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Influence of Saharan Dust on the Composition of Urban Aerosols in Palermo City (Italy)

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Abstract: The Mediterranean Basin is involved in a recurring phenomenon wherein air masses laden with dust from North Africa impact the southern regions of the European continent. Saharan dust has been associated with increased mortality and respiratory symptoms. Palermo is a large coastal city, and in addition to the impact of desert dust particles, it has a mixture of anthropogenic sources of pollutants. In this study, we collected Saharan dust samples during August 2022 and October 2023, following a high-intensity Saharan dust event, and measured concentrations of 33 major and trace elements as well as Rare Earth Elements (REE). The mineralogical characterization of the deposition dust collected during Saharan events revealed calcite, dolomite, quartz, and clay minerals. The presence of palygorskite is indicative of Saharan events. Seven elements (Ca, Mg, Al, Ti, Fe, K, and Na) account for 98% of the total analyzed inorganic burden. Elemental ratios are valuable tools in atmospheric sciences for estimating sources of air masses. The results highlight that the city of Palermo is mainly affected by dust from the north-western Sahara.

Keywords: Saharan dust; elemental ratios; Rare Earth Elements

Citation: Varrica, D.; Alaimo, M.G. Influence of Saharan Dust on the Composition of Urban Aerosols in Palermo City (Italy). *Atmosphere* **2024**, *15*, 254. https://doi.org/10.3390/atmos15030254

Academic Editors: Avelino Eduardo Saez, Alexandros Papayannis and Patricia K. Quinn

Received: 13 December 2023
Revised: 15 February 2024
Accepted: 16 February 2024
Published: 21 February 2024

1. Introduction

The Mediterranean Basin is involved in a recurring phenomenon wherein air masses laden with dust from North Africa impact the southern regions of the European continent. This atmospheric transport of Saharan dust significantly influences the levels of particulate matter (PM) in the atmosphere [1]. The interplay between these dust-laden air masses and PM concentrations underscores the importance of understanding their dynamics and implications for environmental and public health.

Mineral dust originating from the Sahara Desert stands out as a main natural contribution to atmospheric aerosols on a global scale [2]. Airborne dust plays a significant role in influencing both global and regional climates through its interactions with solar and terrestrial radiation. The investigation of Dust Optical Depth (DOD) temporal variations is crucial in assessing climatic impacts and understanding multifaceted effects within the Earth–atmosphere system, as well as its implications for human health [3,4]. This phenomenon is linked to latitudinal dependence, in which there are more noticeable effects in southern areas compared to northerly regions within the European continent [5–8].

The dry climate and the scarcity of rainfall in the Mediterranean basin favor a long residence time of PM in the atmosphere, consequently impacting the air quality.

The effects of mineral particles on people's health and the environment have been examined in several prior studies [9–11]. Airborne desert dust has significant impacts on various scales, ranging from local to global. Desert dust is capable of traveling long distances in the atmosphere [12]. In addition to affecting air quality, desert dust also has broader impacts on climate and biogeochemistry [13–15]. As mentioned, North Africa alone contributes significantly to global dust emissions (55%). The fact that North Africa, the Middle East, and Asia together (∼87%) account for a large percentage of global emissions implies that these regions play a crucial role in the global distribution of desert dust [16].

Monteiro et al. [17] reported that the occurrence of maximum dust concentrations in Crete on 22 March 2018 had far-reaching impacts across various sectors, including meteorology, agriculture, transportation, energy, society, and emergency response systems. These impacts affected multiple aspects of daily life and infrastructure. While it poses health risks to individuals, leading to increased mortality and respiratory symptoms, it also plays a role in shaping climatic processes, soil fertility, and nutrient cycles on a broader scale [18]. Several studies assessed the impact of dust on surface solar radiation, focusing on an extreme dust event. Aerosols modulate the radiation field of the Earth–atmosphere system with several implications for life on Earth. The physical mechanisms through which they influence the radiation budget are manifold [19,20]. When low atmospheric pressure forms in the Mediterranean to the west of Sicily, the island is hit by warm winds coming from Africa; these are commonly considered together under the name "Sirocco". These winds, as is known, transport considerable quantities of reddish dust, which has also been found at extremely high latitudes, as far away as Siberia [21]. The impact of the Saharan dust events (SDEs), in the urban areas of Sicily, appears to be more significant on particles with PM < 10 μm compared to particles with dimensions less than 2.5 μm. The final effect is not only an increase in concentration but also a change in chemical composition [18,22].

The increasingly frequent studies aimed at the problems of air pollution, whether linked to natural factors or human activity have made it possible to recognize various minerals in the dust transported by the winds. Some of these minerals, both due to their fibrous structure and their small size, and which are selectively transported in the aeolian environment, are of extreme and particular interest due to the pathological implications that they seem to have on the respiratory system of various living beings, including humans. The impact of SDEs on coarse particles can be attributed to the introduction of mineral dust from the Sahara, which contains a mix of various chemical compounds, including minerals like quartz, calcite, and clays [21]. The provenance of dust transported from desert areas and deposited elsewhere on oceans and continents can be determined using various observational techniques. These methods have evolved over the years to provide insights into the origins and pathways of dust deposition. Some of these techniques include satellite imagery, air mass back trajectories, concentration and compositional analyses of specific elemental tracers. Some of these tracers include elements or isotopes unique to certain geological formations or regions. Isotopic tracers, such as Sr, Nd, and Pb isotopes, have been extensively used to trace the provenance of dust. These isotopes serve as unique fingerprints that can help researchers identify and track the sources of dust across different regions and time periods. Their application allows for a more comprehensive understanding of dust provenance and transport dynamics on both local and global scales [23,24].

