# Monitoring the contribution of desert dust intrusion to $PM_{10}$ concentration in Northern Cyprus

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## Abstract

Air quality in the Mediterranean basin has been affected by $PM_{10}$ pollution induced by transported desert dust and local emission. The study used $PM_{10}$ data from Nicosia, Kyrenia, Guzelyurt and Famagusta urban representatives, Kalecik rural background and Alevkayasi regional background. HYSPLIT model and satellite data were used to identify dust days and dust input was quantified using the method suggested by the European Commission. Anthropogenic background contribution of each site was then estimated by subtracting the regional background concentrations. A total of 35 dust days occurred on Cyprus island within the 3-years period; mostly during winter and spring. Daily $PM_{10}$ concentration on dust days can reach up to 400 μg/m$^3$. After removing dust background, annual $PM_{10}$ concentrations were 48-58 μg/m$^3$ in Nicosia, 42-47 μg/m$^3$ in Famagusta, 40-50 μg/m$^3$ in Kyrenia, 33-41 μg/m$^3$ in Guzelyurt, 21-28 μg/m$^3$ in Alevkayasi, and 32-38 μg/m$^3$ in Kalecik. $PM_{10}$ concentrations were higher during winters in the urban sites. Despite the high frequency of dust events, only a fraction of exceedances of the standard limit in the urban sites were attributable to dust. Anthropogenic background sources contributions were 12.3 μg/m$^3$ in Guzelyurt, 18 μg/m$^3$ in Kyrenia, 18.4 μg/m$^3$ in Famagusta, 27.8 μg/m$^3$ in Nicosia and 9.7 μg/m$^3$ in Kalecik. Effects of other natural sources that the study did not assess, such as sea salt and local soil resuspension, could be the reason for exceedances.

## Keywords

$PM_{10}$, Dust, HYSPLIT, Aerosol Optical Depth, Northern Cyprus

## Introduction

Particulate Matter (PM), also known as aerosols, are complex mixture of tiny particles and liquid droplets that are composed of number of substances which include organic chemicals, acids, metals and dust and soil particles. The United States Environment Protection Agency (USEPA) (2015) listed particulate matter as one of the most common pollutants in the atmosphere. PM in the atmosphere may originate from various natural and anthropogenic sources. Natural sources of PM include crustal dust, sea salts, pollen and volcanic ashes. Human sources include burning fossil fuels in power plants, domestic heating, combustion engines of motor vehicles, re-suspension of dust by road traffic, quarrying and agricultural activities. Dust is transported into the receptive atmosphere by lifting and advection of non-vegetative soil in the desert. Wind can lift dust at an atmospheric altitude ranging from 1500 m to as high as 8000 m above ground level into the receptive site which may persist for days to few weeks especially on cloud free days (Vautard et al. 2005).

The island of Cyprus experiences high PM concentration from anthropogenic sources such as vehicular emissions, burning of solid fuel, road side dust resuspension, local soil resuspension and emission from industrialized European countries (Kubilay et al. 2000, Querol et. al. 2009, Achilleos et al. 2014). Also due to its close proximity to the Sahara Desert and the Arabian Peninsula, $PM_{10}$ concentration over the island has been heavily impacted by desert dust storm (Achilleos et al. 2014). Epidemiological investigations have linked increased cardiovascular, respiratory diseases and mortality to the exposure of people to high $PM_{10}$ concentration during dust episodes in the region (Middleton et al. 2008, Neophytou et al. 2013). This is evident in the Turkish Republic of Northern Cyprus (TRNC) as there is an increasing number of mortality resulting from $PM_{10}$ related diseases such as asthma and cardiovascular disease (State Planning Organization Statistics and Research Department (SPOSRD), 2015).

Yearly, Saharan dust contributes 5-10 μg/m$^3$ to the annual mean $PM_{10}$ concentration over the Mediterranean, which is higher than the 0-3 μg/m$^3$ it contributes to Northern Europe (Vautard et al. 2005). Desert dust intrusion may result in extreme $PM_{10}$ concentration in the island which may persist for few days (Middleton et al. 2008, Querol et al. 2009, Achilleos et al. 2014). Even among the Mediterranean countries, Cyprus is characterised as an epitome area where Saharan dust episodes cause high $PM_{10}$ concentration. Average $PM_{10}$ concentrations on dust days, as measured in Southern Cyprus regional background, could reach up to of 1000 μg/m$^3$ (European Environment Agency

(EEA), 2012). Previous studies investigating $PM_{10}$ concentration over the island and the contribution of local and foreign sources found that concentration of $PM_{10}$ in the regional, rural and urban background exceed that of most Mediterranean sites of equal background characterization (Querol et al. 2009, Achilleos et al. 2014).

Research on air quality across Europe often do not consider investigating remote locations such as Cyprus (Karagoulian et al, 2015, Priemus and Postma, 2009). The few previous investigations done in the region; were mainly carried out to cover the southern part of the island (Querol et al. 2009, Mazouridez et al. 2015, Achilleos et al. 2014, Neophytou et al. 2013, Middleton et al, 2008). Mouzourides et al. (2015) investigated the role of trans-boundary sources of $PM_{10}$ in South Cyprus as a representative of South Eastern Mediterranean using Dust Regional Atmospheric Model from Barcelona Super Computing Centre (BSC/DREAM) and meteorological parameters. Their findings revealed that $PM_{10}$ concentration, in 19% of the days that they examined, exceeded the critical value of 50 μg/m$^3$ and were highly related to westerly dust from Sahara desert. The simulations they used identified sources, mode of dispersion and intrusion of the dust into the island. Despite that, the study made no attempt to quantify the amount of the dust or the contribution of dust to the concentration of particulates. Achilleos et al. (2014) used a combination of satellite imageries, Aerosol Optical Depth (AOD) and Hybrid Single Particle Integrated Trajectory (HYSPLIT) to identify dust days, and regression analysis to estimate the contribution of dust in an urban site and a regional background in South Cyprus. Their computations revealed that the overall concentrations and exceedances were higher than most European sites.

