Since the P-value for the chi-square test from the Mood's median test is less than 0,05, the medians of the samples are significantly different at the %95,0 confidence level. The outputs show that the dates with and without confirmed contribution of

Table 4.9: Results of Multiple Range Tests for daily Al concentration (ng/m^3) by presence or absence of arid region dust contribution

Level	Count	Mean (ng/m^3)	Homogeneous Groups
No	181	68.6683	A
Arid region dust	131	121.257	B

Contrast	Sig.	Difference	+/- Limits
Arid region dust - No	*	52.5884	27.1299

* denotes a statistically significant difference.

arid region dust are statistically significantly different with respect to rural Al concentration. This was expected, as Al was expected to increase with arid region dust transport. The mean level for those days with arid region dust contribution is almost twice as much as those days without this contribution. Because of the statistically significant difference, the Box-and-Whisker is also given below in Figure 4.10.

The statistical analysis was repeated for Fe and Si. The medians of the samples are not significantly different at the %95,0 confidence level for Fe, but it is the opposite for Si, like for Al. Si's box and whisker plot is also given below Figure 4.2. The mean and median for Si on episode dates are again approximately double the amounts on the dates without episodes. These results are thought to confirm that, the rural elemental PM_{10} range Al and Si are good indicators for arid region dust episode. Normally, Fe should also have the same character. It was also considered a better approach in Uzunpinar et al. (2023) to utilize Al and Si data instead of Fe, with a justification that Fe is generally in harmony. There could be issues about lower number of Fe data as discussed previously, or maybe other issues. This could not be totally understood. A higher emphasis was given to Al and Si in the thesis than to Fe, for arid region dust.

Regarding these 693 dates, 11 of them are seen to have coinciding (in more than one nearby station) combined PM_{10} and SO_2 episodes. This was considered as a justification for eliminating these dates from the list. Because they were considered to be associated with another source of pollution (possible association with volcanic activity contribution will be mentioned in the next section in more detail).

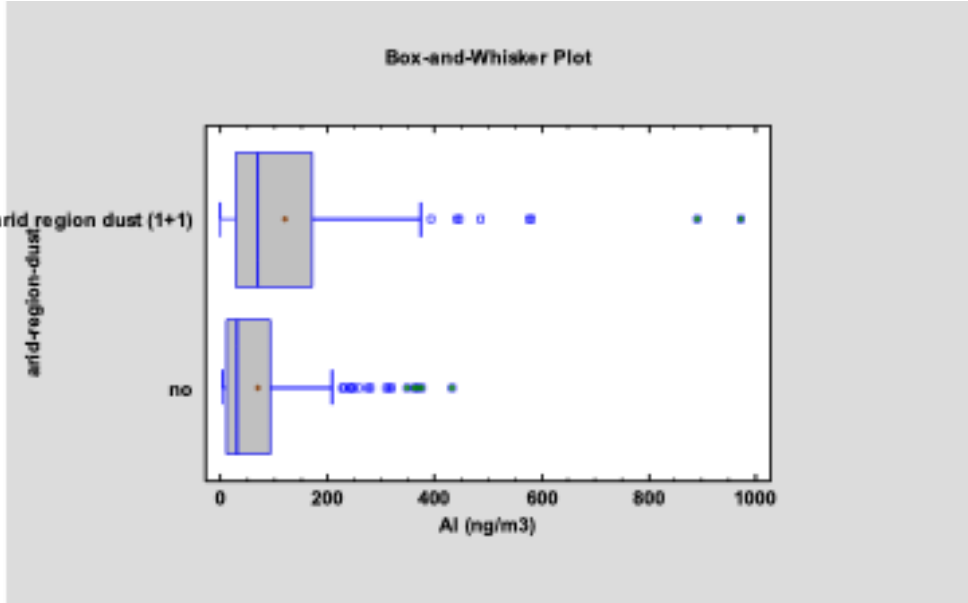

Figure 4.10: Box-and-whisker plot for Al (ng/m^3) for arid region dust episode dates and the rest

Table 4.10: Variation of Fe (ng/m^3) with existence or absence of coinciding arid region dust contribution

arid-region-dust	**Count**	**Average (ng/m^3)**	**Standard deviation (ng/m^3)**	**Median (ng/m^3)**	**Minimum (ng/m^3)**	**Maximum (ng/m^3)**
arid region dust	68	1385.95	1214.23	1541.87	6.18358	4749.42
no	89	1412.79	991.71	1784.2	2.61265	4543.29
Total	157	1401.16	1090.04		2.61265	4749.42

Table 4.11: Results of Multiple Range Tests for daily Fe concentration (ng/m^3) by presence or absence of arid region dust contribution

Level	Count	Mean (ng/m^3)	Homogeneous Groups
Arid region dust	68	1385.95	A
No	89	1412.79	A

Contrast	Sig.	Difference	+/- Limits
Arid region dust - No		-26.8406	347.904

* denotes a statistically significant difference.

Table 4.12: Variation of Si (ng/m^3) with existence or absence of coinciding arid region dust contribution

arid-region dust	Count	Average (ng/m^3)	Std deviation (ng/m^3)	Median (ng/m^3)	Minimum (ng/m^3)	Maximum (ng/m^3)
arid region dust	124	332.274	424.57	191.23	1.44472	2427.06
no	170	180.894	224.215	94.0569	1.40653	1145.19
Total	294	244.741	332.079		1.40653	2427.06

Table 4.13: Results of Multiple Range Tests for daily Si concentration (ng/m^3) by presence or absence of arid region dust contribution

Level	Count	Mean (ng/m^3)	Homogeneous Groups
No	170	180.894	A
Arid region dust	124	332.274	B

Contrast	Sig.	Difference	+/- Limits
Arid region dust - No	*	151.38	75.3255

* denotes a statistically significant difference.

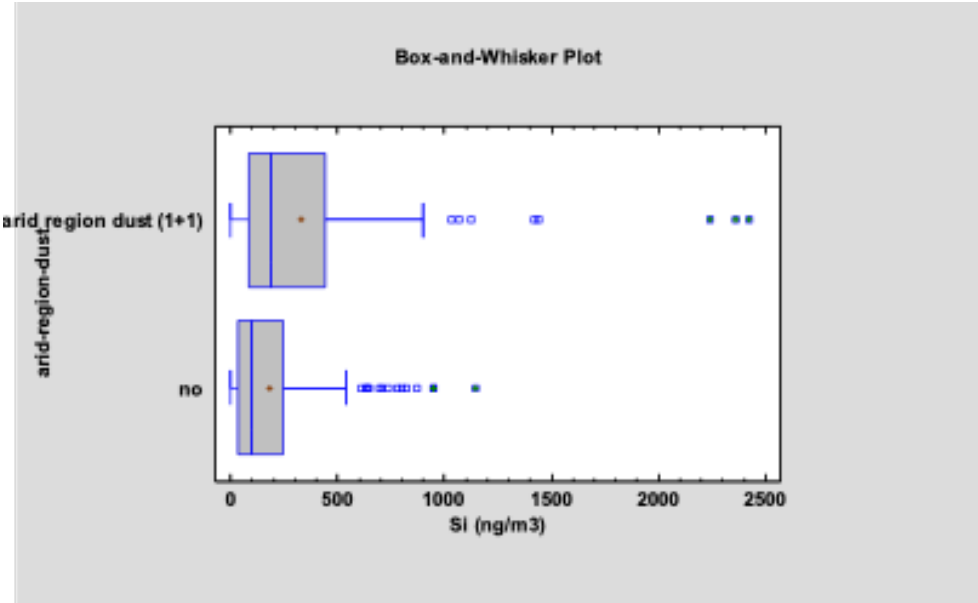

Figure 4.11: Box-and-whisker plot for Si (ng/m^3) for arid region dust episode dates and the rest

At the quantification step, the first step was to subtract the sea salt aerosol contribution (the contribution being separately discussed in section 4.4) amount in terms of rural PM_{10} values. Afterwards, the different statistical indicators were applied. It was seen that the moving 50 percentile method yielded 49, the moving 40 percentile method yielded 43, the moving 30 percentile method yielded 36, and the moving average method yielded 68 negative values computed as arid region dust contribution for the 693 dates. This is relevant to only the contribution computation, whereas discussion on negative values computed as "remaining" PM_{10} values (after subtraction of the contribution from nearby stations' PM_{10} data) can be seen shortly after the discussion of this first group of negative values obtained. The moving averaging method being seemingly the most erroneous one is not surprising since this method is not trustworthy with this dataset given the huge data gaps (although the computation was made with "moving" averages, data gaps are seen as an issue where they exist within the ± 15 days window excluding the episode dates). Regarding the computations with percentile, the decrease in the number of negative contribution amounts resulting from the decrease in percentile was expected. Choosing a lower percentile could be interpreted as estimating the background concentration at a lower amount and, thus, the arid region dust contribution at a higher amount. The selection of a

conservative indicator when compared to the 40 percentile, as suggested by European Commission (2011) seems justified as a negative contribution does not make sense. Furthermore, the data gaps are a concern, e.g., for the consecutive 10 arid region dust episode dates at the beginning of the dataset (02-11.04.2014), the background concentration was calculated as the same for each date within this 10-day period due to the deficits in rural PM_{10} data availability, in all methods. An important aspect of the choice of statistical indicator, besides the negative values aspect, is known to be the level of background concentrations computed. According to European Commission (2011), the use of 40 percentile of 30 (±15) days where the evaluated days are placed in the middle position and excluded days was validated in the Iberian Peninsula but not in other countries. If there exist no known statistical indicators that better reproduce PM_{10} background concentration, the suggestion given by European Commission (2011) is the use of a more conservative indicator, like the average of the PM_{10} concentrations registered during 15 days before and 15 days after the analyzed dust outbreak episode excluding the days with the identified episode or the moving 50 percentile of 30 days. Here, an important issue is the avoidance of underestimation of the background concentrations. When the background concentrations computed according to these different methods were compared with the literature, it was seen that they corresponded to the non-dust period in other stations, according to the EEA report.

The dates with negative contributions were not included in the computations. One reason for the negative contributions could be the previously explained comprehensive identification of dates, some of which probably have only incremental increases in PM_{10} due to arid region dust. It is thought that the PM_{10} level was so little increased by arid region dust that together with some probable cleaning effects, the net level of PM_{10} was not really increased with respect to background concentrations. Cleaning can be due to subreasons such as the arrival of air masses from particularly clean air masses or windy conditions. Wind was not investigated in this thesis in detail, but there is limited data about tornadoes, as mentioned in Section 4.4, and only 1 of the 36 dates -still only one of the 49 dates- was seen to correspond to a known tornado.

Taking the 36 negative contribution dates as an example case, there was some more in-

vestigation. Some noticed backtrajectories reaching Greenland were also considered (in this study, there was not a comprehensive analysis with respect to such backtrajectories, but this situation was noted for some days). It was seen that backtrajectories pointing at Greenland belong to the dates 14.11.2017 and 16.11.2017, just a few days before one date with a negative contribution, 19.11.2017. In three others with negative contribution dates, there is a 15-20-day gap between the date and the backtrajectory to Greenland, which is considered irrelevant. For 19.11.2017, this situation can be partly associated with the negative contribution value. In another one, the situation seems clearer: negative contribution value at 21.01.2018 after the backtrajectory for 20.01.2018.

The minor overall increase in PM_{10} was also checked with Multi-model analysis. Such dates should have dust shown by only light blue color, and this was recognized to be mainly the case for at least 23 of these 36 dates (this is not a straightforward counting, considering the different 3-hour intervals for which Multi-model output images are provided to users for each day).

A second reason could be that arid region dust arrived in the region but not exactly in Marmaris, with no or little effect on rural levels. Such a situation results in a 0.5 score in TRAJSTAT analysis (arrival to close or very close points were scored as such), the note "partially" in Multi-model analysis, or higher scores in analyses other than rural station data analysis. When TRAJSTAT scores were checked, it was seen that 23 of them had 0.5 scores at maximum. When multi-model analysis results were checked, it was seen that only 5 of them had the note "partially," but the majority (23) of the 36 dates with negative contribution values were found to have -1 scores from rural station data. When arid region dust arrival was detected at the region but not specifically to Marmaris, this is sufficient to count the date as an arid region dust episode date, but the dependence on rural concentrations complicates the quantification process. Out of the remaining 13 dates of the 36 dates with negative contribution values, 10 have 0 scores from rural station data. They are similarly considered to have a complicated nature for the subsequent steps because these dates do not seem to offer consistent data that can be securely used for quantification with rural data. Thus, in the following steps, 33 dates out of the 36 dates with such low scores from the rural station data analysis were excluded with satisfactory justification.

The remaining 3 dates (15.8.2016, 17.10.2016, 1.5.2017) among the 36 dates with negative contribution values all have Al and Si values above the median, and Multi-model, AOD, and satellite (Aqua) photograph analyses score as 1. The date 17.10.2016 additionally has confirmation from the rural and nearby stations' data analyses without any missing confirmation. However, this low number, 3, of remaining unexplained discrepancies was considered satisfactory to continue the quantification, omitting these negative contribution values too.