The health effects of desert dust are less understood than the health effects of air pollution in urban areas, where the particles are predominantly anthropogenic [12]. The complexity arises from the diverse composition of desert dust, which can vary based on the source region and the types of minerals and particles it contains [25]. Saharan dust is mostly composed of tectosilicates, like quartz and feldspar. Additionally, it contains a group of clay phyllosilicates comprising illite, kaolinite, and smectite [26]. Saharan dust events, in regard to the daily limit values and annual averages of PM_{10} established by the Directive of the European Parliament [27], show high concentrations of particulate matter, potentially exceeding regulatory limits. Therefore, these episodes have an impact on air quality [28].

The study in Seville, Spain, revealed that during Saharan dust outbreaks, the chemical composition of PM_{10} changed. In addition to the expected increase in natural dust particles, there was a notable increase in anthropogenic pollutants. The concentration of anthropogenic pollutants was reported to be twice as high during dust outbreak days compared to non-dust outbreak days [29,30].

PM_{10} and $PM_{2.5}$ from various sources, including desert dust, can cause respiratory and cardiovascular problems, emphasizing the importance of addressing these air quality issues [31,32]. Staffogia et al. [33] confirmed that desert dust outbreaks pose a significant risk to human health, particularly due to exposure to PM_{10} during such natural events. The chemical composition of particulate matter includes mineral dust, metals, metalloids, sea salts, ammonium sulphate and nitrate, organic matter, and elemental carbon [34]. Some components of particulate matter can vary in size, composition, and origin, and certainly pose greater health risks than others. Among the inorganic compounds found in PM, metallic elements [35], particularly trace elements, emitted from various sources such as geological materials, the resuspension of soil dust, construction activities, transportation, oil burning, combustion waste, and other industrial activities [36].

The Mediterranean Basin is highly influenced by ambient particles of both natural and anthropogenic origin deriving from the marine boundary layer, Saharan desert, and European mainland [37]. It is useful to underline the growing awareness that the atmosphere plays a crucial role in the transport of pollutants in coastal and oceanic environments [38].

The periodic occurrences of Saharan dust seasonally carry large amounts of metals and metalloids of natural origin into the Mediterranean basin and adjacent continental regions. The two sources, geogenic and anthropogenic, differ chemically, especially in terms of trace element content.

Identifying the sources of trace elements present in the environment can indeed be challenging, especially when attempting to attribute them to specific locations or origins. This difficulty arises due to the complex nature of atmospheric transport and the diverse range of sources that contribute to trace element emissions.

In some cases, there might be an inclination to place more emphasis on anthropogenic sources when studying trace elements in the environment. This emphasis often occurs because anthropogenic activities such as industrial processes, vehicular emissions, and the combustion of fossil fuels are known to release various trace elements into the atmosphere. These activities are typically concentrated in specific regions or urban areas, making their impact more noticeable and sometimes easier to study or regulate. However, natural sources, particularly desert dust from events like Saharan dust storms, can also significantly contribute to the presence of trace elements in the environment [39,40].

Soil can be considered among the major contributors to particulate matter (PM) in the atmosphere [37,41,42]. In a typical urban environment in Southern Europe, such as Barcelona, natural sources, including sea spray, biogenic emissions, and mineral dust, were found to contribute around 20% of the PM mass. In addition, the study by Kassomenos et al. [43] further highlights the significance of natural and secondary particles to PM_{10} levels in different European cities such as London, Athens, and Madrid [41]. Mineral dust (with a mass fraction of 13%) is one of the largest natural PM sources globally. However, on local scales, this value depends on the area studied, as it is strongly affected by extensive spatial variability [42]. The contribution of PM can be due to natural processes such as erosion and wind transport but can also be due to human activities, e.g., traffic causes soil dust to be resuspended. Non-crustal sources contribute significantly to some elements in particulate matter [44–46]. The difficulty lies in identifying the natural sources of PM and distinguishing them from anthropogenic components. The enrichment factor (EF) is widely used to assess anthropogenic and natural impacts on PM [42,47,48].

Palermo is a large coastal city with multiple sources of anthropogenic pollutants in addition to the effects of desert dust particles. This study combines air quality observations and data signatures of Saharan dust intrusion in Sicily and evaluates their impact on PM time series. Monitoring and studying the changes in particle composition during Saharan dust events in the urban area of Palermo are essential for understanding the impacts on air quality, human health, and the environment.

2. Material and Methods

2.1. Sampling and Analysis

The city of Palermo is situated on the north-eastern coast of Sicily along the wide bay ("Piana di Palermo") overlooked by Mt. Pellegrino (606 m a.s.l.). It is delimited in the NE by the Tyrrhenian Sea and surrounded by mountains ("Monti di Palermo") elevated

500–1000 m above sea level. The study area is entirely covered by sedimentary rocks, including limestone, clay, marly clay, and white or yellow quaternary biocalcarenite [49].

