REPUBLIC OF TURKEY
The Ministry of Agriculture and Forestry
Turkish State Meteorological Service

Evaluation of Atmospheric Aerosols over West Asia

2003-2020

West Asia

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1. INTRODUCTION

1.1. Atmospheric Aerosols (Particulate Matter)

Particles suspended in solid and liquid form in the atmosphere are defined as aerosols (Particulate Matter - PM). Coarse Particulate Matter (PM10) is less than 10 micrometers in diameter. PM10 primarily comes from road traffic, agriculture activities, river beds, construction sites, mining operations, and similar activities. Fine Particulate Matter (PM2.5) is less than 2.5 micrometers in diameter and a product of combustion, primarily caused by burning fuels. A single human hair is approximately 70 micrometers or seven times larger than the largest PM10 particles in diameter and is almost 30 times larger than the largest fine particle, PM2.5 (Figure 1).

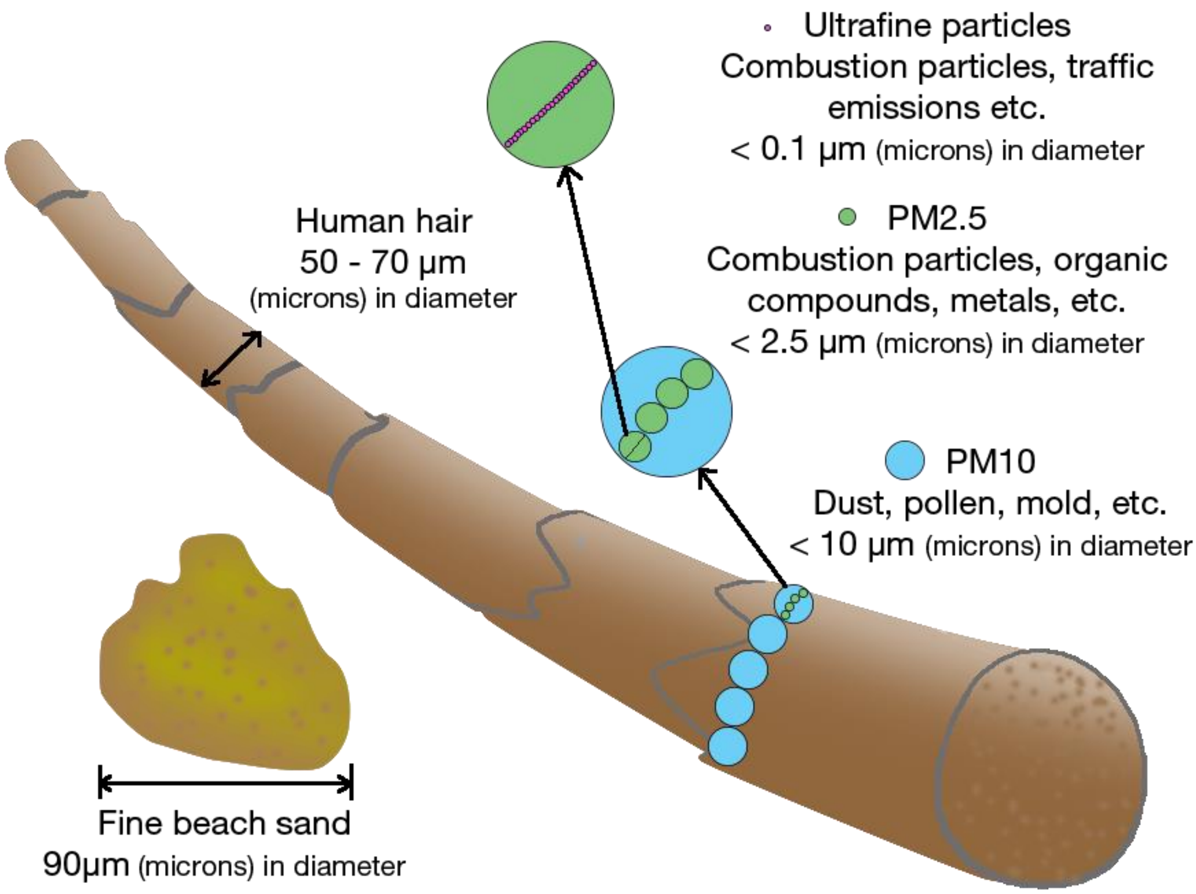

Figure 1. Sizes of Atmosoheric Aerosols (vfa-solutions.com)

1.2. Dust Sources

Approximately 1,000 Tg to 2,000 Tg (1-2 billion tons) of dust is emitted to the atmosphere from the deserts every year (Tanaka et al., 2006). The most important sources of dust aerosols are located in the Northern Hemisphere, primarily over the Sahara and Sahel in North Africa, the Middle East, Central and South Asia respectively (Choobari et al., 2014). Potential areas for dust storms are illustrated on Figure 2. The annual amount of dust released from the Sahara into the atmosphere is about the half of dust released from all sources on Earth, while the dust released from the Sahara and Middle East regions is about 70% of global annual dust emissions. The annual amount of dust emitted from Arabian Peninsula (Middle East) to the atmosphere was estimated to 221 million tons (Tanaka et al., 2006).

