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The Impact of Weather Parameters on Atmospheric PM2.5 at Al-Hasan Industrial Zone, East of Irbid- Jordan

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Abstract

Particulate Matters less than 2.5 micrometers (often referred to as $PM_{2.5}$) were measured in Al-Hassan Industrial Estate (HIE) in Irbid city, 72 Km north of Amman, the capital of Jordan. Data sets on the $PM_{2.5}$ emissions and meteorological conditions were collected over 6 years (from March 2010 to December 2016) by Jordan Ministry of Environment. The present paper studies the effects of the meteorological conditions on $PM_{2.5}$ levels. It is found that the largest average concentration of $PM_{2.5}$ is 39.77 $\mu g/m^3$ with standard deviation 49.42$\mu g/m^3$ which occurred in 2013, while the smallest average concentration of $PM_{2.5}$ is 22.2 $\mu g/m^3$ with standard deviation of 25.99 $\mu g/m^3$ which occurred in 2016; this is due to the positive relationship of $PM_{2.5}$ with temperature and its negative relationship with humidity. Furthermore, we conducted a nonparametric Kruskal-Wallis (KW) test to compare the average $PM_{2.5}$ level in working and nonworking hours. The KW test produced a p-value=0(<0.05), which indicates higher average $PM_{2.5}$ levels in working hours. The data indicate that the yearly average of $PM_{2.5}$ levels exceed the permissible limits of the Jordanian standards ambient air quality for the records of all years. Pronounced seasonal variation indicates that the $PM_{2.5}$ levels were generally higher in the summer months than its levels in the winter months, which means that the meteorological conditions have a significant impact on the $PM_{2.5}$ concentrations in the study site.

Keywords: Air Pollution, Statistical Analysis, Al-Hassan Industrial Estate (HIE), Meteorological Parameter, Particulate Matter.

1. Introduction

Air pollution continues to receive considerable attention worldwide because of its negative effects on human health and welfare (Dockery and Pope, 1994; U.S. EPA 1999a; U.S. EPA 1999b; Jeff and Hans 2004). Particles less than 2.5 micrometers ($PM_{2.5}$) are classified as air pollutants with a diameter of less than 2.5 micrometers. $PM_{2.5}$ includes various directly emitted primary and secondary aerosols that are formed through chemistry of gaseous precursors in the atmosphere (Seinfeld and Pandis, 2006). Their small sizes enable them to reach deep parts of the respiratory system and lung airways in the human body. It is a mixture of microstructure solids and liquid droplets in the air (Y. Li, 2013). $PM_{2.5}$ particles consist of multiple compounds and are formed from primary and secondary participles (Zhao *et al*., 2013).

Aerosols are introduced into the atmosphere from a variety of anthropogenic sources, including transport, industrial activities, and biomass burning, as well as from natural sources, such as volcanic eruptions, sea salt, soil dust suspension, and forest fires. Most particulate emissions from combustion sources are $PM_{2.5}$ mass fractions. Fine particles can be directly emitted by sources or produced by condensation, coagulation, or gas-to-particle conversion, the last being common to combustion sources. Detailed descriptions of atmospheric aerosols can be found in the literature (Seinfeld and Pandis 1998; Finlayson-Pitts and Pitts, 2000).

Primary particles are emitted directly from the source, like combustion industrial processes and in natural processes (e.g., volcanic eruption). Secondary particles are formed indirectly through nucleation, condensation or processes where the gaseous pollutants (SOx, NOx, NH_3, VOCs) are involved in particle formation or growth. Secondary sulfate and nitrate particles formed from SOx or NOx precursors are usually the dominant component in $PM_{2.5}$ particles. As a result of the chemical components in secondary participles, the effect of high $PM_{2.5}$ concentrations on both environmental and human health (Wang and Hao, 2012).

Meteorological conditions play important roles in $PM_{2.5}$ concentrations due to their mixing, dispersion, transportation and formation of aerosol particles. Therefore, temporal variations in a pollutant concentration arises from the variations in local meteorological conditions, like wind speed, wind direction, temperature and relative humidity (Elminir, 2005; Satangi *et al*., 2004). To give a better understanding of the causes of air pollution, we must study the influences of meteorological parameters on the pollutants.

The development of industrial and services sectors in Jordan accompanied with the growth of Jordanian population result increase in the pollutants emitted to the ambient air, which in turn causes degradation of the air quality in many areas and adversely impact the public health (Cohen *et al*., 2005).

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A few studies were conducted to assess the air quality in Jordan. The Royal Scientific Association (RSS) have monitored PM_{10} and $PM_{2.5}$ in Al-Hashymeia, a town where most of Jordan industries are concentrated during the interval March, 2000 through February 2001 (Asi *et al*., 2001). Their results showed that PM_{10} and $PM_{2.5}$ have exceeded the Jordanian 24 hour standard of 120 µg/m^3 during 20 days out of 50 days constitute the whole sampling period. Hussein *et al*. (2011) measured the submicron particle number concentrations in the urban/suburban atmosphere of Amman–Jordan during the spring of 2009 and found that during the morning rush hours the number concentrations were as high as 120 × 103 and 75 ×103 1/cm^3 at the urban and suburban sites during weekly workdays. Abu-Allaban *et al*. (2011) measured air pollution (dust, SO_2, NO_x and CO) emitted from a modern cement plant that will be constructed in the Jordan Badia South-East of Amman. They found that the TSP concentration is expected to be high at the limestone quarry, which provides the factory with its main raw material, because it generates lots of dust as a result of rocks mining and crushing. Therefore, it is so important to study ambient air quality of the residential areas that are close to the air pollution sources.

The main aims of the present study are to identify $PM_{2.5}$ levels in (HIE) and to compare the recorded averages of $PM_{2.5}$ with the Jordanian standards JS 1140/2006. It aims also studying the impact of pollution controlling parameters, such as temperature, humidity and wind on the behavior of pollution (Ministry of Environment Reports unpublished between 2010 -2016).