However, all these investigations were restricted to the southern part of the island. Conclusions derived from these studies could not necessarily reflect $PM_{10}$ situation in the northern part of the region as meteorological conditions, building characteristic, land use pattern; economic activity and other anthropogenic factors vary between the north and south. These variations influence air flow and hence a spatial variation in $PM_{10}$ concentrations (Pandis et al. 2005, Neophytou et al. 2013). Clear differences in climatic condition can be observed between cities in the region as distances and elevation from sea, which are significant factors that reflect differences in relative humidity and temperature, are not uniform over the island. Similar investigations are therefore required for the TRNC.

A preliminary assessment of the ambient air quality in the TRNC conducted in 2002-2003, under the Air Quality Framework Directive, revealed that the level of $PM_{10}$ concentration exceeded the EU air quality objective and are affected significantly by urban sources, traffic and desert dust (Environmental Protection Department (EPD), 2015). Presently Air Quality in the TRNC is measured and maintained using strictly data from ground based monitoring stations, making it nearly impossible to estimate the contributions of the various sources.

Globally, measurements and models have been the main methods used (often in combination) for assessing air quality and determining sources of pollution (Priemus and Postma, 2009). However, due to mechanical failures experienced in ground based monitoring stations, at EU level; air quality standards should be assessed more in combination with models and satellite observations (Priemus and Postma, 2009, European Commission (EC), 2011). Atmospheric model calculations are mathematical computer simulations of the sources and dispersion of substances in the atmosphere.

HYSPLIT (Draxler and Rolph, 2015) is considered to be one of the most reliable atmospheric models at this stage. The model is a complete system for simulating simple air parcel trajectories to complex dispersion and deposition. It computes the advection and pathways of pollutant particle hence its effectiveness in tracking dusty wind sources. Several investigators have used HYSPLIT to accurately identify desert dust intrusions and track their source area, for example Ashrafi et al. (2014) simulated dust event over Iran using HYSPLIT, Escudero et al. (2011) apportioned dust outbreak in the Mediterranean via HYSPLIT application and Escudero et al. (2006) determined the contribution of Saharan dust source to $PM_{10}$ concentration in the central Iberian Peninsula using HYSPLIT.

To identify and estimate dust contribution, satellite measurements and observations such as AOD and Angstrom Exponent Value (α) from Moderate Resolution Imaging and Spectra Radiometer (MODIS) are used alongside HYSPLIT. AOD is a quantitative measurement of the extinction of solar beam by haze or dust between the observation point and the top of the atmosphere. It is a dimensionless number that defines the quantity of particulates in the vertical column of the atmosphere over a particular location during observation. AOD is the easiest, most precise and unique parameter used with ground based measurement to determine PM load (Holben et al. 2001). Angstrom Exponent Value on the other hand is a qualitative indicator of the sizes of aerosols. The value has been used to characterize aerosols from biomass burning in South America and Africa (Eck et al. 2001, Reid et al. 1999), urban emission (Eck et al. 2001, Kaskaoutis and Kambezidis, 2006), desert-dust aerosol in Africa and Asia (Masmoudi et al. 2003). Ground based measurement, AOD and α are used in combination to study desert dust contribution (Achilleos et al. 2014, Mazouridez et al. 2015, Barnaba and Gobbi, 2004).

To address the air quality monitoring problems related with $PM_{10}$ concentration in TRNC, as mentioned earlier, this study used a combination of HYSPLIT model, satellite imagery, MODIS products (AOD and α), ground based measurements and an EC proposed method based on Escudero et al. (2007) to monitor the level of concentration of $PM_{10}$ in the ambient air and measure the contribution of dust and background emission to the $PM_{10}$ concentration in the country. Based on the available literature, nearly no attempt has been made to assess the contemporary $PM_{10}$ situation and quantify the contribution of natural and anthropogenic sources in the country.

The study aims at ascertaining the level of $PM_{10}$ pollution in the ambient air for the period of 2012-2014 and the contribution of desert dust to this pollution. The following objectives were set for the study:

- Identifying dust storm days and quantifying the amount of dust deposited in the ambient air over the study area.
- Evaluating the $PM_{10}$ concentration attributable to land use characteristic.
- Assess the level of compliance to EU $PM_{10}$ concentration limit and to determine whether cases of exceedances were caused by desert dust intrusion.

The significance of this study is mainly to provide complementary data to the existing ground based measurements for a comprehensive air quality management. The study will also provide a framework for checking whether the EU $PM_{10}$ concentration limit in the ambient air has been exceeded. Exceedances of $PM_{10}$ concentration limit can only be determined after the removal of the amount contributed by natural sources. The result of such estimation is important for formulating policies and designing strategies on the amount and place where emission needs to be cut off.

Quantifying $PM_{10}$ contribution by natural sources provides information required in estimating population exposure to $PM_{10}$ pollution necessary for health impact assessment. It worthy of notice that this study did not consider estimating the contribution of other natural sources of $PM_{10}$ such as sea salt, pollen and volcanoes. Therefore, the effect of desert dust investigated here should not be generalised as the effect of all natural sources.

# Methodology

## Description of the Study Area

TRNC is the northern part of the island of Cyprus which is located in the Eastern Mediterranean. The island covers an area of 9,251 km² and is located off the south coast of Turkey, west coast of Syria, west of Lebanon, northwest of Israel, north of Egypt and east of Greece. Figure 1 is a satellite image showing the location of the island in the Mediterranean.


*__Figure 1:__ Relative Location of Cyprus in the Mediterranean (Source: Google Earth 2017).*

Cyprus has a subtropical climate which is characterized as semi-arid with warm rainy winters around November to late March (average temperature of 17-18ºC during the day and 8-10ºC at night and average precipitation of 100 mm) and hot dry summers around June to late September (average temperature is around 33ºC during the days and 23ºC during the nights and average precipitation is around 4 mm). During winter, temperatures are higher over the inland than at coastal areas and vice versa in the summer. Spring season covers the period of April and May. Autumn is a short transition period to winter.

During winter westerly and south westerly surface winds prevail over the Eastern Mediterranean, while northerly and north-westerly winds prevail during summer periods. Variability in strength and direction in the wind blowing over Cyprus is influenced by the eastward moving cyclones crossing over the Mediterranean sea, sea and land breezes temperature differences, the continental anticyclone that stretch over Eurasia, the low pressure belt of North Africa, the monsoon low in summer, orographic factors and causes (Achilleos et al. 2014).