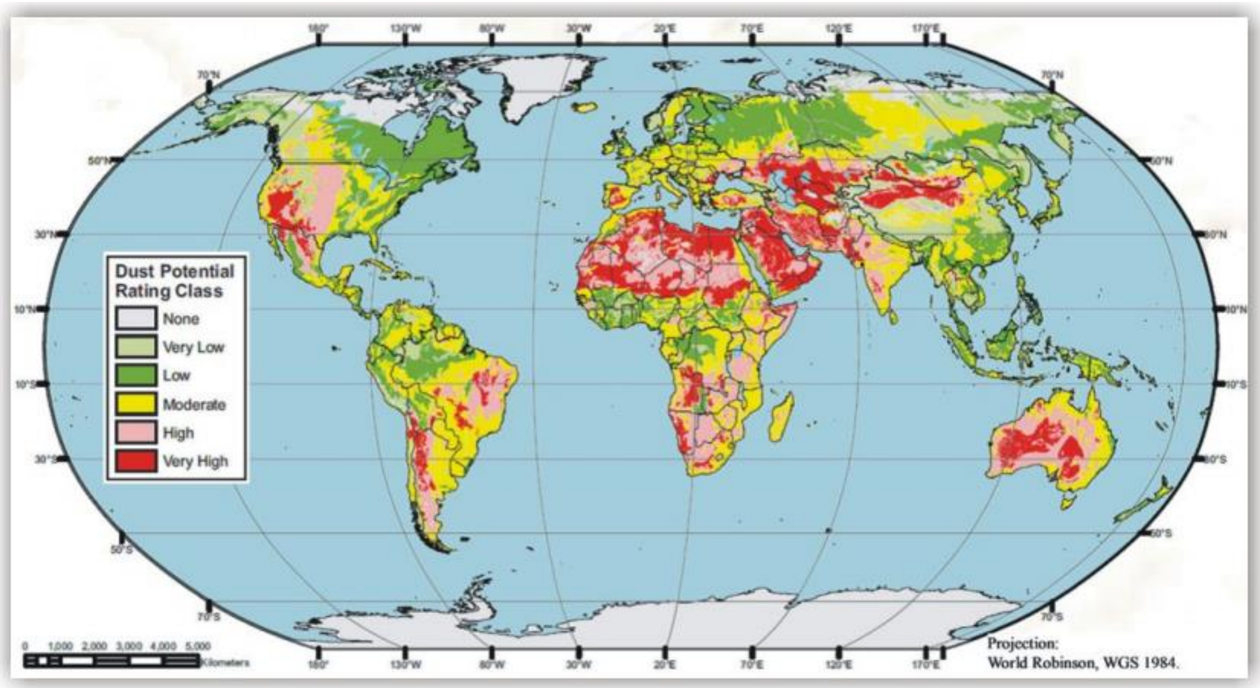

Figure 2. Global Dust Potential Map. Source: DTF (2013) (UNEP, WMO and UNCCD,. 2016)

It is generally accepted that the Arabian Peninsula, Syria, Iraq and Iran (Figure 2) are among the most important primary dust sources of the West Asian region (Prospero et al., 2002; De Longueville et al., 2010; Boloorani et al. al., 2013; Muhs et al., 2014; WMO and UNEP, 2013).

In the study conducted by Tanaka et al. (2006); all dust source areas in the world and the amount of dust thrown into the atmosphere from these areas have been calculated and calculated dust emissions were mapped by De Longueville et al. (2010) (Figure 3).

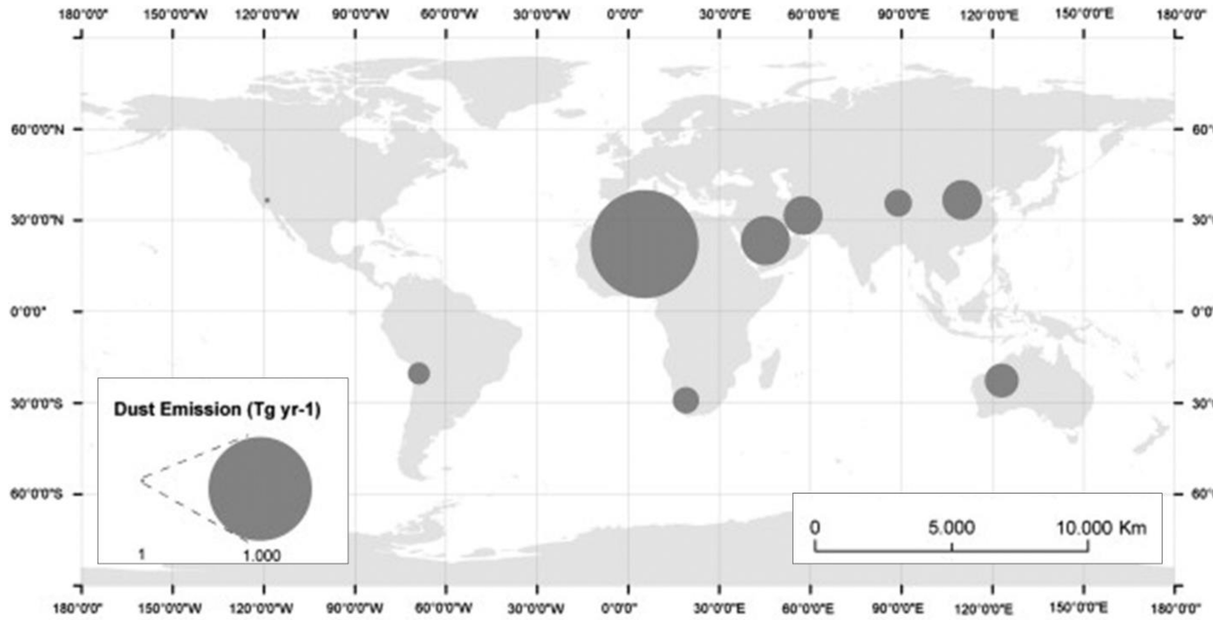

Figure 3. Amount of dust emitted into the atmosphere (De Longueville et al., 2014)

According to the calculations in the study; total of 1877 Tg (≈1.9 billion tons) dust enters the atmosphere from deserts annually (Table 1).

