Spatiotemporal Variation of Particulate Fallout Instances in Sfax City, Southern Tunisia: Influence of Sources and Meteorology

Moez Bahloul, Iness Chabbi, Ali Sdiri, Ridha Amdouni, Khaled Medhioub, and Chafai Azri

Unité de Recherche "Etude et Gestion des Environnements Côtières et Urbains", Faculté des Sciences de Sfax, Université de Sfax, BP 1171, 3000 Sfax, Tunisia

Correspondence should be addressed to Chafai Azri; chafaiazri@yahoo.fr

Received 7 May 2015; Revised 25 June 2015; Accepted 28 June 2015

1. Introduction

Air pollution usually results from diverse factors including mining activities, metallurgy, chemical industries, road and air traffic, household waste incineration, and industrial wastes [1, 2]. The composition of various gaseous and particulate pollutants that are emitted to the atmosphere depended on the origin, the emission conditions (i.e., flow of distribution near sources), and the exposure to the industrial plumes. In addition to the above-mentioned factors, weather conditions (e.g., wind speed and direction, temperature inversion, anticyclones, and cyclones) may effectively contribute to air pollution. It is well known that pollutants distribution in the atmosphere depended on dispersal phenomena that are, in turn, directly related to meteorological parameters (i.e., daylight hours, wind, temperature and humidity of the air, atmospheric stability, and precipitations [3]). During the atmospheric transport, the composition of original pollutants can be modified by mixtures of substances and aggregates from different origins, with various sizes and chemical compositions depending on the sources, the weather, and the environment [4]. In fact, chemical reactions between pollutants and atmospheric compounds may take place to produce secondary pollutants. In these conditions, the origin of atmospheric pollution becomes quite ambiguous [5]. Therefore, it may be more convenient to study not only the atmospheric composition but also the fallout settling. Within this context, the present work has been undertaken to evaluate the atmospheric particulate fallout instances near the main industrial zone of Sfax City (southern Tunisia). To achieve this goal, solar saltern was chosen as receiving environment because of (1) the homogenous support of the deposits (aquatic surface) and (2) the exposition to the main sources of pollution.

2. Material and Methods

Spatial and temporal variation of the deposition fluxes above Sfax solar saltern was recorded by monitoring the weekly rate deposition of particulates using collectors installed in twenty sites (i.e., P12, TS2, TS35, TS56, TS38, S6, TS3, TS16, TS20, TS25, PM2, R2, R3, P11, TS7, TS10, TS12, TS13, TS32, and TS42, Figure 1). These site abbreviations were conserved as predetermined by the technical staff of the solar saltern. Study samples were collected during the period extending from November 11, 2012, to April 15, 2013, during which Sfax area received limited rainfall storms and low Saharan dusts...
input [22]. Sampling procedure was carried out according to the NF standard 43-007, 2008, by using DIEM plates. “Air Quality—Ambient Air—Determination of the Mass of Dry Atmospheric Depositions—Sampling on Deposit Plates—Preparation and Treatment” clearly described the placement of plates, coated with petroleum jelly, to analyze and subsequently treat the collected samples. The particulate phase dry deposition flux was measured using two smooth deposition plates (22.2 × 7.5 cm² for each one) that were pointed at 1.5-meter height into a metal holder. The dimensions of each greased strip placed on the deposition plate were 10 × 5 cm². Two greased strips mounted on deposition plates with a total collection area of 100 cm² were used for each deposition sample. This type of deposition plate was used successfully as a surrogate surface by others to directly measure particulate dry deposition [23, 24].

For the purpose of the present study, deposition plates and strips were washed with alcohol and dichloromethane to remove all the impurities. Finally, strips were dried at 105°C, adequately numbered, and stored in separate containers for subsequent use. Those strips are made of aluminum (5 × 10 cm²) and covered with petroleum jelly. According to the NF standard 43-007, 2008, strips have to be placed. Afterward, GPS coordinates of all sampling points were registered for further mapping.

After the sampling period of 7 days, strips were collected and submitted to the following laboratory treatments to collect dust samples:

(i) Connect the Erlenmeyer flask with screw to the pump.

(ii) Weigh the virgin filter in a precision balance (three weightings).

(iii) Place the filter on top of the Buckner funnel; place the top part and the spring that allows the joining of both parts.

(iv) Using a pipette, place a small amount of dichloromethane on the surface of the strip containing dust.

(v) Scrape with a spatula.

(vi) When the strip is completely cleared, proceed to the filtration connecting the pump.

(vii) Remove the filter from the Buckner funnel and weigh the sample with a precision balance (three weightings).

