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# Particulate Matter (PM10) Sources in Bizerte, Tunisia Using Logistic Regression Model

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*Abstract*— **Short-term exposure to particulate matter ($PM_{10}$), the total mass of PM with a diameter of 10 micrometers or less, has been linked to increased morbidity and mortality. Most of the dust particles released to the atmosphere worldwide is emitted by Saharan Desert in North Africa. This paper evaluates the effect of dust particles from African regions on $PM_{10}$ concentrations in Bizerte, Tunisia using a logistic regression statistical methodology. The 2004 and 2005 $PM_{10}$ measurements were obtained by the Tunisian National Agency for Environmental Protection, ANPE, pollution monitoring station and for the same period, 6-day back trajectories were generated using the NOAA-HYSPLIT. The study found that the DLV exceeded the 50-µg/m³ limit 293 times in 2004 and 257 times in 2005. Significant associations have been found between far air sources and the measured concentrations for both 2004 (OR=1.024, 95% CI = 1.016-1.032) and 2005 (OR=1.013, 95% CI = 1.003-1.022). The model performance has significantly improved when shorter back trajectories (closer source regions) were considered. The feasibility of using a logistic regression statistical methodology to evaluate the effect of air masses from African regions on $PM_{10}$ concentrations in Bizerte, Tunisia has been demonstrated.**

*Index Terms:* **air pollution, north Africa, particulate matter; logistic regression, back trajectories, Saharan Desert, Tunisia**

## I. INTRODUCTION

Numerous health studies have found that air pollution negatively affects human health, welfare, and ecosystems. Particulate matter is responsible for reducing visibility and solar radiation, affecting climate, and can intensify the chemical effects of other pollutants (Houthuijs, et al., 2001; Batterman, et al., 2014). Short-term exposure to particulate matter ($PM_{10}$), the total mass of PM with a diameter of 10 micrometers or less, has been linked to increased morbidity and mortality (Adar, Filigrana, Clements, & Peel, 2014; Cuspilici, Monforte, & Ragusa, 2017; Caramagna, Famoso, Lanzafame, & Monforte, 2015; Lanzafame, Monforte, Patanè, & Strano, 2015; Longueville, Ozer, Doumbia, & Henry, 2012). Both the European Union (EU) Directive 1999/30/CE and the World Health Organization (WHO) have identified guideline values below which the damage to health is minimized (WHO, 2019). Studies have shown that African Sahara dust causes exceedances in regional background $PM_{10}$ concentrations in many southern European regions such as Albania, Iberian Peninsula, and south Italy (Mandija, Bushati, Zoga, & Vila, 2011; Contini, et al., 2010; Salvador, et al., 2014; Escudero, Querol, Avila, & Cuevas, 2006; Cuspilici, Monforte, & Ragusa, 2017; Nava, et al., 2012).

There are not many state-run air pollution monitoring stations in the southern Mediterranean coasts. This has limited the number of studies performed to investigate the air quality concerns in the north of Africa in spite of the importance of the African continent, which produces nearly half of the global mineral dust every year, and despite the proximity of the Saharan desert. In addition, African combustion emissions have significantly increased during the last few years (Longueville, Ozer, Doumbia, & Henry, 2012; Liousse, Assamoi, Criqui, Granier, & Rosset, 2014).

Tunisia is one of the few African countries that has an air pollution monitoring network, covering the different regions of the country, and placed in such a way to include urban, peri-urban, and industrial stations. These stations are run by the National Agency for Environmental Protection, Tunisia, ANPE (ANPE, 2019). These stations are equipped to measure several pollutants including particulate matter with diameters < 10 microns ($PM_{10}$). The specific nature of the measured pollutants depends on the location and date of entry in service of the given station, This Tunisian data availability has led to a

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relatively better understanding of $PM_{10}$ concentrations in the region. Kchih et al 2015 (Kchih, Perrino, & Cherif, 2015) have found that aerosols' chemical composition was heavily affected by dust winds from Sahara Desert. Bouchlaghem and Nsom 2012 (Bouchlaghem & Nsom, 2012) evaluated the influence of atmospheric transport scenarios on $PM_{10}$ levels in five Tunisian sites using back-trajectories analysis. The study found that Saharan desert contributed to high levels of $PM_{10}$ concentrations in the different Tunisian cities.