Table 1. Dust emissions from deserts to the atmosphere (Tanaka et al., 2014).

	Emission ($Tg\ yr^{-1}$)	Dry deposition ($Tg\ yr^{-1}$)	Wet deposition ($Tg\ yr^{-1}$)	Burden (Tg)	Dry lifetime (days)	Wet lifetime (days)	Total lifetime (days)
North Africa	1087	723 (67%)	363 (33%)	9.09	4.6	9.1	3.1
Arabian Peninsula	221	129 (58%)	92 (42%)	1.65	4.7	6.6	2.7
Central Asia	140	94 (67%)	46 (33%)	1.05	4.1	8.3	2.7
Western China	68	39 (57%)	29 (43%)	0.42	3.9	5.2	2.2
Eastern China	146	90 (62%)	56 (38%)	0.67	2.7	4.3	1.7
North America	2	1 (59%)	1 (41%)	0.01	3.9	5.5	2.3
South America	44	20 (45%)	24 (55%)	0.30	5.5	4.6	2.5
South Africa	63	41 (64%)	23 (36%)	0.47	4.2	7.6	2.7
Australia	106	65 (61%)	41 (39%)	0.92	5.2	8.2	3.2
Total	1877	1202 (64%)	675 (36%)	14.6	4.4	7.9	2.8

1.3. Mineral Dust Impacts and Dust Seasons

Mineral dust aerosols have a key role in the atmospheric radiation budget and hydrological cycle through their radiative and cloud condensation nucleus effects. Mineral dust aerosols are blown into the atmosphere mainly from arid and semi-arid regions where annual rainfall is extremely low and substantial amounts of alluvial sediment have been accumulated over long periods. They are subject to long-range transport of an intercontinental scale, including North African dust plumes over the Atlantic Ocean, summer dust plumes from the Arabian Peninsula over the Arabian Sea and Indian Ocean and spring dust plumes from East Asia over the Pacific Ocean. Mineral dust aerosols influence the climate system and cloud microphysics in multiple ways (Choobari et al., 2014).

According to the Intergovernmental Panel on Climate Change (IPCC) when the global average temperatures increase by 1.0°C, the Mediterranean basin will increase by 1.5°C and the precipitation will decrease by 12%. It is stated that the areas that will be most affected (sensitive) by climate change are the Mediterranean, Australia, Central America, South Africa and South

America. Furthermore, IPCC accepts mineral dust as a very important component of atmospheric aerosols, one of the main climate variables. According to the IPCC's latest climate predictions, it is expected that sand and dust storms will be more intense as the frequency and severity of the drought has increased (IPCC 2013).

In the literature, it is stated that desert dust, especially rich in iron content, has effects on ocean and marine life and land (Jickells et al., 2005). In addition, sand and dust storms negatively affect the daily life of exposed people. It is known that those with respiratory and heart diseases, the elderly and children are most affected by these events. Studies conducted in Africa have shown that there is an important link between cases of meningitis in children and dust storms (Perez, 2010). Dust storms also negatively affect air and sea transportation. In areas close to dust source areas, airports are closed during storms, and there are major problems in road transportation.

Transport from North Africa to the Eastern Mediterranean occurs predominantly during spring and is commonly associated with the eastward passage of frontal low-pressure systems. Dust from sources in the Middle East is more typically transported to the Mediterranean in the fall (Middleton et al., 2001)

2. MATERIAL AND METHODOLOGY

2.1. Aerosol Optical Depth (AOD)

Aerosol Optical Depth (AOD) provides important information about the concentration, size distribution, and variability of aerosols (desert dust, sea salt, haze, and smoke particles) in the atmosphere. It is a dimensionless number related to the amount of aerosol distributed within the vertical column of atmosphere over the observation location. AOD provides a quantitative measure of the extinction of solar radiation due to aerosol scattering and absorption (Gkikas et al., 2009). Heavy dust regions are defined by AOD higher than 0.3. Around deserts, AOD values are above 1.0 and usually below 3.0 (NASA, 2005).

Giovanni website provides a simple way to visualize, analyze, and access Earth science remote sensing data, particularly from satellites, without having to download the data. It includes data for aerosols, atmospheric chemistry, atmospheric temperature and moisture, and rainfall. It was developed by the Goddard Earth Sciences Data and Information Services Center (GES DISC).

2.2. Angstrom Exponent (AE)

The Angstrom Exponent (AE) is an exponent that expresses the spectral dependence of aerosol optical thickness (τ) with the wavelength of incident light (λ). It provides additional information on the particle size, aerosol phase function and the relative magnitude of aerosol radiances at different wavelengths. AE (computed from τ measurements on two different wavelengths) can be used to find τ on another wavelength using the relation below:

$$\tau_\lambda = \tau_{\lambda_o} \left(\frac{\lambda}{\lambda_o}\right)^{-\alpha}$$

$$\alpha = \text{Angstrom exponent}$$

The Angstrom Exponent is a useful quantity to evaluate the particle size of atmospheric aerosols or clouds, and the wavelength dependence of the aerosol/cloud optical properties. It is inversely related to the average size of the particles in the aerosol: the smaller the particle size, the larger the Angstrom Exponent is. Therefore, low AE values indicate strong presence of coarse aerosols relating to the dust events.

In areas with high AOD and small AE averages, large aerosols (desert dusts) appear to be dominant in the atmosphere (Patel et al., 2016). Figure 4 summarizes AOD and AE relationship related to aerosol types.

