

# Study the Level of Air Pollution from Al Hassan Industrial Estate in Irbid-Jordan

Sana'a Odat

**Abstract**—Air pollutants, including PM<sub>2.5</sub>, SO<sub>2</sub>, NO<sub>x</sub> and CO, were measured in Al-Hassan industrial estate (HIE) in Irbid Governorate, 72 Km north of Amman. Data relating to pollution in HIE has been collected from all sources that had measured the level of pollution in this area during the period from Nov.2010 to Nov.2011. The effects of local meteorological conditions were studied by statistical analysis. The main results of the study show that the gaseous pollutants levels monitored were low and no exceedances to the Jordanian standards limit of the ambient air no. 1140/2006 for NO<sub>2</sub>, SO<sub>2</sub> and CO limits. It has, indeed, shown that PM<sub>2.5</sub> levels exceeded the daily limit specified in the Jordanian Standards. This might be attributed to the prevailing Khamasin winds, which become active in spring, especially between April and May, in addition to the high temperature and the low average of rainfall and the lack of humidity, thus helping the increase of the suspended air in the atmosphere.

**Index Terms**—Air pollution, Al-Hassan industrial estate (HIE), concentration meteorological parameters PM<sub>2.5</sub>.

## I. INTRODUCTION

Air pollution continues to receive a great deal of interest worldwide due to its negative impacts on human health and welfare. Several studies reported significant correlations between air pollution and certain diseases including shortness of breath, sore throat, chest pain, nausea, asthma, bronchitis and lung cancer [1]–[3]. Extreme effects of air pollution include high blood pressure and Cardiovascular problems [4]. Correlations between air pollution and increased morbidity and mortality rates were reported [5], [6]. The World Health Organization states that 2.4 million people die each year from causes directly attributable to air pollution [7]. Epidemiological studies suggest that more than 500,000 Americans die each year from cardiopulmonary diseases linked to breathing fine particle air pollution.

Another study has shown a strong correlation between pneumonia related deaths and air pollution from motor vehicles in UK [8]. In addition to its negative health impacts, air pollution is known to cause injuries to animals, forests and vegetation, and aquatic ecosystems. Its impacts on metals, structures, leather, rubber, and fabrics include cracks, soiling, deterioration, and erosion [9].

Meteorological parameters play important roles in air pollutants formation, dispersion, transport and dilution. Therefore, the variations in local meteorological conditions, such as wind direction, wind speed, temperature, and relative

humidity, can affect the temporal variations in pollutant concentration [10], [11]. An analysis of the influences of meteorological parameters on the pollutants at a specific site can contribute to a better understanding of the causes of air pollution. The development of industrial and services sectors in Jordan, accompanied with the increase of Jordanian population and the increase of the number of vehicles result in an 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. Therefore, it is so important to study ambient air quality of the residential areas that are close to the air pollution sources. Ministry of Environment, based on its mandate, signed agreement No. 75/2008 with Air Studies Division / Energy, Water and Environment Consultations and Projects of the Royal Society to study the ambient air quality in Al Hassan industrial estate (HIE) in Irbid. The main aims of this is to identify the air pollutants levels in (HIE) and to compare the recorded hourly, daily and yearly averages of different air pollutants with the Jordanian standards JS 1140 / 2006. It aimed also to study the (HIE) in order to determine the impact of pollution controlling parameters (wind speed, wind direction, temperature and relative humidity) on the behavior of pollutants in this place.

## II. METHODOLOGY

### A. Study Site

Irbid governorate is one of the most developed regions in Jordan, and was recently announced by his Majesty King Abdullah II as a Zone of Economic Development. The urbanized areas are mainly located in the middle and northeastern parts which characterized by a high population density, while in the remaining parts of the study area, the low population communities are sparsely distributed. The climate of the study area is characterized by more than 370 mm mean annual rainfall that is decreasing gradually from the west (450 mm/year) to the east (200 mm/year). Mean winter air temperature ranges from 5 to 9 °C, and mean summer air temperature ranges from 22 to 29 °C [12].