The association between high $PM_{10}$ concentrations and Saharan dust documented in the above Tunisian studies was based on either chemical characterization or by analyzing Saharan dust when standard limits were exceeded. To the best of our knowledge, a statistical method of logistic regression modeling has not been used to investigate this association. In this paper, a robust methodology of a logistic regression model is used to investigate the effect of air masses from African regions on $PM_{10}$ concentrations in Bizerte, located in the north of Tunisia (Figure 1). The hypothesis to be verified is that high concentrations of $PM_{10}$ are associated with air episodes from Sahara Desert in Africa. The study also presents analysis of $PM_{10}$ measured during a two-year period and compares the $PM_{10}$ values to the World Health Organization and Tunisian Guidelines

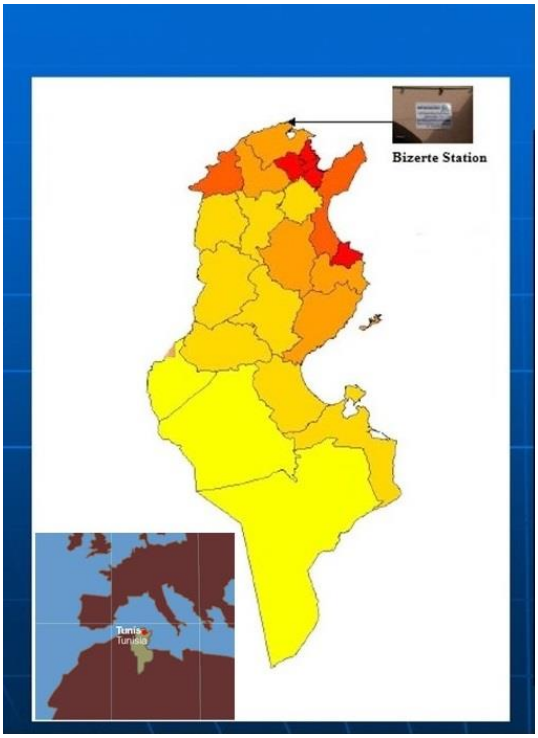


Figure 1. Map of Europe and North Africa, showing Tunisia and the locations of Bizerte monitoring station.

## II. METHODOLOGY

Measurements of $PM_{10}$ concentration were acquired from the National Agency for Environmental Protection, Tunisia, ANPE. The monitoring station is located in Bizerte City center (37 16' N, 9 52' E), a few kilometers from major industrial facilities such as Bizerte refinery and Bizerte cement factory. The station has a Beta Gauge monitor (Thermo ESM Andersen, Model FH 62 I-R) that measures the mass concentration of particulate matter, in which the suspended particles are collected on a moveable filter tape. Ambient air is sucked through a sampling tube whose inlet is placed above the station and dust particles are deposited on a filter. The latter is automatically unfolded and passed between the beta source and a Geiger–Müler meter. The difference in the meter readings before and after the aspiration yields the value of the mass accumulated on the filter. The station is also equipped to measure simultaneously meteorological parameters, i.e. wind speed and direction, atmospheric pressure, relative humidity temperature, and solar radiation. The station is connected in a network with the agency headquarters. The measurements are recorded every 15 minutes and sent automatically to the main computer at the headquarters for storage and processing. For this study, we acquired the 2004 and 2005 $PM_{10}$ data courtesy of the ANPE. An effort was made to acquire reliable data from more recent years but was unsuccessful due to recurrent technical problems in the Bizerte station. However, $PM_{10}$ measurements from other close by cities indicate an essentially invariant statistics over the period of time extending from 2004 to 2018.

To investigate the $PM_{10}$ regional sources, air back trajectories were calculated using the National Oceanic and Atmospheric Administration's Hybrid Single Particle Lagrangian Integrated Trajectory (NOAA-HYSPLIT) model (http://ready.arl.noaa.gov/HYSPLIT.php). HYSPLIT can be run interactively on the READY web site (NOAA, 2019). It is an atmospheric dispersion model that uses numerical methods to track and compute the air pollutants' time history. It is divided into two main models: (1) an Eulerian model that considers a space-fixed frame in time to solve the advection-diffusion equation, and (2) a Lagrangian model that considers a frame that moves and changes over time. It also solves the advection and diffusion equation, but from the particle perspective. Input data to NOAA HYSPLIT include date, time, latitude, longitude, trajectory duration and direction (backward or forward), number of trajectories and trajectory height at arrival point. Since the source of the reaching air is of interest in this study, the back trajectories were selected. Gerasopoulos (Gerasopoulos, et al., 2001) suggested that the uncertainty of the air-mass origin could increase when more than 3-day back trajectories are used. However, (Lee, Kwok, Cheung, & Yu, 2004) showed that the use of back trajectories is satisfactory even up to 157 hours (about 6.5 days) prior to the measurement. In the present study, 6-day trajectories were used because shorter air trajectories might not lead to the actual source for example the trajectory might end up in the middle of the Mediterranean Sea, which is not a plausible air pollution source location, while continuing the calculations would most likely indicate the real source.