In all -moving percentile and moving average- computations, the remaining PM_{10} levels after deduction of arid region dust episode contribution amount were computed as negative for 6 dates (17.8.2015, 31.10.2016, 13.3.2017, 24.3.2017, 4.5.2017 and 6.5.2017 in all computations) and 1 date (31.10.2016 among these dates in all) for the Muslihittin and Milas Ören stations respectively. The reason for the other 5 dates not having negative values at Milas Ören station is that there was no computation due to the absence of that station's PM_{10} data. The remaining PM_{10} levels -i.e., the background PM_{10} concentration computed on those dates- were never computed as negative for any dates at the rural station as it did not involve any subtraction process. The common characteristics of the aforementioned 6 dates are as follows: i) Na level is above median in all (meaning a high amount of sea salt aerosol to be subtracted at first from rural PM_{10}, but at the same time high rural PM_{10} levels, maybe neutralizing the effect of this), ii) almost no TRAJSTAT confirmation for Africa: three are rejected at all heights, two are confirmed for Asia and Arabian peninsula, one confirmed for Africa at only one altitude (with the source region being different from Africa, a different impact on PM_{10} levels can be anticipated), iii) all but one of them received 1 score from Multi-model analysis which aided their confirmation (when checked again for colors, a mixture of light and dark blue color with a score 1 was seen at different hours for the first and fifth dates, only light blue with a score 0.5 for the second date, only light blue with a score 1 for the remaining dates), iv) four of them have AOD confirmation both on overall and seasonal basis, v) they have 0 or 0,5 scores from satellite photograph analysis (this was checked with Aqua too and the scores were not increased), vi) they do not have any confirmation from nearby stations' PM_{10} data analysis (but it should be kept in mind that one station lacked PM_{10} data for 5 dates which eliminates the possibility of confirmation as this analysis is based

on simultaneous PM_{10} increases). Considering items ii, iii, and v together, it could be considered that low levels of arid region dust may have arrived on those dates, but this does not explain the negative "remaining" value, which is just the opposite case. These dates are mostly in spring (March and May), corresponding to the high arid region dust contribution expectation, leading to low remaining values. It can always be considered a possibility that the high-altitude rural station received the arid region dust episode contribution, but the nearby stations did not. This possibility was also underlined by European Commission (2011). If TRAJSTAT analysis was, in general, found to be confirming these dates, one approach could be analyzing the heights recorded in backtrajectory computation for each of these dates, but this is not considered meaningful in this situation. Meanwhile, regarding TRAJSTAT, the date 24.3.2017 is among the 35 dates previously mentioned as confirmed by TRAJSTAT with a 1500 m agl backtrajectory computation with a link to Asian and Arabian arid regions alone and the date just before 4.5.2017, i.e., 3.5.2017, is also seen to be within this set of dates.

It is possible for the remaining values to have been underestimated due to the altitude differences, even including those computed as positive values (an alternative computation method for this possibility will be mentioned shortly, based on the Guidance). Yet overestimation of remaining values may also be the case, e.g. for the dates when the dust has reached the nearby stations in larger amounts than it has reached the rural station. Within this framework, the examples where dust seems to have not reached the rural station at all, but only the nearby stations, can be remembered as an issue on the side of the overestimation possibility. Another possibility is linked to the correlation between a rural station and nearby stations, regardless of altitude differences. In the TÜBİTAK (2019) from which the rural data were derived, for cross-check of the PM_{10} levels with the other stations' PM_{10} measurements, the average and median concentrations of another rural station (in Ankara) were compared to surrounding stations and found to have similar results with the air quality monitoring stations operated by the Ministry in Ankara. However, it was mentioned that one issue could not be understood. The highest concentrations among the overall data were not seen in the data from the Ministry stations (e.g., approximately 1500 $\mu g/m^3$ was reported in the study, whereas the maximum was lower than 200 $\mu g/m^3$ for the other stations) despite

similar averages or median concentrations and dates. This could be considered as a possible point about the correlation between the Marmaris rural station and nearby stations. With low concentrations falsely recorded during episodes at nearby stations, if this can be deemed as the case, the remaining levels are prone to be calculated as lower than real values and even as negative.

All in all, the reason for the negative remaining levels could not be exactly understood. It may or may not be linked to the source region different from North Africa. The number of the negative remaining values -the PM_{10} values remaining after subtraction of arid region dust contribution, calculated as negative- which is 6, was considered to be quite a low number when considered against 693 episode dates or 1404 total dates. Besides these dates are seen as commonly valid for all computation methods.

In the Guidance, it was mentioned by the European Commission (2011) that "in very few cases," an air mass with high Saharan dust load leads to different influences at certain heights. This possibility may be realized because that the selected regional background reference stations are located at substantially higher altitudes than the related urban networks. Such an altitude difference is the case for the stations in this thesis, especially for the rural station when compared to Milas Ören station. This possibility of differing influences was explained as a problem yielding negative remaining PM_{10} values computed for the urban network, associated with the limited representativeness of the reference stations. For such cases, it is firstly suggested to utilize average Saharan contributions obtained in the reference regional background station and other closest regional background stations. This thesis did not consider this possible, with background data from one rural station in total. As the second suggestion, it is advised by the European Commission (2011) to utilize the urban sites' PM_{10} data instead of the background station's data. Because there were 6 negative values in all computation methods employed and described until here, this alternative method was also employed as an alternative. While doing this, the suggestion of the European Commission (2011) is seen as utilizing the urban site PM_{10} data with again the moving 40 percentile method. However, considering the remarks about selecting a more conservative indicator than the 40 percentile for the regions outside the Iberian peninsula, this method was also used with a more conservative indicator, the moving average. Besides, the nearby stations' data was not directly utilized for this compu-

tation, but rather after subtracting the sea salt aerosol contribution, as also previously done with the rural station PM_{10} data in the methods described until here. The results obtained from this new computation with the moving average method involve 303 and 33 negative contribution values at Muslihittin and Milas Ören stations, respectively. Given the high number for Muslihittin, the computation was not continued for that station. It should be remembered that the altitude difference of the rural station is much less from the Muslihittin station than from the Milas Ören station. This can be considered as a reason to think that the nearby station (Muslihittin station in this case) PM_{10} data did not need to be used, but rural data was enough for the computation of the remaining values at the Muslihittin station. Another way of interpreting this is that the negative remaining values at Muslihittin may not be easily attributed to altitude differences (the other possible factors were discussed above).

For the Milas Ören station, when the dates with missing PM_{10} data preventing the computations (for either moving average or subtraction) were eliminated, there were 168 dates for which the remaining PM_{10} level at Milas Ören station could be calculated. None of these remaining PM_{10} values were negative. This is an advantage, although the number of negative remaining values was only one previously. As mentioned before, the already-positive values may also be underestimated using the previous method. Additionally, previously, the computation was conducted with the rural PM_{10} data, and again, the moving average method was seen to allow for the calculation of the remaining PM_{10} level at Milas Ören station for 158 dates, a similar number. Thus, there does not seem to be a disadvantage to coverage of the dates with quantifiable remaining PM_{10} levels either, as far as Milas Ören is concerned.

Based on the discussion above, the computations for arid region dust contribution were made with the rural PM_{10} data for the Muslihittin station and with the Milas Ören station's own PM_{10} data for the Milas Ören station. The statistical computation method used in both is the most conservative method detected with respect to the rural station data, i.e., the one with the highest number of negative contribution values at the rural site: the moving average. The results are tabulated in Table 4.14

The number of dates included in quantification at the end is reduced when compared to the beginning, 693 dates). According to the moving average method, there are only

Table 4.14: Average Annual Arid Region Dust Contribution according to moving average method with rural data

Year	**Average Contribution ($\mu g/m^3$)**
2014	19.69
2015	26.13
2016	27.36
2017	22.15
2018	5.53

* per quantifiable episode dates

** till only 31.01.2018, with 2 dates taken into account for the table in total

79 dates on which the arid region contribution can be computed at the end. The rest of the 693 dates were excluded from quantification at different steps due to the issues described until now, including the absence of rural station data. 543 of the dates identified as arid region dust episode dates lack rural station PM_{10} data. An approach in future studies could be to set the existence and perhaps even confirmation by the rural station data as the condition to start quantification for a specific date if the main purpose is quantification. A similar decision was made in the Maltese study Environment and Resources Authority (2020) at the beginning, mentioning that although there are probably many dates when African dust reached their site, milder events would be difficult to quantify and thus only the dates with exceedance or close-to-exceedance status shall be taken into consideration for quantification. In some other studies, the list of dates was determined via confirmation by more than two different analyses, one example being Cuspilici et al. (2017) where coinciding agreement of HYSPLIT backtrajectories, AOD, and DREAM model surface concentration outputs was searched for regarding the dates showing exceedance of the 50 $\mu g/m^3$ daily limit value. However, the 693 dates already identified in this study can be regarded as useful in other respects than aiding quantification, such as a better understanding of variation by time. Below are some statistical data on this. Table 4.15 is given to demonstrate the average annual arid region dust contribution.

Spring is seen to have the highest contribution in Table 4.15, and this is in harmony

Table 4.15: Average Seasonal Arid Region Dust Contribution according to moving average method with rural data

Season	**Average Contribution (µg/m^3)**
Winter	9.49
Spring	40.24
Summer	18.85
Autumn	16.67

* per quantifiable episode dates

** till only 31.01.2018 for the year 2018

with the literature stating the highest effect of Saharan dust in the spring season, such as Diapouli et al. (2017). Following the same logic, possibly due to missing many dates with higher potential for contribution (such as Spring dates) than January alone, the year 2018 has the lowest contribution among the years studied.

The daily contribution percentage of the arid region dust to the rural daily PM_{10} was also computed for all 79 dates daily. If calculated directly for the whole period, the average contribution will be %2.93 at the rural site. When this overall percentage figure is compared with the figures given in Literature Review, it is seen that the figure is close to those given for the cities Porto, Barcelona, Milan, and Florence but much lower than that for Athens, in Diapouli et al. (2017), and slightly above the figure given for Elche city in Clemente et al. (2023). There may be several factors to explain this. The data gaps being a barrier against full computation may partly constitute the explanation. The resulting percentages may be higher in the studies that did not start computation by subtracting the sea salt aerosol contribution portion from the background station PM_{10} records. Another factor was the -omitted dates due to data gaps. When the percentage is calculated with only the quantifiable dates, the average contribution to rural PM_{10} ranges between %4.89 and %93.05. The average of the percentages from each date is %51.99, much higher than the previous figure.

4.3 Volcanoes

The dates that had combined PM_{10} and SO_2 episodes or rural combined PM_{10} and S episodes may indicate volcano activity contribution. There are 77 such dates. However, considering that the SO_2 could have been converted to SO_4 during its transport from Etna or Stromboli to Marmaris, it was preferred to take only the dates with rural combined PM_{10} and S episodes into account, to be on the safe side (still a discussion can be seen in the coming parts shortly). There are 68 such dates.

It was recognized that, interestingly, 61 out of these 68 have a K concentration higher than the median. This can be due to the presence of particulate potassium compounds in Mt Etna emissions, as mentioned before. Thus, it was chosen to focus on these 61 dates.

For example, for February 2017, the satellite SO_2 data shows the possible arrival of SO_2 from Etna or Stromboli to a location close to Muğla. However, these dates were already identified as arid region dust transport dates, not necessitating further quantification for volcanoes, based on Section 3.3.

It should be remembered that the interval 22 - 26.12.2015 is close to the dates specified by Aloisi et al. (2017a) as the highest eruption date in the preceding 20 years duration back then, having other supporting records of volcanic activity. Below is the Figure 4.12 SO_2 satellite product for 14.12.2015, showing SO_2 near Muğla. This date is also close to the date 12.12.2015 regarding ash emissions from Etna according to Chamber of Geological Engineers (2017), and again, the information on the first days of December 2015 having the most violent volcanic events observed during the preceding two decades with a few months of high activity period Aloisi et al. (2017a).

For the year 2017, similar dates, i.e., 14-15.12.2017, the satellite SO_2 data and TRAJSTAT support the assumption that the combined PM_{10} and SO_2 increase could be due to volcanic activity contribution. Below is the satellite SO_2 output for 15.12.2017, as shown in Figure 4.13. Meanwhile, TRAJSTAT backtrajectory for 14.12.2017 at 1500 m asl illustrated as Figure 4.14 also indicates the arrival of a big air mass with SO_2 from Etna to Marmaris on the date.