## Description of the Monitoring Stations

This study used $PM_{10}$ data obtained from the monitoring sites in TRNC which are monitored by the Air Quality Monitoring Network, Environmental Protection Department, Ministry of Environment and Culture, TRNC. A total of six monitoring stations which reflect some of the land uses in the region were selected. The positioning and characterization of these stations are within the EU framework legislation given in section C Annex III of CAFE-Directives 2008/50/EC on ambient air quality and cleaner air for Europe. Figure 2 shows the locations of the monitoring sites while Table 1 provides a summary of the characteristics of the monitoring sites.

*__Table 1:__ Sampling sites and their characteristics*

| Site | Type of site | Coordinates | Above Sea Level |
|---|---|---|---|
| Nicosia | Urban | 35.20 N 33.35 E | 108 m |
| Famagusta | Urban | 35.13 N, 33.93 E | 3 m |
| Kyrenia | Urban | 35.33 N, 33.31 E | 8 m |
| Guzelyurt | Urban | 35.20 N, 33.00 E | 51 m |
| Kalecik | Rural-Industrial | 35.34 N, 34.00 E | 10 m |
| Alevkayasi | Rural | 35.30 N, 33.53 E | 608 m |

## Method of Data Collection

24 hours $PM_{10}$ concentrations were measured in the air quality monitoring stations and the average taken. These daily average $PM_{10}$ data was collected from the EPD of TRNC. The data collected cover the three year study period (January 1st, 2012 through December 31st 2014) for all the monitoring sites. It was observed that within the period there were days with missing data coverage which were due to power failure or mechanical faults.


***Figure 2:*** *Spatial arrangements of $PM_{10}$ monitoring sites in TRNC (Google Earth 2017).*

**Desert Dust Storm Identification**

Identification of dust events influencing particulate matter concentration is a multi-task which may demand the use of various tools such as ground PM concentration data, aerosol maps, receptor and dispersion modelling and back trajectory analysis. To identify dust event days in this study, the methods described by the 2011 Commission Staff Working Paper of the Council of EU with the reference "Establishing guideline for demonstration and subtraction of exceedances attributable to natural sources" under the Directive 2008/50/EC on ambient air quality and cleaner air for Europe was referred to. Combination of other methodologies used in previous researches was also employed. The procedures will be discussed in further detail in the following sections:

**High $PM_{10}$ level identification**

The occurrence of a dust storm was assumed to wholly affect the concentration of $PM_{10}$ in the region and cause high $PM_{10}$ level. High $PM_{10}$ level was defined as days with concentration above the 95th percentile value. Presence of possible dust episode was recognized by high $PM_{10}$ levels occurring in the same day at the sampled sites, especially a sudden high increase in the regional background station.

**Identification using MODIS Products**

Mean daily measurement MODIS AOD 550 nm and α from Giovanni Satellite Based Earth Science Online Data System were used to identify the particulate type. The data system was developed and managed by the National Aeronautic and Space Administration (NASA), Goddard Earth Sciences Data and Information Service Centre. The data are acquired by the MODIS sensor on both aqua and terra satellites on a spatial resolution of 1° ×1°.

AOD value of 0.01 corresponds to an extremely crystal clear atmosphere with little amount of aerosols, and a value of 0.4 and above means a very dusty aerosol dense atmosphere. While α is a qualitative measure of the sizes of aerosols. The value is inversely related to the average size of the particles in the atmospheric aerosols; that is to say, the smaller the particle the higher α (NOOA, 2015).

Therefore, high AOD value reflects high total atmospheric concentration of particulates and a lower α indicates the particles are of coarser sizes. A combination of high AOD value of >0.3 and α <0.9 indicates the particulates are of desert dust origin. Barnaba and Gobbi (2004) recommended these indicator values for analysis of dust particles over the Mediterranean.

**Identifying Dust using HYSPLIT Model**

To verify a dust episode identified using the above method, a 5-day backward trajectories of air masses originating from the Sahara or Arabian Peninsula at three different altitudes of 750, 1500 and 2500 m above sea level were examined. HYSPLIT Model (Draxler and Rolph, 2015) which is provided by the National Oceanic and Atmospheric Administration (NOAA) Air Resource Laboratory (ARL), available at Real Time Environmental and Display System Website was used to compute the trajectories. Archive re-analysis meteorological data provided by the National Centre for Atmospheric Research (NCAR) was used as the composite data for this computation. HYSPLIT model is a computer based simulation model that is used to compute air parcel trajectories, dispersion and or deposition of atmospheric based pollutants (Draxler and Rolph, 2015). This model uses a combination of both Eulerian and Lagrangian approaches to track the source point of dust events using the u- and v- components of the wind, temperature, height and pressure at different level of the atmosphere and the resulting backward trajectory contains information about the origin and pathways of the dust transport (Banacos and Ekster, 2010). Air parcel trajectories that originate from the desert indicate possible presence of dust.

The identification of the dust event days largely depends on the availability of data for the days in focus. Dust events days include the days where the dusty wind from desert arrived the region and the subsequent days where significant amount of dust persists in the atmosphere. HYSPLIT model identified the arrival of the dust while the presence of dust in the atmosphere were basically identified using the combination of the $PM_{10}$ concentration data, AOD and α in accordance with the criteria mentioned in the methodology for determining possible dust in the atmosphere.

Lastly some days have missing AOD or α, or in some cases; both are missing. There are also days where ground based $PM_{10}$ concentration were not captured in some of the monitoring stations. Such missing data is expected to hinder the study from identifying some possible dust days and hence the calculated dust contribution may underestimate the actual contribution.

**Identifying Dust Storm using Satellite Imageries**

MODIS satellite images on air aqua and terra platform retrieved from NASA's website database were also used to support the identification.

Other methods that are recommended by the EU and applied by investigators to identify dust storm events include mineralogical analysis, and dispersion and receptor modelling. These methods were not applied in this study as the former requires PM samples and the later requires data on hourly concentrations which were not available for this investigation.