AE >> 0.9 FINE particles
AE << 0.7 COARSE particles (Patel et al., 2016)

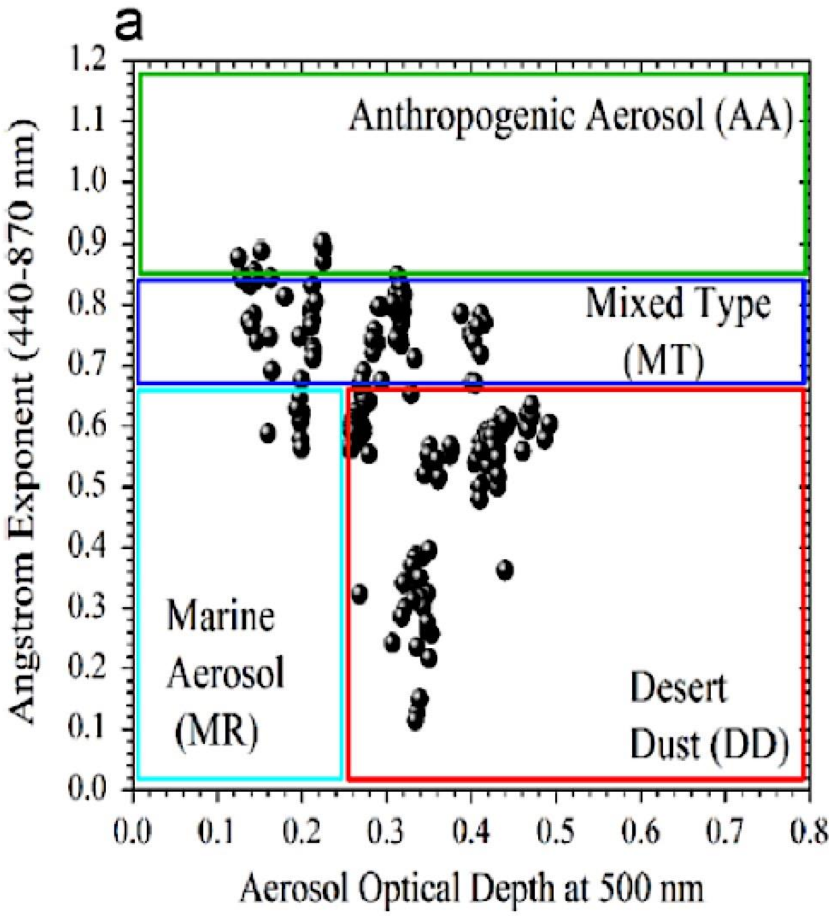

Figure 4. Aerosol Optical Depth versus Angstrom Exponent with aerosol types (Patel et al., 2016)

2.3. Observation Data and Method

Dust particles, one of the most common aerosols in the atmosphere, have high optical depth (AOD) and low Angstrom Exponent (AE) values due to their large particle diameters. MODIS aerosol products monitor the optical depth of aerosols over oceans and continents globally. AOD is a unitless parameter that usually ranges from 0 to 1. As the amount of aerosols in the atmosphere increases, the AOD value also increases. When strong or very strong sand and dust storms are experienced in an area, AOD reach values above 1.

In the study, Aerosol Optical Depth (AOD) and Angstrom Exponent (AE) data (collection 6.1) of MODIS device on NASA Aqua satellite were used. Spatial and temporal changes of mean AOD and AE values for the regions (Figure 5) in the analyzes were examined. Aqua-MODIS (550 nm) AOD and AE data were obtained from NASA's website (https://giovanni.gsfc.nasa.gov/giovanni/) and analyzed. Angstrom Exponent (AE) parameter is used for the detection and evaluation of particle sizes. Angstrom Exponent is calculated using measurements made on different channels of satellite observations such as MODIS, MISR and SeaWiFS. The small AE indicates that the aerosol diameters are large, meaning that large diameter particles such as dust are more dominant in the environment. High values of AE indicate that small-scale aerosols such as anthropogenic emissions are much more dominant in the environment.