With the aim of assisting Jordanian economic development, in March 1998 the Trade Representative of the United States established the Al-Hassan Industrial Estate in Irbid, north Jordan as the initial Jordanian Qualifying Industrial Zone (QIZ), (Fig. 1). Al-Hassan industrial estate (HIE) is the largest (QIZ) in the Kingdom of Jordan, that located in Irbid Governorate., HIE was designated as the first QIZ in the world and developed in three phases with a total area of 117.8 ha. It accommodates more than 101 industries creating 16440 Job opportunities, [13].

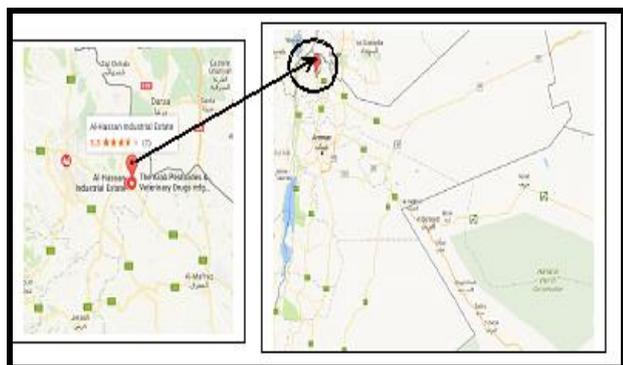


Fig. 1. Location map of the study area [14].

### B. Monitoring Procedures

The air samples are analyzed for Carbon Monoxide (CO) concentrations using analyzer Infrared Fluorescence, Nitrogen Oxides (NO, NO<sub>x</sub> and NO<sub>2</sub>) concentrations using analyzer Chemiluminescence. The SO<sub>2</sub> analyze done using Ultra-Violet Fluorescence, PM<sub>2.5</sub> analyze done using Beta – Attenuation (Ministry of Environment 2010 -2011). Additionally wind speed, wind direction, ambient temperature and relative humidity (Meteorological department 2010-2011).

### C. Statistical Analysis

The daily mean concentrations of pollutants SO<sub>2</sub>, NO<sub>x</sub>, CO and PM<sub>2.5</sub> were obtained from unpublished sources conducted by both Royal Scientific Society (RSS) and Ministry of Environment. The data were entered into a personal computer to be analyzed using the statistical package for social sciences (SPSS) version 18 Software version 4. The Kolmogorov–Smirnov test, histogram plot, and Q–Q plot are used to examine the normality of air pollutants and meteorological data. It was found that most of the variables were normally distributed.

## III. RESULTS AND DISCUSSION

### A. Pollutant Concentrations

Hourly average concentration, Daily average concentration, Monthly average concentration and Yearly average concentration of pollutants SO<sub>2</sub>, NO<sub>x</sub>, CO and PM<sub>2.5</sub> are listed in Table I.

TABLE I: HOURLY, DAILY, MONTHLY AND YEARLY AVERAGE CONCENTRATION OF POLLUTANTS

pollutants	Hourly Average con.	Daily Average con.	Monthly Average Conc.	Yearly Average Conc.	Highest Monthly rates
SO <sub>2</sub> (ppm)	0.249	0.104	0.008	0.002	0.008
NO <sub>x</sub> (ppm)	0.108	0.030	0.019	0.008	0.019
CO (ppm)	4.81	-----	1.035	-----	1.035
PM <sub>2.5</sub> (µg)/m <sub>3</sub>	-----	156	36	27	36