For the same period of time of $PM_{10}$ measurements, 6-day back trajectories were generated using the NOAA-HYSPLIT model for every day. As a result, 366 images of the 6-day back trajectories were generated for 2004 and 365 images for 2005. Supplementary File S1 is a step-by-step guideline of how to run HYSPLIT. Examining the generated back trajectories, two possible regional sources of $PM_{10}$ that reached Bizerte, Tunisia were identified i.e. African and non-African sources. For example, on December 3, 2004 an African episode shown in Figure 2-A occurred over the studied area. The daily average $PM_{10}$ concentration recorded on this day at the Bizerte station was very high, 466 µg / m³. This suggests that a transport from the Sahara Desert occurred during this episode. All other episodes that reached Bizerte were considered non-African episodes. As an example of non-African episodes, a trajectory that reached Bizerte on December 16, 2004 originated from eastern Europe as shown in Figure 2-B. This episode recorded an average $PM_{10}$ concentration of 51 µg / m³. The hypothesis is that high concentrations of $PM_{10}$ are more likely to be associated with air episodes from African regions (i.e. Sahara Desert), while low $PM_{10}$ concentrations are more likely to be associated with non-African sources. The African region includes possible sources of dust such as Morocco, Algeria, Tunisia, Libya, and Egypt. The non-African region includes all other sources such as Europe, northwest Asia, and east Canada, in addition to ocean-originated sources, as shown in Figure 3. Consequently, the 6-day back trajectories were labeled based on their source to African and non-African episodes. A logistic regression model was performed between $PM_{10}$ sources (1 = African source, 0 = non-African source) and the $PM_{10}$ measured concentrations measured at Bizerte station at the conventional 5% level of significance. ¬¬ All data analyzed during this study are included in this published article (Supplementary File S2). The R-programming code is also included (Supplementary File S3).

The logistic regression results elucidate the different regional sources of high and low $PM_{10}$ concentrations reaching Bizerte. It is very important to mention that the regional sources of $PM_{10}$ in the below analyses were first determined exactly at the starting location of the 6-day back trajectories. Using this classification, the $PM_{10}$ sources will be called far regions as they are far away from the study area.

In few cases, it was quite difficult to clearly classify the episode as African or non-African depending entirely on the starting location of the 6-day back trajectories. In the example shown in Figure 4, the episode started at a non-African source (the Atlantic Ocean) but spent some time over the African region. One might argue that the episodes flowing over African regions could carry higher $PM_{10}$ concentration when arriving to the study area. For this reason, a second method of $PM_{10}$ source classification was considered. It is based on the recent area over which air masses had flown. In contrast to the first analyses type, the second one is called closer regions. It would consider an African episode any episode that either has its starting location in Africa or that passes over Africa in its 6-day trajectory.