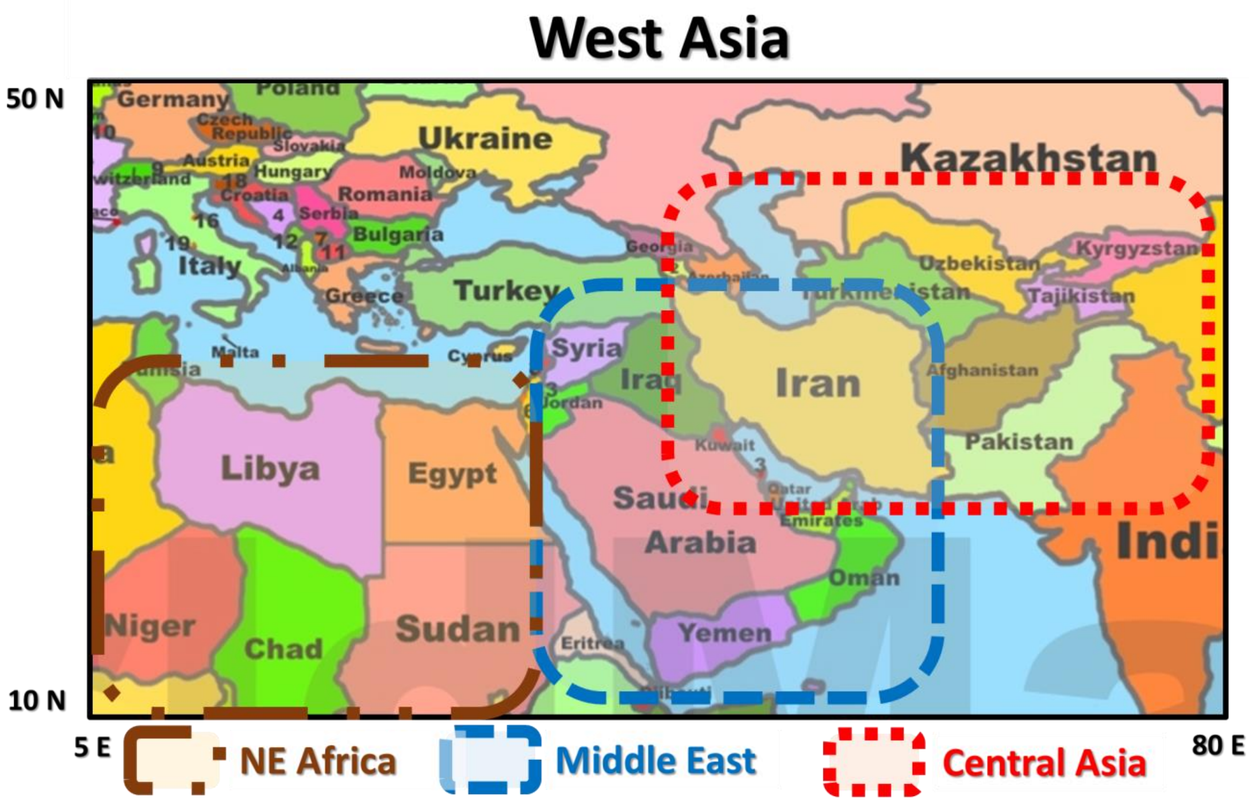

Figure 5. West Asia Domain

3. RESULTS

Spatial Analysis of Aerosol Optical Depth (AOD) Data

Based on the Aerosol Optical Depth (AOD) data obtained from MODIS - Aqua satellite for the years 2003-2020 (Table-2.a and Figure-6.a); although there is no significant change in the global scale, there are increasing and decreasing trends at the regional scale.

Regional AOD averages has been calculated from high to low; Middle East, Africa, West Asia, Turkey, Global and Europe, respectively. AOD averages of the Middle East, Africa and West Asia were found to be much higher than the values of Turkey, Europe and Global. The main reason for high AOD averages calculated in these regions is that they contain source areas.

It is seen that the increase in AOD, which started in all regions since 2007, started to decrease as of 2012, and decreased after an increase in 2018 (Figure 2.a).

Table 2.a. Annual variation of mean AOD values of study regions

Year	Global	Turkey	Europe	Africa	Middle East	West Asia
2003	0,1622	0,1857	0,1741	0,3119	0,3323	0,3093
2004	0,1583	0,1686	0,1589	0,3170	0,2972	0,2859
2005	0,1619	0,1698	0,1571	0,3274	0,3112	0,2758
2006	0,1622	0,1852	0,1660	0,3187	0,3279	0,2984
2007	0,1660	0,1954	0,1636	0,3251	0,3362	0,2872
2008	0,1670	0,2068	0,1608	0,3288	0,3857	0,3547
2009	0,1645	0,2090	0,1627	0,3114	0,3834	0,3321
2010	0,1665	0,1888	0,1491	0,3534	0,3700	0,3254
2011	0,1724	0,1997	0,1596	0,3255	0,3982	0,3395
2012	0,1704	0,1913	0,1461	0,3301	0,4007	0,3425
2013	0,1595	0,1787	0,1410	0,2973	0,3590	0,3098
2014	0,1621	0,1819	0,1477	0,3055	0,3240	0,3140
2015	0,1725	0,1901	0,1397	0,3395	0,3709	0,3162
2016	0,1630	0,1765	0,1382	0,3326	0,3426	0,2946
2017	0,1620	0,1850	0,1398	0,3422	0,3733	0,3022
2018	0,1666	0,2014	0,1527	0,3307	0,4057	0,3505
2019	0,1674	0,1896	0,1468	0,2869	0,3491	0,2991
2020	0,1705	0,1807	0,1382	0,3034	0,3228	0,2818
Average	**0,1653**	**0,1880**	**0,1523**	**0,3215**	**0,3550**	**0,3122**

According to the Angstrom Exponent (AE) data obtained from MODIS - Aqua satellite for the years 2003-2020 (Table 2.b and Figure 6.b); It was found that the values calculated at the Turkey, Europe and Global (world) scales are high, and human-induced emissions with much smaller diameters are dominant in these regions, rather than large-sized natural aerosols such as desert dust.

Table-2.b. Annual variation of mean AE values of study regions

Year	Global	Turkey	Europe	Africa	Middle East	West Asia
2003	1,2646	1,4346	1,4373	0,5523	0,7338	0,9666
2004	1,2665	1,4455	1,4583	0,5489	0,7750	0,9807
2005	1,2636	1,4397	1,4519	0,5263	0,7730	1,0051
2006	1,2539	1,4411	1,4483	0,5573	0,7530	0,9556
2007	1,2704	1,4305	1,4589	0,5637	0,7783	1,0025
2008	1,2445	1,4014	1,4467	0,5356	0,6690	0,8584
2009	1,2514	1,4333	1,4725	0,5653	0,6617	0,9109
2010	1,2460	1,4492	1,4458	0,5020	0,6669	0,9061
2011	1,2429	1,4543	1,4513	0,5303	0,6649	0,8961
2012	1,2510	1,4320	1,4320	0,5531	0,6585	0,9063
2013	1,2537	1,4442	1,4455	0,5640	0,6926	0,9502
2014	1,2463	1,4484	1,4184	0,5116	0,7366	0,9146
2015	1,2223	1,4556	1,3735	0,4275	0,5930	0,8843
2016	1,2218	1,4399	1,3764	0,4275	0,6251	0,9153
2017	1,1795	1,4198	1,3082	0,3733	0,5500	0,8513
2018	1,1870	1,4571	1,3446	0,4383	0,5604	0,7851
2019	1,2141	1,4580	1,3483	0,4972	0,6759	0,9348
2020	1,2251	1,4397	1,3647	0,5072	0,7212	0,9614
Average	**1,2391**	**1,4402**	**1,4157**	**0,5101**	**0,6827**	**0,9214**

