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WHAT IS THE IMPACT OF MINERAL DUST ON AIR QUALITY IN SOUTHERN TUNISIA? ANALYSIS OF 2 YEARS OF PM_{10} CONCENTRATION AND METEOROLOGY MONITORING

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Abstract. Southern Tunisia is a region very prone to wind erosion because of its soil features, and the development of mechanized agriculture. Moreover, this region is located downwind the Sahara, which is the main source of mineral dust in the world. For these reasons, dust haze is frequently observed in this region. If some authors have already documented air quality in the northern part of Tunisia, no equivalent studies have ever been conducted for southern regions even though Dahech & Beltrando (2012) highlighted the potential negative impact of mineral dust on air quality in Sfax. This is why a ground-based station dedicated to the monitoring of mineral dust was installed at the Institut des Régions Arides (IRA) of Médenine to document the temporal variability of mineral dust concentrations in southern Tunisia. We present here the results from the two first years of measurements of meteorology, PM_{10} concentration, and direct solar radiation.

Keywords: mineral dust, PM_{10}, southern Tunisia, air quality.

1. Introduction

The south of Tunisia is a region very prone to wind erosion, the mechanism that produces mineral dust: soils are sandy, the precipitation scarce, and the vegetation sparse. Moreover, the development of mechanized agriculture has increased this phenomenon during the last decades (e.g. Akrimi et *al.*, 1993). Finally, this region is located downwind the Sahara desert, which is the main source of mineral dust in the world. For all these reasons, dust haze is frequently observed in southern Tunisia.

If some authors have already documented air quality in the northern part of Tunisia (e.g. Bouchlaghem et *al.*, 2009), no equivalent studies have ever been conducted for the south of the country even though Dahech & Beltrando (2012) highlighted the potential negative impact of mineral dust on air quality in Sfax. This is why, in February 2014, a ground-based station dedicated to the monitoring of PM_{10} (Particulate Matter lower than 10 µm) concentration was installed at the Institut des Régions Arides (IRA) of Médenine (Tunisia) in collaboration with the Laboratoire Interuniversitaire des Systèmes Atmosphériques (LISA) and the Institut de Recherche pour le Développement (IRD) to document the temporal variability of mineral dust concentrations in southern Tunisia.

In the present study, after a brief presentation of the station, the results from the two first years of measurements of PM_{10} concentration are discussed according to Tunisian air quality standards. Using the concomitant measurements from a meteorological station and a sunphotometer made at the station as well as backward trajectory analysis, the nature and origin of the highest PM_{10} concentrations monitored at the station are also discussed.

2. Presentation of the station

2.1. Location

The station is located in the arid part of Tunisia, in the north east of the Jeffara plain, where a mean annual rainfall between 135 and 215 mm yr^{-1} was recorded during the 1949-2001 period in 8 meteorological stations (Kallel, 2001). It is installed in the campus of the IRA Médenine in El Fjé (33.49963N; 10.64255E) as identified by the red dot in the satellite image in Figure 1. This institute is located in an agricultural area, mainly dominated by olive tree plantations, at more than 20 km north east of the main town of the area, Medenine (about 70,000 inhabitants). It is 5 km west of the Boughrara Gulf, a very shallow sea water area, about 20 km south of the Gabes gulf, and about 50 km east of the Matmata Mounts.

Figure 1. Location of the station (red dot), and of the main geomorphological features of southern Tunisia.

2.2. Measurements

All the instruments are installed at 2 m height from the flat roof of the higher building of the campus, i.e. about 14.5 m above the ground level. The dust monitoring station of El Fjé is conceived according to the model of the stations of the Sahelian Dust Transect (Marticorena et *al.*, 2010), now part of the International Network to study Deposition and Atmospheric chemistry in AFrica (INDAAF). The same kind of instruments were chosen for their capability to resist to severe dusty and meteorological conditions.

2.2.1. Meteorology

Basic meteorological measurements are performed to monitor wind speed and direction, air temperature, air relative humidity, atmospheric pressure, and rainfall. All instrumentation used is from the Campbell Scientific company. Wind speed and direction are measured using a Gill 2D type Windsonic anemometer, air temperature and relative humidity using a HMP60 probe, atmospheric pressure using a SETRA CS100 barometer, and rainfall using an ARG100 Tipping Bucket Rain gauge. Data acquisition uses a CR200 data logger. Measurement frequency is 10 s, but nominal data acquisition time is 5 min. Concerning wind speed, maximum and mean values measured during the 5 min time period are stored.