**Quantifying Desert Dust**

In order to measure the amount of $PM_{10}$ concentration attributed to desert dust storm episodes, the Escudero et al. (2007) based conservative method suggested by EC, (2011) under the Directive 2008/50/EC was employed: A moving average of $PM_{10}$ concentration of 15 days before and 15 days after the identified dust episode (excluding any dust day which may occur within the period) was calculated. The calculated value corresponds to a moving 50th percentile of 30 days. The calculated 30 days average is the supposed $PM_{10}$ concentration assuming there was no dust intrusion. The net dust amount was calculated by subtracting the 30 days average value from the high $PM_{10}$ concentration.

Escudero et al. (2007) based methods are scientifically validated (EC, 2011). The methods save time, cost and are simple to use. Unlike chemical analysis methods which may require long analysis time, expertise and laboratory costs. The methods were earlier applied by Querol et al. (2009) to the whole of the Mediterranean basin. The other Escudero et al. (2007) based method requires subtracting a monthly moving 40th percentile (excluding days with dust influence) from the bulk concentration of $PM_{10}$ of the dust day in the regional background site, the returned value is the net dust $PM_{10}$ concentration for the region; hence the net dust contribution for each site can be calculated by subtracting this net dust $PM_{10}$ concentration. However, this method was not preferred here because the other sites (especially Kalecik) were found to reproduce a better $PM_{10}$ concentration on some dust event days than the regional background site, thus making the method not applicable as the subtraction of net 40th percentile from these sites on such days would yield a negative $PM_{10}$ concentration.

**Estimating Background Sources Contribution**

After removing the contribution of dust, the impact of local natural particulate sources such as soil and sea salt were assumed to be the same at all the sites. Then daily background concentration of each site was estimated as the difference between the daily concentration in the site and the daily concentration in the regional background. The new data base created became the "$PM_{10}$ urban" or "industrial" contribution variables, depending on the dominant land-use in the site.

This method provides a good understanding of the level of emission from a background collectively where data for each emission sources is not available. Moreno et al. (2005) used this approach to assess the influence of urban sources in Spain. Achilleos et al. (2014) also used same method for similar investigation in South Cyprus.

## Data Analysis

Microsoft Office Excel package was used to compute annual and monthly mean concentrations, percentages and frequency of exceedances of mean daily concentrations and dust contributions. Results were depicted using simple bar charts and tables.

To account for the loss of $PM_{10}$ data capture during the estimation of exceedances of daily average concentration in calendar year, an adjustment was made to the available data. The adjustment assumes that the fraction of missing values that would have surpassed the EU limit is equivalent to the fraction of the available value that exceeded the limit. This approach was used on a quarterly basis, as EC (2013) suggested, and is computed as shown in equation 1:

$$Eq=\left(Vq \times \frac{Nq}{nq}\right) \qquad \text{Equation 1.}$$

Eq in equation 1 refers to the estimated number of exceedances for the calendar quarter in question (qi). Vq refers to the observed number of exceedances for same calendar quarter. Nq is the number of days in the calendar quarter whereas nq is the number of days with valid daily values for the calendar quarter. q refers to the four calendar quarters in a year, that is to say; q= 1st, 2nd, 3rd, or 4th. The total number of exceedances (Ex) for the calendar year is then estimated as the summation of the estimated number of exceedances for all the calendar quarters of the years; as given in equation 2.

$$Ex=\sum_{q=1}^{4} eq \qquad \text{Equation 2.}$$

# Result and Discussion

The study identified dust storms, its frequency of occurrence and seasonal variability in the region. The study also estimated dust and local background contribution to $PM_{10}$ concentration in the sampled sites.

## Dust Storm Occurrences and Impact on Daily Concentrations

A total of 35 dust storm days were identified for the three years period in the region. The identified dust days and their daily $PM_{10}$ average concentration are shown in Table 2 (see appendix), 4 dust days (less than 1% of the year) occurred in 2012, 8 dust days (2% days of the year) in 2012 and 24 dust days (7% days of the year) in 2013. These percentages correspond within the 1% (1993) - 9% (1998) dust days earlier estimated in the region (Achilleos et al. 2013). 75 percentile of the dust days in the urban areas fall within a mean daily concentration of ≥ 100 µg/m³, 75 percentile of the dust days in Guzelyurt have a mean daily concentration of ≥ 70 µg/m³, while in Alevkayasi and Kalecik; a 75 percentile of ≥50 µg/m³ was estimated.

On the other hand, dust storms were more frequent in 2013. Concentrations of $PM_{10}$ in the sites range from 40 µg/m³ on minor dust days to 280 µg/m³ on intense dust days. The frequency of dust storm occurrence in 2013 was also high in the Mediterranean city of Athens, Greece, however maximum daily average $PM_{10}$ concentration on dust days were 125 µg/m³, less intense than those recorded in Cyprus (AIRUSE 2015). Frequent occurrence of dust in the Mediterranean is possibly as a result of drought and anthropogenic disturbances (such as clearing of vegetation cover) on the Saharan soil.

In 2014, daily average concentration of $PM_{10}$ range from 45 to 400 µg/m³. Estimated dust contribution range from 10 (06 May, 2014) to 360 µg/m³ (03 Mar 2014).

Dust storms in the three years were found to intrude the island in each of the four seasons in a year. However, only 3 dust days were experienced in the summer throughout the study period and 75% of the dust episodes occurred during the winter months especially March and November. A 14 day long dust episode was found to occur in November 2013. Similarly to this investigation, dust storms occurrences in neighbouring Israel for that year were also found to be in winters and spring, and summers were dust free (Krasnov et al. 2014). While contrary to this, AIRUSE (2015) found that dust storm that year in Athens were more frequent and pronounced during spring and summers.

Amount of dust deposited on dust days depends to an extent on the distance from the source region. Intrusion originating from closer proximity such as Egypt, Morocco and the Arabian Peninsula are found to be more pronounced than intrusions from far sources such as Mali, Niger Republic or Mauritania. Some amount of the dust may probably have been deposited elsewhere as they travel towards the Mediterranean, as dust are often deposited along the travel path to their destination (Moreno et al. 2005). Therefore, less deposition is expected when dust originates from far distance as the loss along travel path is likely to be more.