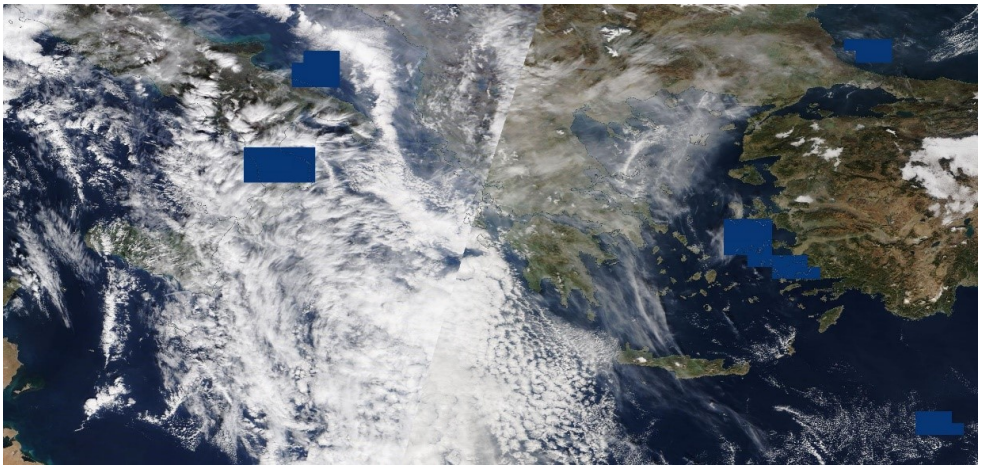

Figure 4.12: Lower troposphere SO_2 satellite output for 14.12.2015

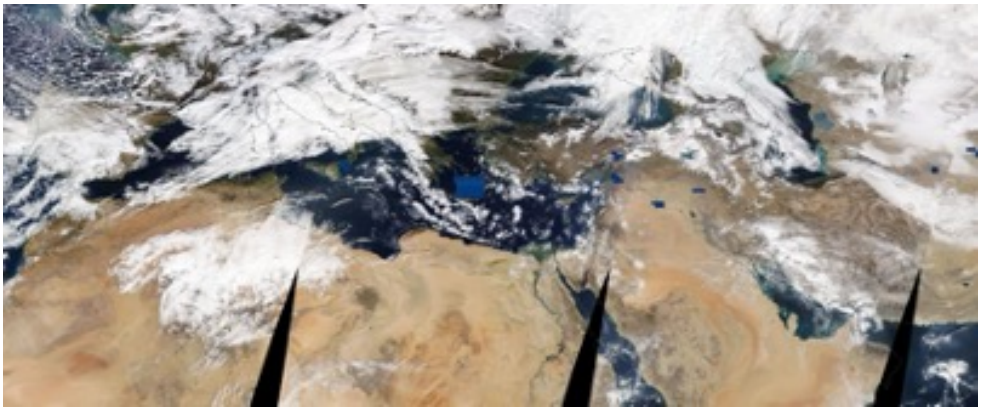

Figure 4.13: Lower troposphere SO_2 satellite output for 15.12.2017

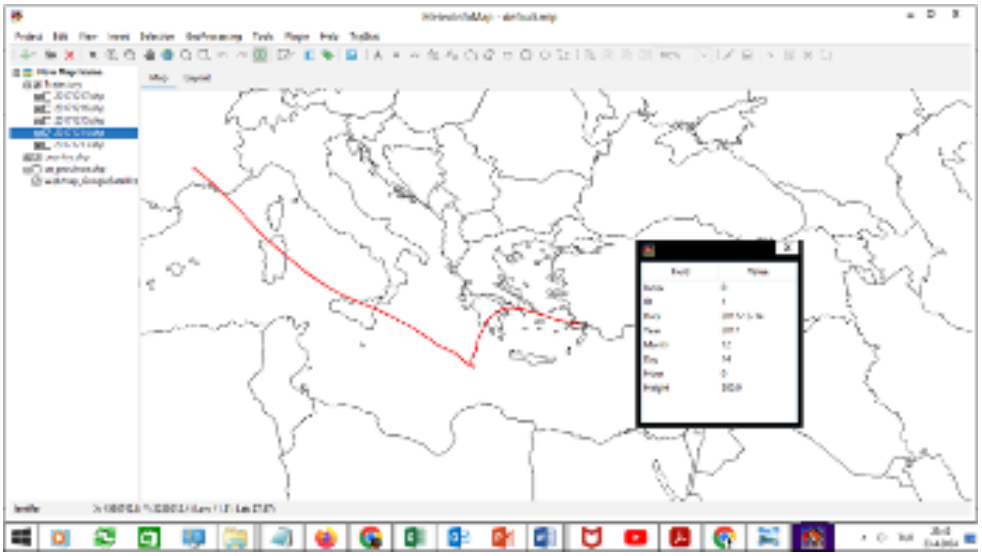

Figure 4.14: Backtrajectory for 14.12.2017

There were also dates that could not be evaluated according to PM_{10} or S data merely due to the absence of such data. 19-22.11.2017 constitute an example case where probably volcanic activity contribution cannot be numerically detected due to the absence of data. Below are the SO_2 satellite outputs showing transport of SO_2 plume from 19.11.2017 to 22.11.2017, from Etna or Stromboli to Muğla illustrated in Figures 4.15, 4.16, 4.17 and 4.18. Meanwhile, TRAJSTAT backtrajectories for not 22.11.2017 but this time 20.11.2017 show the arrival of air mass from the location of Etna to Muğla.

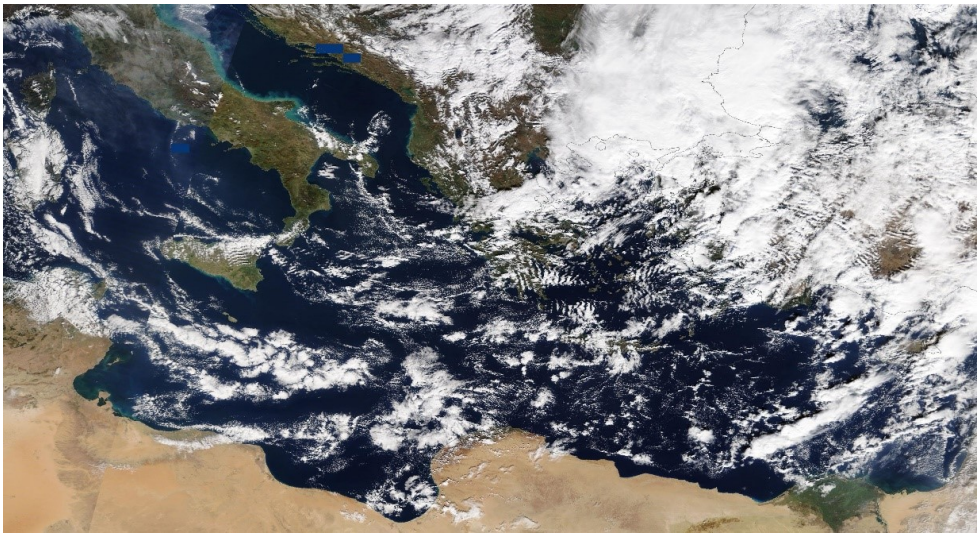

Figure 4.15: Lower troposphere SO_2 satellite output for 19.11.2017

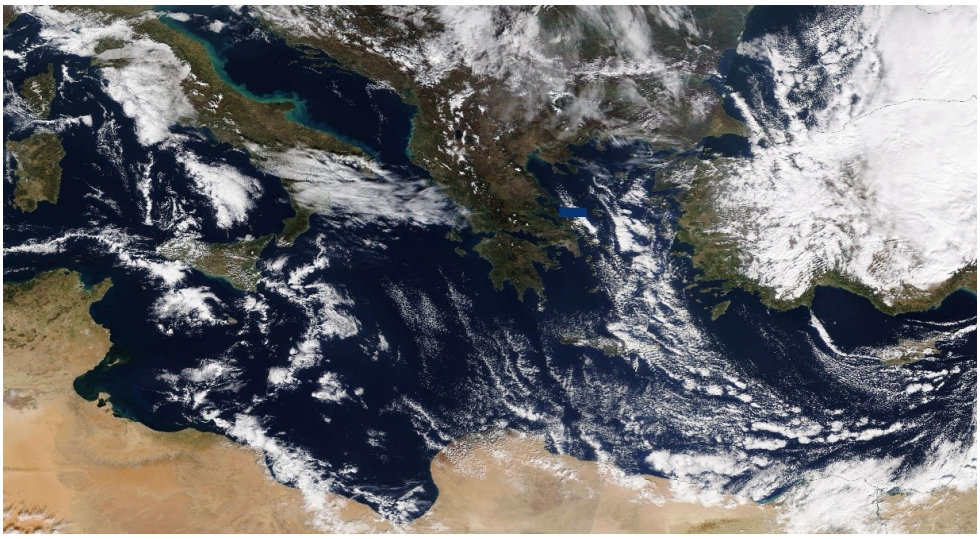

Figure 4.16: Lower troposphere SO_2 satellite output for 20.11.2017

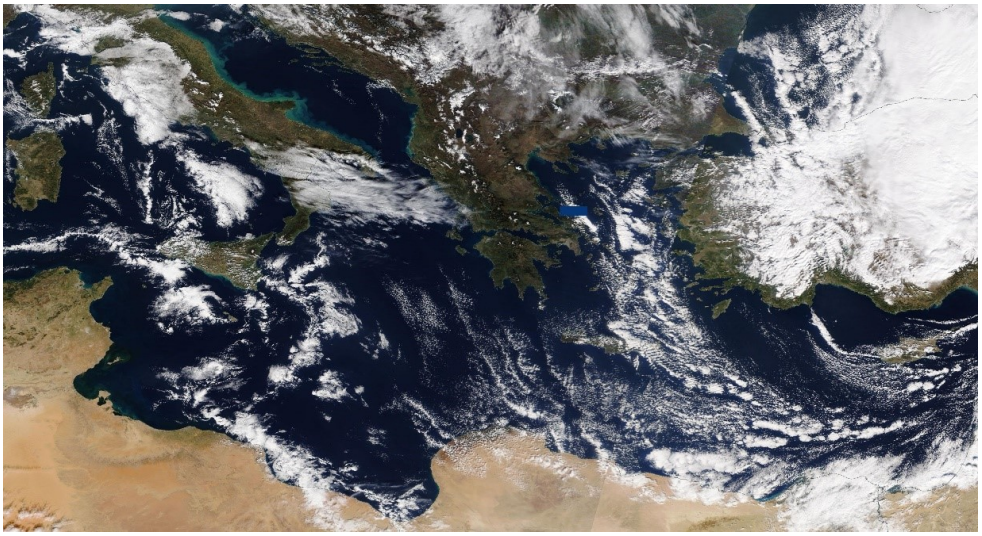

Figure 4.17: Lower troposphere SO_2 satellite output for 21.11.2017

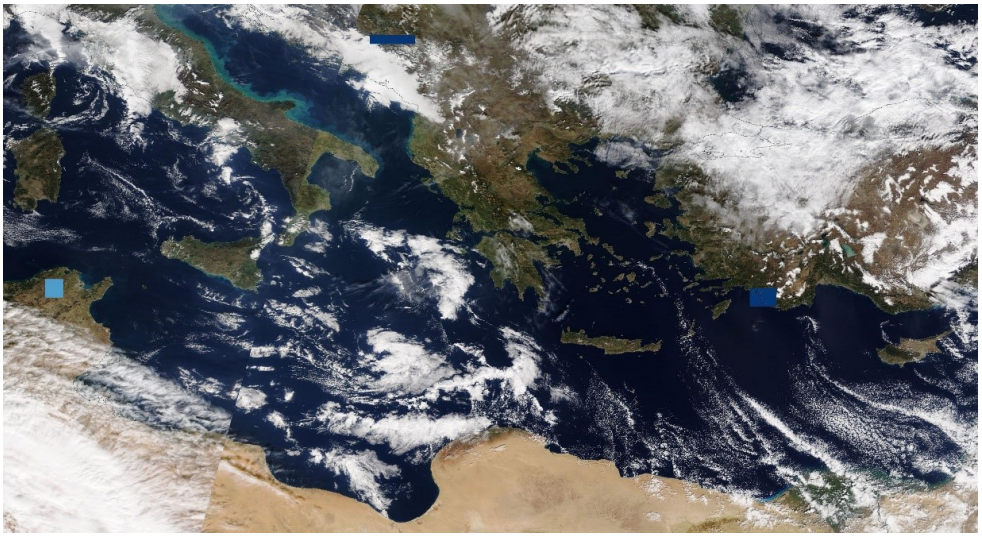

Figure 4.18: Lower troposphere SO_2 satellite output for 22.11.2017

Regarding the 693 arid region dust episode dates, 11 of them are seen to have coinciding (in more than one nearby station) combined PM_{10} and SO_2 episodes. As pointed out at the beginning of this section and in the previous section, this could be a reason for eliminating these dates from the list. When checked with the literature, it is seen that in Eritrea, the average time to convert the volcano Nabro's SO_2 to sulfate was found to be 27 days by Liu et al. (2019). This is quite a long residence time when it is considered that 5-day backtrajectories are suggested by the European Commission (2011)to be computed for North African dust. However, the figures given by Liu et

al. (2019) include the detection of sulfate at altitudes higher than 10 km, indicating stratospheric transport. SO_2 is known to have longer residence times in the stratosphere than in the troposphere Sangeetha et al., 2018. It is thus understood that the SO_2 analyzed by Liu et al. (2019) reached the stratosphere before complete conversion to sulfate. On the other hand, the average residence times of SO_2 at the volcano site in Montserrat island, North America, were analyzed in another study and found to be in the order of only minutes (L. A. Rodríguez et al., 2008). On the contrary, this would indicate that SO_2 cannot reach the rural station at all before conversion to sulfate. The difference is considered to be relevant to whether the eruption is a large explosive eruption enabling the SO_2 to reach the upper troposphere and stratosphere, as pointed out in the literature (Liu et al., 2019). Meanwhile, about the dataset of this thesis, for the dates 14-15.12.2017, it was seen that Etna's contribution was confirmed as described above despite the combined PM_{10} – SO_2 episodes coinciding with each other in nearby stations. In this thesis this could not be checked for the date 14.12.2015, the date close to a known violent eruptive activity in Etna, simply because coinciding peaks or the reverse case could not be detected on that date due to data gaps. Thus, in the end, it is considered that such coinciding episodes may not be a strong reason for elimination from the potential list of volcanic activity contribution dates. Still, to be on the safe side and for practical reasons, only those dates with combined PM_{10} and S data at the rural station were continued to be considered in this section.

For reasons of practicality, in the cases when there was a simultaneous arid region dust episode and volcanic activity episode, the contribution to PM_{10} levels of these two were not distinguished from each other. Regarding the 61 dates, after excluding those already identified as arid region dust transport dates, 25 dates remain.

The dates with 1-day intervals were merged for practicality in analyses, which leads to the following dates: 22-26.12.2015, 3-6.2.2016, 17.8.2016, 24.10.2016, 3.1.2017, 19.2.2017, 26.4.2017, 7.5.2017, 28 – 29.7.2017, 2.8.2017, 26-27.8.2017, 19-21.9.2017, 27-30.9.2017, 9.11.2017 and 12.12.2017. Further eliminating the dates when simultaneous PM_{10} and SO_2 episodes occurred in Muslihittin station and the consecutive dates, the size of the set of dates is reduced to 12 dates: 24.10.2016, 19.2.2017, 7.5.2017, 28 – 29.7.2017, 2.8.2017, 26-27.8.2017 and 27-30.9.2017.

For some of those dates, some are considered to be linked to possible volcanic activity contribution, such as with satellite SO_2 images, including clouds covering the middle area between Etna and Marmaris in a whirling mode. There are satellite SO_2 images where the SO_2 plume is seen to be on the way being transported from Etna to Marmaris, or which include SO_2 plume beyond Marmaris as if it has passed through. However, there is no direct indication from the satellite SO_2 images for any date that can be used without interpretation. The uncertain images were not taken into consideration after this step, to be on the safe side.

When TRAJSTAT backtrajectories were analyzed for those dates ±1, it was seen that the air mass passes directly from Etna for 7.5.2017, 28.7.2017 (at least the 100 m asl calculation), along with 25.10.2016, 20.2.2017 and 27.9.2017 (1500 m asl calculation). None was confirmed via the 500 m asl calculation of TRAJSTAT. It was considered that the confirmed date is a sign of the need to confirm the impact of volcanic activity on consecutive dates, e.g., 27.9.2017 for the rest of 27-30.9.2017 in the list. Because the air quality data are already in conformity with the whole consecutive range. 20.2.2017 is another date added this way, but it is among the arid region dust transport dates, so it was excluded.

Thus, it was seen that quantification can be done for the following dates: 24-25.10.2016, 19.2.2017, 7.5.2017, 28 – 29.7.2017, and 27-30.9.2017. Of these 10 dates in total, 7 dates, however, yielded negative contribution values at the rural station, and the calculations for those days were omitted. The results for the remaining 3 dates are as follows for the Muslihittin station as shown in Table 4.16. There are no Milas Ören PM_{10} data for these 3 dates.

As seen all of these dates are from the year 2017. Two of them are from July, the summer season, and 1 from September, the autumn season. The highest contribution percentage is at 29.7.2017, %12, corresponding to 4,6 (µg/m^3).