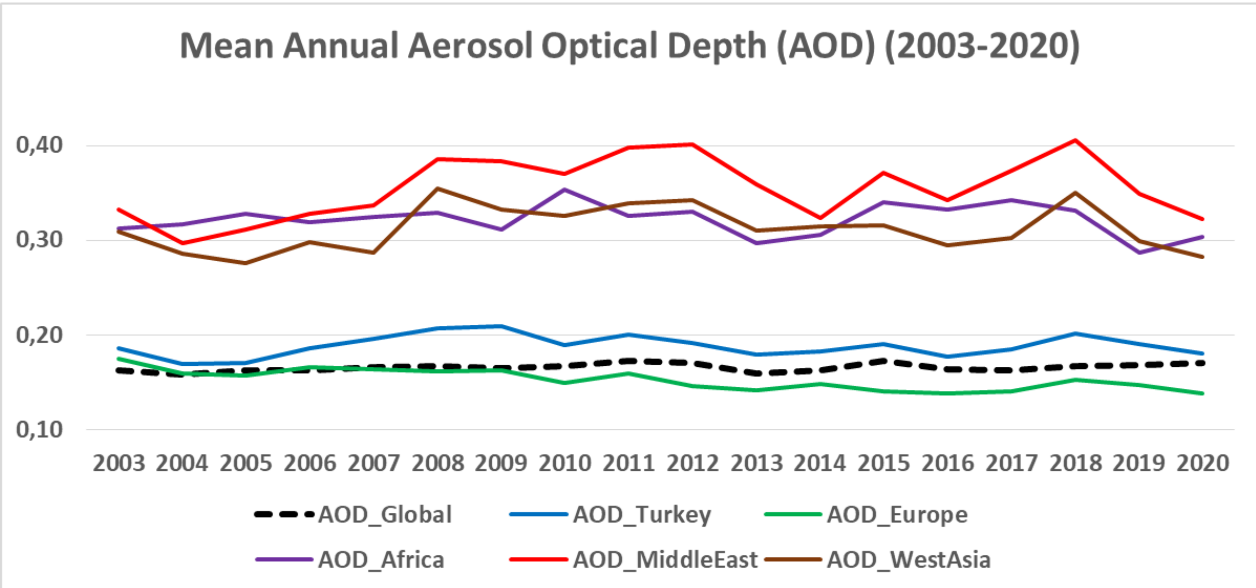

Figure 6.a. Mean annual AOD changes of study regions

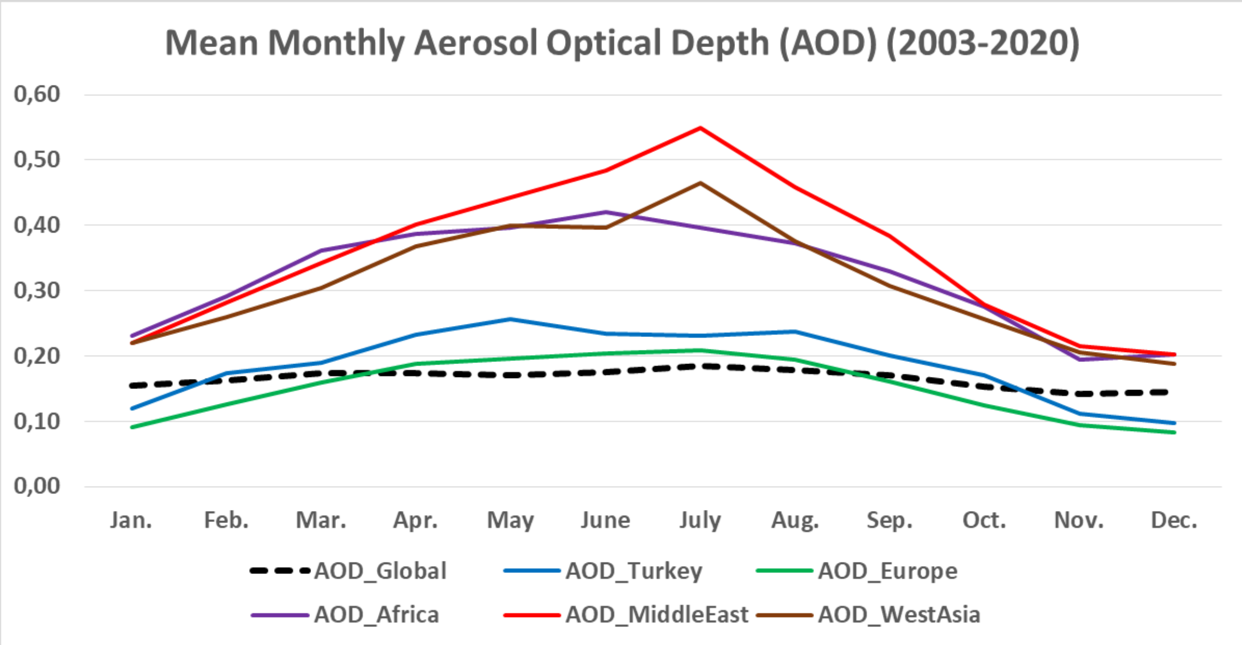

Figure 6.b. Mean annual AE changes of the study regions

When the monthly mean AOD values (Table 3.a, Figure 7.a) are examined, the highest values in the Middle East and West Asia regions were calculated in July, while higher values were found in the spring months for Turkey and Africa. While there is no significant change globally on a monthly basis, it has been determined that the AOD values decrease in the winter period in Europe.