Palermo has a typical Mediterranean climate characterized by hot summers and temperate winters. The prevailing winds generally blow from east to west. During autumn and spring, warm winds, notably the Sirocco winds, often blow from the south-east. These winds can carry dust from the Sahara Desert across the Mediterranean basin, affecting the city's air quality. The primary natural sources of trace elements in the air are wind-blown dust and sea spray. However, potential local pollutants are mainly attributed to emissions from vehicular traffic and small-scale manufacturing industries.

Nine composite deposition dust samples were taken between August 2022 and October 2023 after dust transport events occurred, originating from the Sahara Desert region. The samples were collected on the roof terrace of a building in an urban area with medium-high vehicular traffic in Palermo. The dust sample was collected using a brush and a plastic tray. A total of 30 g of dust samples was stored in plastic bags. The sample was sieved through a 100 µm sieve to remove extraneous stones, pebbles, and grass. Particulate matter larger than 100 µm was discarded. Major and trace elements as well as Rare Earth Elements (REE) in the deposition powder were analyzed at Activation Laboratories Ltd. (Ottawa, ONT, Canada) by ICP-MS and XRF (Al, As, Ba, Ca, Cd, Ce, Co, Cr, Cu, Eu, Fe, K, La, Li, Lu, Mg, Mn, Mo, Na, Nd, Ni, Pb, Rb, Sb, Se, Si, Sm, Sr, Ti, U, V, Yb, and Zn). For the determination of ICP-MS, the digestion uses a combination of concentrated hydrochloric and nitric acids. The OREAS-45d, OREAS-922, OREAS-907, OREAS-263, OREAS-130, OREAS-521, OREAS-620, and OREAS-610 standard reference materials were employed. The tested values were all >92% of the certified values. Several replicates yielded precision in the ranges 5–10% (major elements) and 15–22% (trace elements and REE), respectively. The mineralogical characterization was examined by X-ray diffraction at the Department Scienze della Terra e del Mare (DiSTeM), University of Palermo. In the same period of dust sampling, data relating to the concentrations of PM_{10} and $PM_{2.5}$ in various monitoring stations in the city of Palermo were collected from the ARPA Sicilia site (accessed on 17 February 2024, https://www.arpa.sicilia.it/temi-ambientali/aria/). Three monitoring stations (PA2, PA3, PA4) are close to roads with medium-high-density traffic, and two (PA1 and PA5) are located in suburban sites (Figure 1).

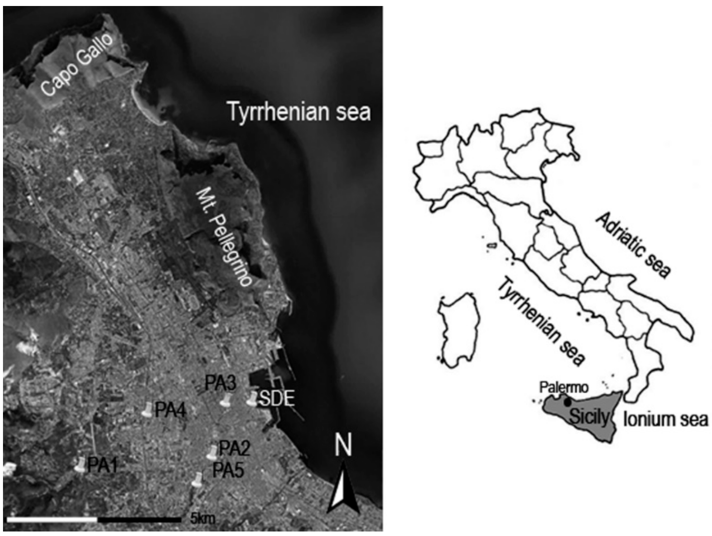

Figure 1. Map of sampling sites.

2.2. Enrichment Factor (EF)

The Enrichment Factor (EF) is defined as EF = $(X/Ref)_{sample}/(X/Ref)_{soil}$, where X is the element of interest, and Ref is the reference element. The index sample indicates the analyzed sample, whereas the soil index is relative to the average concentration of X and Ref in the local parent material. There are no universal fixed rules for the choice of reference element, except that it must be immobile and almost exclusively of crustal origin. In calculating the enrichment factor, Al, Fe, Sc, and Ti are the elements most often used as the reference. In this study, we have chosen aluminum as the reference element based on these considerations: (1) it is of high natural abundance, (2) it is easily determined by conventional techniques, and (3) it may be assumed as derived wholly from soil sources. For the local parent material, we used the average local soil (LS), which is made up of carbonate rocks (80%), clay minerals (10%), and "terra rossa" soil (10%) collected in areas not influenced by anthropogenic sources [35].