2. Methodology

2.1. Study Site

With aim of assisting Jordanian economic development, in March 1998 the Trade Representative of the United States established the Al-Hassan Industrial Estate in Irbid city, north Jordan as the initial Jordanian Qualifying Industrial Zone QIZ, (Figure 1). The (HIE) is the largest QIZ in the Kingdome of Jordan which is located in Irbid Governorate, 72 Km north of Amman the capital. The HIE is established in 1991 and in 1998 was designated as the first QIZ in the world and Developed in three phases with a total area of 117.8 ha. Furthermore, it accommodates more than 101 industries with a total invested capital of more than JD 222.5 million creating 16440 Job opportunities (Amman Chamber of Industry, 2013).

2.2. Monitoring Procedures

Ministry of environment,based on its mandate, signed agreement NO. 75/2008 with air studied division energy, water and environmental consultations and projects of the royal scientific society to study the ambient air quality of industrial states including the HIE. Therefore, careful equipment selection, methods development and testing and thorough quality assurance and quality control (QA & QC) procedures are essential for producing reliable and comparable $PM_{2.5}$ data (Tu *et al*., 2007). Hence, Air monitoring station (2m X 2.5m X 3m) was placed on a concrete mat (3m X 4m) and provided with special instruments. The station is designed to provide continuous measurement of $PM_{2.5}$ using Beta – Attenuation analyzer. Additionally, meteorological parameters, such as temperature, wind direction, relative humidity and wind speed were also measured. Continuous automatic measurements of all identified parameters have been made every five minutes for the periods of 2010 through 2016 (Ministry of Environment Reports unpublished between 2010 -2016).

It is worth to mention that the monitored data have been received daily by the air studies division via telecommunication system, which were transferred to data analysis software accessible by Ministry of environment via internet (Ministry of Environment Reports unpublished between 2010 -2016).

2.3. Statistical Analysis

On hourly, daily, monthly and yearly scales obtained from unpublished sources conducted by both Ministry of Environment and RSS. The statistical Package for Social Sciences (SPSS) version 22 was used to analyze the data. Two types of statistical analysis will be used, namely the descriptive and inferential statistics. Descriptive statistics, such as average, standard deviation, Median, the interquartile range (IQR), Pie chart and lines charts. While inferential statistics, such as 95% confidence interval for the mean and kruskal-wallis test were used.

3. Results and Discussion

3.1. Statistical Characterization of Air Pollutants

Monitoring results shows that the yearly average concentration was 28.69 (µg)/m^3, Table 1. Whereas the Monthly average concentration was 28.56 (µg)/m^3, Table 2. The highest monthly rate is a record for the month of August 2013, it reaches 36.54(µg)/m^3, Table 3.

Figure 1. Location map of HIE

Table 1. Yearly average, standard deviation, median, IQR and 95% confidence interval for the PM $_{2.5}$ levels in HIE

Year	Average	St.Dev.	Median	IQR	95% Confidence Interval	
					Lower	Upper
2010	37.1035	80.8942	21.875	20.5057	22.6727	51.2753
2011	29.5972	23.8388	31.8201	14.6852	26.36261	32.54097
2012	23.9463	18.7919	23.820	17.1134	20.77615	26.82021
2013	39.7714	49.4184	29.140	24.5175	28.09758	50.20544
2014	26.5690	3.1596	27.0491	0.8992	25.24753	27.80115
2015	23.0492	46.7258	16.410	15.6265	16.25825	29.42693
2016	22.2041	25.9953	20.590	13.4780	17.57633	26.36342
Overall	28.6929	41.8811	26.23	16.750	22.40650	34.04152

Table 2. Monthly average, standard deviation, median, IQR and 95% confidence interval for the $PM_{2.5}$ levels in HIE

Month	Average	Std. Dev.	95% Confidence Interval	
			Lower	Upper
January	24.0381	19.0896	22.69030	25.38776
February	24.8819	23.6027	21.80771	28.07834
March	29.0672	37.5579	25.25550	31.58773
April	23.7215	31.6786	21.68449	25.75884
May	25.8802	29.9985	21.68449	25.75884
June	29.4490	31.3732	23.74753	28.01118
July	33.2296	44.4486	31.04164	35.41965
August	36.5494	86.7679	31.11956	41.97980
September	30.9106	57.2160	24.25743	37.56323
October	29.8027	37.3931	27.10813	32.49639
November	28.2640	18.8436	26.81223	29.71444
December	26.9519	25.3761	25.24194	28.66128
Overall	28.56212	36.9455	25.20121	30.86855

Table 3. Descriptive statistics and 95% Confidence interval (C.I) of $PM_{2.5}$ levels by month and year at HIE