Analysis of the computed trajectories showed that about 65% of the dust intrusions into the island were from the Saharan desert, specifically the western part of the Sahara. The remaining dust storms originated from the Arabian Peninsula. Dust intrusions in 2014 reached the island in a lower vertical height than dust storms in the previous years. Dust arriving at lower vertical height implies more deposition at the ground especially on cloud free days.

Figure 3 shows an example of computed backward trajectories arriving Cyprus. The dusty wind arrived Cyprus on 02 March, 2014 from western part of Sahara, Egypt and the Arabia. Figure 4, which is a satellite view of the dust event, shows the dust originating from Sahara desert and covering the Mediterranean, which was cloudless at the time of deposition. In examining satellite views, cloud cover were seen to be associated with cyclonic conditions on some dust days, therefore obstructing clear view to the dust. However, the dust event on 02 March, 2017 was a good example of deposition on cloud free day. Concentration of $PM_{10}$ reached 280 µg/m³ in Kalecik and a shade above 200 µg/m³ in the other sites.

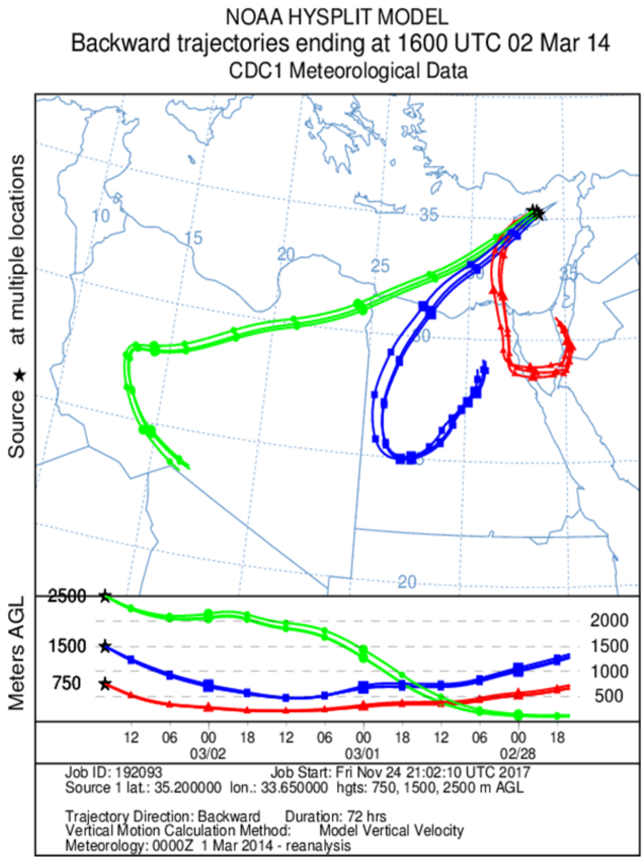


***Figure 3:*** *Backward trajectories ending in Cyprus showing the arrival of dust on 02 March 2014.*

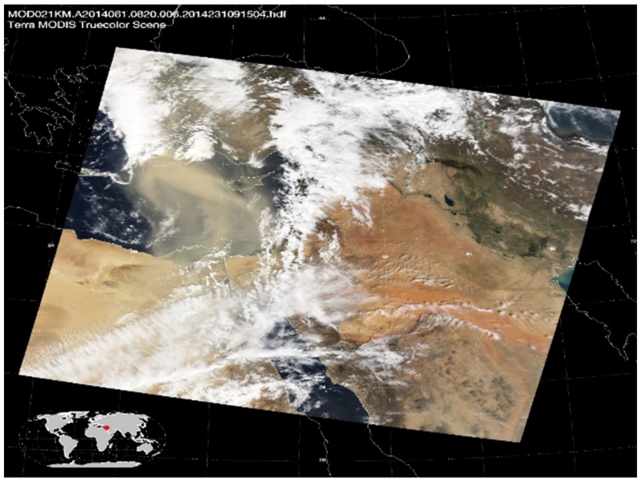


***Figure 4:*** *MODIS satellite imagery over the Mediterranean on 02 Mar 2014.*

## Contribution of Background Emission

Emission from urban background contribution was estimated for Nicosia, Kyrenia, Famagusta and Guzelyurt and industrial background contribution was estimated for Kalecik. As it can be seen in Figure 5, overall average urban background contribution for the three years period were 12.3 µg/m³ in Guzelyurt, 18 µg/m³ in Kyrenia, 18.4 µg/m³ in Famagusta and 27.8 µg/m³ in Nicosia. Industrial background contributed 9.7 µg/m³ to the overall average concentration of $PM_{10}$ in Kalecik. Kalecik is predominantly affected by emission from thermal station which after burning fossil fuel may give out high amount of coal fly-ash to the atmosphere.