3. Results and Discussion

The mineralogical characterization of the deposition dust collected during the Saharan event revealed that in addition to calcite, dolomite, and quartz, which are the main minerals, some phyllosilicates such as kaolinite, illite, smectite, and palygorskite were also present. The mineralogical phases determined correspond to what was previously found by Alaimo and Ferla [21] and Varrica et al. [35]. The presence of calcite, dolomite, and quartz can be associated with the geological formations surrounding the study area. In particular, palygorskite is a mineral that is not present in local rocks, and since it is found occasionally, it could be considered a tracer mineral of Saharan dust intrusion events in the city of Palermo. Varrica et al. [50], using ATR-FTIR analysis on PM_{10} filter samples collected during the Saharan events, highlighted absorbance peaks typical of clay minerals. The identification of specific clay minerals such as palygorskite, illite, and kaolinite in dust samples is consistent with the geological composition of the Sahara Desert [51]. Thirty-three chemical elements were determined in samples of deposition dust collected during Saharan events (Table 1). Seven elements (Ca, Mg, Al, Ti, Fe, K, and Na) account for 98% of the total analyzed inorganic burden. To estimate the mineral dust contribution from elemental constituents associated with crustal origin, we used the equation from the model presented by Lokorai et al. [52] that converts the elements into their common oxide. From the calculation of mineral dust oxide, a contribution between 37 and 56% can be estimated. The same calculations have been applied to evaluate the mineral dust contribution in PM_{10} filters collected during Saharan events, highlighting contributions in the 39–42% range.

Table 1. Main statistical parameters of elemental concentrations in deposition dust during Saharan events. Data are expressed in % and mg kg^{-1}.

	Al	Ca	K	Fe	Mg	Na	Si	Ti
	%	%	%	%	%	%	%	%
Mean	1.88	7.42	1.22	2.67	2.04	0.10	6.40	0.37
Median	2.03	7.58	0.50	2.71	1.93	0.09	6.91	0.40
Min	0.84	7.00	0.43	2.15	1.61	0.07	2.86	0.20
Max	2.75	7.73	2.71	3.53	2.71	0.16	9.38	0.45
	As	**Ba**	**Cd**	**Co**	**Cr**	**Cu**	**Li**	**Mn**
	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
Mean	4.23	176	0.24	11	34	75	26	406
Median	4.46	176	0.23	10	37	68	24	397
Min	3.15	129	0.06	8	21	35	20	291
Max	4.80	232	0.49	15	41	126	33	582
	Mo	**Ni**	**Pb**	**Rb**	**Sb**	**Se**	**Sr**	**U**
	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
Mean	1.56	39	36	25	0.82	0.37	257	1.54
Median	1.49	34	33	24	0.79	0.30	229	1.47
Min	0.78	24	17	16	0.27	0.18	192	1.01
Max	2.66	70	66	33	1.78	0.74	555	2.40
	V	**Zn**						
	mg kg^{-1}	mg kg^{-1}						
Mean	43	153						
Median	46	168						
Min	11	57						
Max	60	199						
	La	**Ce**	**Nd**	**Sm**	**Eu**	**Yb**	**Lu**	
	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	
Mean	17	38	18	3.83	0.73	0.83	0.11	

Dongarrà et al. [53] report a contribution of mineral dust estimated at 31% and 35% for $PM_{2.5}$ and PM_{10}, respectively. Therefore, the mineral dust results from the contributions of soil dust resuspension on local rocks and Saharan dust intrusion. Because the city of Palermo is located along the Tyrrhenian coast, it is possible to hypothesize a marine origin, especially for crustal elements such as Ca, Mg, and K. The sea salt concentration was calculated based on the water-soluble Na and sea water composition [54], with the assumption of the complete marine origin of Na [53]. For the SDE samples, the marine contribution of those elements of an average of 1% was calculated.

Elemental ratios are valuable tools in environmental and atmospheric sciences for estimating sources of air masses and identifying regional differences in the chemical composition of dust [52,55]. The study of the elementary relationships between specific elements such as Al, Si, Fe, Mg, K, Ca, and Ti can provide valuable information on the presence of Sahara dust and the possible origin of the Sahara dust that crossed the Mediterranean, reaching Europe. Scheuven et al. [56] have discussed the use of certain elemental ratios to discriminate dust source zones. In particular, the characterizing ratios are Ca/Al, Mg/Al, Fe/Al, and the elemental ratio (Ca + Mg)/Fe. The latter encompasses a north–south gradient, with the highest ratios in north-west Africa [56]. Unfortunately, the distinctions between North African regions of origin are not always clearly identified. The elemental ratio (Ca + Mg)/Fe helps to identify from which African regions the dust originates. In particular, (Ca + Mg)/Fe ratio value of >2 is signifies the north-western and north-eastern regions; dust coming from southern Algeria is characterized by a ratio between 0.6 and 1.2; for the sub-Saharan region, a value <0.85 is expected; and for the regions of origin in the east, (Ca + Mg)/Fe = 0.8–2.2. According to Scheuvens et al. [56], a low ratio of Ca/Al, less than 0.5, was identified in samples from central and southern Algeria and the Sahel zone. This suggests that the dust source for these regions might have specific characteristics related to this ratio. According to Blanco et al. [57], identifying dust sources depends on the ratios of Ca/Al, K/Ca, and Fe/Ca. When the Ca/Al ratio is higher than the K/Ca and Fe/Ca ratios, the most predominant source of dust is the northwestern Sahara. This suggests that different regions have distinctive dust source characteristics, and these ratios can help distinguish between them. Comparing the elemental ratios determined in the Sahara dust samples (from SDEs) with the values reported above, it can be seen that the city of Palermo is mainly affected by dust from the north-western Sahara (Figure 2). This tendency is confirmed by the ratios (Ca + Mg)/Fe > 2, Mg/Al > 0.3, and Ca/Al > 1.0 for all dust samples taken during the Saharan events (Figure 2).