Month		Year													
		2010	C. I	2011		2012		2013		2014		2015		2016	
Jan	Mean	-		36.20	(33.71, 38.69)	20.181	(19.32, 21.04)	23.412	(22.46, 24.37)	27.862	(27.85, 27.86)	22.945	(22.19, 23.70	13.626	(12.35, 14.9)
	St.Dev	-		34.03		11.965		13.262		0.0442		10.526		17.705	
	Min	-		12.87		0.050		0.030		27.790		0.000		0.000	
	Median	-	-	33.25		19.085		23.200		27.860		26.010		9.015	
	Max	-		804.5		67.19		74.92		27.940		77.180		138.19	
	IQR	-		0.08		21.605		18.513		0.0800		8.770		11.997	
Feb.		-		33.120	(33.12, 33.12)	23.699	(22.10, 25.30)	20.876	(19.57, 22.18)	27.717	(27.71, 27.7)	28.90	(25.49, 32.31)	15.359	(13.94, 16.76)
		-		0.0401		21.539		17.182		0.0399		45.06		19.061	
		-	-	33.050		0.190		0.060		27.650		0.00		0.350	
		-		33.120		21.275		17.00		27.720		19.90		11.48	
		-		33.19		234.68		129.13		27.790		348.95		204.35	
		-		0.060		21.64		19.91		0.0700		19.88		12.365	
March		52.30	(46.32, 58.28)	30.402	(29.80, 31.01)	30.85	(28.06,33.64)	24.112	(23.31, 24.92)	27.571	(27.56, 27.57)	21.374	(20.74, 22.01)	16.862	(15.45, 18.27)
		83.28		8.382		38.89		11.181		0.0442		8.843		19.582	
		0.00		0.100		0.09		0.160		27.490		0.070		0.090	
		24.20		32.97		24.16		29.350		27.570		25.780		11.655	
		1036.6		33.050		287.07		152.110		27.650		70.580		240.790	
		41.56		0.070		19.19		14.068		0.0800		11.445		16.185	
April		32.27	(28.31,36.23)	18.524	(17.26,19.79)	22.765	(22.01,23.52)	25.34	(21.98,28.69)	27.421	(27.42,27.42)	17.673	(15.92, 19.42)	22.06	(19.92, 24.20)
		54.15		17.350		10.346		45.87		0.0427		23.943		29.30	
		0.01		0.000		0.150		0.66		27.350		0.070		0.01	
		16.91		14.350		22.760		16.38		27.420		13.795		13.27	
		588.80		138.00		61.650		589.15		27.490		439.880		309.76	
		19.23		016.50		16.587		19.03		0.0800		12.603		16.15	
May		29.57	(25.97, 33.17)	25.13	(22.14, 28.12)	24.376	(23.3, 25.41)	37.49	(35.015, 39.1)	27.271	(27.27, 27.28)	20.522	(19.65, 21.40)	16.793	(15.63, 17.96)
		50.05		41.62		14.388		34.45		0.0442		12.150		16.190	
		0.25		1.00		1.090		1.47		27.190		0.070		0.040	
		15.72		18.70		25.075		29.13		27.270		19.800		13.420	
		501.20		552.80		181.03		505.80		27.350		82.170		250.710	
		15.74		19.48		16.535		16.14		0.0800		13.757		16.415	

Month	Year													
	2010	C. I	2011		2012		2013		2014		2015		2016	
June	22.57 29.46 0.01 14.89 379.60 13.21	(20.42, 24.72)	25.190 20.639 0.000 23.25 275.20 20.505	(23.68, 26.70)	30.719 0.0427 30.650 30.720 30.790 0.0800	(30.72, 30.72)	61.05 64.33 0.01 44.14 567.7 44.59	(56.35, 65.75)	27.120 0.0427 27.050 27.120 27.190 0.0800	(27.12, 27.12)	16.904 11.254 0.030 14.735 78.180 13.725	(16.08, 17.73)	22.589 7.907 0.000 23.530 81.750 0.070	(22.01, 23.17)
July	25.88 39.27 0.38 19.23 483.90 15.10	(23.06, 28.70)	30.698 24.775 0.000 32.30 244.30 18.175	(28.92, 32.48)	30.472 2.009 11.570 30.570 61.340 0.0800	(30.33, 30.62)	74.22 93.50 0.75 59.09 1664.3 61.36	(67.50, 80.94)	26.970 0.0442 26.890 26.970 27.050 0.0800	(26.97, 26.97)	15.419 12.637 0.130 12.615 186.050 16.387	(14.51, 16.33)	28.950 25.671 0.000 23.40 151.71 13.887	(27.11, 30.79)
August	88.93 208.38 1.04 33.95 1528.10 24.57	(73.96, 103.9)	30.31 29.53 0.00 32.17 351.10 17.75	(28.19, 32.43)	21.038 9.442 0.150 20.185 60.600 12.267	(20.36, 21.72)	46.32 59.95 0.80 34.96 989.10 29.38	(42.01, 50.63)	26.817 0.0443 26.740 26.820 26.890 0.0800	(26.81, 26.82)	16.935 24.866 0.060 12.950 459.890 12.063	(15.15, 18.72)	25.487 20.975 0.160 23.210 140.890 8.578	(23.98, 26.10)
September	25.985 17.101 2.950 26.130 179.900 18.660	(24.74, 27.23)	30.353 21.648 0.100 32.03 218.30 16.105	(28.77, 31.93)	17.514 8.310 0.120 15.950 63.730 9.567	(16.91, 18.12)	46.48 32.51 4.88 38.47 244.50 34.88	(44.11, 48.85)	26.667 0.0429 26.590 26.670 26.740 0.0700	(26.66,26.67)	52.40 140.95 0.19 16.60 1314.27 19.16	(42.1, 62.70)	16.971 8.190 0.320 16.20 54.230 11.780	(16.37, 17.57)
October	31.40 44.41 4.29 18.62 680.60 20.25	(28.21, 34.59)	32.417 23.440 0.200 31.86 154.45 16.275	(30.73, 34.10)	24.57 32.75 0.40 19.80 640.87 14.39	(22.22, 26.92)	48.83 64.94 7.21 34.96 1028.9 30.88	(44.16, 53.50)	26.516 0.0443 26.440 26.520 26.590 0.0700	(26.51, 26.52)	21.216 25.461 0.420 14.495 255.970 15.010	(19.37, 23.05)	23.67 28.59 0.59 22.03 517.5 9.44	(21.62, 25.72)
November	27.466 25.029 0.350 20.20 186.400 17.905	(25.64, 29.29)	32.246 17.395 1.500 31.74 166.30 0 0.110	(30.97, 33.52)	21.239 12.444 0.100 19.800 114.330 17.395	(20.33, 22.15)	39.815 20.943 7.840 34.665 173.200 21.407	(38.28, 41.34)	26.366 0.0429 26.290 26.370 26.440 0.0700	(26.36, 26.37)	22.720 19.610 0.000 23.440 181.360 13.680	(21.29, 24.15)	27.997 18.642 0.260 25.375 204.15 18.335	(26.64, 29.36)
December	33.367 11.882 4.740 33.41 140.20 00.078	(32.51, 34.22)	30.522 4.750 0.270 31.62 31.700 00.080	(30.18, 30.86)	19.799 12.972 0.730 16.900 86.770 20.560	(18.87, 20.73)	27.921 3.808 5.170 28.01 79.480 0.080	(27.65, 28.19)	20.683 8.794 0.660 26.23 71.390 13.078	(20.05, 21.31)	20.71 28.68 0.47 13.34 296.81 11.58	(18.65, 22.77)	35.67 54.83 0.02 22.60 525.79 0.09	(31.73, 39.61)

