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Research Article

SEASONAL INVESTIGATION OF ATMOSPHERIC DESERT DUST AFFECTING SANLIURFA USING MODIS SATELLITE AND HYSPLIT MODEL DATA

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ABSTRACT

Million tons of dust are transported every year primarily from the Sahara Desert, Syria and Arabian Peninsula, which are close to Turkey. In this study, Sanlıurfa, was selected as an observation station to investigate the extent of long range transport of dust influencing Southeastern Anatolia Region for the first time. Hence, PM_{10} and $PM_{2.5}$ types of dust were collected into filters through dust collection device during 2012 year and the amount was determined. The source of the dust at 500, 1000 and 1500 meters, also, was analyzed using the model of HYSPLIT. MODIS aerosol product was used for satellite images of dusty days. The source of these dusts carried over long distances was found, with HYSPLIT, to be Sahara Desert in particular, Syrian desert and deserts in the Arabian Peninsula. Dust collected daily through dust collection device into PM_{10} and $PM_{2.5}$ filters was found to come more frequently in transition seasons of as PM_{10} of 550 μg m^{-3}, $PM_{2.5}$ of 213 μg m^{-3} in spring; as PM_{10} of 620 μg m^{-3}, $PM_{2.5}$ of 240 μg m^{-3} in autumn which are all above the minimum standard levels (50 μg m^{-3}) accepted by the WHO.

Keywords: Air quality, desert dust, atmospheric particulate matter, hybrid single-particle lagrangian integrated trajectory model (HYSPLIT), moderate resolution imaging spectroradiometer (MODIS) satellite.

1. INTRODUCTION

The main part of aerosol mass loading is constituted by dust released into the atmosphere through surface winds originated from dry soils [1]. Almost 20% of the earth's surface is formed by arid and hyperarid areas near the boundaries of deserts [2]. Suspended dust is transmitted inside the atmospheric wind flow in the air. The dust residence time in the atmosphere, which is partially similar to the dust life time, altitude of dust layer, prevailing atmospheric circulation characteristics, and buoyancy and gravitational forces, determines the transport distance to a large extent. On the other hand, it is assumed that particles with 70 μm and larger sizes deposit in a period of time which is almost one day. Atmospheric turbulence allows only finest particles with 70 μm diameter and less to be kept aloft, and these particles

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can stay in the atmosphere for some weeks and eventually be carried along a great distance downwind [3]. Still, so called 'giant' particles which have a size of >100 μm sometimes exist at distant areas (>1000 km) [4, 5]. There is a growing scientific interest in global emission, transport and features of dust from desert areas carried globally as a result of crustal aerosols' climatic and biogeochemical impacts. The Sahara is a primary source of dust among the deserts in the globe with its emissions estimated in the range of 600–700×10^6tonnes per year [6, 7]. The dust originating from Sahara is the most important natural origin of particulate matter (PM), with around 2 × 10^8tons of aerosols produced per year, which are transported towards the Atlantic Ocean, to the Mediterranean Sea and Southern Europe [8, 9]. Thirteen events on average per year were detected over the Iberian Peninsula preferably during May to August [10, 11]. [12] reported about 5–15 incidences per year over southern Germany. These events are explained through a mid-latitude disturbance in the North African continent [13, 14]. In the Mediterranean, a correlation has been determined between high levels of PM_{10} and the African dust intrusion [15]. It has been shown in one of the latest studies that contribution of African dust to PM_{10} concentration declines exponentially with latitude (from south to north) and increases longitudinally from 25°E eastwards [16]. The tropospheric aerosol mass is largely composed of mineral dust aerosol, which consequently has an effect on the climate of the Earth and the atmospheric characteristics in many ways. The tropospheric aerosol mass is largely composed of mineral dust aerosol, which consequently has an effect on the climate of the Earth and the atmospheric characteristics in many ways. Mineral dust aerosol can influence the climate in a direct or an indirect way, nutritional system in sea environments and processes about geochemistry. Furthermore, a strong association has been identified in epidemiologic studies considering the particulate matter with serious problems of health like diseases about respiratory and cardiovascular system, cardiovascular diseases, pulmonary and systemic inflammation, lung cancer and even death [17, 18]. World Heath Organization (WHO) and European Commission Directive 2008/50/EC set threshold limits both for PM_{10} and $PM_{2.5}$ to protect public health. WHO sets 24-h average and annual limit values for PM_{10} as 50 and 20 μg m^{-3}, respectively, while those for $PM_{2.5}$ are 25, and 10 μg m^{-3}, respectively. Threshold limits set by the European Commission for annual and 24-h average PM_{10} are 50 and 40 μg m^{-3}, respectively, whilst annual average $PM_{2.5}$ limit was determined as 25 μg m^{-3}.