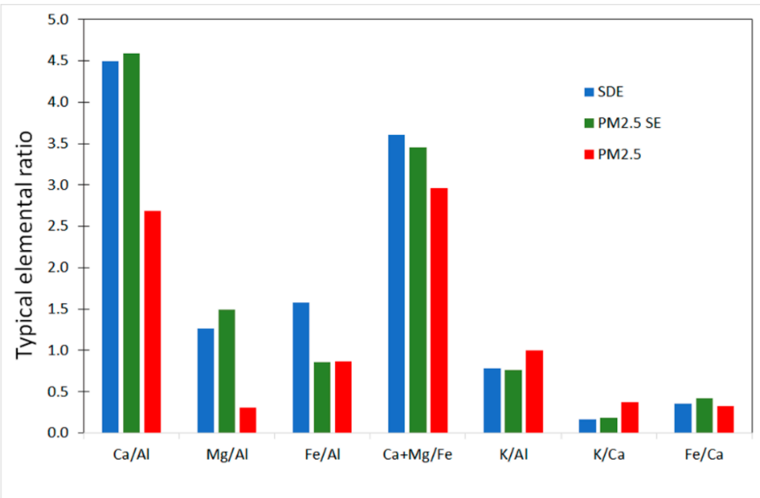

Figure 2. Elemental ratio in samples of deposition Saharan dust (from SDEs), $PM_{2.5SE}$ (SE: Saharan event) and $PM_{2.5}$ (normal days).

Furthermore, according to Chiapello et al. [58], a higher Ca/Al ratio and low K/Al and Fe/Ca ratios are identifiers of dust coming from the northern and western Sahara. Figure 2 shows elemental ratios calculated in PM2.5 samples during Saharan events (SE) and normal days (Dongarrà G., personal communication). The values obtained for the $PM_{2.5SE}$ filters are comparable with those found in the dust sample (from SDEs) but are different from the $PM_{2.5}$ filters sampled during normal days. Rare Earth Elements (REEs) are valuable tools in geochemistry and environmental sciences for various applications, including identifying rock formation processes and as markers to track the atmospheric deposition of particulate matter [59,60]. Chondrite-normalized REE patterns of the SDE samples are shown in Figure 3, along with those regarding the main lithotype present in the study area and the soils coming from the Sahara of North Africa. Dust collected during the Saharan event in Palermo shows a similar pattern of desert soil to that in the Northern Algeria/Tunisia area (Hassi-Messaout). However, a positive Ce anomaly cannot be ruled out in the SDE sample. Ce is an element widely employed in automotive catalytic converters, where it is introduced as CeO_2 to promote the water–gas shift reaction and to store oxygen [61].

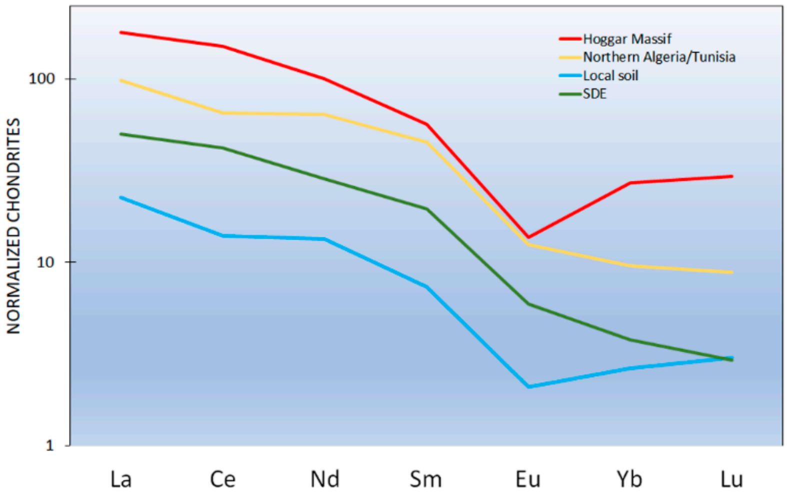

Figure 3. Log-normal plot of chondrite-normalized REE pattern of local soil of Palermo, deposited Saharan dust (from SDEs), dust of Northern Algeria/Tunisia (Hassi-Messaout) [62], and Hoggar Massif [63] dust samples.

BSC-MONARCH maps were used to observe the transport of air masses from the Sahara for specific days when dust events occurred [64,65] (Figure 4). The trajectories shown in Figure 4 align well with the chemical data, particularly the elemental ratios and Rare Earth Element (REE) patterns, confirming that the dust originated from the northern and western Sahara.

Information on the natural or anthropogenic origin of trace elements was inferred from the calculation of enrichment factors (EFs), which were calculated by dividing their relative abundances in the SDE samples by their average relative abundances in local soils [35] and the continental crust.

From Figure 5, it appears that for many elements, the enrichment factors calculated based on the two substrates are similar (Ba, Co, Cr, Fe, K, Ni, Ti, and V). However, for other elements such as, Ca, Cd, Cu, Li, Mg, Mn, Mo, Na, P, Pb, Rb, Sb, Sr, U, and Zn, the EFs calculated when considering the continental crust as the substrate are higher. Considering that among the critical issues of using the enrichment factor is the choice of the reference substrate [66] and, certainly, the fact that the composition of the continental crust is different from the representative composition of the rocks surrounding the city of Palermo, it is possible to deduce that the low content of metals of anthropic origin in dust from the Sahara result in a reduction in the concentrations of trace metals and metalloids of anthropic origin in atmospheric particulates [35,67].