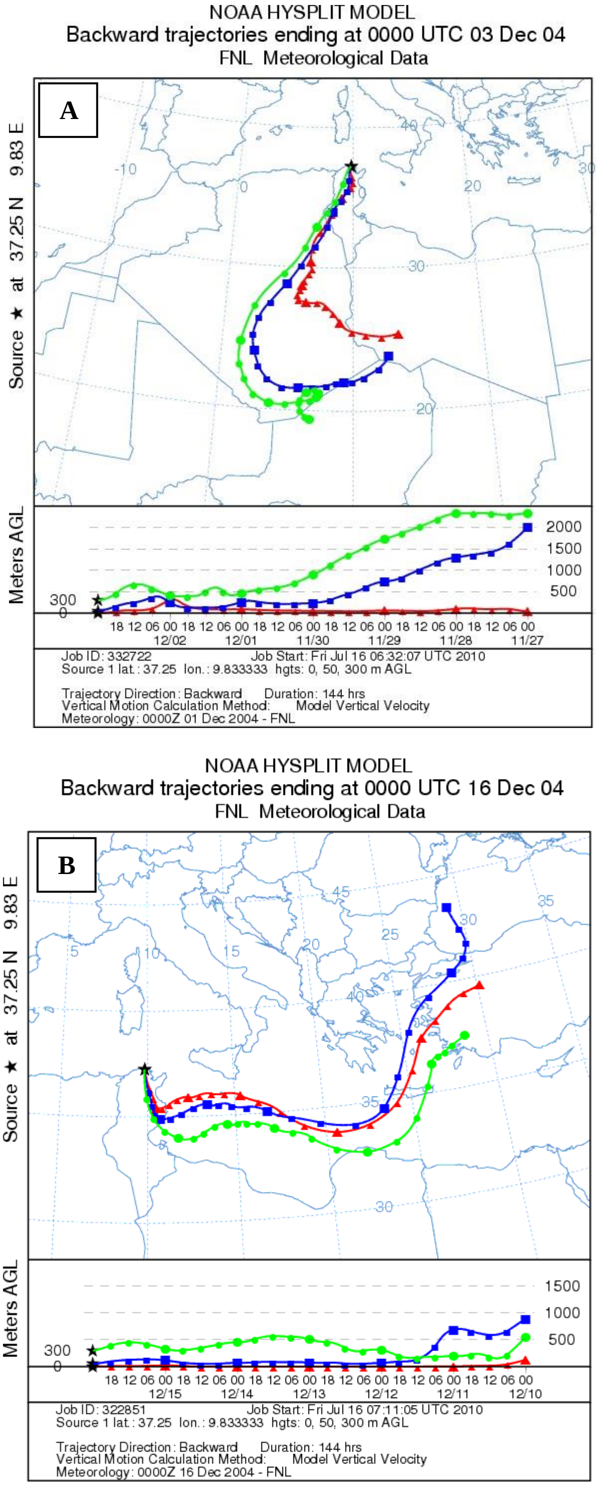


Figure 2. 6-day HYSPLIT back trajectories for altitudes of 0 (red curve), 50 (blue curve), and 300 m (green curve) corresponding to: (A) An African episode that occurred on December 3, 2004; (B) An Eastern European episode that occurred on December 16, 2004.

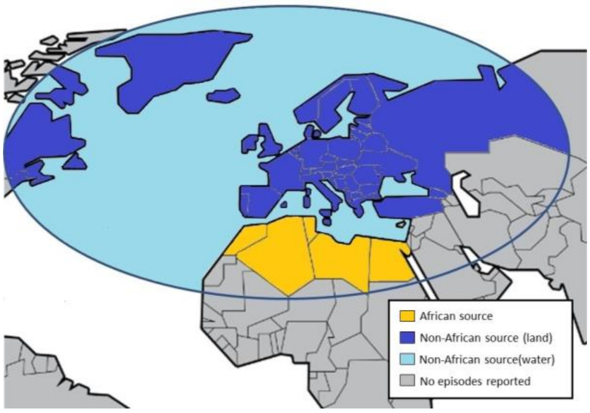


Figure 3. Study domain where all sources of 6-back trajectories has been reported. Yellow indicates that trajectories were generated in North Africa. Dark and light blue mean trajectories were generated in locations outside of Africa.

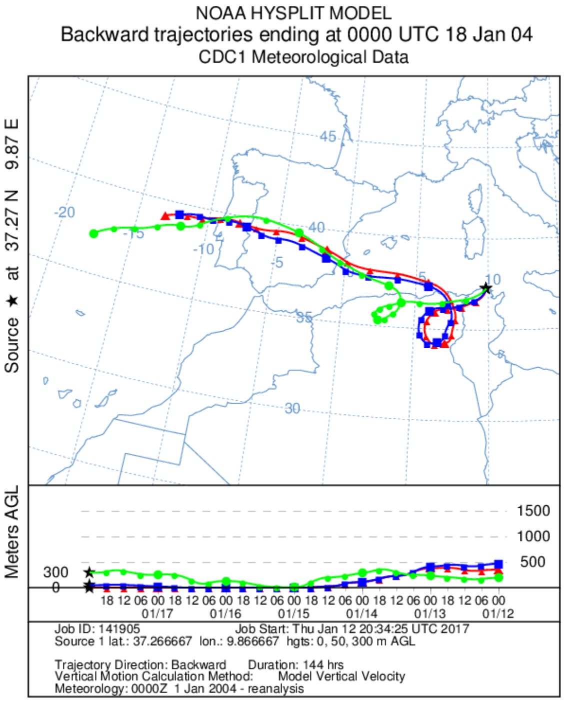


Figure 4. A NOAA HYSPLIT model 6-day back trajectory that identifies Atlantic Ocean as a far source and north Algeria as a closer source for aerosols potentially impacting air quality in Bizerte, Tunisia

## III. RESULTS AND DISCUSSION

The WHO Daily Limit Value (DLV) for $PM_{10}$ is 50 µg/m³ to be exceeded only 7 times a year. The annual average of $PM_{10}$ should not exceed 20 µg/m³ (Escudero, Querol, Avila, & Cuevas, 2006; Bouchlaghem K. , Nsom, Latrache, & Haj Kacem, 2009). These guideline values cannot fully protect human health; however, they have been selected to provide an environment that protects public health as below these values the damage to health is minimized (WHO, 2019). The Tunisian air quality standards are less stringent than the WHO guidelines. For example, the Tunisian DLV of $PM_{PM}$ is 260 for health and 80 µg/m³ for welfare, not to be exceeded more than once a year; the annual average is 80 µg/m³ for health and 40-60 µg/m³ for welfare.

The daily average $PM_{10}$ concentration during 2004 and 2005 measured in Bizerte frequently exceeded the WHO 50-µg/m³ standard daily limit as shown in Figure 5. The DLV exceeded the 50-µg/m³ limit 293 times in 2004 and 257 times in 2005. On the other hand, the Tunisian health DLV was exceeded only three times in 2004 and was not exceeded in 2005. The annual means were respectively 88 and 93 µg/m³ in 2004 and 2005, well above the WHO annual limit and exceeding the Tunisian annual limit.