The purpose of this study is to highlight the impact of long-range dust transport on the observed PM mass concentrations. To end this, PM samples were collected during 2012 at Sanlıurfa, which is located at the intersection of dust transport routes.

2. MATERIALS AND METHODS

2.1. Study Area

Located in Southeastern Anatolia Region with a Syria border, Sanlıurfa has a semi-arid climate, which tends to have hot summers and warm winters considering the data of 42 years obtained from directorate of meteorology. It shows the features of a semi-desert climate owing to the difference between daytime and night time temperatures, which increases particularly in transitional seasons of spring and autumn.

Sanlıurfa is a significant city since it is in the intersection of air flows from large deserts such as Sahara, Syria and Arabian Peninsula (Figure 1c) which leads very frequent PM exceedances within the city.

Gent PM_{10} Stack Filter Unit (SFU) sampler operating in accordance with the EPA standard was deployed in this study to collect $PM_{2.5}$ and PM_{10} samples, simultaneously. Sampler was located in Environmental Engineering Department of Harran University (Sanlıurfa, Turkey) (37.17^o N -39.00^o E and 550 Elevation) at a height of 10 m. Sampling location is depicted in Figure 1a and 1b. The study area was carefully selected by ensuring that it is away from the main road, it is not located in the area of industrial organizations and the content and amount is not affected by any particles as Harran University has a fuel-oil heating system.

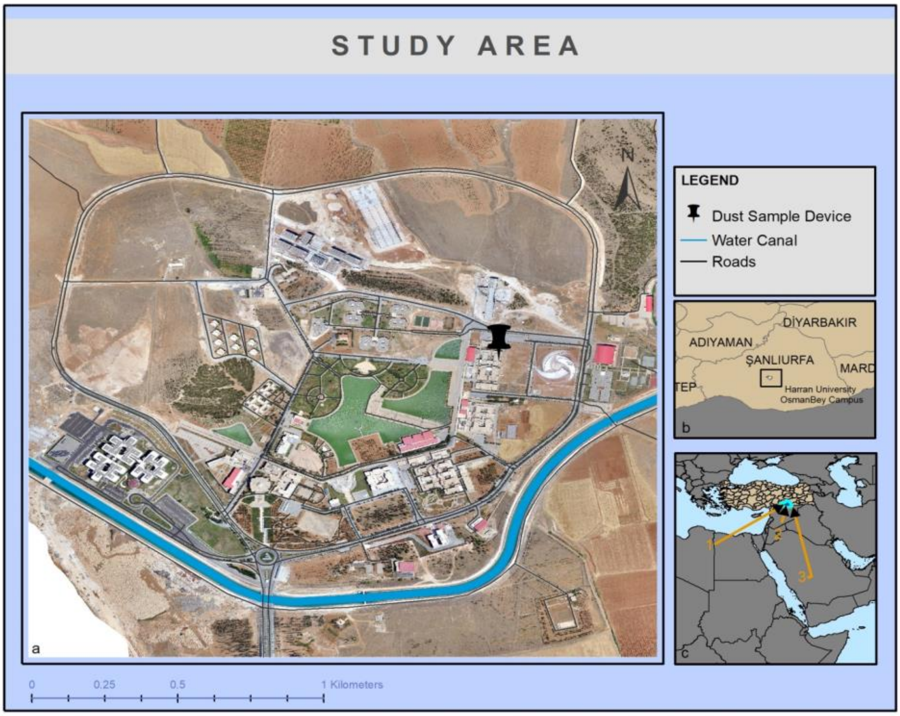


Figure 1. (a) Study area where PM sampler was located, (b) Location of Sanlıurfa, (c) Main directions where dust transported to Sanlıurfa