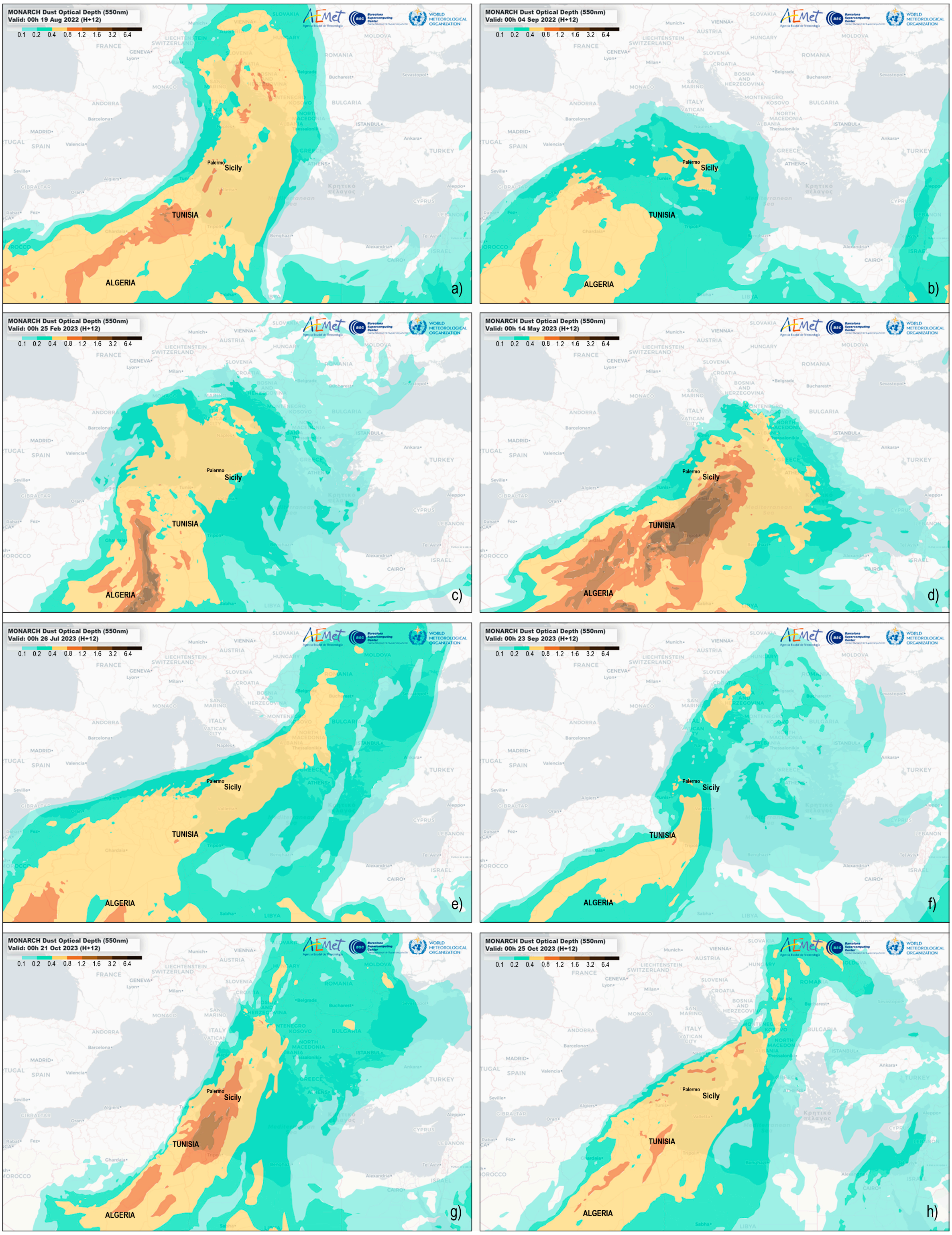

Figure 4. Maps of DOD by MONARCH model for the Mediterranean area (accessed on 17 February 2024: https://dust.aemet.es/) for specific days when dust events occurred (**a**) 19 August 2022; (**b**) 4 September 2022; (**c**) 25 February 2023; (**d**) 14 May 2023; (**e**) 26 July 2023; (**f**) 23 September 2023; (**g**) 21 October 2023; (**h**) 25 October 2023.