When the monthly mean Angstrom Exponent (AE) averages (Table 3.b, Figure 7.b) are analyzed, that the monthly averages calculated for Europe and Turkey are the highest, in other words, smaller particles belonging to anthropogenic emissions are dominant in these regions. Angstrom Exponent (AE) averages were calculated lower as expected in Africa, Middle East and West Asia regions where desert dusts are more effective.

Table 3.a. Monthly variation of mean AOD values of the study regions

Month	Global	Turkey	Europe	Africa	Middle East	West Asia
January	0,1545	0,1193	0,0905	0,2310	0,2204	0,2191
February	0,1632	0,1740	0,1254	0,2906	0,2818	0,2600
March	0,1742	0,1901	0,1595	0,3609	0,3430	0,3040
April	0,1734	0,2332	0,1886	0,3869	0,4018	0,3670
May	0,1697	0,2561	0,1963	0,3957	0,4418	0,4000
June	0,1753	0,2348	0,2034	0,4210	0,4840	0,3963
July	0,1842	0,2316	0,2090	0,3969	0,5498	0,4656
August	0,1784	0,2377	0,1937	0,3720	0,4580	0,3764
September	0,1699	0,2009	0,1615	0,3302	0,3839	0,3080
October	0,1534	0,1705	0,1239	0,2758	0,2788	0,2562
November	0,1420	0,1112	0,0941	0,1947	0,2147	0,2051
December	0,1452	0,0968	0,0821	0,2026	0,2021	0,1883
Average	**0,1653**	**0,1880**	**0,1523**	**0,3215**	**0,3550**	**0,3122**

Table-3.b. Monthly variation of mean AE values of the study regions

Month	Global	Turkey	Europe	Africa	Middle East	West Asia
January	1,2365	1,4753	1,4920	0,6676	0,8565	1,1203
February	1,1954	1,4667	1,4762	0,5238	0,7201	0,9852
March	1,1358	1,4501	1,3426	0,3993	0,6183	0,8450
April	1,1659	1,4870	1,3752	0,3732	0,5815	0,7873
May	1,2241	1,4878	1,4262	0,3825	0,4940	0,7156
June	1,2297	1,4512	1,4131	0,3205	0,5196	0,7673
July	1,2575	1,3983	1,3475	0,3878	0,5111	0,7570
August	1,2766	1,3613	1,2711	0,4802	0,6052	0,7971
September	1,3091	1,3789	1,4231	0,5738	0,7051	0,9538
October	1,2926	1,3963	1,4546	0,5884	0,7682	1,0019
November	1,2788	1,4591	1,4756	0,6802	0,9134	1,1789
December	1,2675	1,4708	1,4910	0,7437	0,8996	1,1475
Average	**1,2391**	**1,4402**	**1,4157**	**0,5101**	**0,6827**	**0,9214**