2.2.2. PM_{10} concentration

Atmospheric concentrations of PM_{10} are measured using a Tapered Element Oscillating Microbalance (TEOM™ 1405 from Thermo Scientific) equipped with a PM_{10} inlet (Thermo Scientific). The microbalance is installed in an air-conditioned room about 5 m vertically below the inlet. A

complete description of the TEOM™ measurements and associated limitations can be found in Marticorena et *al.* (2010).

2.2.3. Aerosol Optical Depth

Aerosol Optical Depth (AOD) and the corresponding Angström exponent are derived from the measurements of a Cimel sunphotometer from the AERONET (AErosol RObotic NETwork)/PHOTONS (PHOtométrie pour le Traitement Opérationnel de Normalisation Satellitaire) network (Holben et *al.*, 1998; http://aeronet.gsfc.nasa.gov/) at 4 wavelengths (1020 nm, 870 nm, 675 nm, and 440 nm).

2.2.4. Data selection

The annual recovery rate is nearly 100% for all the instruments composing the meteorological station. For PM_{10} concentrations, it ranges between 77 and nearly 100%. Most of the time, missing data correspond to particular events such as episodic operations of maintenance on the instruments (filters changing, cleaning, control, etc.), electricity failures or break down of the computer connections. Data selection then consisted in rejecting data associated with the above-listed acquisition problems.

3. Methods

3.1. Tunisian air quality standards

In 2007, Tunisia adopted air quality standards to ensure every citizen the right to a healthy environment and sustainable development (Law No. 2007-34 of 4 June 2007 on air quality and Decree No. 2010-2519 of 28 September 2010 on limit values to the source of air pollutants stationary sources). Table 1 presents the Tunisian standards for airborne particles (considered here as PM_{10}).

Table 1. Tunisian ambient air standards NT 106 04 for airborne particles.

Type of average	Authorization of excess	Limit value relative to health (µg m^{-3})	Limit value relative to well-being (µg m^{-3})
Annual	-	80	40-60
Daily	once a year	260	120

As a comparison, Table 2 presents the European air quality standards entered into force on 1 January 2005 for PM_{10}. These values are twice lower on an annual basis, and more than 5 times lower than the limit value relative to health defined for Tunisia.

Table 2. European air quality standards for PM_{10} since 1 January 2005.

Type of average	Authorization of excess	Concentration (µg m^{-3})
Annual	-	40
Daily	35 times per year	50

3.2. Determination of the origin of the episodes of high daily mean PM_{10} concentration

In this study, a high daily mean PM_{10} concentration is defined as a daily average PM_{10} concentration ≥ 120 µg m^{-3}, which is the limit value relative to well-being according to Tunisian ambient air standards (see Table 1).

For each of the identified episodes, the origin of the air-masses was determined using the online version of the HYbrid Single Particle Lagrangian Integrated Trajectory model (HYSPLIT; Draxler & Rolph, 2015; Rolph, 2015). 24h-backward trajectories were computed using the ensemble model ending at the ground at the station with the GDAS (Global Data Assimilation System) meteorological database at 0.5°. In order to confirm the presence of dust during the air-mass displacement, we used the AOD at 550 nm derived from the measurements of the Moderate Resolution Imaging Spectroradiometer (MODIS) on-board the Aqua satellite using the Deep Blue algorithm (Hsu et *al.*,

2004; 2006). Figure 2 illustrates the corresponding HYSPLIT and Deep Blue AOD maps for the case of the 22nd January 2015 for which the measured daily mean PM_{10} concentration was 282 µg m^{-3}.