One reason for the negative contributions computed could be that a small amount of volcanic emission actually reached Marmaris. Perhaps the volcanic activity on that day was not intense, or due to other geological or meteorological reasons, the volcanic emission arrival was not at high amounts. The consideration of SO_2 may also have caused or worsened this situation for some dates. For some dates, maybe

Table 4.16: The calculated contribution and the associated original PM_{10} at Muslihittin station

Date	**Muslihittin** PM_{10} **(µg/m^3)**	**Volcanic activity contribution (µg/m^3)**
28.7.2017	43.5	0.6
29.7.2017	38.4	4.6
28.9.2017	48.0	0.3

PM_{10} was declining, but the date was taken into account in the first place owing to a high SO_2 value. It is thought that the PM_{10} level was so little increased by volcanic activity that together with some probable cleaning effects, the net level of PM_{10} was not really increased with respect to background concentrations. Cleaning can be due to subreasons such as the arrival of air masses from particularly clean air masses or windy conditions. Wind was not investigated in this thesis in detail, but there is limited data about tornadoes, as mentioned in Section 4.5

Regarding quantification, since no separation was made between arid region dust episode and volcanic activity episode contributions for the arid region dust episode dates, and thus since the quantities were calculated for only the rest of the dates, the quantities found for volcanic activity contribution can be regarded as lower than the real case.

4.4 Forest Fires

Below is the list of forest fires obtained from these satellites and the literature in Table 4.17. Data from the two different satellites and the literature can be seen in the order of dates. The forest fires in Greece were also investigated, but no forest fires were detected in proximity to Muğla. Some of the dates are indicated as forest fire dates by both MODIS and VIIRS satellites. This might bring higher confidence in considering forest fires for these dates. Nevertheless, the fact that the majority of these dates were not confirmed by the other satellite shall not necessarily exclude the dates from the list of forest fire dates because there might be differences due to various factors, such as the different orbit schedules of these two satellites. One of these factors is the success of VIIRS in detecting smaller fires than MODIS, for the fires detected by only VIIRS do not seem to have lasted long (Demirel and Türk, 2023).

Table 4.17: Satellite Reports for Muğla, Greece

Date	**In Muğla / Greece**	**Satellite / Other report**	**Source**	**If satellite, number of relevant satellite measurements**	**Known natural reason?**
14.03.14	Muğla	Satellite	VIIRS	2	No
20.03.14	Muğla	Satellite	VIIRS	3	No
09.06.14	Muğla	Satellite	MODIS	1	No
12.06.14	Muğla	Satellite	VIIRS	1	No
20.07.14	Muğla	Satellite	VIIRS	3	No
21.07.14	Muğla	Satellite	VIIRS	2	No
04.08.14	Muğla	Haber-ler.com, 2014		N/A	No
22.08.14	Muğla	Satellite	MODIS	17	No
	Muğla	Satellite	VIIRS	44	No

Table 4.17 – continued from previous page

Date	In Muğla / Greece	Satellite / Other report	Source	If satellite, number of relevant satellite measurements	Known natural reason?
	Muğla	Haberler.com, 2014		N/A	No
23.08.14	Muğla	Satellite	MODIS	3	No
	Muğla	Satellite	VIIRS	19	No
24.08.14	Muğla	Satellite	VIIRS	1	No
08.09.14	Muğla	Satellite	MODIS	2	No
17.09.14	Muğla	TRT Haber, 2014		2	Yes-Lightning
02.10.14	Muğla	Satellite	VIIRS	1	No
11.10.14	Muğla	Satellite	MODIS	1	No
19.10.14	Muğla	Satellite	VIIRS	5	No
07.11.14	Muğla	Satellite	VIIRS	3	No
08.11.14	Muğla	Satellite	VIIRS	1	No
25.11.14	Muğla	Satellite	VIIRS	1	No
25.12.14	Muğla	Satellite	VIIRS	1	No
07.02.15	Muğla	Satellite	VIIRS	2	No
22.04.15	Muğla	Satellite	VIIRS	1	No
10.05.15	Muğla	Satellite	VIIRS	3	No
20.06.15	Muğla	Satellite	VIIRS	1	No
25.06.15	Muğla	Satellite	VIIRS	1	No
20.07.15	Muğla	Satellite	VIIRS	1	No
	Muğla	Satellite	VIIRS		No
14.08.15	Muğla	Satellite	MODIS	6	No
	Muğla	Satellite	VIIRS	5	No

Table 4.17 – continued from previous page

Date	In Muğla / Greece	Satellite / Other report	Source	If satellite, number of relevant satellite measurements	Known natural reason?
15.08.15	Muğla	Satellite	MODIS	2	No
25.08.15	Muğla	Satellite	VIIRS	1	No
25.08.15	Muğla	Satellite	VIIRS	2	No
02.09.15	Muğla	Satellite	VIIRS	2	No
09.09.15	Muğla	Satellite	VIIRS	2	No
09.10.15	Muğla	Satellite	VIIRS	1	No
06.11.15	Muğla	Satellite	VIIRS	1	No
12.11.15	Muğla	Satellite	VIIRS	1	No
24.12.15	Muğla	Satellite	VIIRS	1	No
30.12.15	Muğla	Satellite	VIIRS	1	No
02.01.16	Muğla	Satellite	VIIRS	1	No
24.01.16	Muğla	Satellite	VIIRS	3	No
01.03.16	Muğla	Satellite	MODIS	1	No
	Muğla	Satellite	VIIRS	1	No
22.03.16	Muğla	Satellite	VIIRS	1	No
19.04.16	Muğla	Satellite	VIIRS	1	No
28.04.16	Muğla	Satellite	VIIRS	1	No
06.06.16	Muğla	Satellite	VIIRS	1	No
08.06.16	Muğla	Satellite	VIIRS	2	No
18.06.16	Muğla	Satellite	MODIS	1	No
17.06.16	Muğla	Satellite	VIIRS	1	No
27.06.16	Muğla	Satellite	MODIS	3	No
	Muğla	Satellite	VIIRS	2	No
29.07.16	Muğla	Satellite	VIIRS	1	No
13.08.16	Muğla	Satellite	VIIRS	3	No
21.08.16	Muğla	Satellite	VIIRS	1	No

Table 4.17 – continued from previous page

Date	In Muğla / Greece	Satellite / Other report	Source	If satellite, number of relevant satellite measurements	Known natural reason?
26.08.16	Muğla	Satellite	VIIRS	1	No
04.09.16	Muğla	Satellite	VIIRS	1	No
	Muğla	Natural Disasters-2016 (2017)		N/A	Yes: Lightning
09.09.16	Muğla	Satellite	VIIRS	1	No
30.09.16	Muğla	Satellite	MODIS	2	No
	Muğla	Satellite	VIIRS	1	No
15.10.16	Muğla	Satellite	VIIRS	1	No
18.10.16	Muğla	Satellite	MODIS	1	No
26.10.16	Muğla	Satellite	VIIRS	1	No
27.10.16	Muğla	Satellite	VIIRS	4	No
28.10.16	Muğla	Satellite	VIIRS	1	No
02.11.16	Muğla	Satellite	VIIRS	3	No
15.11.16	Muğla	Satellite	VIIRS	1	No
18.11.16	Muğla	Satellite	VIIRS	1	No
20.11.16	Muğla	Satellite	MODIS	1	No
	Muğla	Satellite	VIIRS	2	No
26.11.16	Muğla	Satellite	VIIRS	1	No
08.12.16	Muğla	Satellite	VIIRS	2	No
11.12.16	Muğla	Satellite	VIIRS	1	No
15.12.16	Muğla	Satellite	VIIRS	1	No
21.12.16	Muğla	Satellite	VIIRS	1	No
15.02.17	Muğla	Satellite	VIIRS	2	No
16.02.17	Muğla	Satellite	VIIRS	1	No

Table 4.17 – continued from previous page

Date	In Muğla / Greece	Satellite / Other report	Source	If satellite, number of relevant satellite measurements	Known natural reason?
17.03.17	Muğla	Satellite	VIIRS	1	No
19.06.17	Muğla	Satellite	MODIS	1	No
	Muğla	Satellite	VIIRS	6	No
29.06.17	Muğla	Satellite	VIIRS	2	No
21.07.17	Muğla	Satellite	MODIS	1	No
26.08.17	Muğla	Satellite	VIIRS	1	No
01.09.17	Muğla	Satellite	VIIRS	3	No
06.09.17	Muğla	Satellite	MODIS	10	No
	Muğla	Satellite	VIIRS	6	No
	Muğla	DHA, 2017		N/A	No-cigarette
07.09.17	Muğla	Satellite	MODIS	6	No
	Muğla	Satellite	VIIRS	42	No
	Muğla	Newspaper Source		N/A	No-cigarette
11.09.17	Muğla	Satellite	MODIS	2	No
	Muğla	Satellite	VIIRS	1	No
14.09.17	Muğla	Satellite	VIIRS	1	No
23.09.17	Muğla	Satellite	VIIRS	1	No
05.10.17	Muğla	Satellite	VIIRS	1	No
18.10.17	Muğla	Satellite	VIIRS	1	No
22.10.17	Muğla	Satellite	VIIRS	1	No
11.11.17	Muğla	Satellite	MODIS	1	No
	Muğla	Satellite	VIIRS	1	No
24.12.17	Muğla	Satellite	VIIRS	7	No

It is mentioned that the biggest forest fire of the year 2014 occurred in Milas, Muğla, on 22 August 2014, harming 543 hectares of forest land according to the ÇEKUD[24] This fire was confirmed by MODIS and VIIRS data, as seen in Table 4.17. According to the data given by General Directorate of Forestry (OGM) Forest District in Muğla (2023), this fire is the only forest fire affecting more than 500 hectares of land from 2014-2018.

There are 85 dates determined as forest fire dates in the table above. There is no K data for 62 of them. Out of the remaining 22 dates, half (exactly 11) dates are seen to have K concentrations above the median. The corresponding K concentration is in the range 32.1 – 339.4 ng/µg/m^3. Meanwhile, the total number of dates with a K concentration above the median is 155.

Again, as seen in Table 4.17, for almost all of them, no cause (lightning, anthropogenic ignition or ignorance, etc.) is mentioned in the sources of information. The anthropogenic cause of the fire is mentioned as a cigarette for the fire which took place on 6-7.9.2017. The natural cause of the fire is mentioned as lightning for the fire which took place on 17.9.2014. It is mentioned in Chamber of Geological Engineers (2017) reports that 24 different lightning strikes occurred, causing 24 different forest fires on 04.09.16. There is information on damaging lightning strikes on the website of the European Severe Weather Database[25], but it is not relevant to forest fires. An approach could assume that all forest fires contribute naturally to PM_{10} levels. This is not because of assuming all are lightning-originated. Because they are outside the usual list of anthropogenic pollution sources, i.e., traffic, industrial, and residential combustion. Another approach is the one adopted by European Commission (2011). Remembering that only forest fires with exact natural causes can be considered natural according to this guidance, the lack of information on the cause of each fire is of concern in this second case. The literature provides aid via the ratio of the forest fires with natural causes to the total, as mentioned in Chapter 2. The number of forest fires with natural causes can thus be computed based on ratios. According to these two approaches, the forest fire contribution was calculated in two alternative ways.

[24] https://www.cekud.org.tr/en/

[25] https://eswd.eu/cgi-bin/eswd.cgi

The table below includes figures derived from literature for the study period of this thesis for the natural portion. Since the year 2018 after its first month is not included in the thesis, and considering that the distribution of causes can also vary seasonally (e.g., for lightning), it is thought that the annual figure from the study by Demirel and Türk (2023) can be omitted for the year 2018. Instead, an average from 2015-2017 can be considered for January 2018 and for the year 2014, a year not included in the article. Figures from other literature are also included in the table. These figures on causes are valid for the entire country. However, it is considered that the distribution of causes can also differ according to the location, e.g., the investment initiatives, local culture, etc., with respect to the anthropogenic portion of causes, which require analyses beyond the scope of this thesis.

Table 4.18: Forest fire causes data compiled from literature

Year	Forest fires with natural causes	Total	Percentage (%)	Scope	Source
2014			11.0	Whole Türkiye	average computed from 2015-2017 data Demirel and Türk (2023)
			8-10	Whole Türkiye	General Directorate of Meteorology (2018)
			39.4	Muğla	General Directorate of Forestry (OGM) Forest District in Muğla (2023)
2015	258	2163	11.9	Whole Türkiye	Demirel and Türk (2023))
			8-10	Whole Türkiye	General Directorate of Meteorology (2018)
		214	N/A	Muğla	Demirel and Türk (2023)
			30.7	Muğla	General Directorate of Forestry (OGM) Forest District in Muğla (2023)
2016	320	3242	9.9	Whole Türkiye	Demirel and Türk (2023)
			8-10	Whole Türkiye	General Directorate of Meteorology (2018)
		303	N/A	Muğla	Demirel and Türk (2023)

Table 4.18 – *Continued from previous page*

Year	**Forest fires with natural causes**	**Total**	**Percentage (%)**	**Scope**	**Source**
			29.8	Muğla	General Directorate of Forestry (OGM) Forest District in Muğla (2023)
2017	280	2362	11.9	Whole Türkiye	Demirel and Türk (2023)
			8-10	Whole Türkiye	General Directorate of Meteorology (2018)
		190	N/A	Muğla	Demirel and Türk (2023)
			30.0	Muğla	General Directorate of Forestry (OGM) Forest District in Muğla (2023)
2018	858	7767	11.0	Whole Türkiye	average computed from 2015-2017 data from Demirel and Türk (2023)
			8-10	Whole Türkiye	General Directorate of Meteorology (2018)
			50.1	Muğla	General Directorate of Forestry (OGM) Forest District in Muğla (2023)

When the forest fire dates determined in this study are compared with the number of forest fires given in the article Demirel and Türk (2023), the article's list seems remarkably extensive. It is possible that the two different sets of dates have different details, such as causes, or that some minor fires could not be detected by satellites and were not written in newspapers due to their small size. Regarding percentage of forest fires with natural causes, higher figures (close to or higher than %30 yearly and overall %36.7 for the study period of this thesis according to General Directorate of Forestry (OGM) Forest District in Muğla (2023)) are encountered as specific to Muğla than for whole Türkiye (%8-10 according to General Directorate of Meteorology (2018) and %9.9- %11.9 according to Demirel and Türk (2023)). When considered together with the high lightning strike frequency seen in the Vaisala map for the period 2016-2023 for Muğla compared to overall Türkiye, high figures for Muğla are considered realistic. Thus, taking the figures specific to Muğla into account, the resulting percentages of fires with natural causes selected for each year are %39.4 for 2014, %30.7 for 2015, %29.8 for 2016, %30.0 for 2017, and again %39.4 for 2018.