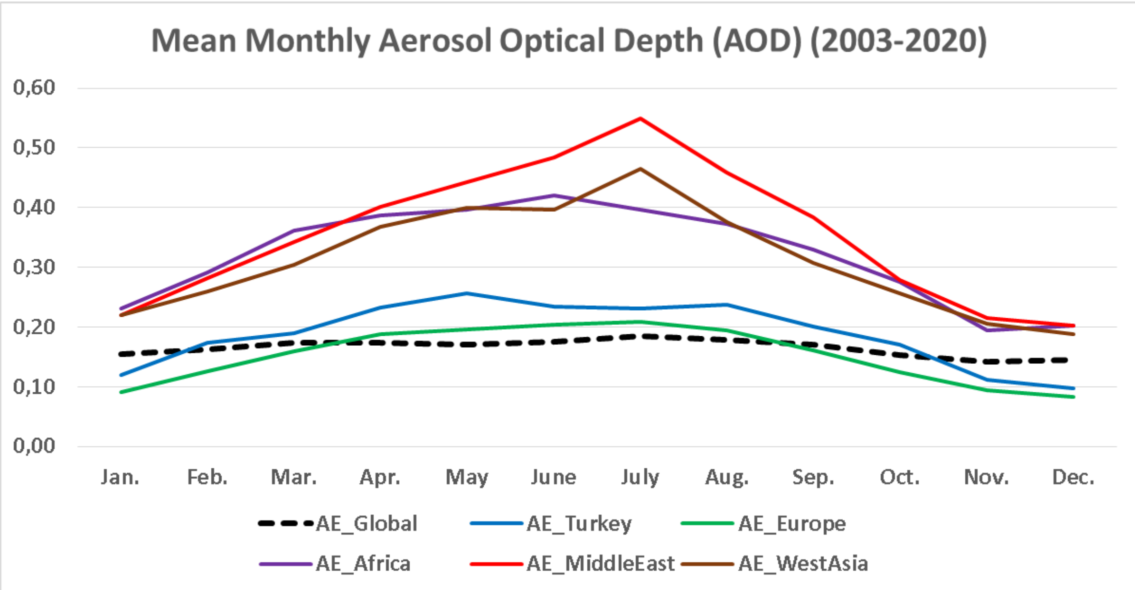

Figure 7.a. Monthly changes of mean AOD values for study regions

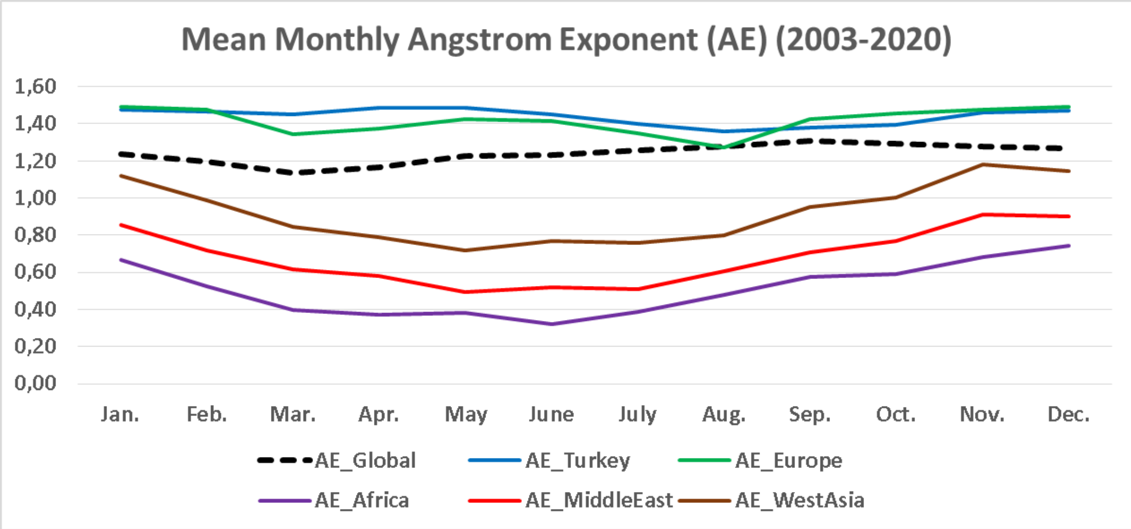

Figure 7.b. Monthly changes of mean AE values for study regions

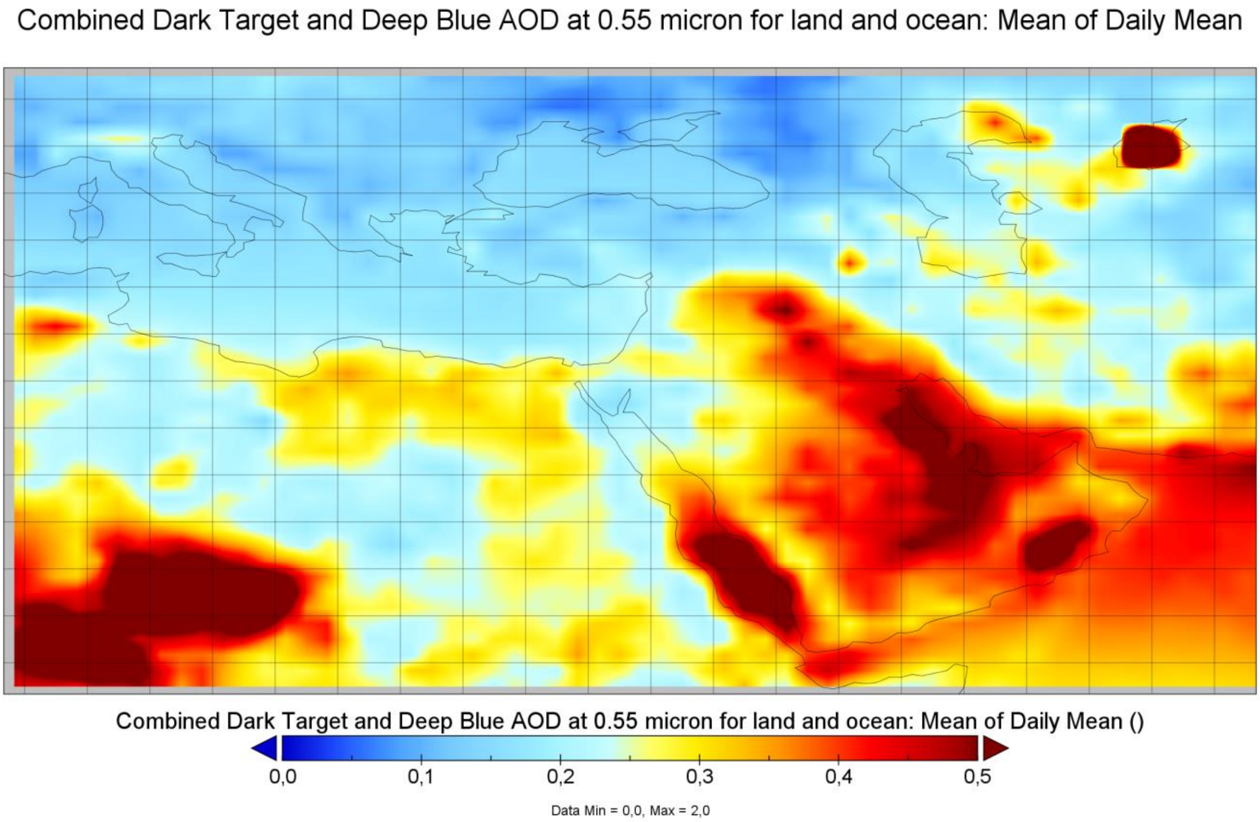

Figure 8. Mean AOD

4. CONCLUSION

Dust monitoring is significant not just for mineral dust forecasting and early warning but also research purposes. Satellite and ground-based observations guide aerosol forecast model development recently and have been made more readily available for model evaluation and assimilation (Benedetti et al., 2018). The parameters, we have used for our research, Aerosol Optical Depth (AOD) and Angstrom Exponent are fundamental ones in dust observation.

The amount of annual mean AOD does not show a significant change globally. However, on a regional scale, annual mean AOD shows different patterns for the Middle East and Central Asia. The highest AOD values are observed between the years 2008-2012. There is another peak in 2018 for the Middle East and Central Asia.

Establishment of new dust observations around dust source regions and effected regions will provide more knowledge about dust characteristics and basis for further research over West Asia region. They will also contribute to dust observation network at Global Atmosphere Watch (GAW) Program of World Meteorological Organization (WMO).

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