Nine campaigns of measure were carried out by covering the selected period on a weekly basis. The weekly fluxes of atmospheric fallout instances were expressed in g/m². Meteorological data such as air temperature, humidity, atmospheric pressure, wind velocity, and dominant wind direction was obtained from the meteorological station of Sfax Airport, the closest station to the sampling sites.

3. Climatic Characteristics of Sfax City

Sfax, a southern city of Tunisia (latitude 34°45′ N; longitude 10°46′E), borders the Mediterranean Sea (Figure 1). Its semiarid climate is therefore influenced by marine exposure generating a well ventilated area by low to moderate wind, rarely exceeding 5 m/s [22]. However, the influence of both continental and maritime air masses may lead to hot and dry summer with relatively cold and wet winter. Average temperature was estimated to be 12.3°C for winter season and 24.9°C for summer. It is to be mentioned that hot season is much longer than cold one, lasting more than five months per year (May—September) with an average temperature >24.2°C. As for rainfall, the region received about 217 mm/year with high seasonal and annual fluctuations.

4. Industrial Activities

Sfax is considered as the most industrial city of Tunisia. The main industrial activities included phosphate treatment (“SIAPE” plant), soap manufacturing (“SIOS-ZITEX”), and lead secondary melting industry (“FP Sfax Sud”). Most of those activities are located to the southern edge of the city; they threatened the environment because of their high emission of sulfur oxides (SOx) and particulate matter that largely exceeded the Tunisian standards [21]. SIAPE factory released about 4.5 tons/day of particulate matter with high amounts of sulphate, phosphorous compounds, and SOx, largely exceeding the permissible emission standards (8 and 20 times for particulate matter and SOx, resp.). For instance, soap industry discharged about 5.2 tons per day of particulate matter (>10 times the permissible emission standards value). Concerning the main source of particulate matter emissions, one can adopt the following sequence: SIOS-ZITEX (46%) > SIAPE (39%) > lead melting industry (15%) (Figure 2). In this regard, Azri et al. [25] stated that SIAPE and the lead melting industry were the main sources of heavy metals, as confirmed by the high enrichment factor of particulate matter with regard to heavy metals. They demonstrated that SIAPE was the main source of heavy metals (Zn, Ni, Cd, and Cu) with more than 9 g of Zn per ton of treated raw materials (equivalent to 8 kg/day of Zn emitted in the atmosphere); the emission factors of Ni, Cd, and Cu ranged between 2 and 3.2 g/ton. As for lead foundry, the emission of Pb was evaluated to be 68 kg/ton (equivalent to 200 kg/day of Pb released in the atmosphere). In contrast, the emission factors...
Table 1: Variation of the weekly fluxes (g/m²) of dry particulate fallout during the period of study.

| Sites | C1    | C2    | C3    | C4    | C5    | C6    | C7    | C8    | C9    | Weekly average fluxes (g/m²) |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------------------------------|
| TS3   | 1.128 | 2.444 | 0.940 | 2.256 | 2.256 | 0.376 | 1.128 | 0.376 | 0.752 | 1.295                         |
| TS16  | 0.799 | 2.632 | 0.752 | 1.128 | 0.752 | 0.376 | 0.752 | 0.564 | 0.376 | 0.903                         |
| TS20  | 0.564 | 3.008 | 0.940 | 1.316 | 1.880 | 1.504 | 0.564 | 0.752 | 0.940 | 1.274                         |
| TS25  | 0.470 | 2.256 | 1.128 | 1.504 | 3.760 | 0.940 | 0.376 | 0.752 | 0.752 | 1.326                         |
| PM2   | 0.376 | 1.504 | 1.034 | 1.410 | 1.880 | 0.799 | 2.257 | 0.752 | 0.940 | 1.010                         |
| R2    | 0.752 | 1.128 | 1.010 | 0.376 | 3.759 | 0.376 | 0.376 | 0.940 | 0.376 | 1.693                         |
| R3    | 0.752 | 2.256 | 0.987 | 0.893 | 1.880 | 0.799 | 2.257 | 0.752 | 0.752 | 1.258                         |
| PI1   | 3.383 | 0.376 | 1.445 | 0.634 | 0.752 | 1.504 | 3.947 | 1.128 | 0.376 | 1.693                         |
| PI2   | 1.880 | 5.146 | 1.880 | 0.505 | 2.256 | 0.940 | 2.256 | 8.271 | 1.880 | 2.779                         |
| TS35  | 1.880 | 9.915 | 1.662 | 0.570 | 1.504 | 1.034 | 3.947 | 4.694 | 1.124 | 2.927                         |
| TS38  | 1.880 | 8.717 | 1.771 | 1.601 | 0.940 | 1.128 | 3.102 | 6.485 | 1.316 | 2.993                         |
| S6    | 1.316 | 7.319 | 1.717 | 2.632 | 0.376 | 1.081 | 3.524 | 5.992 | 1.504 | 2.807                         |
| TS2   | 2.162 | 0.376 | 0.376 | 1.504 | 0.752 | 5.639 | 1.128 | 1.124 | 1.316 | 1.597                         |
| TS7   | 2.232 | 2.820 | 1.880 | 0.752 | 1.504 | 3.383 | 0.376 | 0.376 | 0.752 | 1.564                         |
| TS10  | 2.303 | 5.263 | 0.376 | 2.256 | 1.128 | 1.128 | 1.504 | 0.750 | 1.504 | 1.801                         |
| TS12  | 2.444 | 2.632 | 0.752 | 0.728 | 0.376 | 0.752 | 7.519 | 1.128 | 1.146 | 1.622                         |
| TS13  | 1.880 | 3.806 | 3.008 | 0.940 | 0.705 | 0.887 | 0.376 | 1.498 | 1.504 | 1.622                         |
| TS32  | 0.752 | 5.827 | 1.730 | 0.376 | 0.752 | 1.504 | 3.419 | 1.128 | 0.752 | 1.804                         |
| TS36  | 0.752 | 4.135 | 1.744 | 1.504 | 0.564 | 1.292 | 3.313 | 3.360 | 1.128 | 1.977                         |
| TS42  | 3.007 | 4.981 | 2.369 | 1.128 | 0.658 | 1.398 | 1.897 | 2.244 | 0.752 | 2.048                         |