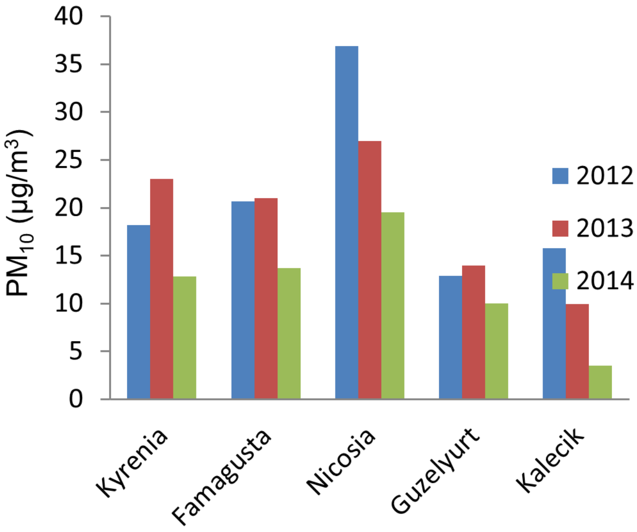


***Figure 5:*** *Annual average contribution of background sources.*

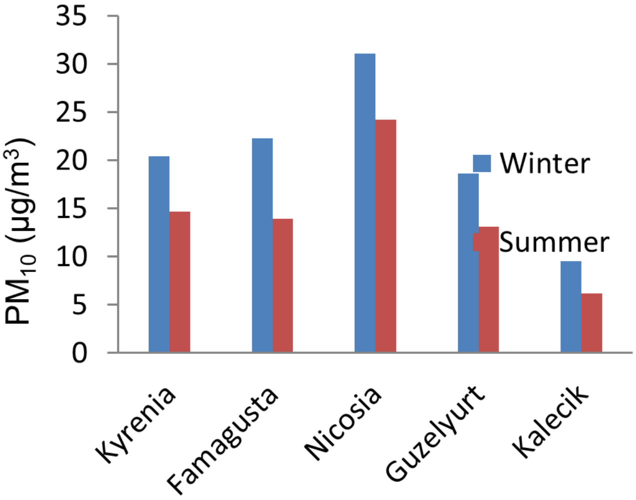


***Figure 6:*** *Overall seasonal average contribution of local background emission.*

Effect of urban background to $PM_{10}$ is spatially associated with traffic and population density. Nicosia among the urban sites, has the densest population and traffic hence the highest concentration while Guzelyurt has the lowest population and traffic density among the urban sites and hence the lowest concentration. Background sources of emission in the urban sites are majorly road dust resuspension and traffic emission, domestic heating and burning of solid fossil fuel, building construction and industries (especially in Nicosia). Shipping could contribute to the bulk of emission in Kyrenia and Famagusta. Current regulation regarding emission is not in compliance with the EU Directives. Field burning is still practiced in the country and these could be a major contributor of $PM_{10}$ load in the affected sites (EPD 2015).

Figure 6 shows the average contribution of background emissions in relation to seasons. Overall background contribution to $PM_{10}$ concentration is more during the colder months than the warmer season, except in Teknecik where the background contribution is seen to be more in the summer. Usually urban sites experience winter sanding of roads.

## Daily Average Concentration and Exceedance of the Limit Standard

The EU directive sets a daily average threshold value of 50 µg/m³. This value is not permissible to be exceeded in 35 days (9.6% days) in a year. As summarized in Table 3, Nicosia, Kyrenia and Famagusta urban sites exceeded the daily average concentration of 50 µg/m³ in more than 35 days in all the years (with and without dust effect). Exceedances of daily average limit solely as a result of dust events range from 4.4 to 10% in Kyrenia, 4.2 to 13.8% in Kyrenia and 0 to 6.3% in Nicosia.

Guzelyurt was within the 35 days limit in 2012. However, the limit was exceeded in the two subsequent years. The limit was exceeded in 2013 in Kalecik. Both exceedances of the 35 days limit in Guzelyurt and Kalecik were not as a result of dust effect. In the regional background, daily average concentrations were below the 35 Days limit.

***Table 3:*** *Percentage days with daily mean concentration above the EU 50 µg/m³ threshold value (A= with dust and B= without dust)*

| Site | Year | | |
|---|---|---|---|
| | **2012** | **2013** | **2014** |
| Kyrenia | A=18.6<br>B=17.7 | A=37.5<br>B=34.2 | A=16.4<br>B=14.7 |
| Famagusta | A=20.4<br>B=18.6 | A=32.2<br>B=26 | A=18<br>B=15.3 |
| Alevkayasi | A=1.6<br>B=0.5 | A=6.8<br>B=2.2 | A=7.3<br>B=5.7 |
| Guzelyurt | A=22.7<br>B=7.4 | A=16.9<br>B=13.6 | A=11.7<br>B=11.2 |
| Kalecik | A=51.1<br>B=22.2 | A=16.7<br>B=10.1 | A=8.5<br>B=1.9 |
| Nicosia | A=51.1<br>B=51.1 | A=45<br>B=43 | A=35.1<br>B=43 |

## Overall and Annual $PM_{10}$ Concentrations

The overall average $PM_{10}$ concentration was calculated as 54.7 µg/m³ with a Standard Error (±) of 0.9 µg/m³ for Nicosia and when the dust effect was removed the overall concentration decreased to 46.2 µg/m³. The overall average concentration for Kyrenia and Famagusta was 43.2 µg/m³ ±0.6 µg/m³ and 43.6 µg/m³ ±0.6 µg/m³ respectively and when the dust effect was removed the concentration reduced to 41.4 µg/m³ in Kyrenia and 41.8 µg/m³ respectively. Guzelyurt has an overall average of 37.5 µg/m³ ±0.58 µg/m³ with dust effect and 35.6 µg/m³ without the effect of dust. Kalecik has an overall concentration of 35.3 µg/m³ ±0.6 and 32 µg/m³ when the effect of dust intrusion