#### A.1. Sulfur Dioxide (SO<sub>2</sub>)

Sulfur dioxide (SO<sub>2</sub>) is a poisonous gas. It agitates the tissues of eyes, noses, pharynxes and lungs. Once absorbed by a human body, SO<sub>2</sub> operates as an internal toxin that would possibly impair the nervous and respiratory systems. SO<sub>2</sub> is a colorless gas and so cannot be visible when it infiltrates. Neither can it be seen in a stormy weather. It

moves as an invisible cloud, usually in the wind direction. It is a heavier gas than air and tends to fall on low lands, such as ditches, drainages and holes, where it goes well as a fatal gas. The degree of SO<sub>2</sub> effect depends on its concentration in air, as well as on the victim's allergy and exposure duration. So if SO<sub>2</sub> condensation in air amounts to 100 ppm, it then develops eye and throat inflammation, headache, nausea, cough and the olfaction becomes useless within 3-15 min [14]-[18]. The degree of SO<sub>2</sub> condensation in air is based on the quantity of fuel consumption and the ratio of sulfur in there.

Monitoring results show that hourly average of SO<sub>2</sub> was 0.249ppm and the daily average was 0.104ppm, whereas the yearly average was 0.002ppm. And the highest monthly rate is a record for the month of September 2011, it reach 0.008ppm, Table I.

Fig. 2 shows the daily average and max. Hourly average concentrations of SO<sub>2</sub> at the monitoring site Nov. 2010 – Nov. 2011; its lowest level was in March and the max in June at a rate of 0.010 and 0.24 ppm respectively. It also clearly proves an exceeding to the 0.14 ppm limit of the Jordanian standards.

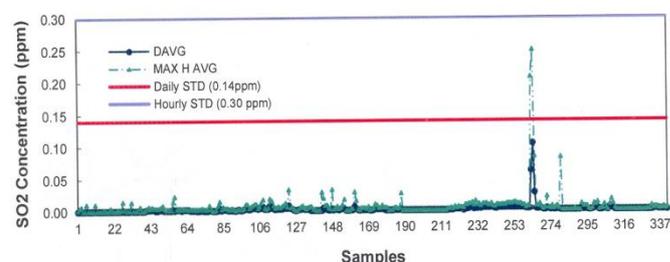


Fig. 2. Daily average and max. Hourly average concentrations of SO<sub>2</sub> at the monitoring site (Nov. 2010 – Nov. 2011).

#### A.2. Carbon Monoxides (CO)

Carbon Monoxide (CO) is a gas with no color or smell. It emanates from the incomplete combustion interaction of hydrocarbon fuel. However, the main source of this gas is the traffic movement on road, especially the benzene operating vehicles. In fact, the CO affecting danger on man lies in its potential of creating carboxyl hemoglobin in man's blood, which really causes man's blood inability to carry oxygen to his organs. As such, it exposes to further danger those people who suffer from the inefficiency of extending oxygen to heart and brain (e.g., patients of coronary artery) [19]–[22].

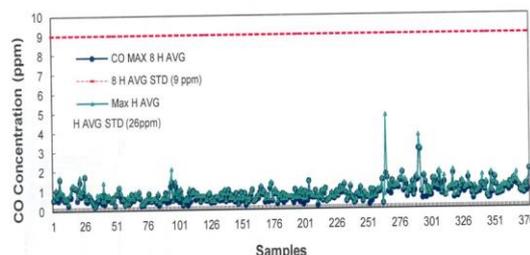


Fig. 3. Max. Hourly average & Max. 8- hrs. Average concentrations of CO at the monitoring site (Nov. 2010 – Nov. 2011).

Monitoring results show that hourly average of CO was 4.81ppm, whereas average concentration reach to 1.035ppm. No excess to hourly limits as determined by the Jordanian standards at 9 ppm was noted, Table I. Fig. 3 shows Max. hourly average & Max. 8- hrs. Average concentrations of CO

at the monitoring site during Nov. 2010 – Nov. 2011; its clearly proves No exceeding to the 8 HAVG STD (9 ppm) and its proves that no exceeding to HAVG STD (26 PPM) limit of the Jordanian standards.

The highest monthly rate is a record for the month of August 2011, it reach 1.035ppm, Fig. 4.