C1: from 11 to 17 November 2012.  
C2: from 25 November to 1 December 2012.  
C3: from 2 to 8 December 2012.  
C4: from 30 December 2012 to 5 January 2013.  
C5: from 27 January to 2 February 2013.  
C6: from 3 to 9 February 2013.  
C7: from 24 February to 2 March 2013.  
C8: from 12 to 18 March 2013.  
C9: from 9 to 15 April 2013.

of the selected metals (i.e., Pb, Zn, Ni, Cd, and Cu) by the SIOS-ZITEX plant were insignificant.

5. Results and Discussions

Atmospheric particulate fallout instances as well as their spatiotemporal distribution were studied in detail to find out their most significant impact on the southern urban zone of Sfax area, southern Tunisia. Depending on current pollutants sources and weather conditions, the obtained results are described below.

5.1. Distribution of the Atmospheric Particulate Fallout Instances. Atmospheric particulate fallout instances recorded in the southern area of Sfax City showed highly variable values; the weekly flow values ranged from 0.376 to 9.915 g/m² (Table 1) with an average of 1.750 g/m². This value was lower than the permissible values fixed by the French (AFNOR) and German (TA-LUFT) standards (i.e., 7 and 2.45 g/m² for AFNOR and TA-LUFT, resp.). The maximum weekly flux largely exceeded the relevant standards (1.5 to 4 times) in several sites. Furthermore, the registered fluxes were significantly different from those reported in other studies (Table 2) [6–20]. Based on their behavior (i.e., trends and amplitudes), spatial distribution of particulate fallout fluxes can be classified into three main groups (Figure 3):

(i) The first group included TS3, TS16, TS20, TS25, PM2, R2, R3, and PI1 study sites with weekly fluxes ranging...
between 0.376 and 3.76 $g/m^2$. It presented about 42% of the studied sites with somewhat similar trends.

(ii) The second group represented about 26% of the studied sites (i.e., PI2, TS35, TS36, TS38, and S6) with higher weekly fluxes (about 9.915 $g/m^2$) and high variable trends.

(iii) The third group covered 32% of the studied sites (i.e., TS7, TS10, TS2, TS12, TS13, TS32, and TS42) characterized by moderate fluxes (5.827 $g/m^2$) combined with moderately variable trends.

Cluster analysis was carried out using the ITCF statistical software package [26] to classify variables (i.e., sites of collection) based on the average linkage method. Pearson correlation coefficients were also used instead of the Euclidean distance that may lead to erroneous conclusions [27]. The establishment of dendrogram related to the study sites allowed deciphering the same main groups previously identified (Figure 4).