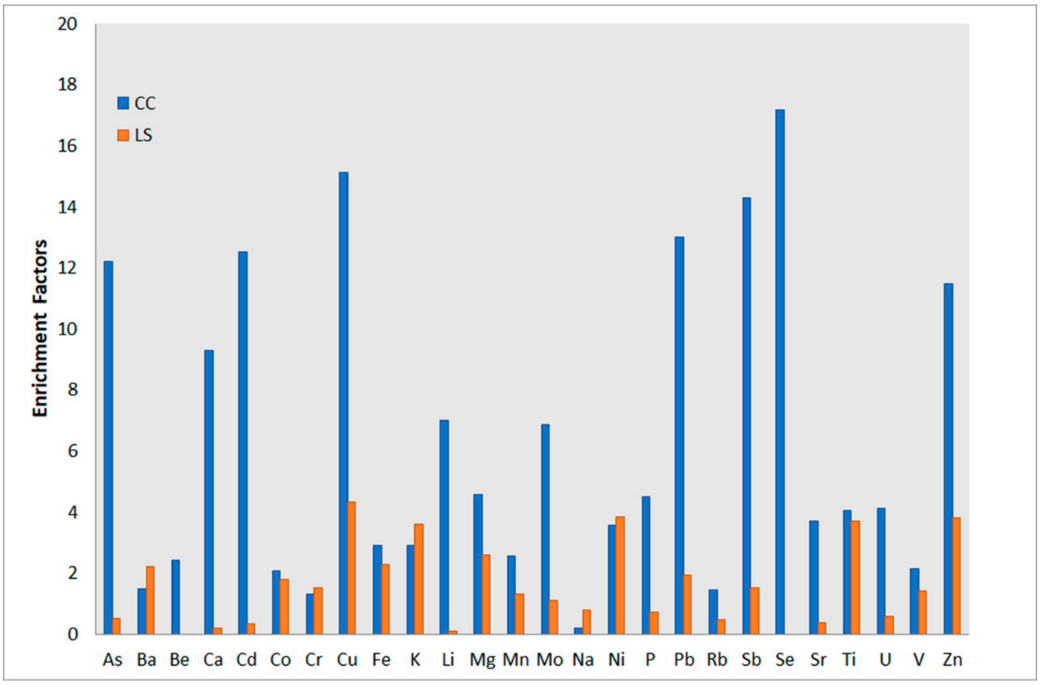

Figure 5. Average enrichment factors (EFs) for the analyzed elements in deposited Saharan dust (from SDEs). The EFs were calculated considering the continental crust (CC) and local soil (LS) as reference substrates.

For the collection period of the deposited dust, the concentrations of PM_{10} and $PM_{2.5}$ for the reference year are provided by the Regional Agency for Environmental Protection (ARPA) in Sicily. Table 2 lists the statistics of ambient PM_{10} and $PM_{2.5}$ mass levels collected in Palermo at several sampling stations characterized by varying traffic density from August 2022 to October 2023. The PM_{10} average values observed in the monitoring stations varied from 19.7 (PA5) to 28.8 (PA4) µg m^{-3}. The $PM_{2.5}$ levels in the three monitoring stations varied from 10.2 (PA5) to 13.5 (PA3) µg m^{-3} (Table 2).

Table 2. Average PM_{10} and $PM_{2.5}$ mass concentrations, $PM_{2.5}/PM_{10}$ ratio in normal days and during Saharan events in the air monitoring station. Concentration data expressed in µg m^{-3}.

	PA 1	**PA2**	**PA3**	**PA4**	**PA5**
	suburban	medium-high traffic	medium traffic	medium-high traffic	suburban
		During Saharan event			
PM_{10}	75.9	58.4	61.0	66.2	55.0
$PM_{2.5}$		22.4	24.2		20.6
$PM_{2.5}/PM_{10}$		0.38	0.40		0.38
		Normal condition			
PM_{10}	20.5	23.1	25.4	28.8	19.6
$PM_{2.5}$		13.4	13.5		10.2
$PM_{2.5}/PM_{10}$		0.58	0.53		0.52

During the analyzed period, samples were taken from nine Saharan dust events, which produced a significant increase in PM_{10} and $PM_{2.5}$ mass concentrations in Palermo. These episodes represent 10% of the days of the analyzed period, thus increasing the concentrations, especially that of PM_{10} compared to $PM_{2.5}$. In particular, an increase in the concentration of PM_{10} at the background station of PA1 is more evident, which, during Saharan dust events, reaches average PM_{10} concentrations of 75.9 µg m^{-3} compared to the value detected for $PM_{2.5}$ in the PA5 suburban station of 20.6 μg m^{-3}. In general, it can be noted that in streets with higher traffic density, the atmospheric $PM_{2.5}$ and PM_{10} loads during the Saharan events were up to approximately 180% and 240% higher than during normal conditions at the same stations. At the suburban stations, the atmospheric $PM_{2.5}$ and PM_{10} loads during the Saharan events increased up to approximately 200% and 275% compared to normal conditions. In Palermo, during a high-intensity Saharan dust event, a PM_{10} of 360 μg m^{-3} and a $PM_{2.5}$ of 50 μg m^{-3} were recorded, respectively (Figure 6).