As mentioned in Section 3.4, the duration of the fire needs to be evaluated to decide on the statistical indicator to be utilized while determining the background concentration. The daily fires were not considered to have a duration "significant compared to 30 days". The longest duration was 3 days, as with the 22-24.08.14 and 26-28.10.16 episodes. Hence, it was unnecessary to change the computation method, and the 30-day method was adopted.

The quantification could be done for only 24 dates among the 84 dates. Because the remaining 60 dates lack rural PM_{10} data. For those 24 dates, there were also some important data gaps affecting calculation. For the forest fire date 24.01.2016, no calculation could be done with 15 dates before the forest fire. Before the forest fire on 18.10.2016, there was only 1 data. After the forest fires on 09.09.16 and 27-28.10.2016, there were only 2 data for each. All of these 5 dates were also excluded. There were 19 remaining dates out of 84 forest fire dates for which the background concentration could be calculated. Still, the forest fire contribution amount was found to be negative for 11 out of the remaining 19 dates among the 84 forest fire dates. This computation was done with average values. The computation was repeated with median levels instead. This time there were similarly 10 dates out of the remaining

19 dates, for which the forest fire contribution amount was found to be negative. The absolute values were decreased: [-44.45, -1.05] replaced with [-8.77, -0.02]. Using more conservative or less conservative statistical indicators is possible. The lower number of negative contribution values means a possibly higher number of negative remaining PM_{10} levels at nearby stations. For this reason, in the absence of a well-established alternative method for forest fire impact quantification in the literature, instead of a new approach that would completely eliminate the negative contributions, it was decided to use one of the methods mentioned as it is, simply by omitting the dates with negative contributions.

The nine or ten dates were excluded from the calculations for these methods and yielded the results given below (Muslihittin station) according to the averaging approach tabulated in Table 4.19 and median approach Table 4.20 respectively. Since Milas Ören PM_{10} data did not exist for any of these dates, the PM_{10} contribution of forest fires to Milas Ören PM_{10} could not be quantified.

As seen in Tables 4.19 and Tables 4.20, there is 1 date in each of the months: June, July, October, November, and December, and 3 dates in August. Yearly, there are 3 dates in 2015 and 5 in 2017.

Table 4.19: Results from the averaging approach for forest fire contribution computation, with the associated original PM10 at Muslihittin station

Date	Muslihittin PM_{10} ($\mu g/m^3$)	Forest fire contribution $\mu g/m^3$)
25.08.2015	55.9	28.2
26.08.2015	53.6	7.1
24.12.2015	189.3	1.5
19.06.2017	45.7	2.6
21.07.2017	69.3	1.1
26.08.2017	46.9	24.3
18.10.2017	90.3	0.6
11.11.2017	90.3	0.1

Table 4.20: Results from the median approach for forest fire contribution computation, with the associated original PM_{10} at Muslihittin station

Date	**Muslihittin PM_{10} (µg/m^3)**	**Forest fire contribution (µg/m^3)**
25.08.2015	55.9	38.6
26.08.2015	53.6	17.1
06.11.2015	174.6	0.6
24.12.2015	189.3	4.1
19.06.2017	45.7	5.1
21.07.2017	69.3	2.7
26.08.2017	46.9	24.8
18.10.2017	90.3	0.5
11.11.2017	90.3	2.6

With the median approach, the daily contribution amounts were generally increased, some reaching almost triple the contribution calculated with the averaging approach. One date was added with the median approach, as the contribution on that day became quantifiable with that approach. The only date added (the only one out of 11 negative contribution dates from the averaging approach not excluded by the median approach) 06.11.2015 shows a very low contribution, only 0,6 μg/m^3. The median approach was preferred due to the gaps in the dataset.

The 9 –or 10- dates with negative contributions additionally excluded from the calculations as explained above could be relevant to a wrong determination of forest fire dates or overestimating background rural PM_{10}. One reason for the negative contributions computed could be that a small amount of forest fire emission actually reached Marmaris. VIIRS is mentioned to be more effective in detecting smaller forest fires than MODIS. Thus, the fires detected solely by VIIRS are expected to have a lower overall impact on PM_{10} levels. Additionally, it is possible that the forest fire occurred in or around Muğla but not exactly in Marmaris and had no or little effect on rural PM_{10} levels (due to, e.g., size of the fire or wind direction, etc.). It is thought that the PM_{10} level was so little increased by fire that, together with some probable cleaning effects, the net level of PM_{10} was not really increased with respect to background concentrations. Cleaning can be due to subreasons such as the arrival of air masses from particularly clean air masses or windy conditions.

If the remaining PM_{10} levels at nearby stations were found to be negative, it could be attributed to the fact that the rural station is closer to forest lands than the Muslihittin and Milas Ören stations. Forest fires thus affect the rural station data more than it does the nearby station data. Subtracting the contribution calculated with respect to the rural station, directly from the nearby stations data thus yields lower-than-real remaining amounts. Although there are no negative remaining PM_{10} values, lower amounts are still a concern.

The natural part of the number of dates of indicated forest fires, 8, can be calculated by the ratios given above. The yearly percentages (%30.7 for 2015 and %30.0 for 2017) were multiplied by the numbers of quantifiable forest fires in each year (3 dates in 2015 and 5 in 2017) to find the number of dates with natural causes. This was

calculated as 1 (0.92) date in 2015 and 1.5 dates in 2017, totaling 2.5 dates in the whole period. These numbers are not very meaningful, owing to the huge data gaps that led to the number 8. In this calculation, the figures derived from literature for a percentage of forest fires with natural causes were directly applied to the list of forest fire dates obtained from satellite data and news. However, it is possible that the distribution of causes may have variation according to the size of the fire, e.g., the investment initiatives, local culture, etc, on different dates. This should be considered since the forest fire dates that could not be detected probably have smaller sizes.

The figures found are based on huge data gaps. Additionally, remembering that the forest fires list was generated mainly for the rectangular region relevant to Mugla, actually, it is possible to include more fires with a broader approach. Because of these two factors, the quantities found for forest fire contribution could be regarded as lower than the real case. On the other hand, since the rural station is in a forest area, unlike the nearby stations, the quantities found for forest fire contribution can be regarded as -the opposite- higher than the real case for the nearby stations, whereas there is no such problem for the rural station.

When the K levels corresponding to the identified forest fire dates were analyzed, it was seen that the range of K levels is very large: 3.04- 334.40. This can be attributed in part to the inclusion of little fires with the help of the VIIRS satellite. As thresholds, direct values for K corresponding to forest fires are not easily found in the literature but are mostly in combination with OC, EC, levoglucosan, etc.

4.5 Sea Salt Aerosols

The tornados can bring sea salt aerosols. The list of days, when tornados seem to have occurred, was determined as: 10.05.2014, 20.06.2014, 06.12.2014, 08.02.2015, 03.03.2015, 10.04.2015, 21.11.2015, 25.11.2015, 28.11.2015, 17.01.2016, 06.02.2016, 23.03.2016, 25.03.2016, 09-10.11.2016. 13 of these 15 dates coincide with the arid region dust episode dates: all except for the dates 21.11.2015 and 06.02.2016.

Sea salt aerosols can contribute together with other natural sources of PM_{10} pollution, such as dust from arid regions. The tornadoes can bring sea salts from the sea to the

coast and possibly bring other dust. Alternatively, they can bring sea salt but clean the air from the previously existing PM_{10} pollution. It is probably the case with the exceptional date 6.2.2016 mentioned above, as will be explained shortly.

The number of dates with Na elemental concentration higher than its median, i.e., 53 ng/m^3, is 154. Only one of them matches the list of dates with identified tornados, which is the date 06.02.2016. The Na concentration was remarkably higher than the median, at the level of 233.2 ng/m^3. This was one of the two tornado dates mentioned above not to coincide with the arid region dust episode. Hence, it can be assumed that the tornado brought Na but, at the same time, perhaps cleaned the air from dust. On that day, the daily PM_{10} concentration at the Muslihittin station seems to have dropped from 70.9 to 30 µg/m^3 (no PM_{10} data in Milas Ören for that day). This situation supports the assumption about cleaning effects.

Sea salt aerosol episodes were intended to be preliminarily determined through Na elemental data time series analysis. However, the Na concentration data was lacking for almost all dates with the known existence of a tornado. The dates with missing Na concentration data cover 14 out of 15 tornado dates, with 1097 dates of missing Na data in total.

Meanwhile, the number of dates with Milas Ören PM_{10} concentration higher than its median, i.e. 33.9 µg/m^3, is 84. Only two match the date list with identified tornadoes, as described above. Out of these 84 dates, 32 dates already have Na concentration data, which is more reliable as it is directly linked to sea salt aerosols. The rural Na and Milas Ören PM_{10} data have only 17 simultaneous daily concentrations higher than their own medians. 13 of them were identified as arid regions with dust episode days.

It was initially considered to also use Milas Ören PM_{10} data to the extent possible to compensate for the data gaps in rural Na concentration data. It was thought that having a rather coastal character rather than urban (located at the coast, low population density, lower PM_{10} concentrations and exceedances than the other stations as mentioned below), Milas Ören data can give an indication of sea salt aerosols in the absence of other known natural contributions to PM_{10}. This assumption must be checked cautiously since the anthropogenic increases in PM_{10} should not be mistaken

for sea salt aerosol contribution.

The dates with missing Milas Ören PM_{10} data covers 13 out of 15 tornado dates, with 1237 dates of missing PM_{10} data from that station in total. There is PM_{10} data for only 9-10.11.2016 among those 15 dates. While the PM_{10} level on 9.11.2016 was 35.2 µg/m^3, slightly above the overall median 33.9 µg/m^3 for the station, it was below median, 20.5 µg/m^3, on the next day which is the second day of the two-days tornado. On day zero, 08.11.2016, it was quite above the median, at the level of 44.5 µg/m^3. Thus, similarly to the date 06.02.2016, it could be possible that the tornado brought Na but at the same time perhaps cleaned the air from dust, in the absence of arid region dust contribution. However, the dates 09-10.11.2016 were also identified as arid region dust episode dates. Furthermore, these dates were confirmed for arid region dust contributions by not two or three analyses in total, i.e., TRAJSTAT, Multi-model, and AOD analyses. Possibly, the arid region dust that arrived did not have as much effect as the cleaning effect of the tornado with respect to the PM_{10} levels. It may the the case that the sea salt aerosol contribution exists within the daily concentration, thus it can be computed, but the daily concentration was not increased, rather decreased, due to the cleaning effect. Here, it should be noted that Diapouli et al. (2017) also mentioned for Porto that sea salt is related to clean air conditions, while no African dust event was recorded during exceedance days.

Thus, it may be thought that taking the idea in the previous paragraph further, the Milas Ören PM_{10} data may be used even for dates with other natural contributions to PM_{10}. Yet it should be reminded that a two-day tornado may have more effect than the others. The anthropogenic contribution on other days is also still of concern. The relationship between rural Na data and Milas Ören PM_{10} data was analyzed by Multiple Range Tests to check if Milas Ören PM_{10} data can really be utilized instead of rural Na data. Below are the results, as can be seen in Table 4.21.

According to the Multiple Range Tests, no statistically significant differences exist between any pair of means at the %95,0 confidence level. Since the P-value for the chi-square test given in the Mood's Median Test output is greater than or equal to 0,05, the medians of the samples are not significantly different at the %95,0 confidence level. In other words, Milas Oren PM_{10} data are not closely correlated with the Na

Table 4.21: Multiple Range Tests for Milas Ören PM_{10} by Na being higher or lower than its median

Na with respect to median	Count	Mean (µg/m^3)	Homogeneous Groups
Na < median	30	34.7843	A
no data	111	37.2197	A
Na > median	26	40.5312	A

Contrast	Sig.	Difference	+/- Limits
Na < median - Na > median		-5.74682	8.4852
Na < median - no data		-2.4354	6.51633
Na > median - no data		3.31142	6.89966

* denotes a statistically significant difference.

data. Based on these outputs, it was decided to conduct the calculation for sea salt aerosols only with rural Na data.

The number of dates with Na elemental concentration higher than its median, 154, intersects with 77 of the 693 arid region dust episode dates. 14 out of 77 are in winter, 16 in spring, 25 in summer, and 22 in autumn, respectively.

For the quantification, the dates without Al concentration were intended to be excluded, in relation to crustal Na. However it was seen that none of these dates have available Na data. The calculation was thus done with all dates with available Na data, 307 in total. 39 of these dates yielded negative contribution values but with low absolute values, ranging from to -0.6 to -0.0 (-0.000015) µg/m^3. The negative value -0.6 is seen only for one date, the second lowest value being a relatively close figure to 0, i.e. -0,1. These dates were accepted with 0 contribution of sea salt aerosol, and the computation was continued.

The sea salt aerosol contribution computations results are as follows: The maximum contribution is 3747.4 ng/m3, 3.7 µg/m^3, on 27.7.2017. The maximum sea salt aerosol contribution in the 77 days intersecting with arid region dust episodes is again 3.7

$\mu g/m^3$ on 27.07.2017.

The fact that the maximum sea salt aerosol contribution occurred on a date with arid region dust episode means the dust transport on that day brought a high amount of sea salt aerosol together with it, sweeping the sea. Yet the minimum contribution on arid region dust episode dates is slightly above the minimum on dates without arid region dust episodes.

On the single date with a tornado record and available Na concentration data, 6.2.16, the sea salt aerosol contribution is 0.7 $\mu g/m^3$. The data gaps with respect to Na concentration prevent a sound evaluation of how the Na concentration and, thus, the sea salt aerosol contribution relate to the presence and absence of tornadoes.

Information regarding the yearly and seasonal variation of average contribution amounts are as given below, in Tables 4.22 and 4.23 respectively.