2.2. Sample Collection

Gent type PM_{10} stacked filter unit (SFU) sampler includes two diameter filter holders sized 47mm, placed in series. The first holder's upstream is a pre impaction stage intercepting particles with 10 mm and larger sizes equivalent aerodynamic diameter (EAD). Operation of the sampler is a flow rate of 16 L min^{-1} to gather particulates with an EAD which has 10 mm and less size in separate coarse (2.5–10 mm EAD) and fine (2.5 mm EAD) size fraction on two sequential 47mm diameter Nuclepore filters. The first filter holder and the second holder are loaded with an an 8 mm pore size (Apiezon coated) Nuclepore polycarbonate filter and 0.4 mm pore size Nuclepore filter, respectively [19]. A 100 laminar air flow cabinet (clean dust free) was used to perform the loading and unloading of the filters in order to reduce the possibility of contamination. Starting date of the sampling is in January 2012, and finished in December 2012. In the course of this period, 730 aerosol filter samples in total were collected with a temporal resolution of 24 h.

2.3. HYSPLIT Backward Trajectories

Possible source areas have been assigned through the HYSPLIT model of the US National Oceanic and Atmospheric Administration (NOAA). Computations of air parcel backward trajectories to Sanlıurfa at 9:00 UTC are carried out for altitudes at 500 m intervals up to 6.5 km, and for up to 315 h. These are conducted through the Windows-based version 4.9 of the model. Vertical velocity fields of the meteorological model provide the vertical motion. For the model input, The National Centers for Environmental Prediction (NCEP) reanalysis data is utilized [20]. Information on prevailing meteorological incidences in the transport is provided by means of the slope of the vertical component of trajectories that are shown in the lower panel of the backward trajectory plots.

Another significant parameter, together with how often and in what amount the dust comes, is to identify the source from which the dust originates in order to determine its chemical and physical characteristics. Therefore, directions of airflow at 500, 1000 and 1500 meters were determined through the program called HYSPLIT by providing coordinates of Harran Üniversitesi, Sanlıurfa (37.17^o N and 39.00^o E), Turkey.

2.4. MODIS Satellite Image

While predominant wind direction in Sanlıurfa is from south-west, transport of particulate matter occurs in the case of south wind from Syria/Sahara deserts located in the south border. Satellite aerosol products are often used to identify dust source areas and patterns of dust transport. It is necessary to make a detailed analysis of dust transport height and its patterns and then to interpret them in order to make the accurate estimation of the effects of dust. Characteristics and transport of dust can be analyzed and dust aerosols can be monitored through various satellites such as Ozone Monitoring Instrument (OMI), MODIS and Meteosat Second Generation. These measurements provide useful information related to the transport and vertical/horizontal distribution of dust [21].

MODIS Aerosol satellite monitors aerosol optical thickness over the oceans globally and some part of continents. Furthermore, aerosol size distribution is obtained over the oceans and aerosol type is obtained over the continents. Daily level 2 data is produced at the spatial resolution of a 10x10 1-km [22].

Data in this study was obtained on a daily basis from Terra and Aqua platforms for the year of 2012.

3. RESULTS AND DISCUSSION

A counterclockwise rotation of cyclones in synoptic scale pulls the cold air mass from northern Europe while it activates warm air mass over Africa. These hot air masses carry the soil in the ground over north Sahara Desert in Africa.

While the particles with a large diameter fall because of gravity and aerodynamic movements, very small particles such as PM_{10} and $PM_{2.5}$ can be transported over a long distance by hanging in the predominant wind.

The first study to determine the dust grain size was carried out by [23] in the USA. Particle sizes were found to vary between 15,6 - 62,5 μm in the early studies. Particle size of desert dust decreases with the increasing distance from source regions. Coarse particles (31-62 μm) can travel up to 320 km from their sources, medium dust (16-31 μm) can be trasporter to 1600 km from its source and finer particles (16 μm) can cover long distances around the globe [24]. Therefore, amounts of PM_{10} and $PM_{2.5}$ collected in our study were determined seasonally.

3.1. PM_{10} and $PM_{2.5}$ in Spring

Cyclonic activities increase along the front line over Mediterranean as a result of meeting of tropical and polar air masses in spring and autumn and counterclockwise rotation of these cyclones to east leads to the transportation of the desert dust over Africa, Arabia and Iran to Turkey, which then causes dusty days.