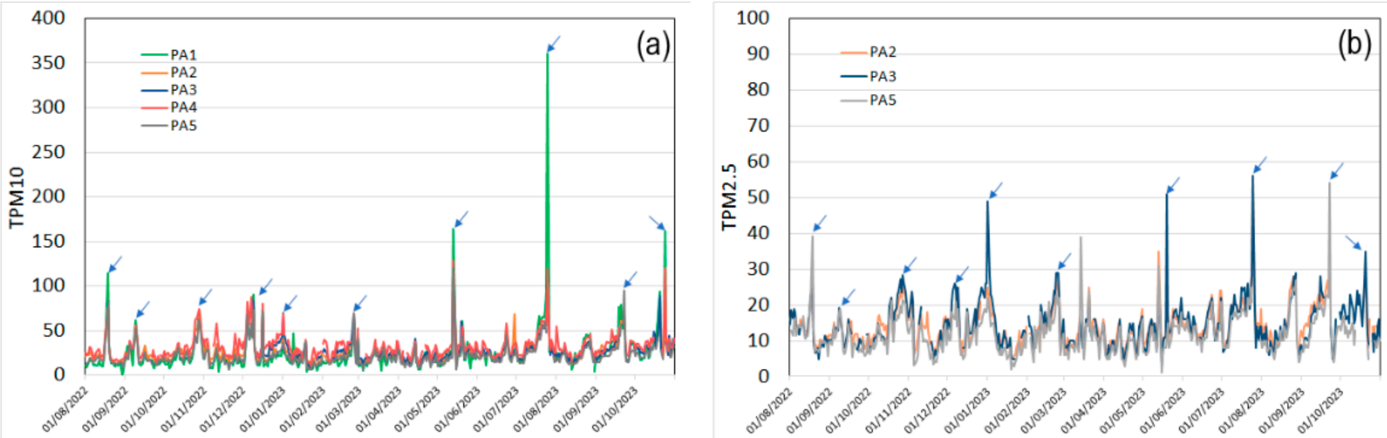

Figure 6. Time-series of daily PM_{10} (**a**) and $PM_{2.5}$ (**b**) mass concentrations measured from August 2022 to October 2023 at sampling stations in Palermo (Italy). The arrows indicate events related to Sahara dust. Concentration data expressed in μg m^{-3}.

In general, Saharan dust, when present as part of particulate matter, tends to have a more significant impact on the larger, coarser fractions of particulate matter rather than the finer fractions [68].

The $PM_{2.5}/PM_{10}$ ratio is used in environmental studies to differentiate PM emissions and identify whether the source is anthropogenic from geogenic.

The average $PM_{2.5}/PM_{10}$ ratio was reported as 0.58 at the PA2 station, suggesting that there is a higher concentration of fine particles relative to the coarser particles, which is typical of urban environments [69]. During Saharan dust events at the same monitoring station (PA2), the $PM_{2.5}/PM_{10}$ ratio drops significantly to 0.38. This shift in the ratio indicates that the presence of Saharan dust alters the usual composition of particulate matter in the area by introducing a higher proportion of coarse particles.

In general, the contribution of Saharan dust in the particulate matter is prevalent in the coarse fractions rather than in the fine ones [68]. The $PM_{2.5}/PM_{10}$ ratio is used in environmental studies to differentiate PM emissions and identify anthropogenic from geogenic sources.

4. Conclusions

The correct analysis of air quality data, including evaluating the influence of natural phenomena, is necessary to define the real levels of urban pollution. The transport of Saharan dust is a natural event extensively studied from different perspectives, recognizing that it has a significant role in the different effects it produces on the climate and the environment. The occurrence of natural events, such as the transport of Saharan dust, can lead to a significant increase in PM_{10} concentrations measured in urban areas. Urban environments are centers of various human activities, industries, transportation, and infrastructure, which contribute to air pollution. An air quality monitoring network within an urban area helps to assess pollution levels, identify sources of pollution, and implement strategies to improve air quality and public health. Furthermore, urban areas are not only affected by local emissions but can also be influenced by natural phenomena such as Saharan dust events. Monitoring networks, therefore, must take these natural events into account to better understand the general dynamics of air quality in cities and accurately assess their impact on public health. The elementary relationships between concentrations of crustal components such as Al, Si, Fe, Mg, K, Ca, and Ti, in correspondence with transport events of Saharan dust, serve as valuable tools in atmospheric sciences for estimating sources of air masses by validating the identification and their quantification more accurately. Comparing the elemental ratios determined in the Saharan dust samples (from SDEs), highlights that Palermo city is mainly affected by dust coming from the north-western Sahara. The enrichment factors calculated considering the continental crust as the substrate for elements such as As, Cu, Li, Mo, Pb, Sb, Se, and Zn are higher with respect to local soil.

Saharan dust has a low content of metals of anthropic origin compared to local sources in the study area; therefore, the introduction of this dust could contribute to lower concentrations of those metals and metalloids in atmospheric particulates in Palermo city. The north-western Sahara is a significant source of dust affecting Palermo, and other factors such as local emissions, weather patterns, and geographical features can also influence the air quality and the concentration of pollutants in the city. Studying and analyzing specific data related to atmospheric conditions and pollutant levels would provide a clearer understanding of the extent of the impact of Saharan dust on reducing anthropogenic pollutants in Palermo's air.

Acknowledging the significance of natural sources like desert dust in contributing to trace elements is crucial for a more comprehensive understanding of air quality, environmental impacts, and human health risks associated with these elements. Balancing the focus on both anthropogenic and natural sources helps in formulating effective strategies for mitigating environmental pollution and minimizing human exposure to harmful trace elements.

Author Contributions: Conceptualization, D.V. and M.G.A.; data curation, D.V. and M.G.A.; formal analysis, D.V. and M.G.A.; funding acquisition, D.V. and M.G.A.; writing—original draft, D.V. and M.G.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by FFR 2023, granted to D.V. and M.G.A.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

Acknowledgments: Dust data and/or 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.

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

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