Table 4.22: Average Annual Sea Salt Aerosol Contribution

Year	**Average Contribution ($\mu g/m^3$)**
2014	N/A
2015	0.07
2016	0.19
2017	0.26
2018	0.03

Table 4.23: Average Seasonal Sea Salt Aerosol Contribution

Season	**Average Contribution ($\mu g/m^3$)**
Winter	0.21
Spring	0.26
Summer	0.25
Autumn	0.22

The main statistical characteristics of monthly sea salt aerosol contribution are given below in Table 4.24 for sea salt aerosol contribution by month of the year, showing statistically significant differences between various months. Furthermore, Mood's

median test shows that since the P-value for the chi-square test is less than 0,05, the medians of the samples are significantly different at the %95,0 confidence level with respect to months. Figure 4.19 also gives the Box-and-Whisker plot.

Table 4.24: Statistical characteristics of monthly sea salt aerosol contribution

Month	**Count**	**Average** ($\mu g/m^3$)	**Standard deviation** ($\mu g/m^3$)	**Median** ($\mu g/m^3$)	**Minimum** ($\mu g/m^3$)	**Maximum** ($\mu g/m^3$)
Jan	24	0.130749	0.158696	0.0928197	0	0.621434
Feb	22	0.410323	0.323741	0.309662	0.0114274	1.27242
Mar	13	0.333106	0.406276	0.18256	0	1.31113
Apr	23	0.221022	0.225526	0.145408	0	0.678998
May	9	0.267287	0.31102	0.153089	0	0.911042
Jun	25	0.106782	0.0918532	0.0920996	0	0.301411
Jul	26	0.3754	0.799391	0.109859	0	3.74748
Aug	32	0.253304	0.410774	0.136748	0	2.1257
Sep	38	0.314775	0.501477	0.139093	0	2.69555
Oct	42	0.204803	0.262402	0.117937	0	1.15306
Nov	19	0.0733057	0.112707	0.0262034	0	0.35769
Dec	34	0.132912	0.268123	0.0233475	0	1.09045
Total	307	0.231255	0.38742		0	3.74748

The overall average contribution of the sea salt aerosol for the whole period is 0.23 $\mu g/m^3$. The daily contribution percentages of the sea salt aerosol to the rural daily PM_{10} were also computed (not for the 62 dates which lacked rural PM_{10} data). The average of these percentages for the whole study period is %5,4. The value %5.4 is between the contribution percentages for Florence and Athens given in Diapouli et al. (2017)for the summer period, however lower than most of the values given in the literature. This can be partly attributed to some studies' possible non-exclusion of the crustal Na portion. It should be noted that, when it comes to contribution to nearby stations' PM_{10} data, the figures found in this study can be regarded as an underestimation as the rural station is at approximately 1 km altitude. Na from sea salt in the sea, or sea salt aerosol, cannot reach this station like a coastal station or like the nearby stations, thus the computation done at the rural station and later used for nearby stations is done with reduced amounts. This second justification, however, may not hold

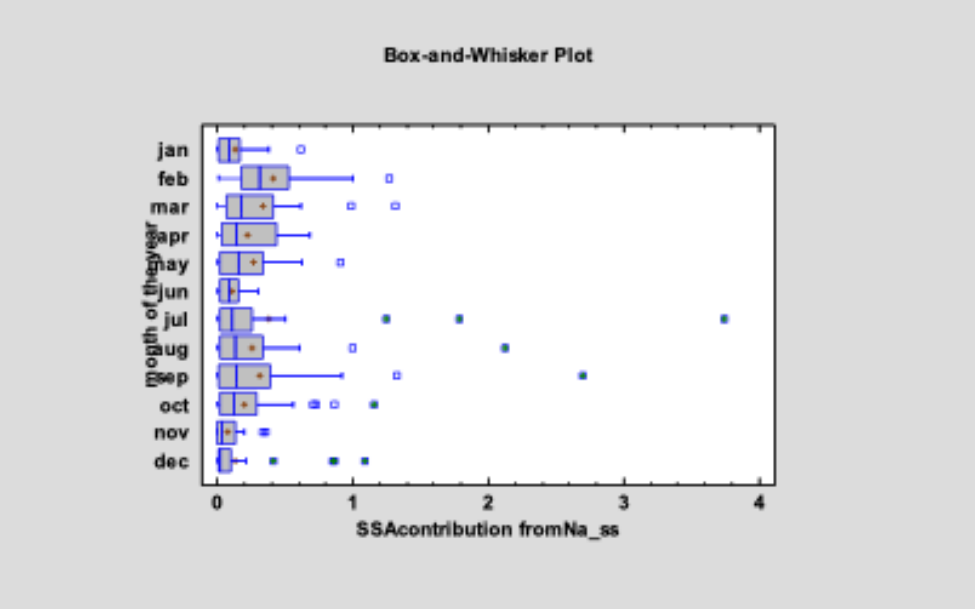

Figure 4.19: Box-and-whisker plot for monthly sea salt aerosol contribution

true for differences from the values found in Clemente et al. (2023) since the rural background station studied therein is also located at a high, even higher, altitude and a higher distance to the Mediterranean Sea. Still, not just distance and altitude but other factors, such as the meteorological characteristics affecting the transport of air masses or -if relevant- the local atmospheric chemistry affecting the composition, need to be considered in such comparisons, which are not subjects studied in this thesis. Nevertheless, it is, in general, still a valid assumption to consider the attenuation of sea salt aerosol concentrations with the distance to the sea (the literature, e.g. Diapouli et al. (2017) in relation to the comparison of the coastal site at Porto to the other sites supports this assumption).

An uncertainty factor associated with sea salt aerosol contribution is about establishing the sea salt-related part of Na. The Na/Al ratio for the crustal case was used to distinguish Na from sea salt from crustal Na. Firstly, it is considered a possibility that there are additional sources for Na. Secondly, there was an assumption about the crustal Na/Al ratio. This approach was also adopted by Calzolai et al. (2015) and Diapouli et al. (2017), based on the generic crustal Na to crustal Al ratio of 0.348 Mason (1966)(, as explained in Chapter 2. If there was no such ratio, the sea salt aerosol contribution would be calculated at elevated levels, utilizing the non-sea salt

related (mainly crustal) Na too in the calculations. However, as also previously mentioned, it was mentioned in Mason (1952) that the amounts mentioned for Na, Al -from which this ratio was derived- are based on determinations in igneous rocks but can reasonably be considered as representing abundances in the crust as a whole. Approximation of igneous rocks or the overall crust to the soil and, more specifically, to the soil in Muğla could be discussed. Without a better figure than this piece of information, it was used like in Diapouli et al. (2017).

4.6 The Anthropogenic Part of PM_{10}

Based on the sections Section 4.2 to 4.5, quantities of relevant natural contributions to the PM_{10} levels recorded in the Muğla province were calculated. The next step was to determine the remaining levels attributable to anthropogenic pollution. The daily natural dust contribution amounts (in terms of PM_{10}) found in previous sections were subtracted -for each contribution day- from available nearby stations' PM_{10} data. Below is tabulated information on the remaining PM_{10} levels computed for both Muslihittin and Milas Ören stations per each of the four types of natural contribution studied in this thesis. At the end of this section, the combined effects of all four types with respect to the remaining PM_{10} levels can also be seen. The first tables are presented in the following order for arid region dust and sea salt aerosol contributions for Muslihittin and Milas Ören, respectively: monthly Tables: 4.25,4.26,4.27,4.28, Seasonal Tables 4.29, 4.30,4.31,4.32 and Annual Tables 4.33,4.34,4.35,4.36. The monthly, seasonal, and annual PM_{10} contribution (reduction) percentages with respect to the nearby station data are calculated from the average values and can also be seen in the tables in the last columns. These contribution values are overall figures, whereas those calculated in previous sections were specific to the quantifiable contribution dates, as mentioned there. For volcanic activity and forest fire contributions, on the other hand, the low number of dates for which the contribution could be calculated was a handicap for such a demonstration of temporal variations. The results are presented for specific dates about remaining PM_{10} values after the deduction of volcanic activity and forest fire contributions for the Muslihittin station. Volcanic activity or forest fire contributions could not be calculated for the Milas Ören station in

Sections 4.3 and 4.4 due to data limitations. The reduction percentages with respect to the Muslihittin data can also be seen in the last columns of these tables. The combined tables presented at the end of the section include the two stations together, as will be explained.

The tables devoted to individual types of natural contributions were prepared, excluding the dates whose contributions could not be calculated due to data availability limitations. The excluded dates can be described with the following characteristics: absent rural or nearby PM_{10} concentration values on or around the dates identified for calculation of the contribution of arid region dust or volcanic activity or forest fires, or absent nearby PM_{10}, rural Na and Al concentration values for calculation of sea salt aerosol contribution. For the Muslihittin station, this meant a limitation of the dates to those with available rural and Muslihittin PM_{10} data with respect to arid region dust. For Milas Ören station, on the other hand, rural data was not required in relation to arid region dust, based on the alternative quantification method employed in Section 4.2. However, it was still necessary for volcanic activity and forest fire contribution computations.

This approach of excluding the dates lacking data was adopted to directly demonstrate the effect of arid region dust, volcanic activity, forest fires, and sea salt aerosol contribution. The dates whose contribution could not be accurately calculated despite the existence of data were still included in the tabulated data in this section. For example, the negative contribution values were accepted as 0, assuming that no arid region dust transport occurred on these dates. The remaining PM_{10} values on the dates with negative contribution values were considered identical to the original PM_{10} values. Meanwhile, the negative remaining PM_{10} values were considered 0, meaning the concentration was totally eliminated due to natural contribution.

An overall assumption for all-natural sources of PM_{10} included is that the natural dust load, which contributes to the PM_{10} levels at the rural station, contributes to the PM_{10} levels at the nearby stations as well, in the same amount. The possible differences from this approach that should be considered are also summarized below, along with the main results.

On the dates when the remaining amount is not less than the daily limit value of 50

μg/m^3 or the annual limit value of 40 μg/m^3, the exceedance of these limit values of the CAFE directive cannot be attributable to natural sources. It should be considered as having anthropogenic origin.

The percentage reductions in monthly, seasonal, and yearly PM_{10} due to the subtraction of arid region dust contribution are given in Tables above. The reductions at Milas Ören can be recognized more easily than Muslihittin. The annual arid region dust reduction at Muslihittin was almost one-tenth of that at Milas Ören (1.3 when compared to 12.06). This difference can, in part, be due to site characteristics. For example, as Milas Ören is not an urban station, it could be logical to think that its concentrations would be more heavily affected by natural contributions without continuous and high anthropogenic contributions. The same discussion was made by Clemente et al. (2023), mentioning that a background site had a much higher Saharan dust contribution (%33 when compared to %9) than an urban location due to the absence of significant anthropogenic emission sources close to the background station. Meanwhile, the arid region dust contribution at Milas Ören was computed with the station's own data instead of the rural data. This was done to account for the approximately 1 km altitude difference between the rural station and Milas Ören station. This was an attempt to prevent the overestimation of contribution and, thus, underestimation of the remaining levels at Milas Ören. The levels were still reduced to a higher extent than for Muslihittin, perhaps due to the urban character of the latter. However, it should be remembered that the data gaps at Milas Ören station were also considerably high, preventing a clear depiction of the actual reduction levels. For example, regarding the comparison at the beginning of this paragraph on annual reductions, it should be noted that two years of data were absent for Milas Ören.

While the month of May is the one with the highest reduction at Muslihittin, the data gaps are a barrier against this evaluation for the case of Milas Ören. Some months, including May, were not associated with quantifiable remaining levels at Milas Ören station. Meanwhile, the month of May, corresponding to the highest contribution, aligns with the literature. Because seasonally, spring is the season when the arid region dust would be expected at the highest amounts or with the highest frequency (e.g., Baltaci, 2021 and Diapouli et al., 2017). The table demonstrating seasonal variation of the arid region dust contribution to Muslihittin is in harmony with this

expectation. For Milas Ören, the remaining levels in spring were not computable. Interestingly, winter is seen to have the highest reduction percentage among all seasons, with computable remaining levels at that station. It is also seen that the highest monthly reduction was observed in December at Milas Ören. The high percentage of dust contribution during winter could not be totally understood, but it is seen to be in line with the findings of Gallisai (2016), where modeled dust deposition for the period 2000 to 2007 was seen to show the highest values in late autumn and winter in the Central and Eastern Mediterranean. It was also mentioned by Varga (2020) for the Carpathian Basin that almost %25 of the Saharan dust deposition was found to have occurred during the winter season. In addition, there are remarks in the literature that the time of the highest frequency of Saharan dust deposition may not match with the highest deposition amount, e.g., in the studies by Baltaci (2021) and Achilleos et al. (2020). It was even mentioned by Achilleos et al. (2020) that one of the sites studied, Cyprus, having the highest frequency among those sites, was generally not in exceedance status for daily limit value. This was attributed to a possible high number of low-contribution dust episodes. Based on the comprehensive method, such as including many dates as confirmed by Multi-model analysis, this may as well be the case in this thesis. Furthermore, the studies mentioned might explain the existence of winter together with spring due to high deposition or due to the high-frequency time of spring sometimes being different from the intense deposition time.

Furthermore, the month of May seems to be the only month where arid region dust contribution calculations can be considered satisfactorily relevant to the daily limit value. Because in May, a monthly average very close to the daily limit was calculated for Muslihittin, although not above 49.64 $\mu g/m^3$. The average reduction calculated for that month, 2.33 $\mu g/m^3$, would mean avoiding exceedance status only if the concentrations were slightly higher. Here, an approximation is being made between monthly averages and daily values for reasons of practicality in terms of representation in tabulated form. The annual averages can also be compared with their own annual limit of exceedance. However, the reduced (remaining) annual levels are always higher than the limit at Muslihittin, and the original levels are always already lower than the limit at Milas Ören. Thus arid region dust contribution does not seem to make a difference in terms of exceedance of the annual limit value. Thus arid region dust contribution

does not seem to make a difference in terms of exceedance of the annual limit value. However, a finding in relation to annual averages of arid region dust contributions is that at both stations, the year 2017 seems to be the year with the highest contribution in percentages.

The remaining PM_{10} values after subtraction of sea salt aerosol contribution to PM_{10}, as shown in Tables 4.27, are again associated with altitude differences. This time, the altitude differences might have led to an underestimation of sea salt aerosol contribution to the rural and nearby stations, as the rural station -from which the data are derived for computing this contribution- is at about 1 km altitude from the sea. Thus, the actual sea salt aerosol contribution may correspond to higher PM_{10} reduction amounts, for which lower remaining levels would be calculated. than calculated in this thesis, by which lower remaining levels would have been calculated. The reductions computed for sea salt aerosol contribution to Muslihittin and Milas Ören are at low levels, similar to each other. The explanation just given may serve as an explanation of this situation.