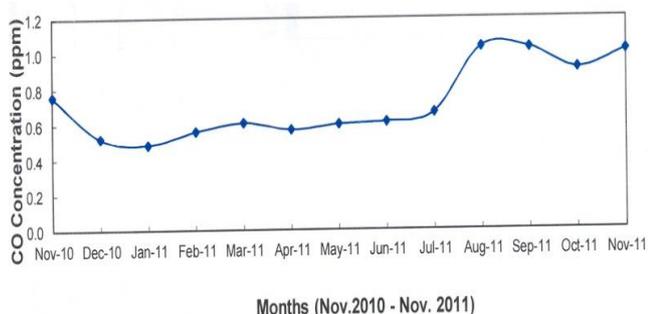


Fig. 4. Monthly average concentrations of CO at the monitoring site (Nov. 2010 – Nov. 2011).

• A<sub>III</sub>. Nitrogen Oxides (NO, NO<sub>2</sub>, NO<sub>x</sub>)

Nitrogen oxides (NO<sub>x</sub>), including nitrogen dioxide (NO<sub>2</sub>) and nitric oxide (NO), are atmospheric trace gases with a short lifetime. They actively participate in the formation of tropospheric ozone and thus harm human health and significantly affect climate [15], [23]. Long-term exposures (e.g., one year) to nitrogen oxide concentrations may damage forest and vegetation [24]. Nitrogen oxides are formed in high temperature combustion processes, mainly in petrol and diesel vehicles [25]. The pollutants have been checked in this study within the limits determined by the Jordanian standards of the ambient air .

Monitoring results show that hourly average of NO<sub>x</sub> was 0.108ppm and daily average was 0.030 ppm, whereas yearly average was 0.008ppm. And the highest monthly rate is a record for the month of Nov. 2011, it reach 0.019ppm, Table I.

Fig. 5 proves that no exceeding to hourly NO<sub>2</sub> (0.21 ppm), the limit of the hourly Jordanian standards,. Whereas Fig. 6 shows that the average daily of NO<sub>2</sub> concentrations were satisfied with the Jordanian standards limit.

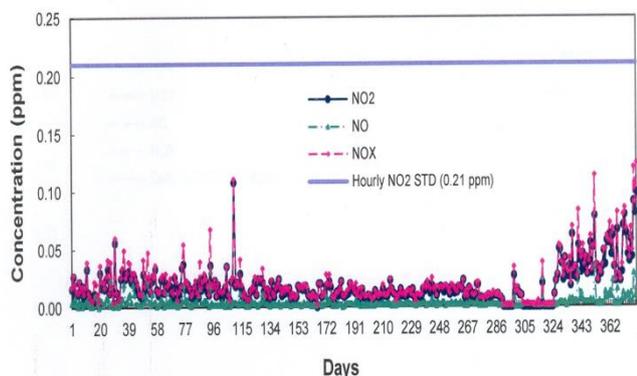


Fig. 5. Daily recorded max. Hourly average concentrations of NO ,NO<sub>2</sub> and NO<sub>x</sub> at the monitoring site (Nov. 2010 – Nov. 2011).

• A<sub>IV</sub>. Particulate Matter (PM<sub>2.5</sub>)

PM<sub>2.5</sub> particles are air pollutants with a diameter less than 2.5 micrometers, small enough to invade even the smallest of airways in human body. Particulate matter pollutant is