The Jordanian standard for annual average $PM_{2.5}$ is 15µg/m^3. Figure 2 shows that there is an exceeding for the Jordanian standards limits 1140/2006 for all the years' record.

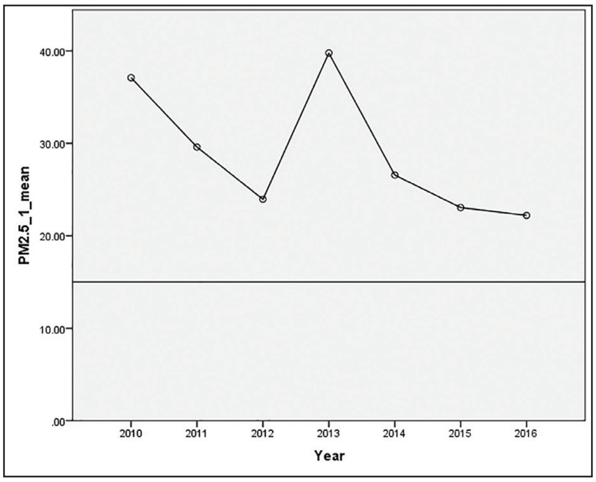

Figure 2. Yearly $PM_{2.5}$ levels at the monitoring site (March 2010 – December 2016)

Figure 3 and Table 4 illustrate the average hourly $PM_{2.5}$ concentration. It can be readily seen that the highest hourly $PM_{2.5}$ reading occurs during peak traffic movement around (9-10am) in the morning and (4-5 pm) in the evenning.

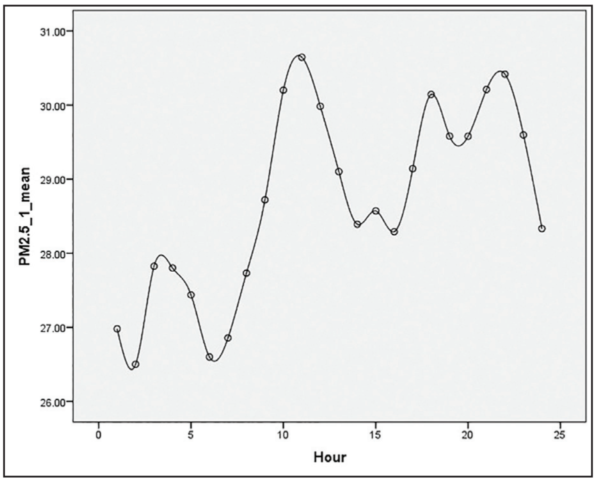

Figure 3. Yearly $PM_{2.5}$ levels at the monitoring site (March 2010 – December 2016)

Table 4. Descriptive statistics and 95% Confidence interval (C.I) of $PM_{2.5}$ levels by hours at HIE

Hour	Average	St.Dev	Min	median	Max	IQR	Confidence Interval 95%	
							Lower	Upper
1	26.9802	35.199	0	26.090	760.34	16.542	25.599	28.360
2	26.5016	40.197	0	24.945	885.30	17.412	24.925	28.078
3	27.8247	56.545	0	24.825	614.00	17.072	25.607	30.042
4	27.8004	58.450	0	23.685	499.30	17.525	25.508	30.092
5	27.4371	56.423	0	23.565	562.41	17.205	25.224	29.649
6	26.5999	41.331	0	23.550	563.28	17.242	24.979	28.220
7	26.8571	39.148	0	23.685	680.60	17.187	25.321	28.392
8	27.7316	37.283	0	25.610	1059.3	17.570	26.269	29.193
9	28.7197	34.829	0	26.390	1422.2	16.737	27.353	30.085
10	30.2009	46.114	0	26.620	951.60	16.277	28.392	32.009
11	30.6443	47.364	0	26.560	863.10	16.430	28.786	32.501
12	29.9824	43.755	0	26.520	760.34	17.042	28.266	31.695
13	29.1011	38.382	0	26.280	885.30	17.097	27.595	30.606
14	28.3909	36.200	0	26.260	614.00	17.382	26.971	29.810
15	28.5711	36.201	0	26.295	499.30	17.007	27.151	29.990
16	28.2904	28.814	0	26.315	562.41	16.790	27.160	29.420
17	29.1407	29.793	0	26.355	563.28	16.332	27.972	30.309
18	30.1429	33.646	0	26.545	680.60	15.902	28.823	31.462
19	29.5804	31.635	0	26.515	1059.3	15.540	28.339	30.820
20	29.5782	32.782	0	26.670	1422.2	15.167	28.292	30.863
21	30.2102	44.929	0	26.600	951.60	15.037	28.448	31.972
22	30.4159	56.269	0	26.550	863.10	15.557	28.209	32.622
23	29.5963	42.168	0	26.535	760.34	16.052	27.942	31.250
24	28.3319	36.210	0	26.320	885.30	15.897	26.911	29.752

Regional dust events and local soil erosion cause high $PM_{2.5}$ readings and the station record high dust measurements during regional dust storms. Figure 4 shows that the highest daily $PM_{2.5}$ concentration was around 36.75 µg/m^3 and 34.94 µg/m^3 occurred on 10th and 20th day, respectivly. This is due to the widespread dust event as well as emissions emanated from local sources including motor vehicles, light industry and domestic heating that lead to high $PM_{2.5}$ readings.