As mentioned above, sources of $PM_{10}$ were first determined exactly at the starting location of the 6-day back trajectories. From the logistic regression results for 2004 data, the estimated odds ratio is 1.024 (95% CI = 1.016-1.032), which suggests that high concentrations of $PM_{10}$ reaching Bizerte tend to occur during episodes from Africa. Another evidence of this association is the sharp increase of the probability curve of $PM_{10}$ source shown by the fitted logistic regression model in Figure 6-A. Note that for every one-unit (1 µg / m³) change in $PM_{10}$, the odds of African source (versus non-African source) increase by 0.024. Similarly, in 2005 analysis the association between high $PM_{10}$ concentrations and African episodes was found. The estimated odds ratio of 1.013 (95% CI = 1.003-1.022) indicates that high concentrations of $PM_{10}$ reaching Bizerte tend to occur during episodes from Africa. Despite the significant association, the fitted model based on 2005 data analysis did not produce the distinct sigmoid shaped curve as shown in Figure 6-B.

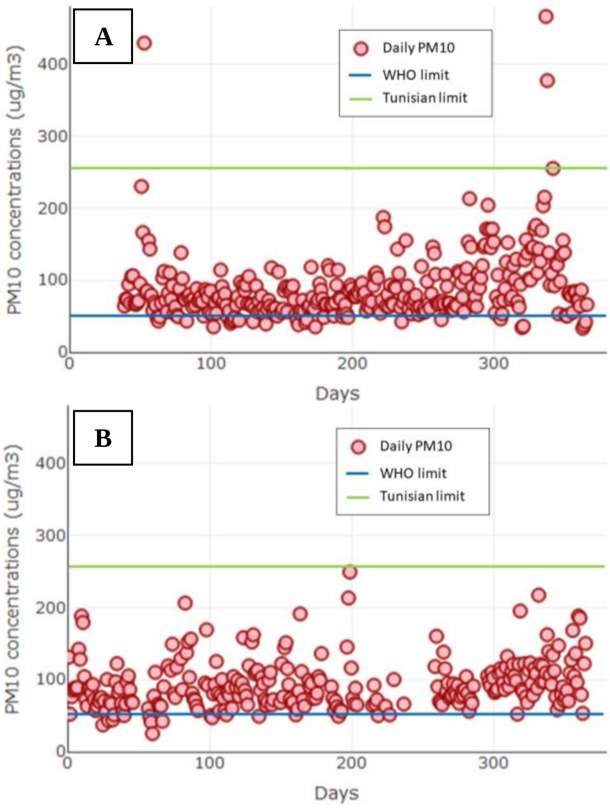


Figure 5. Daily average concentrations of $PM_{10}$ measured at Bizerte monitoring stations: (A) 2004, (B) 2005.The blue line indicates the WHO DLV and green line indicates the Tunisian DLV.

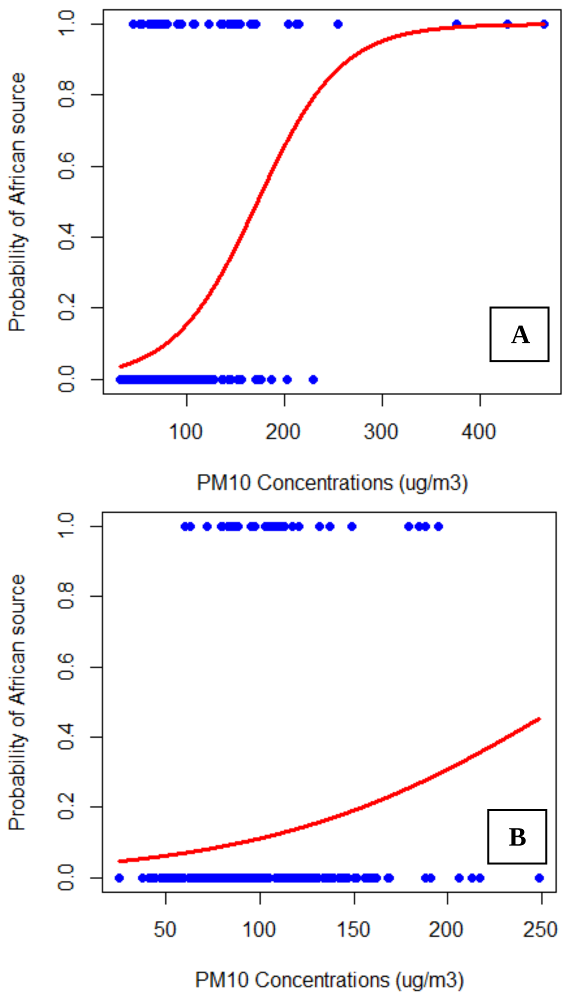


Figure 6. Scatter plots and probability curves of far air sources versus $PM_{10}$ concentrations for: (A) 2004 data; (B) 2005 data