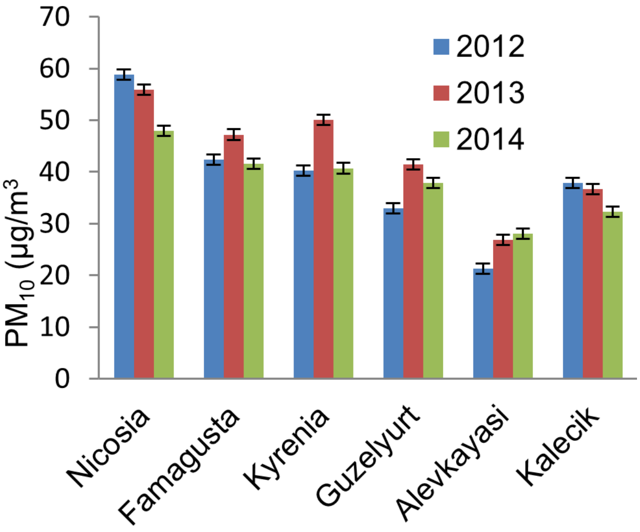


***Figure 7:*** *Annual average concentration of $PM_{10}$ with dust effect inclusive.*

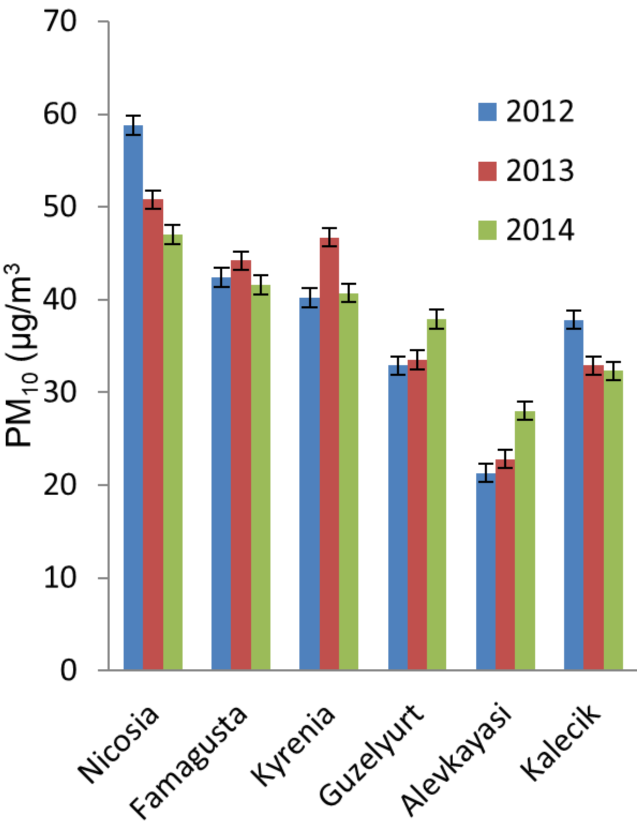


***Figure 8:*** *Annual average concentration of $PM_{10}$ (without dust effect).*

was removed. Alevkayasi regional background has an overall average of 25.4 μg/m³ ±0.6 μg/m³ and an overall average of 23.1 μg/m³ when dust effect was removed.

The annual average $PM_{10}$ concentrations are shown in Figure 7 and 8. Annual average concentrations of $PM_{10}$ (with dust and without dust effect) in Nicosia were above the EU 2006 limit of 40 μg/m³ for all the years. Annual average concentration ranged from 48 μg/m³ (2014) to 59 μg/m³ (2012) and it was found to exhibit a reducing trend after every year. After removing the effect of dust; concentrations only reduced by 1-5%.

$PM_{10}$ Concentrations with dust effect were above the EU limit in all the years for Famagusta. Annual average concentrations were 42-47 μg/m³ with dust effect (Figure 7); however the limit was attained in 2014 after removing the effect of desert dust. Annual average concentration in Kyrenia were exceeded in 2013 and 2014, after removing dust effect the limit was achieved in 2014 (Figure 8). Annual average limit was exceeded in Guzelyurt in 2014 which after removing the effect of dust reduced to an acceptable value of 37 μg/m³.

Concentrations in the rural site and the rural industrial site were all within the EU annual mean limit. Concentrations were in the range 32-37.8 μg/m³ and 26-29 μg/m³ in Kalecik and Teknecik respectively. After removing dust effect, concentration reduced to 30-36 μg/m³ in Kalecik.

Annual average concentration in Alevkayasi ranges from 21-28 μg/m³ with dust effect. After removing effect of dust intrusion, it attained the EU 2010 target value of 20 μg/m³ in 2012. Annual concentrations exhibit an increasing trend Alevkayasi. Cristina et al. (2014) observed similar trend over the years in background sites among the EU sites.

Annual average $PM_{10}$ concentrations (without dust) in Guzelyurt can be compared with 31 μg/m³ in central Mediterranean city of Lampedusa, Italy (Marconi, et al. 2014), 24-30 μg/m³ in Athens suburban site, 26-27 μg/m³ in Milan and Porto urban sites (AIRUSE, 2015). Annual average concentrations in Famagusta and Kyrenia can be compared with 37-43 μg/m³ in Athens urban sites (AIRUSE, 2015), 29-42 μg/m³ in Berlin urban background (Langener, et al. 2011) and 37-43 μg/m³ in Madrid Spain (Salvador et. al, 2015). Annual Average concentration in Nicosia can be compared with those estimated in other Eastern Mediterranean urban sites such as 56 μg/m³ in Nicosia, South Cyprus, (Achilleos et al. 2014), 43-77 μg/m³ in Beer-Sheva, Israel, (Krasnov et al. 2014), 51 μg/m³ in Heraklion, Greece, 57 μg/m³ in Tel-Aviv, Israel, 47 μg/m³ in Istanbul, Turkey (Gerasoupoulos et al. 2006, Karaca et al. 2005). Annual average concentration in Alevkayasi corresponds with other rural sites in the EU such as Berlin rural background 19-25 μg/m³ (Langener et al. 2013), 20-25 μg/m³ in Campisabolos, Spain (Salvador et al. 2015).

Overall average in the regional background and Kalecik were lower than the estimated 32.1 μg/m³ in Agia Marina regional background, southern part of Cyprus (Achilleos et al. 2014), Annual dust contribution in TRNC can be compared with the 5 μg/m³ in Italy (Salvador et al. 2013). Vautard et al. (2005) also reported 5-10 μg/m³ as the annual average in the Mediterranean.

## Conclusion and Recommendation

In this study, inter annual and annual $PM_{10}$ concentrations were analysed in Nicosia urban site, Famagusta urban site, Kyrenia urban site, Kalecik rural industrial background site and Alevkayasi rural background site. Dust episode and their contributions to daily, annual and seasonal $PM_{10}$ concentrations were also estimated as well as the contribution of collective anthropogenic background.

A total of 35 dust days occurred in the island within the 3 years period. Dust intrusion contributed more to $PM_{10}$ concentration during winter and spring, daily concentration could reach as high as 400 µg/m³. Contribution of desert dust to $PM_{10}$ concentration in the study area was averagely; 102 µg/m³ and can range from 22 to 183 µg/m³. Average contribution of dust to the annual average concentration were 8.5 µg/m³ in Nicosia, 2.2 µg/m³ in Kyrenia, 1.8 µg/m³ in Famagusta, 2 µg/m³ in Guzelyurt, 3.3 µg/m³ in Kalecik and 2.3 µg/m³ in Alevkayasi. Overall average urban contribution to $PM_{10}$ concentration was 12.3 µg/m³ in Guzelyurt, 18 µg/m³ in Kyrenia, 18.4 µg/m³ in Famagusta and 27.8 µg/m³ in Nicosia. Average industrial background contribution was 9.7 µg/m³.