The days in the Table 5 suggest a slightly difference between working and nonworking hours averages. In order to see whether difference is a real, we conducted a statistical hypothesis using the Kruskal-Wallis test. The test produced a statistic value 18.66 with one degree of freedom. The corresponding P-value is 0.00, which refers to highly significant test. So, at 5% level of significance, we conclude that the average $PM_{2.5}$ levels are higher in working hours than in nonworking hours.

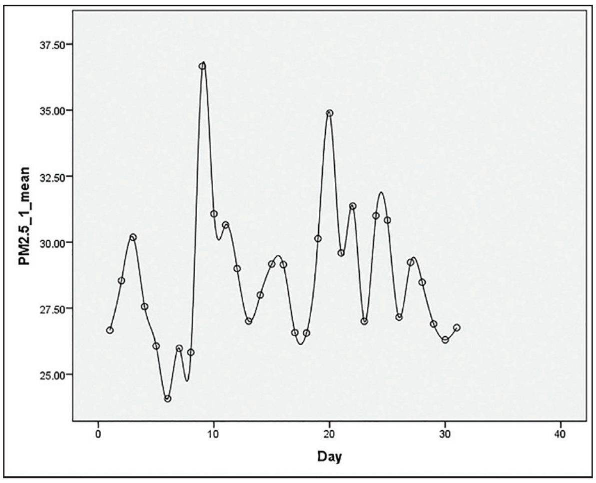

Figure 4. Daily average of $PM_{2.5}$ levels at the monitoring site (March 2010 – December 2016)

Table 5. Descriptive statistic and 95% confidence intervals for $PM_{2.5}$ levels by day status

Working Status	Average	.St. Dev	Min	Max	Median	IQR	Confidence 95% Interval	
							Lower	Upper
Working hours	29.07	39.18	0	1664.3	26.36	17.05	29.073	29.582
Non working hours	28.47	43.42	0	1528.1	26.02	16.52	28.026	28.906

Pronounced monthly variation of $PM_{2.5}$ concentrations showed that $PM_{2.5}$ concentrations were generally higher in the summer months compare with winter months. This might be attributed to the prevailing Khamasin winds, which become active in spring (first peak), where as the second peak it might be because of the low average of rainfall and the lack of humidity, thus helping the increase of the suspended air in the atmosphere (Figure 5).

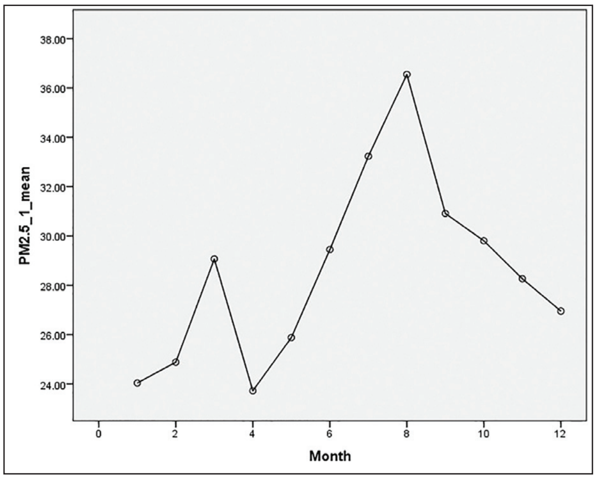

Figure 5. Monthly average of $PM_{2.5}$ levels at the monitoring site (March 2010 – December 2016)

3.2. Meteorology Effect

Meteorological factors, such as wind speed and precipitation, play an important role in determining the pollutant levels for a given rate of pollutant emission. The residence in the atmosphere and the formation of secondary pollutants is controlled not only by the rate of emission of the reactants into the air from the source, but also by meteorological factors wind speed, air temperature and precipitation, (Tayanc, 2000; Singal and Prasad, 2005).

3.2.1. Relative Humidity Effect

Humidity is considered among the meteorological factors that decrease the percent of pollutants concentration. The percent of humidity differs during the period of measurements. As we can see from Figure 6, the concentration of $PM_{2.5}$ in the atmosphere are greatly affected by relative humidity. A definite trend is observed between dust concentration and relative humidity. The $PM_{2.5}$ concentration increases as the relative humidity decreases. The lowest yearly average humidity 56.39% was recorded in 2016 and highest yearly average humidity 73.95% was recorded in 2013 see (Tables (6)–(7)). Whereas the lowest monthly average relative humidity of 47.57% which was recorded in May and highest monthly average relative humidity of 78.62% which was recorded in January (Figure 7). A negative relationship between $PM_{2.5}$ concentrations and humidity, the more relative humidity, the lower the concentration of $PM_{2.5}$. The main reason for this relation is attributed to the role of relative humidity in cleaning the atmosphere's pollutants and the fall of the acid rains.