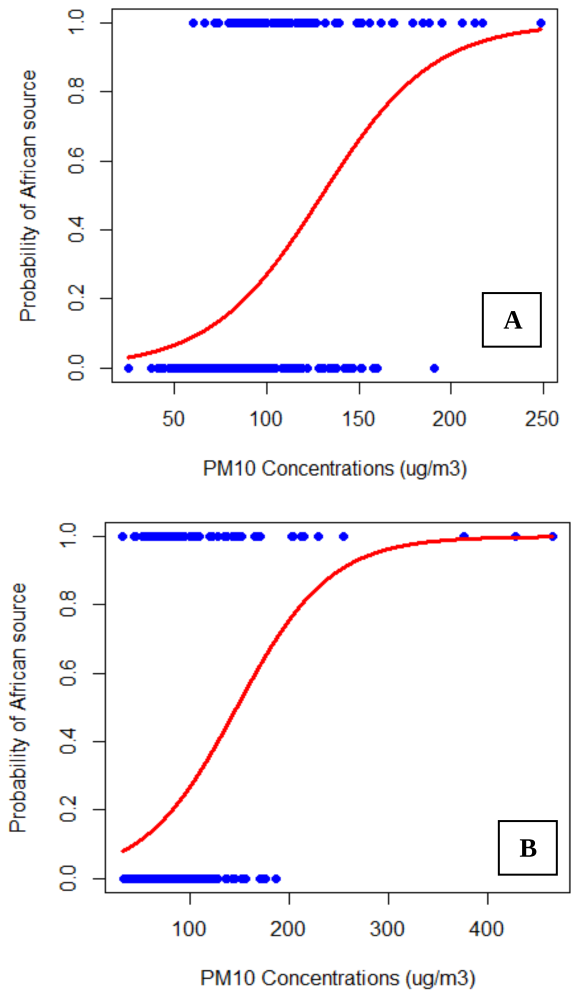


Figure 7. Scatter plots and probability curves of closer air sources versus $PM_{10}$ concentrations for: (A) 2004 data; (B) 2005 data.

The latter observations about the probability curves of far air sources for the year 2005, prompted us to consider closer regions as sources of $PM_{10}$. Significant associations between closer air episode sources and measured $PM_{10}$ concentrations can also be found in both 2004 (OR of 1.022; 95% CI = 1.014-1.029) and 2005 (OR of 1.034; 95% 1.023-1.044). The fitted logistic regression models improved when closer air sources were used (Figure 7). While both far and closer regions had significant association with $PM_{10}$ concentrations at the destination point, closer regions had more influence on $PM_{10}$ concentrations.

The performance of the logistic regression model was investigated by conducting a goodness of fit test which is a measure of how well the observed data correspond to the predicted data. The goodness of fit test was evaluated using two measures, namely: Hosmer Lemeshow test (calibration), and the Receiver Operating Characteristic (ROC) curves (discrimination). The Hosmer-Lemeshow essentially assesses whether the number of expected events from the logistic regression correspond to the number of observed events. The data are ranked then grouped into deciles, in which the sum of predicted probabilities is compared to the observed number of outcomes.

The Hosmer Lemeshow test is approximately distributed as a chi squared. If the Hosmer Lemeshow test shows a statistical significance (p-value is small), this means poor predictions (lack of fit) of the data (Guffey, 2012). The ROC curve which is another way to evaluate a logistic regression performance, can be obtained by plotting true-positive rate (sensitivity) versus false-positive rate (1 - specificity). The area under the ROC curve (AUC) estimates the model accuracy. The AUC ranges from 0.5 to 1 where 0.5 indicates a poor classifier and 1 indicates a good classifier (García-Rodríguez, Malpica, Benito, & Díaz, 2008; Lin, Cheng, Chu, Chang, & Yu, 2011).

First, we investigate model performances based on far regions as a source of $PM_{10}$. The Hosmer Lemeshow test results ($\chi^2(8) = 2.9, p = 0.94$), indicate no evidence of poor fit for the 2004 logistic regression model. The AUC corresponding to the same model is 75.3%, which implies a good predictive capacity (Figure 8-A). Figure (8-B) shows the observed data versus the predicted probabilities from the 2004 model which also present good predictions. For 2005 data, the model is relatively poor fit ($\chi^2(8) = 15.99, p = 0.04$) and that is consistent with both the AUC value of 65.9% (Figure 9-A), and the