composed of a mixture of microscopic solids and liquid droplets suspended in air. These pollutants are made up of a number of components, including SO<sub>x</sub>, NO<sub>x</sub>, NH<sub>3</sub>, organic chemicals, volatile metals (e.g. mercury), soil or dust particles, and allergens [26]. Unlike most air pollutants that consist of only one chemical compound, PM<sub>2.5</sub> particles consist of multiple compounds and are formed from primary and secondary particulates [27]. Primary particles are formed during combustion, industrial processes and in natural processes (e.g. wind erosion). Secondary particles are formed indirectly through nucleation, condensation or processes where gaseous pollutants (SO<sub>x</sub>, NO<sub>x</sub>, NH<sub>3</sub>, VOCs) are involved in particle formation or growth. Secondary sulfate and nitrate particles formed from SO<sub>x</sub> or NO<sub>x</sub> precursors are usually the dominant component in PM<sub>2.5</sub> particles. As a result of the chemical components in secondary particulates, the environmental and health impacts from them are greater than from primary particles. Since PM<sub>2.5</sub> particulates consist of multiple compounds, multi-pollutant controls are needed to reduce PM<sub>2.5</sub> pollutants [28]. Monitoring results show that the daily average was 156 (µg)/m<sup>3</sup>, whereas the yearly average was 27 (µg)/m<sup>3</sup>. And the highest monthly rate is a record for the month of Jan. 2011, it reach 36(µg)/m<sup>3</sup>, Table I.

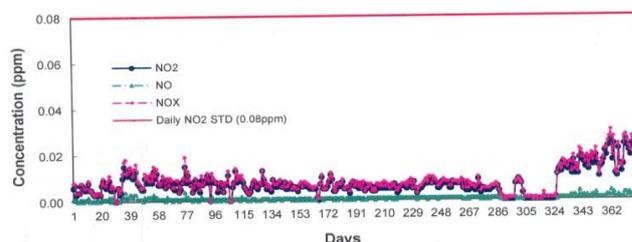


Fig. 6. Daily average concentrations of NO ,NO<sub>2</sub> and NO<sub>x</sub> at the monitoring site (Nov. 2010 – Nov. 2011).

Fig. 7 shows that the Max. daily average was 156 (µg)/m<sup>3</sup> and that causes exceeding the Jordanian standards limits 1140/2006 were in average .65(µg)/m<sup>3</sup> ,i.e 1.7%.

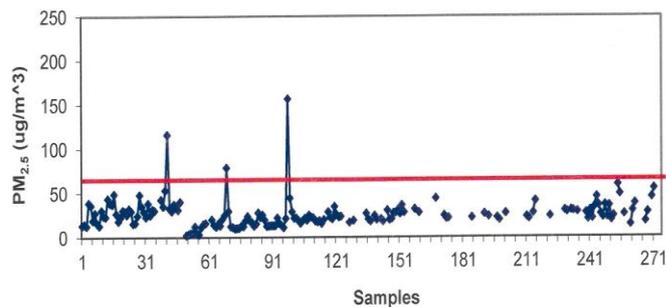


Fig. 7. Daily PM<sub>2.5</sub> levels at the monitoring site (Nov. 2010 – Nov. 2011).

B. The Effect of Meteorology

Meteorological factors such as wind speed and precipitation play important roles in determining the pollutant levels for a given rate of pollutant emission [29], [30]. It is often important to understand the physical processes leading to an observed concentration of pollutants at a given point because the concentration of pollutants, their 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 wind speed, air temperature, and precipitation.

• B.I. Relative Humidity:

Humidity is considered among the meteorological factors that increase the percent of pollutants concentration. The percent of humidity differs during the period of measurements. The lowest daily average humidity, 14.4%, was recorded in 18/April /2011 and highest daily average humidity, 99.7%, was recorded in 3/January /2011, whereas the lowest monthly average humidity, 33.3%, was recorded in Nov. /2011 and highest monthly average humidity, 77.2%, was recorded in Feb. 2011,(Fig. 8). Also, the process of humidity decrease leads to more concentrations of gas contaminations and suspended dust in the air.

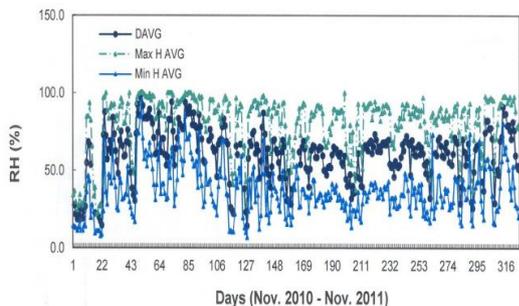


Fig. 8. Daily average max. And min. Hourly average of RH at the monitoring site ( Nov. 2010 – Nov. 2011).