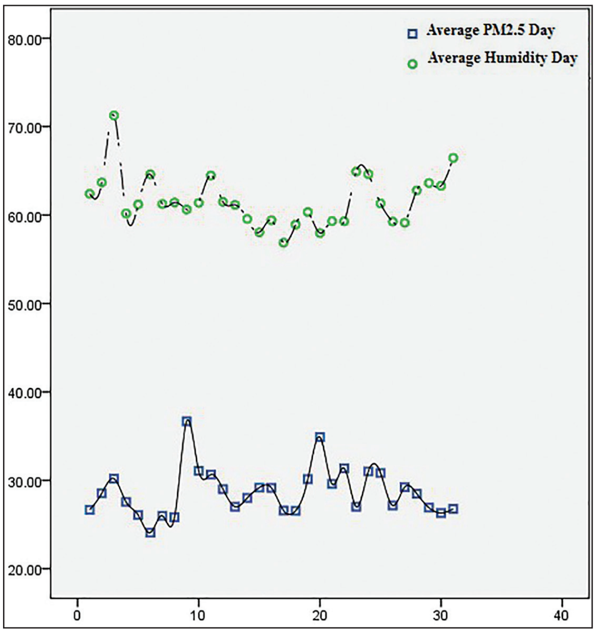

Figure 6. Daily average of humidity and average of $PM_{2.5}$ at the monitoring site (March 2010 – December 2016)

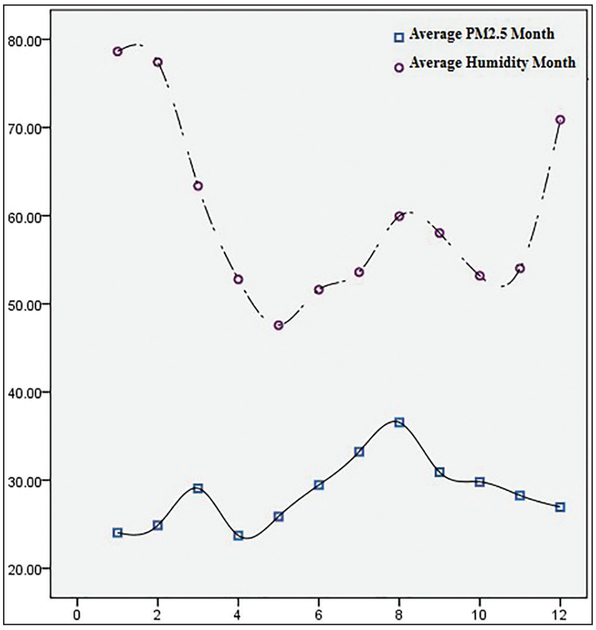

Figure 7. Monthly average of humidity and average of $PM_{2.5}$ at the monitoring site (March 2010 – December 2016)

Table 6. Descriptive Statistics for yearly Relative humidity levels HIE

Year	Maximum	Minimum	Average	Standard deviation
2010	486.53	12.93	56.99	31.63
2011	99.72	14.37	62.73	15.47
2012	98.01	21.07	65.76	18.06
2013	99.35	22.19	73.95	15.75
2014	95.44	21.22	72.87	14.89
2015	88.46	50.79	71.22	12.83
2016	89.42	7.63	56.39	17.75

Table 7. Descriptive statistics for monthly Relative humidity levels in HIE

Month	Maximum	Minimum	Average	Standard deviation
January	99.72	42.05	78.62	11.78
February	486.53	42.59	77.41	39.20
March	97.29	22.21	63.36	16.81
April	92.78	14.37	52.77	19.06
May	73.37	12.93	47.57	14.68
June	68.91	19.07	51.60	12.57
July	68.88	24.55	53.58	9.90
August	73.41	25.75	59.94	9.80
September	75.14	32.31	58.03	10.11
October	86.96	23.46	53.17	15.40
November	98.01	7.63	54.01	23.39
December	94.22	14.79	70.89	16.25

3.2.2. Temperature Effect

The lowest yearly average temperature is 9.42°C, which was recorded in 2015, and the highest yearly average temperature 20.02°C , which was recorded in 2010 (Table 8), whereas the lowest monthly average temperature, 9.08 °C, was recorded in January and highest monthly average temperature 27 °C, was recorded in August, (Table 9).

We found that temperature shows a positive relation between $PM_{2.5}$ concentration and temperature because of the role of the heat in warming up the surface of the earth which warms the air making the air that touch it warm and consequently reducing its density, so it expands and goes upward to be replaced by cold air and so on. This process increases the amounts of the up going air currents and leads to generating more air currents and shaping vertical winds. Thus causing dust and therefore $PM_{2.5}$ increases in the area (Figures 8 - 9).

Table 8. Descriptive statistics for yearly Temperature in HIE

Year	Maximum	Minimum	Average	Standard deviation
2010	92	5	20.02	7.91
2011	32	7	18.03	6.8
2012	30	1	16.09	7.54
2013	21	4	10.70	3.71
2014	19	5	10.01	1.52
2015	13	7	9.42	1.34
2016	32	3	19.14	7.10

Table 9. Descriptive statistics for monthly Temperature in HIE

Month	Maximum	Minimum	Average	Standard deviation
January	15	3	9.08	2.75
February	92	1	10.87	8.32
March	24	2	13.27	4.30
April	28	7	17.46	4.35
May	32	15	21.39	3.28
June	30	21	24.66	2.31
July	32	24	26.96	1.64
August	34	23	27.16	1.76
September	30	21	24.80	1.63
October	30	15	21.92	2.78
November	23	7	15.25	4.01
December	16	6	9.98	2.10

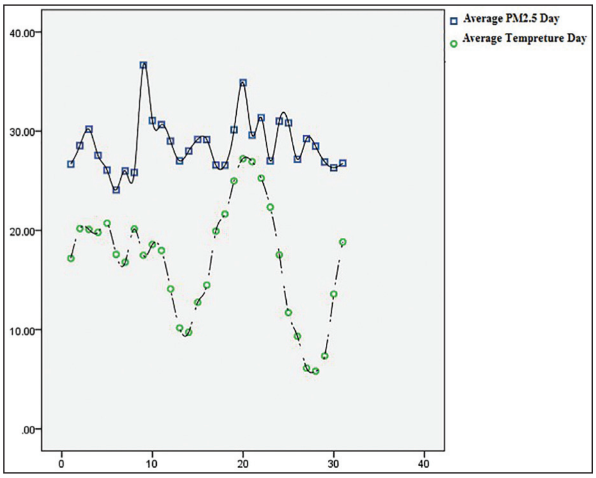

Figure 8. Daily average of Tempreture and average of $PM_{2.5}$ at the monitoring site (March 2010 – December 2016)