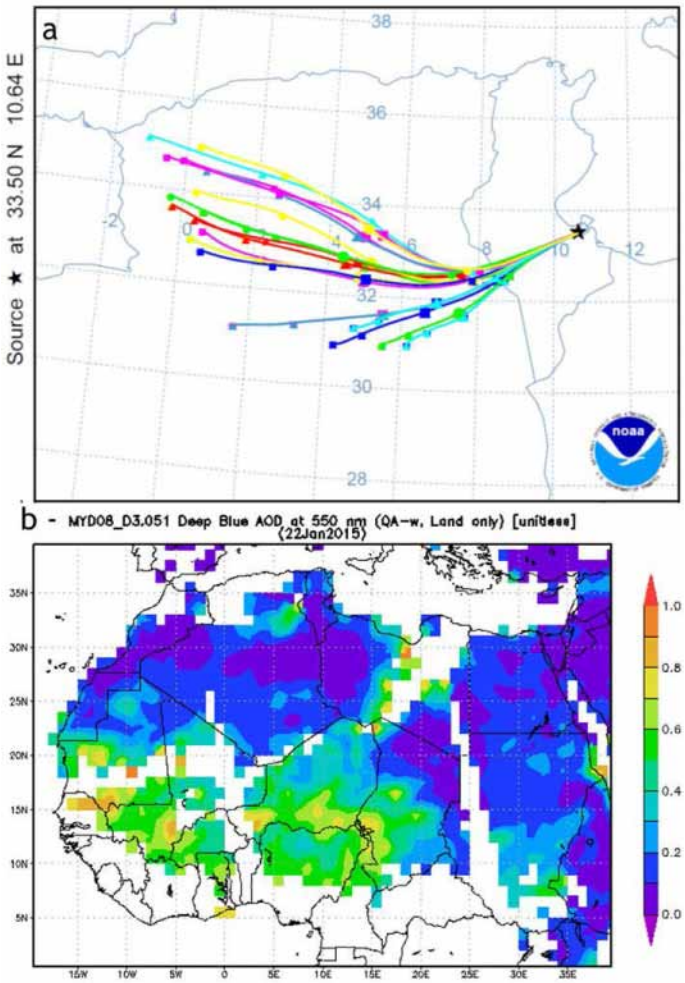

Figure 2. (a) 24h-backward trajectories ending at 1200UTC 22 January 2015 computed using the online version of the HYSPLIT model from El Fjé (black star - 33.50N; 10.64E); (b) MODIS (Aqua) Deep Blue AOD at 550 nm on 22 January 2015.

4. Results and discussion

4.1. Annual mean of PM_{10} concentration

Annual means of PM_{10} concentration of 56 µg m^{-3} and 44 µg m^{-3} were recorded in 2014 and 2015, respectively. These values observe both the limit values relative to health and relative to well-being (Table 1).

Bouchlaghem and Nsom (2012) presented measurements of PM_{10} concentration from 2004 to 2010 made in five industrial, residential, and urban monitoring stations installed in Tunis, Bizerte, Sousse, and Sfax (one in the town centre, and one in an industrial site). During this 7 year-period, the annual average PM_{10} concentration reached 58 µg m^{-3} in Sousse, 80 µg m^{-3} in Bizerte, 87 µg m^{-3} in Sfax centre, 89 µg m^{-3} in Sfax industrial site, and 90 µg m^{-3} in Tunis. These values are very high compared to those recorded in El Fjé. Part of the observed differences may be explained by the location of the northern stations: they are all located in big cities where anthropogenic pollution (due to traffic, domestic heating, industrial activities…) may be important whereas the station of El Fjé is located in a remote place.

From a regional point of view, annual means measured in El Fjé stay however very high compared to the measurements existing for the rest of the Mediterranean basin. As an example, the maximum values of the mean annual PM_{10} levels recorded by Pey et *al.* (2013) on a network of 19 ground-based stations located all along the northern side of the Mediterranean Basin were respectively of 27 and 28 µg m^{-3} in the Athens and Thessalonica suburban sites in Greece.

4.2. Seasonal evolution of PM_{10} concentration

Figure 3 reports the monthly mean and median of the hourly PM_{10} concentration for the period February 2014-February 2016. It can be observed that the monthly arithmetic mean exhibits a well-marked seasonal cycle with maxima higher than 80 µg m^{-3} recorded in winter and early spring, and minima lower than 40 µg m^{-3} observed most frequently during summertime. This seasonal evolution does not completely agree with the results by Bouchlaghem et *al.* (2009) and Bouchlaghem and Nsom (2012). If these authors also pointed out that the average seasonal evolution of PM_{10} concentration is characterized by a winter maximum as retrieved here, they observed a second maximum during summer (July and August) while a minimum is observed in El Fjé. This difference may be explained by the synoptic situation encountered during summertime that favours the intrusion of dusty air masses in the northern part of Tunisia from dust sources activated in West Africa (Querol et *al.*, 2009).