It is considered that the cautious methods used to quantify arid region dust and sea salt aerosol contribution might partially explain the reduction percentages found to be lower than the studies presented in Chapter 2 (e.g.Diapouli et al., 2017). For example, a safe statistical indicator -the moving average- was used for arid region dust contribution computation, and computation was made only after the deduction of the sea salt aerosol contribution. The sea salt aerosol contribution was also cautiously quantified by subtracting the crustal Na from the total Na. Altitude-related issues were already mentioned as another possibility. On the other hand, the computations were not so modest with respect to forest fires: while %1.4 was found as the forest fire contribution at Porto by Diapouli et al. (2017), much higher percentages were found and tabulated in this thesis, for a small set of dates. However, this computation was made only for a specific list of dates, as already explained. This might well be a reason for high amounts, as the computation is focused on the dates with contribution rather than being representative for a wider time range.

Regarding volcanic activity contribution, the remaining PM_{10} values can be seen in Table 4.37 None of the three dates are dates with available data demonstrating ex-

ceedance of the daily limit value in a nearby station (Milas Ören station lacking PM_{10} data and Muslihittin station not having records of exceeding the daily limit). Still, the contribution amount at 29.7.2017, 4.6 µg/m^3, meaning %12 of the PM_{10} concentration of that date, is an amount that shall not be omitted. On many dates of exceedance, this amount of subtraction from nearby station PM_{10} data could mean avoidance of exceedance. Furthermore, as with the case of forest fires, in addition to data availability issues, the fact that volcanic activity contribution was not calculated for the dates coinciding with arid region dust contribution dates shall be remembered. Besides, volcanic activity might have the potential to show effect at different magnitudes than those used in backtrajectory calculations based on arid region dust contribution in the Guidance of European Commission (2011), which need to be determined. Thus, there are reasons to think that the overall volcanic activity contribution to PM_{10} levels may not be negligible -even beyond the date 29.7.2017- and should be further investigated in future studies.

As seen in Table 4.38, forest fire seems to be responsible for exceeding the daily limit value on two dates, 25.08.2015 and 26.08.2015, in the Muslihittin station. The PM_{10} level before subtraction is higher than and after subtraction is lower than 50 µg/m^3 on each of those dates. It should be remembered that the huge lack of data was a serious barrier against computation of forest fire contribution amounts and the region could also have been selected broader. Additionally; the dates coinciding with arid region dust contribution were not calculated for forest fire contribution. Thus two days found to account for exceedances as such could be a modest number of dates for forest fires. However, as discussed before, the contribution amount may also be overestimated in some cases due to the location of nearby stations (nearby stations not being close to some forest areas like the rural station from which the data was used for quantification). This situation could lead to a lower number of dates than two, as just the opposite. Yet considering that the contribution calculated for 25.08.2015 is a remarkable amount, 28.2 µg/m^3, where exceedance at Muslihittin is only at the level of 5.9 µg/m^3, this second factor is considered to be not very likely at least for this date among the two dates.

Table 4.25: Monthly PM_{10} at Muslihittin station before and after subtraction of arid region dust contribution for dates with available quantification data

Month of the year	Median PM_{10} before subtraction ($\mu g/m^3$)	Median PM_{10} after subtraction ($\mu g/m^3$)	Average PM_{10} before subtraction ($\mu g/m^3$)	Average PM_{10} after subtraction ($\mu g/m^3$)	Monthly Reduction (%)
Jan	83.93	83.93	94.61	94.45	0.17
Feb	94.79	93.95	96.01	95.68	0.34
Mar	76.99	76.99	82.83	81.62	1.46
Apr	67.67	66.39	71.51	70.50	1.41
May	47.57	45.81	49.64	47.31	4.69
Jun	50.80	49.89	53.95	53.56	0.72
Jul	60.99	59.33	64.75	63.95	1.24
Aug	65.55	64.67	66.86	65.48	2.06
Sep	59.58	59.58	65.05	64.05	1.54
Oct	62.03	62.03	66.97	66.41	0.84
Nov	104.70	104.70	103.56	103.20	0.35
Dec	92.13	89.76	102.21	101.28	0.91
Average					1.31

Table 4.26: Monthly PM_{10} at Milas Ören station before and after subtraction of arid region dust contribution for dates with available quantification data

Month of the year	Median PM_{10} before subtraction ($\mu g/m^3$)	Median PM_{10} after subtraction ($\mu g/m^3$)	Average PM_{10} before subtraction ($\mu g/m^3$)	Average PM_{10} after subtraction ($\mu g/m^3$)	Monthly Reduction (%)
Jan	31.99	27.27	31.65	28.70	9.32
Feb	N/A	N/A	N/A	N/A	N/A
Mar	N/A	N/A	N/A	N/A	N/A
Apr	N/A	N/A	N/A	N/A	N/A
May	N/A	N/A	N/A	N/A	N/A
Jun	N/A	N/A	N/A	N/A	N/A
Jul	59.84	59.84	59.93	59.61	0.53
Aug	56.10	51.84	52.52	50.51	3.83
Sep	33.74	33.74	33.69	31.65	6.06
Oct	31.89	30.34	33.38	31.11	6.80
Nov	25.32	25.32	30.07	25.05	16.69
Dec	23.23	23.23	26.33	22.23	15.57
Average					8.40

Table 4.27: Monthly PM_{10}at Muslihittin station before and after subtraction of sea salt aerosol contribution for dates with available quantification data

Month of the year	Median PM_{10} before subtraction ($\mu g/m^3$)	Median PM_{10} after subtraction ($\mu g/m^3$)	Average PM_{10} before subtraction ($\mu g/m^3$)	Average PM_{10} after subtraction ($\mu g/m^3$)	Monthly Reduction (%)
Jan	74.63	74.56	92.68	92.55	0.14
Feb	94.49	94.28	97.14	96.75	0.40
Mar	54.74	54.67	68.24	67.90	0.50
Apr	54.84	54.78	60.29	60.08	0.35
May	51.14	51.01	61.60	61.31	0.47
Jun	51.17	51.15	48.27	48.17	0.21
Jul	67.80	67.18	69.15	68.78	0.54
Aug	60.68	60.54	61.27	61.02	0.41
Sep	60.66	59.99	64.73	64.42	0.48
Oct	60.92	60.78	63.45	63.26	0.30
Nov	95.35	95.22	89.72	89.65	0.08
Dec	106.02	105.99	115.14	115.00	0.12
Average					0.33

Table 4.28: Monthly PM_{10}at Milas Ören station before and after subtraction of sea salt aerosol contribution for dates with available quantification data

Month of the year	Median PM_{10} before subtraction ($\mu g/m^3$)	Median PM_{10} after subtraction ($\mu g/m^3$)	Average PM_{10} before subtraction ($\mu g/m^3$)	Average PM_{10} after subtraction ($\mu g/m^3$)	Monthly Reduction (%)
Jan	31.01	30.93	32.86	32.82	0.12
Feb	N/A	N/A	N/A	N/A	N/A
Mar	N/A	N/A	N/A	N/A	N/A
Apr	N/A	N/A	N/A	N/A	N/A
May	N/A	N/A	N/A	N/A	N/A
Jun	N/A	N/A	N/A	N/A	N/A
Jul	N/A	N/A	N/A	N/A	N/A
Aug	56.63	56.49	55.21	54.99	0.40
Sep	39.80	39.56	40.21	39.95	0.65
Oct	31.89	31.84	33.16	33.09	0.21
Nov	N/A	N/A	N/A	N/A	N/A
Dec	30.71	30.64	29.05	28.91	0.48
Average					0.37

Table 4.29: Seasonal PM_{10}at Muslihittin station before and after subtraction of arid region dust contribution for dates with available quantification data

Season of the year	Median PM_{10} before subtraction ($\mu g/m^3$)	Median PM_{10} after subtraction ($\mu g/m^3$)	Average PM_{10} before subtraction ($\mu g/m^3$)	Average PM_{10} after subtraction ($\mu g/m^3$)	Seasonal Reduction (%)
Winter	90.95	89.59	97.90	97.41	0.50
Spring	58.91	57.82	66.52	64.97	2.33
Summer	59.30	57.72	61.91	61.04	1.41
Autumn	69.12	69.12	78.42	77.79	0.80

Table 4.30: Seasonal PM_{10}at Milas Ören station before and after subtraction of arid region dust contribution for dates with available quantification data

Season of the year	Median PM_{10} before subtraction (µg/m^3)	Median PM_{10} after subtraction (µg/m^3)	Average PM_{10} before subtraction µg/m^3)	Average PM_{10} after subtraction (µg/m^3)	Seasonal Reduction (%)
Winter	26.96	26.63	28.85	25.29	12.34
Spring	N/A	N/A	N/A	N/A	N/A
Summer	57.73	57.03	56.32	55.18	2.02
Autumn	31.82	30.23	32.73	29.92	8.59

Table 4.31: Seasonal PM_{10} at Muslihittin station before and after subtraction of sea salt aerosol contribution for dates with available quantification data

Season of the year	Median PM_{10} before subtraction ($\mu g/m^3$)	Median PM_{10} after subtraction ($\mu g/m^3$)	Average PM_{10} before subtraction ($\mu g/m^3$)	Average PM_{10} after subtraction ($\mu g/m^3$)	Seasonal Reduction (%)
Winter	94.49	94.28	103.78	103.59	0.18
Spring	52.94	52.84	63.10	62.84	0.41
Summer	57.59	57.51	59.82	59.58	0.40
Autumn	94.49	94.28	103.78	103.59	0.18

Table 4.32: Seasonal PM_{10}at Milas Ören station before and after subtraction of sea salt aerosol contribution for dates with available quantification data

Season of the year	Median PM_{10} before subtraction ($\mu g/m^3$)	Median PM_{10} after subtraction ($\mu g/m^3$)	Average PM_{10} before subtraction ($\mu g/m^3$)	Average PM_{10} after subtraction ($\mu g/m^3$)	Seasonal Reduction (%)
Winter	30.71	30.64	30.32	30.21	0.36
Spring	N/A	N/A	N/A	N/A	N/A
Summer	56.63	56.49	55.21	54.99	0.40
Autumn	38.00	38.00	36.80	36.64	0.43

Table 4.33: Annual PM_{10} at Muslihittin station before and after subtraction of arid region dust contribution

Year	Median PM_{10} before subtraction ($\mu g/m^3$)	Median PM_{10} after subtraction ($\mu g/m^3$)	Average PM_{10} before subtraction ($\mu g/m^3$)	Average PM_{10} after subtraction ($\mu g/m^3$)	Annual Reduction (%)
2014	59.65	59.42	68.25	67.46	1.16
2015	76.36	75.62	85.50	84.80	0.82
2016	70.20	69.62	78.66	78.22	0.56
2017	58.61	57.06	67.08	65.46	2.42
2018 *	57.95	53.19	76.57	76.04	0.69
Average					1.13

*including only January

Combined reductions: Without excluding the dates on which any of the four types of contribution could be calculated, the combined daily reductions regarding all of these contributions were computed for all dates. The original $\mu g/m^3$ values were excluded where at least one of these four natural contributions could not be computed due to data gaps. It was seen that 32 dates out of 1404 dates have all the necessary air quality station data for quantification of the four types of natural contributions in both Muslihittin and Milas Ören stations. The results for remaining values after combined reductions of all four types of contributions on these 32 dates at Muslihittin and Milas Ören stations are summarized as per months, seasons, and years in Tables 4.39, 4.40, 4.41.

Table 4.34: Annual PM_{10} at Milas Ören station before and after subtraction of arid region dust contribution for dates with available quantification data

Year	Median PM_{10} before subtraction ($\mu g/m^3$)	Median PM_{10} after subtraction ($\mu g/m^3$)	Average PM_{10} before subtraction ($\mu g/m^3$)	Average PM_{10} after subtraction ($\mu g/m^3$)	Annual Reduction (%)
2014	N/A	N/A	N/A	N/A	N/A
2015	N/A	N/A	N/A	N/A	N/A
2016	35.69	32.66	39.05	36.98	5.30
2017	25.12	24.95	28.54	22.39	21.55
2018*	31.99	27.27	31.65	28.70	9.32
Average					12.06

*including only January

Table 4.35: Annual PM_{10} at Muslihittin station before and after subtraction of sea salt aerosol contribution for dates with available quantification data

Year	Median PM_{10} before subtraction ($\mu g/m^3$)	Median PM_{10} after subtraction ($\mu g/m^3$)	Average PM_{10} before subtraction ($\mu g/m^3$)	Average PM_{10} after subtraction ($\mu g/m^3$)	Annual Reduction (%)
2014	N/A	N/A	N/A	N/A	N/A
2015	206.94	206.92	188.7	188.64	0.03
2016	70.93	70.84	83.26	83.07	0.23
2017	58.41	58.29	65.77	65.52	0.38
2018*	70.94	70.88	81.07	81.03	0.05
Average					0.17

*including only January

Table 4.36: Annual PM_{10} at Milas Ören station before and after subtraction of sea salt aerosol contribution for dates with available quantification data

Year	Median PM_{10} before subtraction ($\mu g/m^3$)	Median PM_{10} after subtraction ($\mu g/m^3$)	Average PM_{10} before subtraction ($\mu g/m^3$)	Average PM_{10} after subtraction ($\mu g/m^3$)	Annual Reduction (%)
2014	N/A	N/A	N/A	N/A	N/A
2015	N/A	N/A	N/A	N/A	N/A
2016	40.47	40.47	40.78	40.61	0.42
2017	30.71	30.64	29.05	28.91	0.48
2018*	31.01	30.93	32.86	32.82	0.12
Average					0.34

*including only January

Table 4.37: PM_{10} at Muslihittin station before and after subtraction of volcano contribution for dates with available quantification data

Date	Muslihittin PM_{10} ($\mu g/m^3$)	Remaining Muslihittin PM_{10} ($\mu g/m^3$)	Reduction (%)
28.07.2017	43.50	42.91	1.38
29.07.2017	38.42	33.78	11.98
28.09.2017	48.03	47.78	0.42

Table 4.38: PM_{10} at Muslihittin station before and after subtraction of forest fire contribution for dates with available quantification data

Date	Muslihittin PM_{10} ($\mu g/m^3$)	Remaining Muslihittin PM_{10} ($\mu g/m^3$)	Reduction (%)
25.08.2015	55.91	17.28	69.09
26.08.2015	53.63	36.58	31.79
06.11.2015	174.58	173.93	0.37
24.12.2015	189.27	185.16	2.17
19.06.2017	45.66	40.52	11.26
21.07.2017	69.34	66.59	3.97
26.08.2017	46.94	22.16	52.79
18.10.2017	90.32	89.79	0.59
11.11.2017	90.31	87.68	2.91

Table 4.39 below includes the results summarized per month, only for a simple demonstration of the remaining values and percent reductions across months. However, it is, in fact, not considered very meaningful to analyze 32 dates in total within 12 months as such statistically. The seasonal and annual variations can be considered somehow better in this sense.