Figure 5 illustrated the average flow of each site, showing a significant spatial variability of deposits. The linear regression between particulate deposit fluxes and their respective average deviations (Figure 6) shows that the higher the flux, the higher its standard deviation. The exposure to the industrial plumes (i.e., SIOS-ZITEX, FP Sfax Sud, and SIAPE) of each deposit site indicated that the highest fluxes values were recorded in PI2, TS35, TS36, TS38, and S6 study sites; they are strongly associated with the particulate fallout instances of SIAPE (Figure 7). It is worth noting that the exposure frequency was calculated through the occurrence of industrial plumes crossing each site downstream dominant winds. The methodology was based, first, on the emplacement of the center of the study period dominant wind rose at each point representing the industrial sources presented in Figure 1, second, on the computation of the frequency (%) of dominant wind directions joining each industrial source and study sites receiving maxima of deposit fallout instances, and, finally, on the establishment of industrial plume trajectories (the plume axis was chosen as superimposed to the dominant wind direction) simulated by screen 3 software [28] for identifying the other exposed sites. Therefore, they are the most threatened by the aspect of the particulate deposits (quantitative and qualitative aspects). Further examination of the studied sites indicated that “SIAPE” was the main source of metals released in the atmosphere of the Sfax urban zone [25].

Temporal variation of particulate deposit fluxes demonstrated a weekly average value of 0.376 to 9.915 $g/m^2$, showing large fluctuations (Figure 8) within the same site and

### Table 2: Fluxes of particulate deposits measured at different conditions from several areas over the world.

| Sites                                      | Weekly dry particulate deposits measured at different conditions ($g/m^2$) | Authors |
|--------------------------------------------|--------------------------------------------------------------------------|---------|
| Southern urban Sfax                        | 0.376–9.915                                                              | This work |
| Urban Constantine (Algeria)                | 7.735                                                                    | [6]     |
| Urban Dakar                                | 3.99                                                                     | [7]     |
| Urban New Zealand (Canada)                 | 5.131–37.681                                                            | [8]     |
| Urban British Columbia                     | 2.541                                                                    | [9]     |
| Urban Australia                            | 13.223                                                                   | [10]    |
| Urban China                                | 4.669–17.892                                                            | [11]    |
| Urban Miami, Florida, USA                  | 0.273                                                                    | [12]    |
| Urban Sapporo, Japan                       | 1.211                                                                    | [13]    |
| La Mède (France)                           | 0.166                                                                    | [14]    |
| Kozani (western Greece) Urban zone         | 1.33                                                                     | [15]    |
| Vegoritis (western Greece) Rural zone      | 0.77                                                                     | [15]    |
| Petran (western Greece) Rural zone         | 0.791                                                                    | [15]    |
| Mallorca (Balearic Islands, Spain) Rural zone | 0.119                                                                  | [16]    |
| Tafira, Gran Canaria, Canary Islands (Spain)| 0.175                                                                  | [17]    |
| Montiers-sur-Saulx (France) Rural zone     | 0.031                                                                    | [18]    |
| Marienau, Forbach (France) Industrial zone | 1.435                                                                    | [19]    |
| Chuan-Xin (Taiwan) Industrial zone          | 2.192                                                                    | [20]    |
between sites. The increase of particulate deposit fluxes can be attributed to the combined effect of both neighboring sources and the airflow properties which has been for a long time governed by meteorological conditions.

5.2. Influence of the Regional Meteorology and the Effect of the Particular Conditions. Figure 8 showed that temporal particulate fallout instances are highly variable. Based on particulate deposits, two main periods (i.e., C2 and C8) can be easily recognized for their high fluxes usually associated with the predominant strong cyclonic episodes. Those fluxes values were much higher than those recorded under stable conditions, supposed to be favourable for the accumulation of various pollutants [29]. During C2 and C8 periods, low surface pressures over Sfax (associated with relatively higher wind speeds) were predominant (Figures 9 and 10); unstable weather conditions can be adapted as possible explanation (Figure 11). The meteorological factor in favor of high particles deposition fluxes in these periods can be found, on the one hand, in the highest frequencies of industrial plumes, especially of SIAPE (23% of total observations) crossing the sites (PI2, TS35, TS36, TS38, and S6) (Figure 7), associated with the relative increase of wind speeds reaching 8 m/s. On the other hand, these high fluxes can be accentuated by emission conditions and the existence of obstacles. It was proven in the case of plumes emitted at low altitudes that the wind increases the deposition of particles instead of insuring...
their dispersion, creating hence risk zones of locally increasing pollution levels [30]. The presence of various obstacles enhanced particles deposition speed [31–33]. Previous works at urban Sfax carried out by JICA [34] proved that the actual heights of SIAPE chimneys (between 30 and 70 m) were lower than those necessary for the good diffusion of emissions (equivalent height ≥ 100 m). Furthermore, the existence of phosphogypsum deposit (resulting from processing plants of phosphates) having 20 m height and an area of many hectares, located on the side of Sfax solar saltern at 200 m of the SIAPE, would constitute an obstacle against the emitted effluents (especially by southwest wind directions). Studies carried out by Azri et al. [21] proved that, under extremely unstable atmospheric conditions associated with relatively high wind velocities reaching 8 m/s, very high amounts of various gaseous and particulate pollutants were recorded at both upstream and downstream phosphogypsum deposit, especially at exposed sites to SIAPE plume. Concentrations of such pollutants can be multiplied by a factor of 10. This result was also proved elsewhere [35]. Furthermore, these relatively high wind velocities may enhance earth dust transportation by exceeding the threshold velocity (7 m/s [35, 36]).