In the study carried out by [25], desert dust originating from North Africa and Arabian Peninsula can be transported to 55th parallel north in a period of 47 years in spring between 1959-2006 regarding the dust surface concentration observed. They also reported that it coincides with the period when desert dust transportation is at its highest. As shown in Figure 2 a, much higher values than 50 µg $m^{-3,}$ which is the limit value in the regulation on Ambient Air Quality Assessment and Management, can be seen.

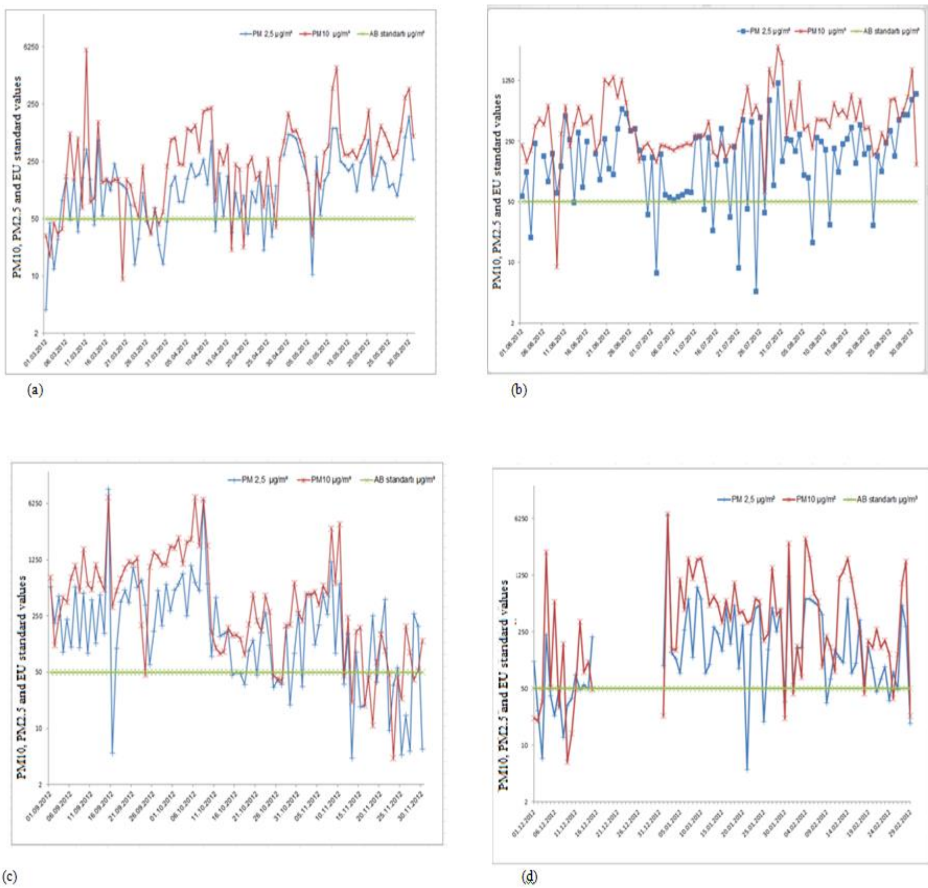
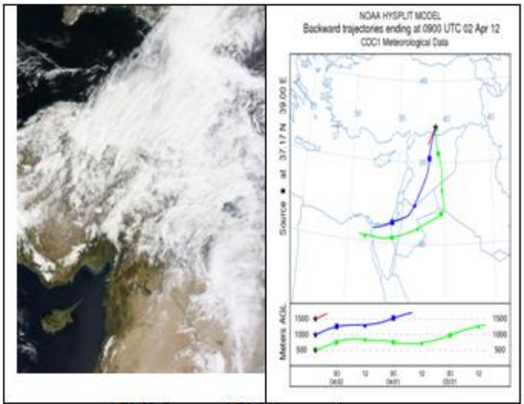


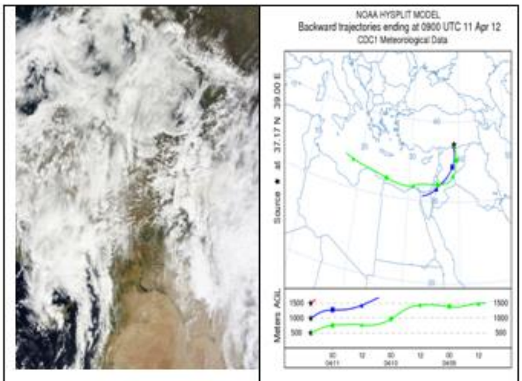
Figure 2. PM_{10} and $PM_{2.5}$ mass concentrations in (a) Spring, (b) Summer, (c) Autumun and (d) Winter

It was reported that the amount of dust falling to Northern Mediterranean per year is 14 grams and this value is lower than only West African coastal region but higher than all other regions under the influence of Sahara [26]. As can be clearly seen in Figure 3 (a) and (b), air mass originating from Sahara has affected our country by leading to long distance transport of particulate matters over Syrian Desert.