• B.II. Temperature

The lowest daily average temperature, 6.6 °C , was recorded in 2/Feb./2011 and highest daily average temperature, 31.5 °C , was recorded in 30/July /2011, whereas the lowest monthly average temperature , 10.2 °C , was recorded in Jan. /2011 and highest monthly average temperature , 26.1 °C , was recorded in July/ 2011, (Fig. 9). Decreases in temperatures considered main reasons for pollutants' concentration, which plays a role in cooling the air touching the surface of the earth, thus reducing the vertical and horizontal mixture for air and its ascendance.

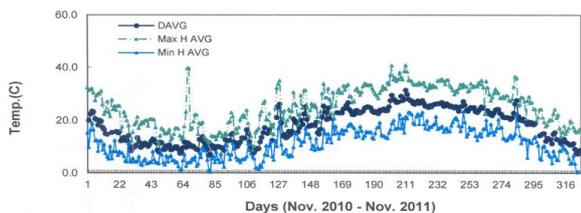


Fig. 9. Daily average max. And min. Hourly average of Temperature at the monitoring site (Nov. 2010 – Nov. 2011).

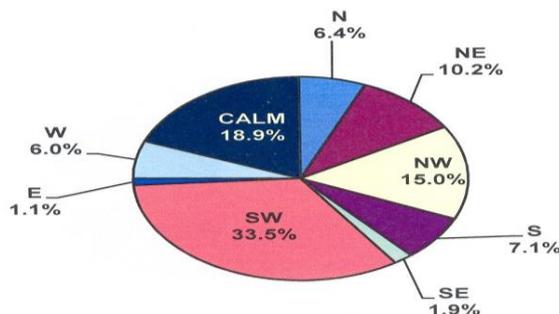


Fig. 10. Wind direction distribution at the monitoring site (Nov. 2010 – Nov. 2011).

• B.III. Wind Direction

Fig. 10 shows the direction of wind distribution during the

period Nov. 2010 – Nov. 2011. This figure clearly shows that the southwest and calm winds are relatively abundant and subsequently increased pollutants concentration there. Southwest has winds increased to 33.5%, calm winds to 18.9% and Northwest winds to 15%. All together, those winds amounted to 67.4%. This actually means that these winds do not disperse or reduce the emissions, rather they increase their concentration.

• B.IV. Wind Speed:

Fig. 11 shows the distribution of wind speed during the period Nov. 2010 – Nov. 2011. Pollutants are expected to be carried away and diluted during day times with high wind speeds. More than 41.4% of Irbid wind blow at speed between 2 – 5 m\|s . This will play a role in having more concentration in gas and dust in Irbid city. It not possible by any means for low speed winds to carry pollutants for further distance.

Results have proved that the concentrations of PM<sub>2.5</sub> were higher and this is might be attributed to the prevailing Khamasin winds, which become active in spring, especially between April and May , in addition to the high temperature and the low average of rainfall and the lack of humidity, thus helping the increase of the suspended particulate matter in the atmosphere.

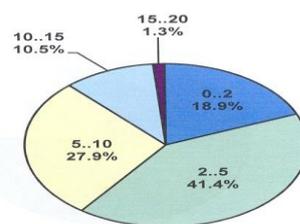


Fig. 11. Wind speed distribution at the monitoring site (Nov. 2010 – Nov. 2011).