Succinct analysis of the synoptic maps revealed that, since November 26, 2012 (i.e., C2 period), Tunisia has been under the influence of many successive surface depressions that took place over the Mediterranean Sea (Figure 9). These depressions were associated with the Mediterranean front that separated the European cold air masses from the Saharan hot ones. A low-pressure zone over Europe (at 500 hPa) was characterized by strong winds. As for the temperature, it clearly decreased during the subsequent days (Figure 12). On November 26, 2012, the rapidly evolving surface depression moved towards the east of Italy. From November 27 to December 1, 2012, many successive surface depressions moved towards the east of the Mediterranean Sea.

On March 13, 2013 (i.e., C8 period), surface depression was centred over Spain. It was persistent over western Mediterranean Sea until March 16, 2013. Then, it moved on March 17 toward the central and eastern Mediterranean Sea. On March 14 and 15, 2013, the meteorological situation can be described as a vertical superposition over western Spain of surface depressions and low geopotentials. The evolution of temperature at 850 hPa (as seen in C2 period) clearly witnessed a decline in the successive days (Figure 13). This particular period, associated with relatively high wind speeds (8 m/s), was characterized, over Sfax, by a cloudy sky and low temperatures (a decrease of 3 to 6°C for maximum registered temperatures at 14:00 LT). These environmental conditions favored the dilution phenomenon that will lead to the decrease of the air constituent concentrations, except for ozone concentrations enriched by the landing stratospheric air masses [37, 38]. However, significant increase of particulate deposition was observed over PI2, TS35, TS36, TS38, and S6 study sites, as seen in C2 situation. This can be explained by high frequencies of industrial plumes especially of SIAPE (23% of total observations) and the increase of surface wind velocities (about 8 m/s).

On March 16, 2013, the surface depression and the low geopotential area, under the dominance of western and northwestern winds, moved to the east. Since March 18 2013, it moved towards Eastern Europe while Tunisia returned to stable weather.

Results presented above were refined by a factorial analysis of correspondences applied both to atmospheric particulate fallout instances collected at the study sites (RMSE, d(TS2), d(TS38), d(TS16), d(TS10), d(TS13), d(TS32), and d(TS42)) through the nine campaigns and to binary numbers related to registered classes for atmospheric surface pressure, wind velocity, wind sectors, air temperature, and humidity. Three classes P1–P3 related to the atmospheric surface pressure were selected (P1 ∈ [1,002; 1,014 hPa]; P2 ∈ [1,014; 1,020 hPa]; P3 ∈ [1,020; 1,030 hPa]). For the wind velocity, three classes V1–V3 were chosen (V1 ∈ [1; 3 m/s]; V2 ∈ [3; 5 m/s]; V3 ∈ [5; 8 m/s]). Four wind sectors S1–S4 were also selected (SI ∈ [0; 90°]; S2 ∈ [90; 180°]; S3 ∈ [180; 270°]; S4 ∈ [270; 360°]). For the temperature, two classes T1–T2 were chosen (T1 ∈ [11; 17.5 C]; T2 ∈ [17.5; 24 C]). For the relative humidity, four classes have been selected (RH1 ∈ [34; 43%]; RH2 ∈ [43; 52%]; RH3 ∈ [52; 61%]; RH4 ∈ [61; 70%]).

The projection over the 1 × 2 factorial plane (presenting the maximum of inertia) of all selected particulate deposit fluxes and meteorological variables shows distinct data groups (Figure 14):

(i) Group GI was characterized by the concomitant effect of the predominant strong cyclonic episodes and SIAPE effluent fallout instances distinguished by an unstable atmosphere (PI) associated with relatively
high velocities ($V_3$) favourable to the accentuation deposit fallout instances in P12, TS35, TS36, TS38, and S6 study sites. The association of these component parameters is well pronounced under the predominance of the western wind’s sector ($S_3$) which drained the industrial plumes, especially of SIAPPE. This group was more pronounced in C2 and C8 campaigns.