Date	PM2,5 ($\mu g/m^3$)	PM10 ($\mu g/m^3$)	Air Temperature (°C)
02.04.2012	44,32	486,59	15,3

(a)



Date	PM2,5 ($\mu g/m^3$)	PM10 ($\mu g/m^3$)	Air Temperature (°C)
11.04.2012	440,64	1126,07	18

(b)

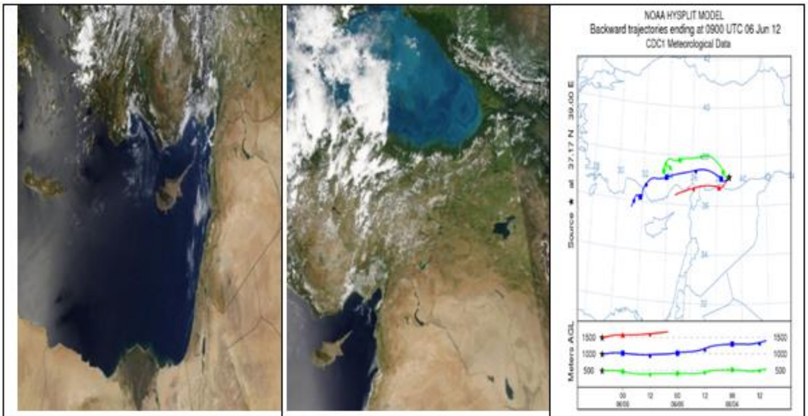
Figure 3. (a) Data related to dust transport via HYSPLIT and MODIS images on 02/04/2012, (b) Data related to dust transport via HYSPLIT and MODIS images on 11/04/2012

Studies conducted on Eastern Mediterranean have indicated that the effect of dust originating from Sahara and Arabian Peninsula on Anatolia is about 20 million tons per year. Up to 80 percent of this, however, reaches to Anatolia in March-April in periods lasting a few days [27]. MODIS images, HYSPLIT model and the device to collect particulate matters helped to find out that transport of dust in March, April and May in and around Sanlıurfa is higher. Considering related literature on MEA, the average outdoor values found in the present study are quite similar to those (PM2.5 and PM10) provided by [28] during a dust period in Israel. As Israel is an area which is often influenced by dust storms as well, dust events could raise the daily levels of PM10 in the center of city (Tel Aviv) to as high as 2100 µg m-3 [29, 30].

3.2. PM_{10} and $PM_{2.5}$ in Summer

It was reported in the study [31] that air streams originating from Azor (mT) and Iceland (mP) move towards North Africa and Arabian Peninsula as a result of the increasing temperature around the 30th parallel north and Intertropical Convergence, ITC, (Movement of the winds towards the center of a cyclone is called convergence. This movement often forces the air gathered towards the center to rise.) which is moving towards the north. Transport of desert dust becomes more difficult in summer as cyclonic activities weaken in Mediterranean Basin [31]. It was found out in this study that dust in the summer exceeds on so many days the level of 50 µg m^{-3}, which is specified in regulations as the standard of EU (Figure 2 b). High amount of dust in June and July is predicted to have resulted from a synoptic pressure movement linked to the increasing temperature.

The dust came from the direction of Sahara and Syria on June 6, 2012. Sanlıurfa was under the influence of a dry deposition for 2 days, as can be clearly seen in Figure 4. This results from regional winds activated in summer and movement of the Continental Tropical air masses in Sahara and Arabian Peninsula towards the north [32].