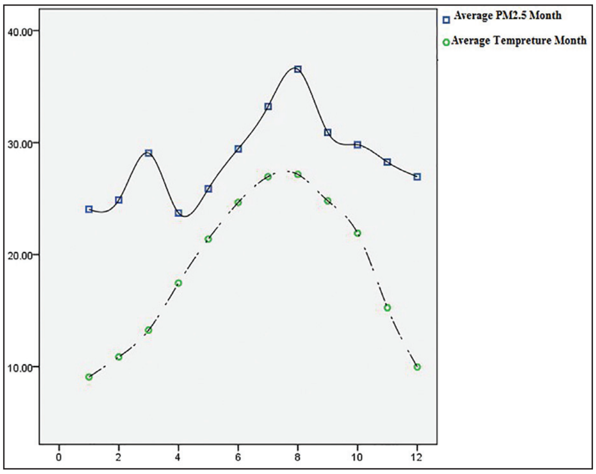

Figure 9. Monthly average of Temperature and average of $PM_{2.5}$ at the monitoring site (March 2010 – December 2016)

3.2.3 Wind Direction Effect

Figure 10 shows the distribution direction of wind during the period March 2010 – December 2016. This figure clearly shows that the calm and North West winds are relatively abundant and subsequently increased pollutants concentration there. Calm has winds increased to 72.23%, and North West winds reach to 10.87%. All together, those winds amounted to 83% a very high degree of wind accumulation that permanently exposes the monitoring site to pollution. This actually means that these winds do not disperse or reduce the emissions; rather they increase their concentration (Al-helou A., 2012).

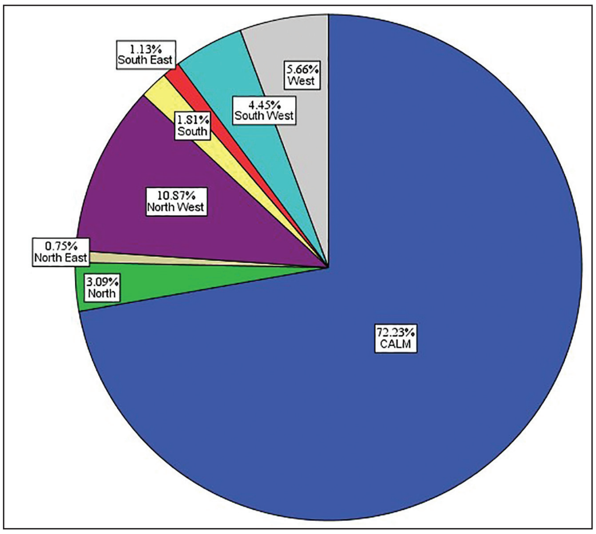

Figure 10. Wind direction at the monitoring site (March 2010 – December 2016)

3.2.4. Wind Speed Effect

Figure 11 shows the distribution of wind speed during the period March 2010 – December 2016. Air tranquility plays an important role in the distance, which the wind may reach, and in its concentration in the surrounding air as well (Al-helou A., 2012). Pollutants are expected to be carried away and diluted during day times with high wind speeds. More than 72.79% of wind blow at speed between 0 –2 m/s. This plays apart in having more concentration in dust in this place were low wind speed cannot carry pollutants for further distance.

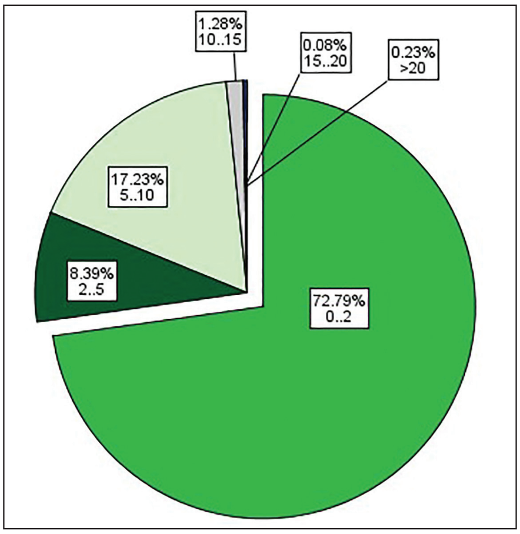

Figure 11. Wind speed distribution at the monitoring site (March 2010 – December 2016)

Conclusions

The results show that the monitoring site in HIE in Irbid has a fairly good air quality throughout most of the year in comparison with the Jordanian ambient air quality standard 1140-2006. The results prove that $PM_{2.5}$ levels are exceeded the permissible of the Jordanian standards ambient air quality limits. Regional dust storms and local soil abrasion contributed to the high $PM_{2.5}$ levels. The most prominent are natural dust from fuel burning, fine particles in stationary, mobile sources and dust emitted from various manufacturing processes in factories located in HIE. This study also shows that the concentration variations in $PM_{2.5}$ are closely related to those in local meteorological conditions (Jaber *et al*., 1997). A positive relationship was found between $PM_{2.5}$ concentrations and temperature, were it shows a negative relationship with humidity. Further, the results show also that calm winds and North West winds reach are the prominent. This actually means that these winds do not disperse or reduce the emissions; rather they increase their concentration (Al-helou, A., 2012). And more than 72.79% of wind blow at speed between 0 –2 m\s. This will play apart in having more concentration in dust in this place. It not possible by any means for low speed winds to carry pollutants for further distance.