The study found that despite the high occurrence of dust events, desert dust was only responsible for exceedance of the 2006 EU mean annual $PM_{10}$ concentration of 40 µg/m³ in Famagusta and Kyrenia in 2014, and Guzelyurt in 2013. However, no exceedance of the 35 days permissible daily average limit of 50 µg/m³ was attributed to dust storms in any of the site analysed/

It's worth reminding that the study only investigated one natural source of $PM_{10}$ (dust storms). Impact of other natural sources such as pollen, sea salt and local soil resuspension were not assessed in this investigation. There is the likelihood that if impact of other natural sources were subtracted, exceedances may not be recorded in the sites. Therefore an investigation is required to ascertain the influences of other natural source of $PM_{10}$. A source apportionment that will include chemical or mineralogical analysis is also needed to evaluate the impact of each anthropogenic source (such as shipping, traffic, domestic burning of fuel, agriculture etc.) to the backgrounds.

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# Appendix

| 2012 | | | | | | |
|---|---|---|---|---|---|---|
| Date D/M | Nicosia (μg/m³) | Famagusta (μg/m) | Kyrenia (μg/m³) | Guzelyurt (μg/m³) | Alevkayasi (μg/m³) | Kalecik (μg/m³) |
| 12/03 | 222.7 | 66.0 | 86.0 | 77.9 | 60.0 | |
| 13/03 | 167.1 | 81.5 | 107.6 | 103.2 | 62.4 | |
| 21/10 | 176.0 | 198.3 | 162.7 | | | 279.0 |
| 22/10 | 176.7 | 198.3 | 162.7 | | | 279.0 |
| 2013 | | | | | | |
| Date D/M | Nicosia (μg/m³) | Famagusta (μg/m) | Kyrenia (μg/m³) | Guzelyurt (μg/m³) | Alevkayasi (μg/m³) | Kalecik (μg/m³) |
| 18/01 | 222.3 | | 87.6 | 44.1 | 126.2 | 154.7 |
| 19/01 | 80.0 | | | 126.2 | 62.3 | 75.0 |
| 23/02 | 132.1 | 95.2 | | 106.8 | 89.8 | 116.5 |
| 24/02 | 77.7 | 78.8 | | 107.2 | 44.4 | 89.5 |
| 11/03 | 138.4 | 90.1 | | 138.4 | 101.1 | 119.9 |
| 12/03 | 108.8 | 60.8 | | 130.2 | 236 | 76.4 |
| 13/03 | 276.8 | 216.6 | | 286.4 | 118.6 | 229.5 |
| 1/04 | 275.8 | 126.7 | 267.2 | 153.8 | 272.6 | 149.4 |
| 2/02 | 112.2 | 88.7 | 125.9 | 239.6 | 94.6 | 87.6 |
| 9/04 | 228.8 | 129.5 | 133.8 | 119.5 | 110.0 | 101.5 |
| 31/05 | 141.3 | 88.7 | 132.8 | 110.9 | 77.0 | 99.3 |
| 31/10 | 128.3 | 64.4 | 78.8 | 72.6 | 53.2 | 58.5 |
| 01/11 | 136.2 | 89.9 | 75.8 | 86.9 | 53.7 | 63.0 |
| 02/11 | 114.3 | 69.0 | 74.5 | 75.1 | 57.0 | 74.1 |
| 03/11 | 70.1 | 83.1 | 61.0 | 64.8 | 56.5 | 79.9 |
| 04/11 | 104.3 | 73.9 | 76.3 | 54.6 | 51.0 | 60.5 |
| 05/11 | 102.7 | 84.9 | | 57.6 | 38.4 | 52.9 |
| 06/11 | 82.7 | 77.2 | 109.3 | 62.3 | 52.1 | 71.2 |
| 07/11 | 77.3 | 102.3 | 91.1 | 71.1 | 48.0 | 84.1 |
| 08/11 | 91.7 | 78.8 | 105 | 62.2 | 60.6 | 84.8 |
| 09/11 | 99.9 | 79.3 | 61.9 | 80.2 | 30.6 | 51.2 |
| 10/11 | 57.6 | 84.2 | 47.4 | 53.3 | 32.9 | 51.7 |
| 05/11 | 102.7 | 84.9 | | 57.6 | 38.4 | 52.9 |
| 06/11 | 82.7 | 77.2 | 109.3 | 62.3 | 52.1 | 71.2 |
| 07/11 | 77.3 | 102.3 | 91.1 | 71.1 | 48.0 | 84.1 |
| 08/11 | 91.7 | 78.8 | 105 | 62.2 | 60.6 | 84.8 |
| 09/11 | 99.9 | 79.3 | 61.9 | 80.2 | 30.6 | 51.2 |
| 10/11 | 57.6 | 84.2 | 47.4 | 53.3 | 32.9 | 51.7 |
| 11/11 | 102.3 | 62.5 | 84.1 | 55.9 | 47.5 | 56.7 |
| 12/11 | 116.7 | 58.3 | 87.6 | 77.4 | 44.1 | 63.6 |
| 2014 | | | | | | |
| Date D/M | Nicosia (μg/m³) | Famagusta (μg/m) | Kyrenia (μg/m³) | Guzelyurt (μg/m³) | Alevkayasi (μg/m³) | Kalecik (μg/m³) |
| 24/02 | 65.4 | 60.2 | 79.6 | 66.1 | 54.9 | 115.1 |
| 2/03 | 228.2 | 228.8 | 77.2 | 76.7 | 103.6 | 293.4 |
| 3/03 | 203 | 203.8 | 402.1 | 153.9 | 196.3 | 402.1 |
| 5/03 | | 116.0 | 119.1 | 98.3 | 79.1 | |
| 6/06 | | 97.3 | 108.5 | 95.0 | 89.3 | |
| 28/06 | 86.5 | 64.8 | 71.6 | 74.3 | 65.8 | 67.7 |