(ii) Group G2 was representative of the periods characterized by the effect of the steady to very steady atmosphere. It was pronounced in most campaigns (except for C2 and C8). During these campaigns, atmospheric surface pressure was higher than 1,014 hPa ($P_2$ and $P_3$), implying a stable to very stable atmosphere. Wind speeds are relatively lower and reach values oscillating between 1 and 5 m/s ($V_1$ and $V_2$).

The deposit fallout instances ($d_{(TS3)}$, $d_{(TS16)}$, $d_{(TS20)}$, $d_{(TS25)}$, $d_{(PM2)}$, $d_{(R2)}$, $d_{(R3)}$, $d_{(P11)}$, $d_{(TS7)}$, $d_{(TS10)}$, $d_{(TS2)}$, $d_{(TS12)}$, $d_{(TS13)}$, $d_{(TS32)}$, and $d_{(TS42)}$) in the remaining study sites (compared to those of the first group) were shown to be influenced by the dominance of the eastern, southern, and western wind’s sector ($S_1$, $S_2$, and $S_4$). The temperature and the humidity were shown without significant effect.

Significant adverse effects of the local industrial activities threatened the environment in Sfax area, especially the southern edge of the city where several activities are being performed. Therefore, it is necessary to undertake a sustainable management policy that would meet the national environmental standards and regulations. More in-depth studies
can provide evidence of the challenges related to environmental sustainability and the implementation of active measures to reduce the adverse effects of particulates emission. It is therefore recommended to take the following considerations into account:

(i) Ensuring adequate treatment of the industrial emissions, especially for SIAPE factory.

(ii) Strengthening the control network of both dry and wet deposits in Sfax urban zones and its suburbs to master pollutants distribution.

(iii) Taking all the measures required for the protection of the environment.

6. Conclusions

The spatial and temporal evolution of the particulate fallout instances in southern urban area of Sfax was studied to find out its environmental impact on the neighboring areas. It was found that particulate fluxes showed significantly variable trends. Based on their behavior (trends and amplitudes), spatial distribution of particulate fallout fluxes can be classified into three main patterns:

(i) The first pattern, covering 42% of sites (TS3, TS16, TS20, TS25, PM2, R2, R3, and PI1), was characterized by fluxes ranging between 0.376 and 3.76 g/m².

(ii) The second pattern concerning 26% of sites (PI2, TS35, TS36, TS38, and S6) recorded high fluxes, reaching 9.915 g/m².

Figure 10: Surface synoptic maps over Sfax on (a) 13/03/2013, (b) 14/03/2013, (c) 15/03/2013, (d) 16/03/2013, and (e) 17/03/2013.
(iii) The third pattern was an intermediate group characterized by moderate fluxes reaching 5.827 g/m²; it represented 32% of sites (TS7, TS10, TS2, TS12, TS13, TS32, and TS42).

Such distribution patterns seemed to be governed by the combined effects between surrounding industrial sources, exposure to industrial plumes, and local airflow characteristics.

Under relatively predominant strong cyclonic situations, the increase in fluxes exceeded the levels recorded under the conditions of relatively strong stabilities that usually enhance pollutants accumulation. The meteorological factor in favour of high fluxes of particles deposition can be found in the highest frequencies of industrial plumes, associated with the relative increase of wind speeds and the effect of the phosphogypsum deposit constituting an obstacle against the emitted effluents.

**Conflict of Interests**

The authors declare that there is no conflict of interests regarding the publication of this paper.
Acknowledgments

The authors would like to thank Messrs. Fathi Bourmech and Ali Sdiri, respectively, Professor at the Faculty of Arts at Sfax and Assistant Professor at the National School of Engineers at Sfax, for careful editing and proofreading of this paper.

References

[1] M. Viana, T. A. J. Kuhlbusch, X. Querol et al., "Source apportionment of particulate matter in Europe: a review of methods and results," Journal of Aerosol Science, vol. 39, no. 10, pp. 827–849, 2008.

[2] B. Wei, F. Jiang, X. Li, and S. Mu, "Spatial distribution and contamination assessment of heavy metals in urban road dusts from Urumqi, NW China," Microchemical Journal, vol. 93, no. 2, pp. 147–152, 2009.