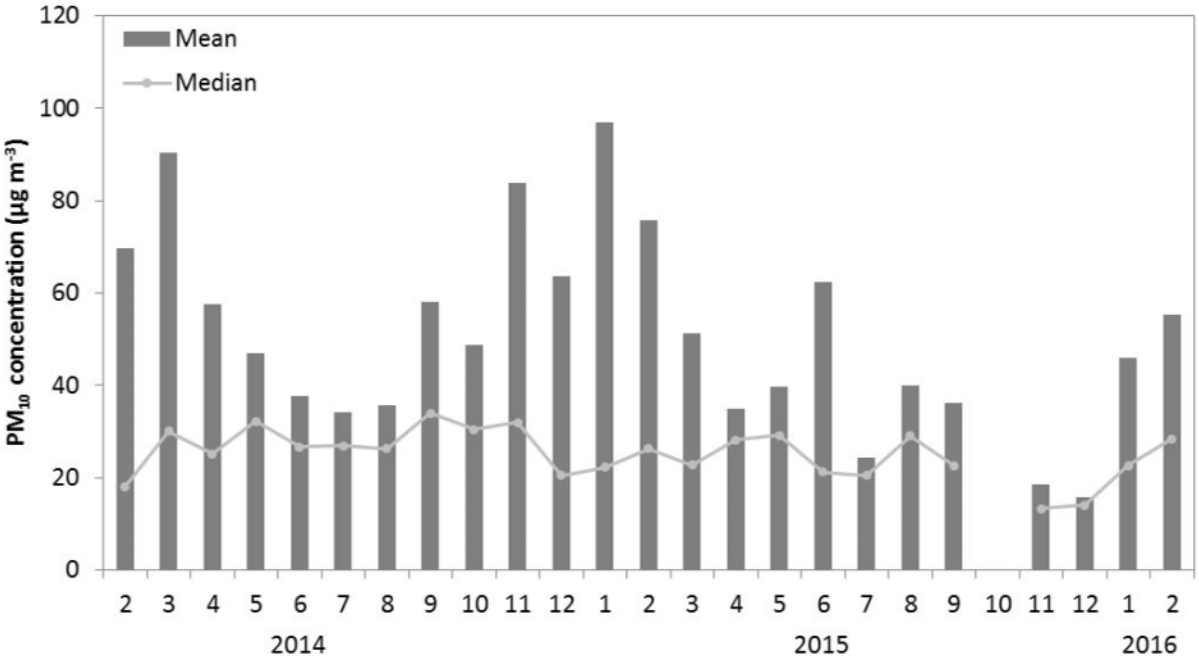

Figure 3. Monthly mean (bars) and median (line with dots) of PM_{10} concentration (in µg m^{-3}) from February 2014 to February 2016.

Contrary to the monthly mean of the hourly PM_{10} concentration, the monthly median values do not show any clear trend all along the period, remaining almost constant around their average value (25.4 µg m^{-3}) as indicated by a low standard deviation (5.5 µg m^{-3}). This difference of pattern between the arithmetic mean and the median suggests that rare but with very high concentration events are responsible for the large amplitude observed for the monthly arithmetic mean. This is what Figure 4 confirms: the daily mean PM_{10} concentration highly varies throughout the year. High PM_{10} concentrations (up to more than 1,000 µg m^{-3} in daily mean) are observed the most frequently during wintertime and springtime, hardly ever in summer, and can sometimes be recorded during several days.