Table 4.39: Monthly PM_{10} concentration at Muslihittin and Milas Ören stations before and after all natural contributions subtraction for dates with all available data

Month of the year	Average PM_{10} concentration at Muslihittin before - after subtraction (µg/m^3)	Monthly Reduction at Muslihittin PM_{10} Contribution (%)	Average PM_{10} concentration at Milas Ören before - after subtraction (µg/m^3)	Monthly Reduction at Milas Ören (%)
Jan	109.54 - 109.30	0.22	38.72 - 32.35	16.45
Feb	N/A	N/A	N/A	N/A
Mar	N/A	N/A	N/A	N/A
Apr	N/A	N/A	N/A	N/A
May	N/A	N/A	N/A	N/A
Jun	N/A	N/A	N/A	N/A
Jul	N/A	N/A	N/A	N/A
Aug	61.93 - 51.84	16.30	56.26 - 53.91	4.17
Sep	71.54 - 68.02	4.92	41.66 - 36.81	11.65
Oct	85.70 - 76.16	11.13	35.29 - 28.23	20.00
Nov	N/A	N/A	N/A	N/A
Dec	84.58 - 81.45	3.70	29.90 - 22.37	25.18
Average		7.25		15.49

Table 4.40: Seasonal PM_{10} concentration at Muslihittin and Milas Ören stations before and after all natural contributions subtraction for dates with all available data

Season of the year	Average PM_{10} concentration at Muslihittin before - after subtraction (μg/m^3)	Seasonal Reduction at Muslihittin PM_{10} Contribution (%)	Average PM_{10} concentration at Milas Ören before - after subtraction (μg/m^3)	Seasonal Reduction at Milas Ören (%)
Winter	92.90 - 90.73	2.33	32.84 - 25.70	21.75
Spring	N/A	N/A	N/A	N/A
Summer	61.93 - 51.84	16.30	56.26 - 53.91	4.17
Autumn	79.50 - 72.60	8.68	38.08 - 31.99	16.00

Table 4.41: Annual PM_{10} concentration at Muslihittin and Milas Ören stations before and after all natural contributions subtraction for dates with all available data

Year	Average PM_{10} concentration at Muslihittin before - after subtraction (µg/m^3)	Annual Reduction at Muslihittin PM_{10} Contribution (%)	Average PM_{10} concentration at Milas Ören before - after subtraction (µg/m^3)	Annual Reduction at Milas Ören (%)
2014	N/A	N/A	N/A	N/A
2015	N/A	N/A	N/A	N/A
2016	74.16 - 66.28	10.62	43.61 - 38.66	11.36
2017	84.58 - 81.45	3.70	29.90 - 22.37	25.18
2018*	109.54 - 109.30	0.22	38.72 - 32.35	16.45
Average		4.85		17.66

* including only January

As with the individual natural contributions of which the effects were quantifiable at both stations, again, the reductions are generally seen to be at a lower extent at Muslihittin than at Milas Ören. The annual contribution of arid region dust at Milas Ören is nearly at the midpoint of the quite wide range %0.5-58 mentioned above. The combined monthly contribution at Muslihittin is again half the contribution at Milas Ören. On an annual scale, this was valid as being even approximately one-fourth. The possible explanation of being an urban station less affected by natural contributions is still valid for Muslihittin, as suggested for a similar case by Clemente et al. (2023). Ultimately, the average monthly and annual combined natural contributions at Milas Ören were found to be the highest monthly or annual contribution rates calculated in this study, as %15 and %18, respectively.

Table 4.41 includes annual figures. If these values belonged to the whole years, the situation would be very polluted (before and after subtraction, all years having values higher than 40 μg/m^3), but the values are only for those dates with all required data. No substantial annual reduction could be observed as a combined effect compared to the annual limit, except for 2016 at Milas Ören. The year 2017 is again the year with the highest percent reduction at Milas Ören, even when with respect to all four natural contribution types. For Muslihitin, the highest reduction year seems like 2016 instead. However, the other two years are totally absent in the table. In terms of seasons, spring and winter were the focus points in relation to individual natural contributions, as discussed above. For combined contributions, no season could be found remarkable compared to the rest of the seasons at both stations together. Unlike the situation with the preceding discussion for individual natural contribution types, the reduction percentages are seen to be high for combined contributions. They are comparable to or even higher than the levels of contribution mentioned by Diapouli et al. (2017). However, it should be noted that this subsection represents the case for only 32 dates with all types of required data. Actually, the number 32 is quite low regarding data availability among the total of 1404 dates. Meanwhile, the contributions found and presented in the three tables lie within the range %0.5-58 compiled by Scerri et al. (2016) for various natural contributions, but this is not very informative due to the width of this range cited by the authors.

CHAPTER 5

CONCLUSIONS

This study has novelties in several dimensions:

- Firstly, this is the first systematic application of the Guidance of European Commission (2011) for the Muğla province. The previous studies did not involve all steps included in the methodology. They also did not involve such a compilation of elemental data (with various elements analyzed for approximately 4 years, albeit with internal time gaps).
- Furthermore, the study is one of the rare studies to study the effects of arid regions other than North Africa on the PM_{10} levels in Türkiye.
- Meanwhile, this study might be the first to investigate the effects of nearby volcanoes on the PM_{10} levels in Türkiye. A method was developed and used, based on the combination of SO_2 satellite data and TRAJSTAT outputs, as well as air quality data.

The date range (30.03.2014 - 21.1.2018) was found to have much higher PM levels than those specified by the European Commission (2011). While the annual limit is set as 40 µg/m^3 and the daily limit of 50 µg/m^{3}can be exceeded only 35 times a year, the three nearby stations in the province Muğla exceed these limits.

Exceedance was not set as a threshold from the beginning of the analyses. Because of this, there were many dates identified as arid region dust episode dates but did not have quantifiable contributions in that respect.

Most of the days, at least one parameter among the estimation methods employed (i.e. the satellite images, TRAJSTAT outputs and DREAM outputs) demonstrate the

arrival of arid region dust at that date to the Marmaris station. Since this study focuses on the Muğla province, the most relevant rural data includes a close rural station in Marmaris/Muğla. Meanwhile, data from the Ministry's coastal station Milas Ören were also regarded helpful for understanding the non-anthropogenic emissions, coupled with sea spray contribution.

At the end of the study, the exceedances were examined with and without the four types of natural contributions (arid region dust, volcanic activity, forest fire, and sea salt aerosol). It was seen that not much change is recognized, except for some probable cases: if the PM_{10} level were slightly higher (in exceedance), then the contribution would be seen to account for part of the exceedance. Mostly the arid region dust contributions were found to be low. However, forest fires were detected as the cause of exceedance on two days out of 1404 dates. Since the forest fires and volcanic activity contributions were not calculated on arid region dust episode dates, there could be even more dates when one of these would be held responsible for exceedances. For the case of volcanic activities, although not regarded as the cause of exceedance, contributions such as 4.6 μg/m^3 on a specific date were calculated, which can be seen as reasons to study their impacts in more depth in the air quality studies.

Combined natural contributions were also calculated. In this case and for individual natural contributions, some percentage reduction figures at Milas Ören were remarkably higher than at Muslihittin. The average monthly and annual combined natural contributions at Milas Ören were found to be the highest monthly or annual contribution rates calculated in this study, as %15 and %18, respectively, within 32 dates. However, these figures were found per the small set of dates with all necessary data for quantification, such as rural and nearby stations data for PM_{10} and elemental concentrations. There were instances that the natural contributions at Milas Ören PM_{10} were calculated at levels a few times the contributions at Muslihittin. This is considered relevant to the fact that Milas Ören is in a cleaner environment, i.e., not an urban station like Muslihittin, and thus more sensitive to natural contributions, in agreement with Clemente et al. (2023).

122 dates were seen to be associated with these other regions, i.e., Asian and Arabian arid regions. This corresponds to %28 of the total backtrajectories demonstrating arid

region contribution, which is a figure lying within the range of contribution %6-%35 calculated by Flores et al. (2017) for Asian arid region contribution to İstanbul PM_{10} in the 2007-2014 period.

On dates with arid region dust episodes, it was found that Al and Si had almost double the amounts they had on non-episode dates.

It was found that K values are higher than the median for the dates under volcanic activity-related natural dust influence. Meanwhile, K values were not found to be strongly associated with forest fires when the identified forest fire dates were analyzed. However, further studies should ensure the absence of such a relationship.

The AOD value 0,48 was recognized as the threshold for confirmation by two other independent analyses: TRAJSTAT and Multi-model. For this reason, this AOD value might be deemed as the threshold for a strong indication of arid region dust contribution to Muğla in the specified period (for the whole period, without seasonal consideration), yet taking into account the possible changes in averages with years that may have taken place since the end of period or will take place in future.

There were some limitations in this study. Firstly, data gaps were a concern. For example, out of the 1404 data studies, only 32 had all the data necessary for the quantification of all four natural contribution types at both Muslihittin and Milas Ören stations.

Another limitation of the analyses was that MODIS satellite photographs from only the Terra satellite were used. It should be added that the results were cross-checked with Aqua satellite photographs within small sets of dates corresponding to possible discrepancies stemming from this situation, where no significant differences were found.

The differences in altitudes of the air quality monitoring stations whose data were used were another concern. It was considered probable that the air masses affecting the rural station at 936 m altitude may not have affected the Milas Ören station at 3 m altitude. For this reason, the arid region dust computations were made with the rural PM_{10} data for the Muslihittin station and the Milas Ören station's own PM_{10} data for the Milas Ören station. Again, due to altitude differences, the sea salt aerosol contri-

butions computed with rural station elemental data can be considered an underestimation for the other stations, especially Milas Ören. Another method -computation with Milas Ören PM_{10} data again- was tried but found inappropriate due to differences from rural station Na data.

Last but not least, as mentioned by European Commission (2011), it is important not only to demonstrate the arrival -and hence to subtract the natural contributions from the PM levels- but also to use the data in future studies to be able to take precautions for public health. This has two meanings:

i. Better understanding the patterns of North African dust arrival and the resulting increases in PM_{10} levels can yield better estimates for warning public in the future.

ii. Because that it is actually possible to limit the anthropogenic emissions unlike African dust or sea spray; air quality measures could focus on better managing the anthropogenic side in the given presence of the known, expected additional burden from these natural pollution sources. This would also serve as a barrier against the utilization of natural air pollution data solely for avoiding air quality control measures, on the contrary, functioning as a tool for reaching better air quality. This principle is also underlined in the Guidance of European Commission (2011) and HKKY, as explained in the preceding sections. Given these deductions about the episodic character of crustal dust transport, the authorities can consider imposing additional restrictions against pollution and introducing warnings for the more fragile parts of the population.

Regarding the second item, however, the lack of necessity to draw up an air quality plan when the exceedances are due to natural contributions was seen in the proposed changes to the CAFÉ directive (European Commission, 2022) and the current version of the directive. In light of these concerns, the implementation of the European Commission (2011) shall be granted delicate consideration in the environmental ethics discussion sphere regarding the ethical implications of proving the natural cause of exceedances -and thereby freeing the lawmakers from bringing precautions for some exceedances-, even including the anthropogenic parts. An excuse for the avoidance of anthropogenic pollution on some dates without further satisfactory concerns shall itself be avoided. This issue is hoped to be handled more carefully by the EU before

enacting the proposed revision to the directive. In the alternative case, the ethical burden is placed on both the policymakers and the researchers in the technical field in the short term. In the long term, again, hope is conserved for the use of technically derived valuable information to bring necessary protection from the simultaneous anthropogenic and natural dust pollution via renewed international policies as well as voluntary acts of developed and/or developing countries to protect their own citizens, by means of not only warnings but also limitation of PM emissions through some measures when other natural dusts are also prone to contribute.

The recommendations for future research include:

- The study can be repeated for other parts of Türkiye. Again, elemental rural data will be beneficial for this purpose.
- Although there is no known additional data from the rural station in Marmaris, after the conduction of the study for other parts of Türkiye, these new results can be compared time-wise. This is considered in relation to the changes in trends over the years.
- Further investigation of the effects of volcanoes on the PM_{10} levels in Türkiye. The volcanic activity records, satellite SO_2 data, TRAJSTAT outputs, and records of combined PM_{10} and SO_2 episodes can be similarly used in other studies as a replication, or the method can be further developed. For TRAJSTAT computations, the elevations to be determined via vertical profiles of the DREAM model, volcanic activity records, or other means can be additionally used. The relationship with K levels can be further investigated.
- In fact, all dates that were rejected by TRAJSTAT but confirmed by other analyses should be considered for further TRAJSTAT computations. It is possible to use the more appropriate elevations, which can be determined via tools such as vertical profiles of the DREAM model.
- The TRAJSTAT backtrajectories arriving at particularly clean regions of the world, such as Greenland, can be of special concern in future studies. The cleaning effect and seasonal character of air masses originating from such regions can be investigated. (It was only modestly considered in this study as a

possible explanation of some of the negative values calculated in Section 4.2)

- The variation in the distribution of causes of forest fires (lightning strike-induced natural forest fires or other forest fires) according to the fire's size can be considered in future studies. Because, as in this study, it may not always be possible to retrieve the exact list of dates of forest fires, with the necessity to conduct the study on a smaller list of probably higher-size forest fires derived from the literature.

- A coefficient better fitting the characteristics of the soil in Türkiye, or specifically Muğla, could be used for conversion of Al concentration data or other data to the crustal portion of Na concentration (0.348 used in this study as Na/Al coefficient for crustal PM_{10} in line with Calzolai et al. (2015) and Diapouli et al. (2017), a generic figure from Mason (1966)).

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