[3] C. Ridame, C. Guieu, and M. D. Loyé-Pilot, "Trend in total atmospheric deposition fluxes of aluminium, iron, and trace metals in the northwestern Mediterranean over the past decade (1985–1997)," Journal of Geophysical Research, vol. 104, pp. 127–138, 1999.

[4] A. M. Al-Dousari, J. Al-Awadhi, and M. Ahmed, “Dust fallout characteristics within global dust storm major trajectories,” Arabian Journal of Geosciences, vol. 6, no. 10, pp. 3877–3884, 2013.

[5] F. Ellouz, M. Masmoudi, K. Medhioub, and C. Azri, “Temporal evolution and particle size distribution of aerosol constituents collected in Northern Tunisia (Boukornine) under sirocco wind circulations,” Arabian Journal of Geosciences, vol. 7, no. 10, pp. 4399–4406, 2014.

[6] N. Serghani, "Mesure de la pollution particulaire et métallique dans l’air au niveau de trios sites urbaines de la ville de Constantine,” in Colloque International Environnement et Transports Dans des Contextes Différents, E. N. P. Actes, Ed., pp. 157–162, Ghardaïa, Algérie, Février 2009.

[7] D. Orange and J. Y. Gac, "Bilan géochimique des apports atmosphériques en domaines sahélien et soudano-guinéen d’Afrique de l’Ouest (bassins supérieurs du Sénégal et de la Gambie),” Géodynamique (Paris), vol. 5, no. 1, pp. 51–65, 1990.
[8] S. K. Marx and H. A. McGowan, "Dust transportation and deposition in a superhumid environment, West Coast, South Island, New Zealand," *Caten*, vol. 59, no. 2, pp. 147–171, 2005.

[9] P. N. Owens and O. Slaymaker, "Contemporary and post-glacial rates of aeolian deposition in the Coast Mountains of British Columbia, Canada," *Geografiska Annaler: Series A: Physical Geography*, vol. 79, no. 4, pp. 267–276, 1997.

[10] G. H. McIntainsh and A. W. Lynch, "Quantitative estimates of the effect of climate change on dust storm activity in Australia during the last glacial maximum," *Geomorphology*, vol. 17, no. 1–3, pp. 263–271, 1996.

[11] Z. Cao, Y. Yang, J. Lu, and C. Zhang, "Atmospheric particle characterization, distribution, and deposition in Xi’an, Shaanxi Province, Central China," *Environmental Pollution*, vol. 159, no. 2, pp. 577–584, 2011.

[12] J. M. Prospero and T. N. Carlson, "Vertical and aerial distribution of saharan dust over the western Equatorial North Atlantic Ocean," *Journal of Geophysical Research*, vol. 77, pp. 5255–5265, 1972.

[13] M. Uematsu, F. Z. Wang, and I. Uno, "Atmospheric input of mineral dust to the Western North Pacific region based on direct measurements and a regional chemical transport model," *Geophysical Research Letters*, vol. 30, no. 6, article #1342, 2003.

[14] AIRFOBEP, "Investigations dans les communes de Châteauneuf-les-Martigues," La Médécampagnejuin 2009–avril 2010, 2010.

[15] E. Terzi and C. Samara, "Dry deposition of polycyclic aromatic hydrocarbons in urban and rural sites of Western Greece," *Atmospheric Environment*, vol. 39, no. 34, pp. 6261–6270, 2005.

[16] J. C. Cerro, S. Caballero, C. Bujosa, A. Alastuey, X. Querol, and J. Pey, "Aerosol deposition in Balearic Islands as overview of the deposition in the Western Mediterranean," in *Proceedings of the 2nd Iberian Meeting on Aerosol Science and Technology—RICTA*, Tarragona, Spain, 2014.

[17] P. López-García, M. D. Gelado-Caballero, D. Santanacastellano, M. Suárez de Tangil, C. Collado-Sánchez, and J. J. Hernández-Brito, “A three-year time-series of dust deposition flux measurements in Gran Canaria, Spain: a comparison of wet and dry surface deposition samplers,” *Atmospheric Environment*, vol. 79, pp. 689–694, 2013.

[18] E. Lequy, C. Calvaruso, S. Conil, and M. P. Turpault, "Atmospheric particulate deposition influence by tree canopy in beech forests in the north of France,” *Science of the Total Environment*, vol. 487, pp. 206–215, 2014.

[19] Commission des Communautés Européennes, “Recueil de recherches charbon Pollution atmosphérique en Côckeries,” EUR 6071 FR, CECCHAR, Paris, France, 1978, Convention No. 6220 EB/3/301 Édité par la Direction Générale “Information Scientifique et Technique et Gestion de l’Information”.