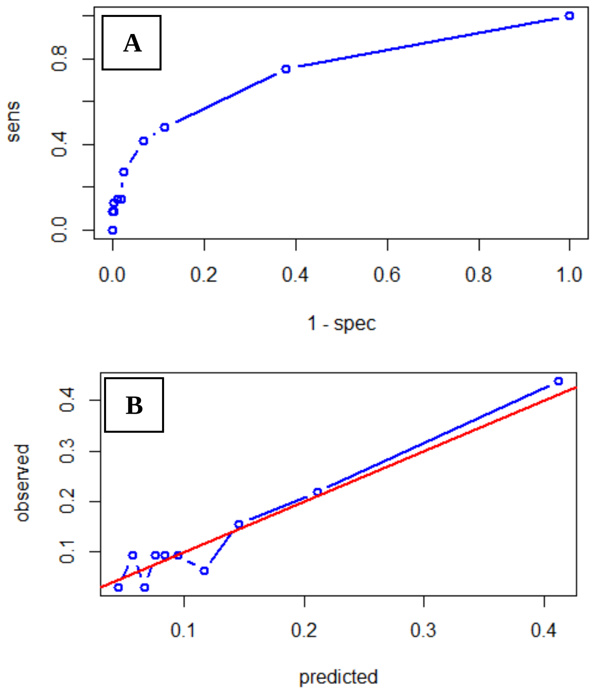


Figure 8. (A) Receiver Operating Characteristic (ROC) curve for the far regions model based on the 2004 data and the area under the curve is 0.75; (B) shows the observed versus predicted values (calibration plot).

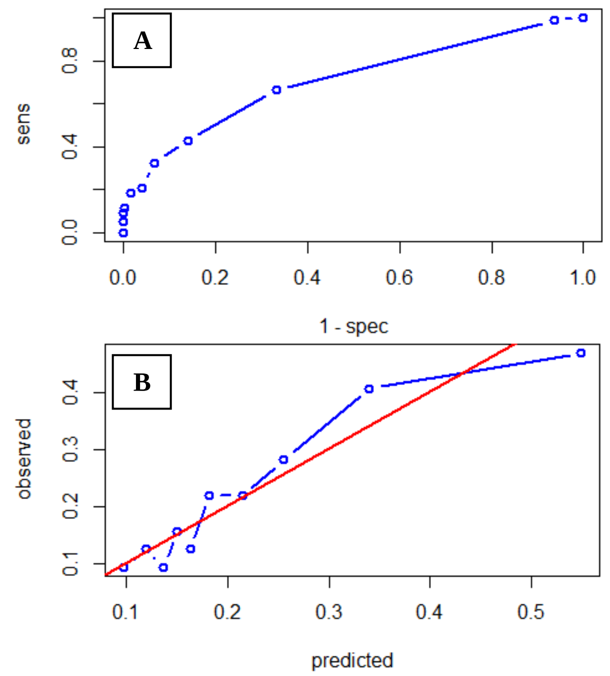


Figure 10. (A) Receiver Operating Characteristic (ROC) curve for the closer regions model based on the 2004 data. The area under the curve is 0.72; (B) shows the observed versus predicted values.

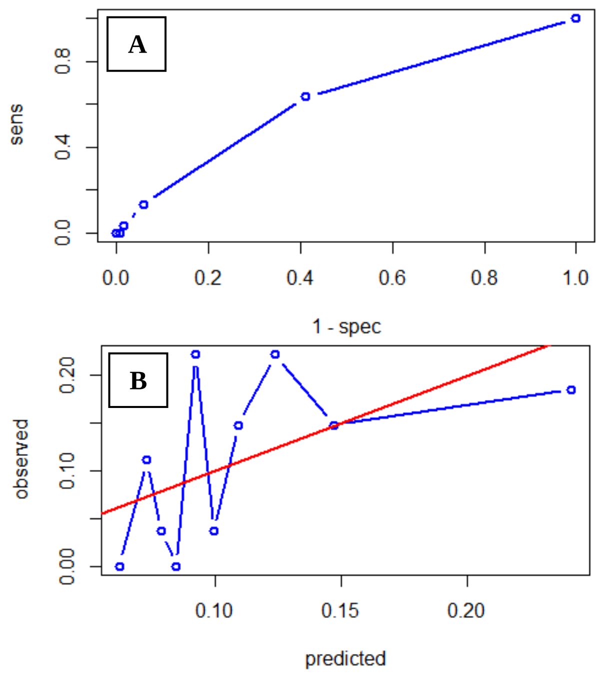


Figure 9. (A) Receiver Operating Characteristic (ROC) curve for the far regions model based on the 2005 data. The area under the curve is 0.66 (B) shows the observed versus predicted values.