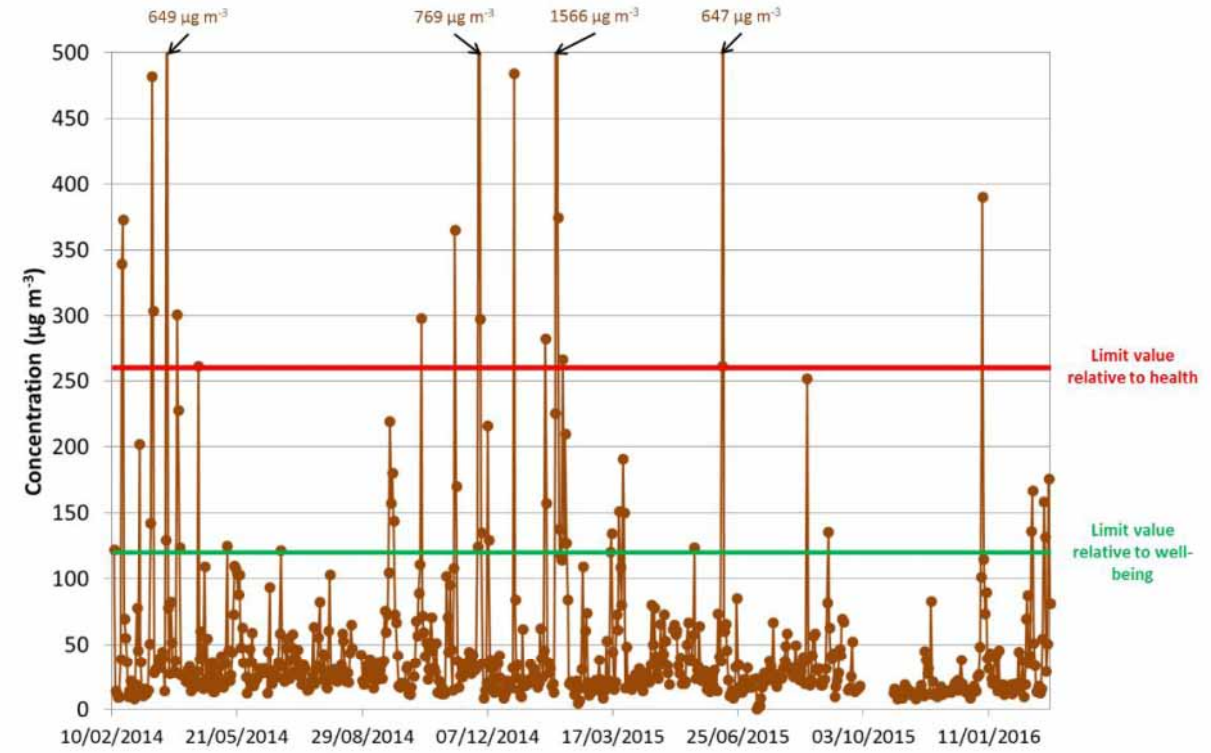

Figure 4. Daily mean of PM_{10} concentration (in µg m^{-3}) from 10 February 2014 to 29 February 2016.

Considering air quality, Figure 4 also shows that the Tunisian standards defined for ambient air are no longer observed. In 2014, the limit value relative to health was exceeded 12 times, and the limit value relative to well-being was exceeded 29 times. In 2015, these values were respectively exceeded 6 and 20 times. It must be highlighted here, that for both year, one month of data is missing, January in 2014 and October in 2015.

Figure 5 presents the monthly frequency of limit exceeding. It shows that limit values were more frequently exceeded and with a higher intensity in autumn and winter, and then in spring.