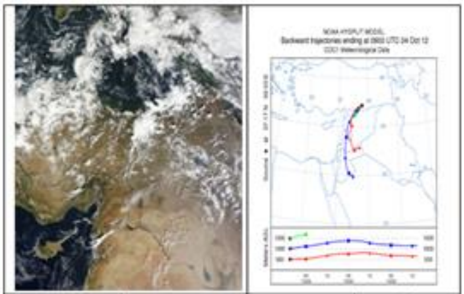
Date	PM2,5 (µg/m³)	PM10 (µg/m³)	Air Temperature (°C)
6.6.2012	168,50	389,95	28,9

Figure 4. Data related to dust transport via HYSPLIT and MODIS images on 06/06/2012

3.3. PM_{10} and $PM_{2.5}$ in Autumn

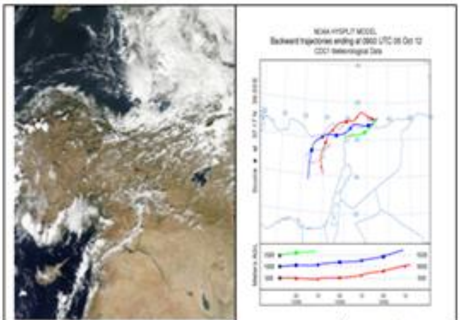
The desert dust in summer was found to reach to 50^{th} parallel north considering the dust surface concentration observed for a period of 47 years. It was reported that the highest amount of desert dust are transported to Turkey during the months of autumn followed by spring [33].

The dust was transported until the early days of October; however, transportation did not occur in the following period because of the cooling air (Figure 2 c). Transport of desert dust in the global system does not occur in all months of the year. It occurs in particular periods. It was reported in the study carried out by [34] that approximately 15-30 dust transport events occur every year in April and October [35]. The number of dust transport events is a lot more in this study. This can be attributed to the fact that Sanlıurfa has a number of fronts of airflow and transport of desert dust has too much of an influence on Sanlıurfa because it borders Syria.It is possible to see transport of dust lasting for 3 days on the dates of October 4-6, 2012. This transport mostly originated from Syrian, Arabian Peninsula and Iranian deserts as a result of air movements in autumn (Figs. 5 a,b and c).



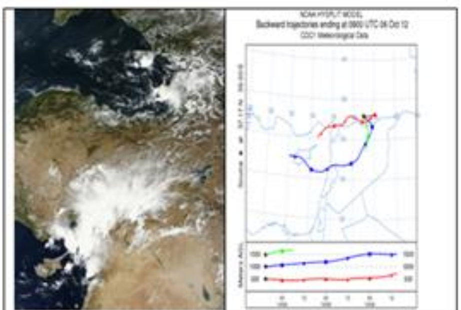
Date	PM2,5 (µg/m³)	PM10 (µg/m³)	Air Temperature (°C)
4.10.2012	251,63	204,35	26,3

(a)



Date	PM2,5 (µg/m³)	PM10 (µg/m³)	Air Temperature (°C)
5.10.2012	1056,12	2238,34	24,7

(b)



Date	PM2,5 (µg/m³)	PM10 (µg/m³)	Air Temperature (°C)
6.10.2012	652,23	7470,21	21,1

Figure 5. (a) Data related to dust transport via HYSPLIT and MODIS images on 04/10/2012, (b) 05/10/2012, (c) 06/10/2012

3.4. PM_{10} and $PM_{2.5}$ in Winter

Air streams coming over polar air mass (cPk) from north in winter cause high pressure conditions by moving towards the south and then accumulating in interior parts of Turkey. The air streams move from areas of high pressure formed in interior parts towards the coastline areas of low pressure and then the air streams formed meet tropical air mass over Mediterranean leading to the formation of Mediterranean front system.

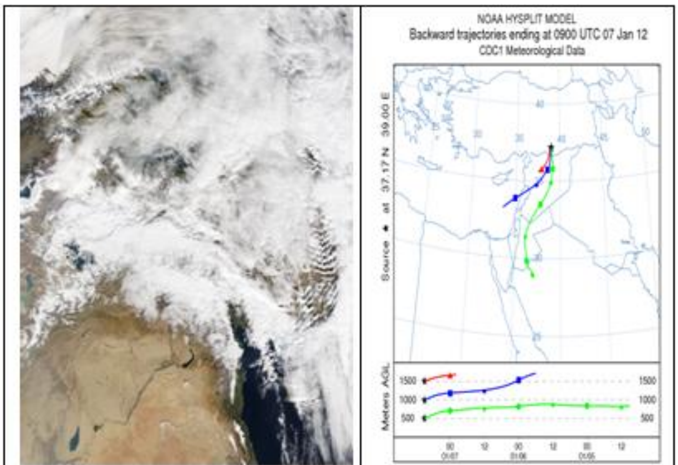
Transport of dust from south (Sahara, Arabia and Iran) decreases as a result of Turkey's possessing high pressure conditions in this season and weakening cyclonic air movements (dynamic depressions).