[20] G.-C. Fang, S.-C. Chang, Y.-C. Chen, and Y.-J. Zhuang, "Measuring metallic elements of total suspended particulates (TSPs), dry deposition flux, and dry deposition velocity for seasonal variation in central Taiwan,” *Atmospheric Research*, vol. 143, pp. 107–117, 2014.

[21] C. Azri, A. Maela, K. Medhioub, and R. Rosset, "Evolution of atmospheric pollutants in the city of Sfax (Tunisia) (October 1996–June 1997)," *Atmosfera*, vol. 20, no. 3, pp. 223–246, 2007.

[22] Direction Générale de l’Aménagement du Territoire (DGAT), "Atlas du gouvernorat de Sfax," Rapport de la Deuxième Phase, Direction Générale de l’Aménagement du Territoire (DGAT), Tunis, Tunisia, 1995.

[23] M. Odabasi, A. Sofuoglu, N. Vardar, Y. Tasdemir, and T. M. Holsen, "Measurement of dry deposition and air-water exchange of polycyclic aromatic hydrocarbons with the water surface samples,” *Environmental Science and Technology*, vol. 33, no. 5, pp. 426–434, 1999.

[24] M. Odabasi, A. Muezzinoglu, and A. Bozlaker, "Ambient concentrations and dry deposition fluxes of trace elements in Izmir, Turkey,” *Atmospheric Environment*, vol. 36, no. 38, pp. 5841–5851, 2002.

[25] C. Azri, A. Tili, M. M. Serbai, and K. Medhioub, “Etude des résidus de combustion des huile liquide et solide et de traitement chimique du phosphate brut dans la ville de Sfax (Tunisie),” *Pollution Atmosphérique*, vol. 174, pp. 297–308, 2002.

[26] STATIT-CF, "Services des études statistiques de l’Institut Technique des Céréales et Fourrages (I.T.C.F.)," Boigneville, 1987.

[27] G. Andreew and V. Simeonov, "Application of cluster analysis to the study of connection between sampling location and composition of sea water samples,” *Fresenius’ Zeitschrift für Analytische Chemie*, vol. 325, no. 2, pp. 146–149, 1986.

[28] US Environmental Protection Agency (USEPA), "Screen 3 model user’s guide,” Tech. Rep. EPA/600/4-90/027F, 1995.

[29] Z. H. Chen, S. Y. Cheng, J. B. Li, X. R. Guo, W. H. Wang, and D. S. Chen, "Relationship between atmospheric pollution processes and synaptic pressure patterns in northern China,” *Atmospheric Environment*, vol. 42, no. 24, pp. 6078–6087, 2008.

[30] A. Robins and T. Hill, “Borne on the wind: Understanding the dispersion of power station emissions,” A Report of Atmospheric Dispersion Research Carried Out Since 1960 by the CEGB and by the Joint Environmental Program on UK, RWE n Power, EDF Energy, International Power, British Energy, Drax Power, Scottish and Southern Energy, and Scottish Power, 2005.

[31] Organisation Mondiale de la Santé, *Manuel de gestion de la qualité de l’air des villes*, OMS, Genève, Switzerland, 1978.

[32] H. Ryde, *The Importance of Meteorology in Building*, Organisation Météorologique Mondiale, Genève, Switzerland, 1970.

[33] W. Bach, “Global air pollution and climate change,” *Reviews of Geophysics and Space Physics*, vol. 14, pp. 429–474, 1976.

[34] Japan International Cooperation Agency JICA, "The study on wastewater treatment and recycling of selected industries in the region of Sfax in the republic of Tunisia," Final Report, JICA, 1993.

[35] L. G. Reydet, *Contribution à l’étude des origines de quelques constitutifs de lauréosol atmosphérique en milieu côtier* [Thèse de doctorat], Université de Paris VII, 1984.

[36] I. Belghith, *Study of the atmospheric aerosol in the region of Sfax: influence of local and synoptic meteorological conditions* [Ph.D. dissertation], University of Tunis II, 1999.

[37] J. L. Baray, S. Baldy, R. D. Diab, and J. P. Cammas, "Dynamical study of a tropical cut-off low over South Africa, and its impact on tropospheric ozone,” *Atmospheric Environment*, vol. 37, no. 11, pp. 1475–1488, 2003.

[38] C. M. Campetella and N. E. Possia, "Upper-level cut-off lows in southern South America,” *Meteorology and Atmospheric Physics*, vol. 96, no. 1–2, pp. 181–191, 2007.