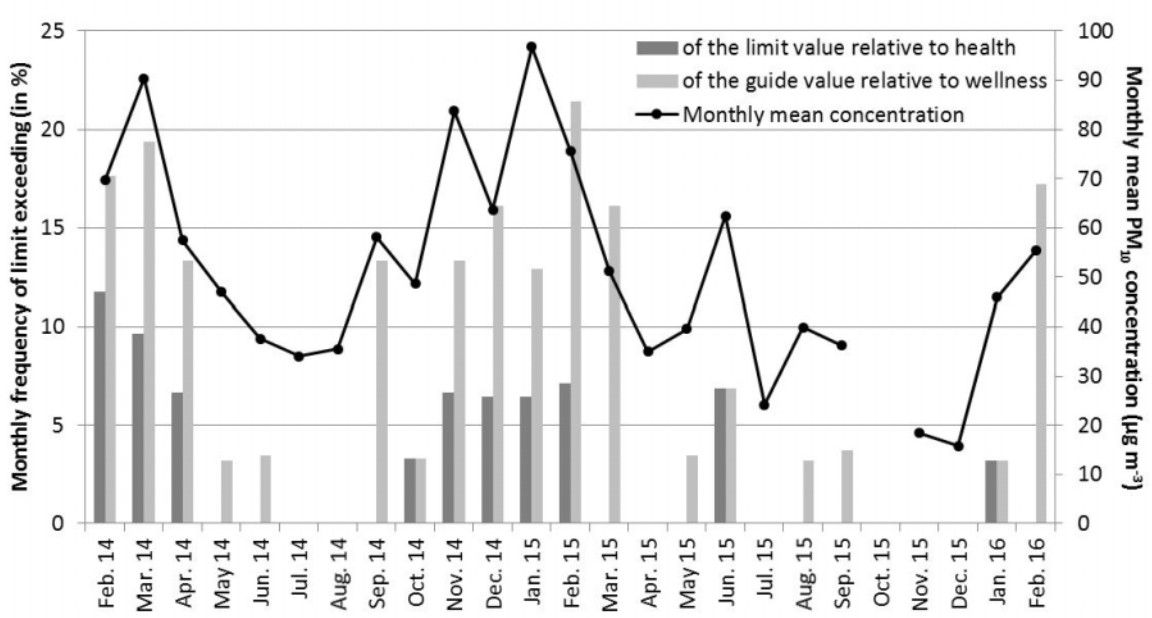

Figure 5. Monthly frequency (in %) of exceeding of the limit value relative to health (dark grey bars) and of the guide value relative to wellness (light grey bars), and monthly mean of PM_{10} concentration (black line with dots; in µg m^{-3}) from 10 February 2014 to 29 February 2016.

4.3. Origin of the episodes of high daily mean PM_{10} concentration

During the period Feb. 2014-Feb. 2016, 53 episodes of high daily mean PM_{10} concentration were observed (see Table 3). They were more frequent in winter and spring (9% in DJF and in MAM respectively) than in autumn (7% in SON), and summer (5% in JJA). For all these days, when sunphotometer measurements were available, AOD was at least > 0.3 once during the day and the Angström exponent was always < 0.4, confirming that the measured aerosol is dominated by coarse particles, in our case mainly mineral dust.

Table 3. Number and percentage of days with high daily mean PM_{10} concentrations according to the season.

Period	Number of days with high daily mean PM_{10} concentration	Number of days with observations	Percentage of days with high daily mean PM_{10} concentration (in %)
DJF	17	198	9
MAM	17	182	9
JJA	8	176	5
SON	11	152	7

The seasonality of the high daily mean PM_{10} concentration can be explained for a large part by the seasonality of high surface wind speed (> 9 m s^{-1}) are more frequent during wintertime and springtime than in summer and fall as illustrated in Figure 6.