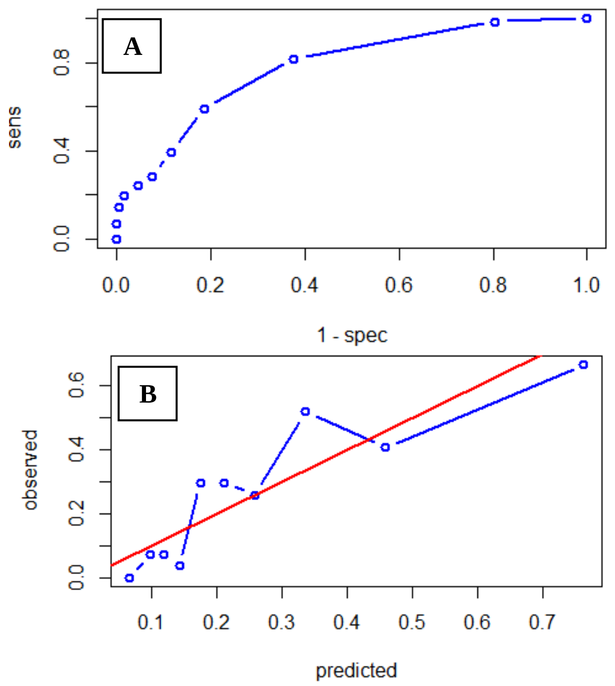


Figure 11. (A) Receiver Operating Characteristic (ROC) curve for the closer regions model based on the 2005 data. The area under the curve is 0.79; (B) depicts the observed versus predicted values.

observed data versus predicted probabilities plot (Figure 9-B).

Subsequently, the performance of logistic regression models based on the closer regions was also investigated. Again, no evidence of poor fit was found for the 2004 model ($\chi^2(8) = 6.27, p = 0.62$) and the AUC is 71.9% (Figure 10-A). A good agreement between observed and predicted values (Figure 10-B) indicate that the model has satisfactory predictive ability. The Hosmer Lemeshow test results ($\chi^2(8) = 14.1, p = 0.08$) of the 2005 data suggest no evidence of poor fit. The area under the ROC curve corresponding to 2005 logistic model is 79.2%, which implies a good predictive capacity (Figure 11-A). As depicted in Figure 11-B, the observed data are in a relatively good agreement with the predicted data.

## IV. CONCLUSIONS

Air masses reaching Bizerte can be categorized into African and non-African episodes according to back trajectory calculations. The African episodes, mostly coming from the Sahara Desert, had very high concentrations and were possibly heavily loaded with dust. The maximum value of the $PM_{10}$ concentration (466 µg / m³) recorded in Bizerte occurred on December 3, 2004 during an African episode consistent with findings of Bouchlaghem et al. (Bouchlaghem & Nsom, 2012) who found maximum daily $PM_{10}$ concentrations occurred in November and December. Episodes from regions other than Africa such as Iberian episodes, European episodes, Atlantic episodes, Eastern European episodes, and Arctic episodes recorded lower averages of $PM_{10}$ concentrations.

This hypothesized association between source of air episodes reaching Bizerte, Tunisia and the measured concentrations of $PM_{10}$ was investigated using logistic regression modeling between $PM_{10}$ measurements and the back trajectory obtained sources. The air source was set as a binary variable with 1 representing African regions and 0 representing non-African regions. 6-day back trajectories were generated using the NOAA-HYSPLIT for every day of the years 2004 and 2005. First, the starting location of the 6-day back trajectories (far regions) was used to classified episodes' sources. The logistic regression model showed significant associations between far air sources and the measured concentrations for both 2004 and 2005. The performance of the 2004 logistic model was good, but the 2005 model was a poor fit. Subsequently, sources of $PM_{10}$ were determined based on recent area (closer regions) over which the air episodes had flown. The logistic regression showed clear associations between closer air sources and the measured concentrations, with a better performance of both 2004 and 2005 models in this case. It can be concluded that episodes originating in Africa or passing over Africa in their trajectories result in high $PM_{10}$ concentrations reaching Bizerte city.

The feasibility of using a logistic regression statistical methodology to evaluate the effect of air masses from African regions on $PM_{10}$ concentrations in Bizerte, Tunisia has been demonstrated in this paper. We hope that the findings of the present work would help local authorities in Tunisia with respect to the exceedances of the WHO DLV and the Tunisian health DLV and their significant differences. This approach can also be used to evaluate sources of air pollution for other pollutants such as nitrogen oxides with the goal of identifying mitigation strategies.

## V. LIMITATIONS

We recognize that the data we are reporting here is from 15 years ago. This is an unusual situation, however the data here are used to develop a robust methodology to investigate the effect of air masses from African regions on particulate matter concentrations in north of Tunisia. Due to recurrent technical problems in the Bizerte station, the more recent measured data had several time periods with missing data. Furthermore, it did not pass our quality assurance/quality control procedures for determining data quality. We think that this paper is sufficiently unique in that it is only one of a few papers that report air pollution data for northern Africa. Also, Tunisia is the only country, except for more recently Morocco, that actually monitors air pollution in northern Africa. It is important to bring awareness to this region and the efforts to understand the regional air pollution, as well as to present a data methodology to verify sources of air pollution.

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## SUPPLEMENTARY

The following files are available: Supplementary File S1: a step-by-step guideline of how to run HYSPLIT, Supplementary File S2: data analyzed during this study, and Supplementary File S3: the R-programming code for data analyses.