Recommendations

Based on the findings, the following are specific recommendations to reduce the potential impacts of pollution in the site:

1. The monitoring process of pollutants in Al Hassan Industrial Estate has many disadvantages, such as changing the sites of the monitoring stations, loss of power, which hinders the data recording process and the discontinuity in recording data made temporal and spatial variability analysis almost impossible.
2. Restricting habitation east and southeast of Al Hassan Industrial Estate and permitting habitation west and northwest by reducing taxes and providing municipal services.
3. Making complete environmental health study including people, soil and water to discover the impact of air pollution on these environmental components.
4. Cooperation between government's research centers and industry will lead to the desired objectives. This is the time to make dialogue between those who make the rules and those who must comply with them.
5. Raising public –awareness and encouraging- public participation in decision making, public awareness has little effect without vigorous dissemination, which could be achieved through public campaigns, promotion of environmental education, and information exchange. This should be as a joint effort between NGOs and government departments. The government should make the flow of information to the public easier and more efficient by establishing service centers (Jaber *et al*., 1997).

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References

[1] Al-helou, A., 2012. Mathematical analysis of how the electrical training center site is affected by air pollution, American Journal of Applied Sciences, 9, 1840-1848.

[2] Abu-Allaban, M. and Abu-Qudais. H., 2011. Impact Assessment of Ambient Air Quality by Cement Industry: A Case Study in Jordan. Aerosol and Air Quality Research, 11: 802–810.

[3] Amman Chamber of Industry, 2013 http :// www.aci.org. Jo/ development/en/, www.linkedin.com/company/amman.

[4] Asi, R., Anani, F. and Asswaeir, J., 2001. Studying Air Quality in Alhashemeiah Area/Zarqa, A Report Prepared by the Royal Scientific Association for the General Institution for the Protection of the Environment, Amman, Jordan.

[5] Cohen AJ, Anderson HR, Ostro B, Pandey KD, Krzyzanowski M, Ku¨nzli N, Gutschmidt K, Pope A, Romieu I, Samet JM, Smith K., 2005. The global burden of disease due to outdoor air pollution. J Toxicol Environ Health A 68(13):1301–1307.

[6] Dockery, D.W. and Pope, C.A., 1994. Acute Respiratory Effects of Particulate Air Pollution, Auun. Rev. Publ. Health, 15,107–132.

[7] Elminir, H.K., 2005. Dependence of urban air pollutants on meteorology, Science of the Total Environment, 350, 225–237.

[8] Finlayson-Pitts BJ, Pitts J., 2000. Chemistry of the upper and lower atmosphere: theory, experiments and applications. San Diego: Academic Press.

[9] Jaber, J.O.Probert,S.D. and Bader,O.,1997 .Energy and environmental issues for Jordan. Applied Energy, 57, 45-101.

[10] Jeff, G. and Hans, P., 2004. Assessment of Environmental Impact of the Holcim Cement—Dundee Plant, Ecology Centre, Retrieved October 13, 2007, from http://www. wbsed.org/web/ project/cement/tf5/ holcmm.htm.

[11] Hussein, T., Abu Al-Ruz, R., Petäjä, T., Junninen, H, Arafah, D., Hämeri, K. and Kulmala, M., 2011. Local Air Pollution versus Short–range Transported Dust Episodes: A Comparative Study for Submicron Particle Number Concentration. Aerosol Air Qual. Res. 11: 109– 119.

[12] Ministry of Environment. (2010 -2016). Amman, unpublished annual report

[13] Satsangi, G.S. Satsangi, A., Lakhani, P. R., Kulshrestha and Taneja. A., 2004. Seasonal and diurnal variation of surface ozone and a preliminary analysis of exceedance of its critical levels at a semi-arid site in India, Journal of Atmospheric Chemistry, 47, 271–286.

[14] Seinfeld JH, Pandis SN., 1998. Atmospheric chemistry and physics: from air pollution to climate change.New York: Wiley.

[15] Seinfeld, J. H., and Pandis, S. N., 2006. Atmospheric Chemistry and Physics: from Air Pollution to Climate Change 2nd Edition, John Wiley & Sons, Inc., Hoboken, New Jersey.

[16] Singal, S.P. and Prasad, R., 2005. Analytical Study of some Observed Micro Meteorological Data, J. Air Pollut. Contr., 1, 44–49.

[17] Tayanc, M., 2000. An Assessment of Spatial and Temporal Variation of Sulfur Dioxide Levels over Istanbul, Turkey, Environ. Pollut., 107, 61–69.

[18] Tu, J.,Xia,Z., wang, H and Lia,W., 2007 .Temporal variations in surface ozone and its precursors and meteorological effects at an urban site in China, AtmosphericResearch, 85, 310-337.

[19] U.S. EPA, 1999a. Environment Fact Sheet: Management Standards Proposed for Cement Kiln Dust Waste. Retrieved October 10, 2003, from http://www.epa.gov/ fed.gstr/EPA-AIR/199/Some/Day-14/a12893.htm.

[20] U.S. EPA, 1999b. National Emission Standards for Hazardous Air Pollutants for Source Categories, Cement Manufacturing Industries Federal Register: 64, 113. Retrieved October 10, 2002, from http://www. epa.gov/ fed.gstr/EPA-AIR/199/Some/ Day-14/a12893.htm.

[21] Wang. S., and Hao. J., 2012. Air Quality Management in China: Issues, Challenges, and Options, Journal of Environmental Sciences, 24, 2-13.

[22] Y. Li, 2013. Construction Dust Accounted for 15.8% of PM2.5 Particles, Beijing Authority Reinforce Construction Waste Management.

[23] Zhao,Ji. H., Kong,H.S. Bai ,Z and Han, B., 2013. Seasonal Variation of Inorganic Composition in Ambient Particulate Matter in Tianjin Offshore Area and Its Source Analysis.China Environmental Science, 31, 177-185.