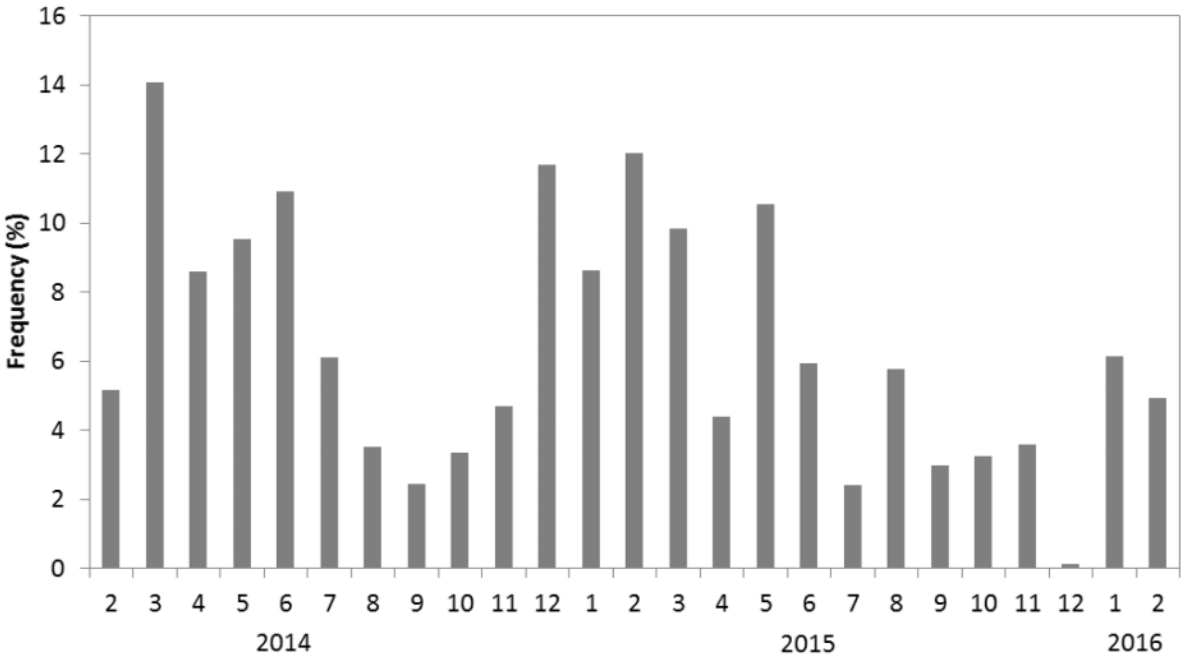

Figure 6. Monthly frequency (in %) of the days for which maximum 5-min wind speed is > 9 m s^{-1} from February 2014 to February 2016.

Using the online version of the HYSPLIT model, we determined that air masses originated mainly from 4 sectors as defined in Figure 7. Table 4 presents the percentage of air masses originating from these 4 sectors according to the season. During the considered period, in winter, most of the episodes of high daily mean PM_{10} concentration were due to medium range transport from the Great Eastern Erg (Sector 2) located at the southwestern border between Tunisia and Algeria (see example presented in Figure 2), and from the chotts in North Africa (Chott El Jerid in Tunisia, and Chott Melrhir in northeastern Algeria; sector 1). On the opposite, during the rest of the year, these episodes mainly came from northern Libya (sectors 3 and 4).

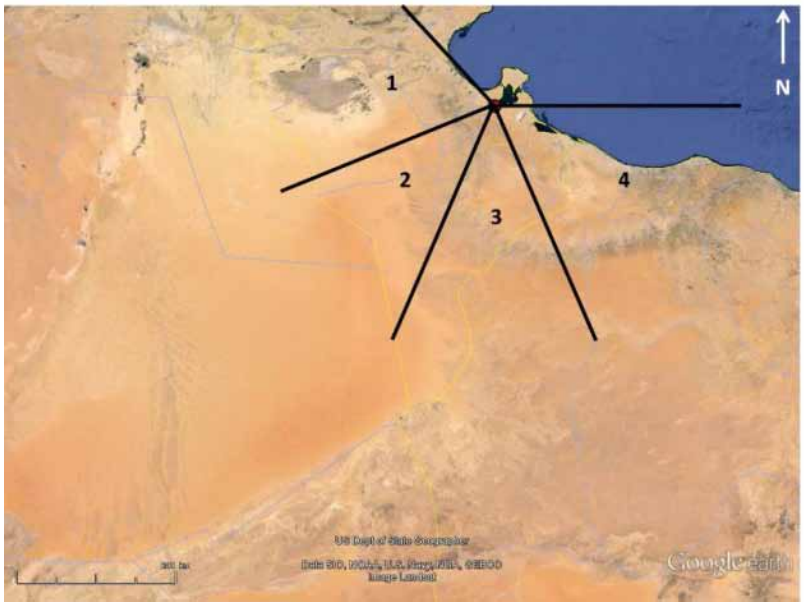

Figure 7. Main sectors of origin of air-masses conducting to high daily mean PM_{10} concentrations observed in the station of El Fjé (identified by the red dot).

Table 4. Percentage of air masses conducting to high daily mean PM_{10} concentrations observed in the station of El Fjé originating from sectors 1 to 4 according to the season.

Period	Sector 1	Sector 2	Sector 3	Sector 4
DJF	26%	48%	19%	7%
MAM	11%	26%	33%	30%
JJA	0%	7%	47%	47%
SON	19%	14%	38%	29%

5. Conclusions

For the first time, two years of continuous measurements of PM_{10} concentration and meteorological parameters in a remote place of southern Tunisia were presented and discussed. It was shown that Tunisian air quality standards were observed on an annual basis in El Fjé. Moreover, the annual mean PM_{10} concentration was lower than what was observed in cities of northern Tunisia. On a daily basis, Tunisian air quality standards were no longer observed, and very high daily mean PM_{10} concentration were measured (up to more than 1,500 $\mu g\ m^{-3}$), the most frequently during wintertime and springtime. During the days when daily mean PM_{10} concentration was $\geq$ 120 $\mu g\ m^{-3}$, mineral dust was identified as the dominant aerosol. It was finally shown that wind erosion at the regional scale (northern Libya, great Eastern Erg, and the region of the Chotts) was responsible of most of the observed episodes.

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