Figure 2 d shows that the amount of dust exceeds the standards of EU in winter; however, it does not exceed much in other months. Dust transport falls to ground as rain in winter owing to the clouds and high level of relative humidity and also because the effect of synoptic pressure enabling the transport is little.

It is not possible to reduce PM_{10} and $PM_{2.5}$ values to low levels and to ensure EU standards since transport of particulate matters results from a natural event. It was clearly identified that any kind of anthropogenic effect does not contribute to this value.

As in the satellite images taken on the dates of 7 January 2012, the direction of the dust was found to be from Sahara and Syrian deserts Figures 6. Dust originating from Sahara with a high temperature mobilized the dust in Syrian deserts. In this case, aerosols may have an effect on the concentration of water droplets and their size distributions [36, 37]. The rain formed particularly in winter following the transport can be attributed to this situation.

It can be seen in Figure 6 hat images are mostly covered with clouds. It can also be observed when viewed carefully that the areas covered with dust are greasier. When HYSPLIT model next to the satellite image viewed, directions of the dust with different sizes stand out. This was taken into consideration in all stages of the study.



Date	PM2,5 (µg/m³)	PM10 (µg/m³)	Air Temperature (°C)
7.1.2012	635,02	1961,34	5

Figure 6. Data related to dust transport via HYSPLIT and MODIS images on 07/01/2012

It can be clearly seen in our study that transport of dust occurs in transition seasons of spring and autumn due to low pressure over deserts in Syria, Iraq and Arabian Peninsula, Sahara Desert in particular.

4. CONCLUSION

It is estimated that cross-continental dust transportation incidences have increased because of the changes in meteorological conditions occurring in parallel with the effects of global warming, destruction of nature, and the increase in the amount of gas released into the atmosphere in recent years. Approximately one fifth of the earth is comprised of deserts. Micron-size dust particles, interfused into the atmosphere through winds created by differences in pressure in deserts, can be carried to very far distances through atmospheric transportation. Million ton dusts are carried every year primarily from the Saharan desert and from Syria and Arabian Peninsula which are close to our country. It is clear that the transportation of dust is a natural phenomenon as it was observed especially in Spring and Autumn which are transition seasons. It was determined by HYSPLIT model that long distance dusts come from primarily the Saharan desert, Syrian Desert and the deserts in the Arabian Peninsula. Transportation from the source was determined by MODIS images; whereby, their effect on the city was confirmed by local cameras. It was observed that, according to the meteorological data, the dust affecting the city creates a core with the matter of air while hanging in the atmosphere and falls on earth through rain. It was determined that dust from the Saharan desert and Arabian Peninsula is generally red and falls on earth like mud; whereas, dust originating from Syria has a brighter color like grayish. Amount of dust was measured daily by collecting PM_{10} and $PM_{2.5}$ with device for summer, spring, autumn, and winter and it was determined that amount of dust increases in spring and autumn that are transition seasons. According to seasonal data, amount of dust was measured approximately as PM_{10} 420 µg m^{-3}, $PM_{2.5}$ 170 µg m^{-3} in summer, as PM_{10} of 550.00 µg m^{-3}, $PM_{2.5}$ of 213.00 µg m^{-3}in spring; as PM_{10} of 620 µg m^{-3}, $PM_{2.5}$ of 240 µg m^{-3} min autumn, and as PM_{10} 315 µg m^{-3}, $PM_{2.5}$ 160 µg m^{-3} min winter which are all above the minimum standard levels (50 µg m^{-3}) accepted by WHO.

This study has obviously showed that the reason why air quality in Sanlıurfa exceeds the values specified by Air Quality Protection Regulation and WHO is not because of anthropogenic reasons but results from a totally natural transportation. Although a human intervention is not discussed here, humans are responsible for so many cross-continental negative effects leading to global warming. Therefore, frequency and concentration of long distance transport of dust is a natural process and necessary precautions should be planned.

Acknowledgement

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