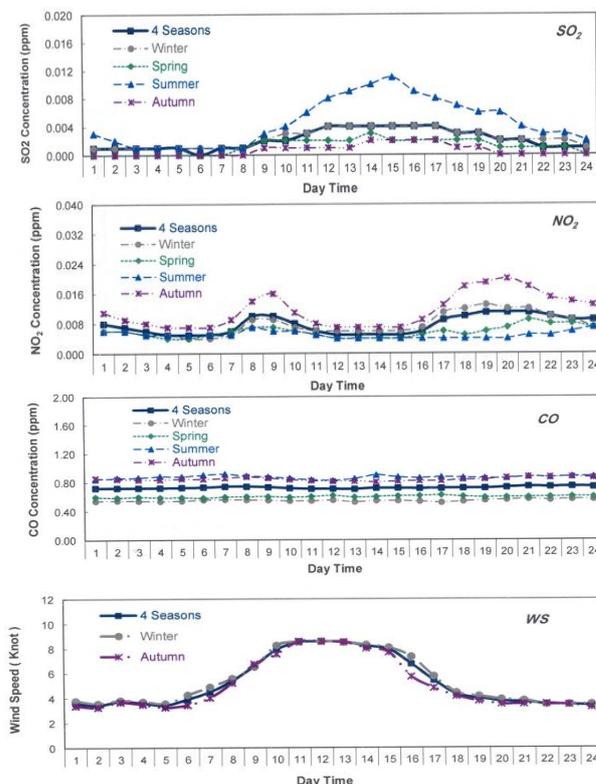


Fig. 12. Average diurnal concentrations of SO<sub>2</sub>, NO<sub>x</sub>, CO(PPM) & Wind speed diurnal average(knot) at the monitoring site ( Nov. 2010 – Nov. 2011).

Fig. 12 shows average diurnal concentrations of SO<sub>2</sub>, NO<sub>x</sub>, CO (PPM) & Wind speed (knot) at the monitoring site during the period Nov. 2010 – Nov. 2011.

Wind speed plays an important role in the distance which the wind may reach and in its concentration in the surrounding air as well. The concentration of SO<sub>2</sub>, NO<sub>x</sub> and CO increases in the summer compared with other seasons and this because the increasing in industrial activities during this season that raise the levels of pollutants, but without leading to exceeded the of Jordanian standards limit.

C. Comparison between Mean of Monthly Variation Values Using Tukey-Kramer HSD

A comparison between mean values calculated using the Tukey-Kramer HSD method is presented in Table II for monthly variation of climatic variables and air pollutants. Concentrations are classified into classes where class A denotes highest concentration, while class L represents the lowest concentration or pollution level. The concentrations of NO<sub>x</sub> and CO are high in winter months comparing with and summer months and this is due to low temperature and heavily working hours at this period. Whereas the concentrations of SO<sub>2</sub> are high in summer months and low in winter months because of Khamasin winds which become active in spring and summer, especially in April and May that increase PM<sub>2.5</sub> concentrations, in addition to the high temperature and the low rainfall which increase the concentration of the suspended particulate matter in the atmosphere.

TABLE II: MONTHLY VARIATION AND MEANS OF CLIMATIC VARIABLES AND AIR POLLUTANTS THROUGH MONTHS

Air Pollutants				Climatic Variables				Month
PM <sub>2.5</sub>	CO	NO <sub>x</sub>	SO <sub>2</sub>	Wind Direction	Wind Speed	RH%	Temperature	
22.49L	1.20	9.14	1.21L	196.78	3.15	63.15H	10.19	1
37.75	1.38H	9.38H	2.94	213.24	3.45	58.89	11.22	2
40.28	0.92	8.38	2.59	217.27	3.27	55.23	14.89	3
45.75	0.81	8.01	2.41	223.62	3.28	44.03	19.41	4
71.57H	0.84	7.40	2.22	233.82	3.43	42.04	22.83	5
60.23	0.86	6.84	3.46	249.12	4.36H	43.04	23.51	6
59.31	0.93	6.61	7.30	262.61H	3.70	53.09	24.36	7
32.17	0.26L	5.46	7.99H	253.23	4.02	48.70	27.97H	8
44.62	0.74	5.83L	2.33	258.26	3.75	52.67	22.50	9
46.25	0.32	7.06	2.19	228.22	2.55	37.31L	22.18	10
37.01	0.36	7.18	3.37	189.43L	2.34L	56.99	13.32	11
34.35	0.20	8.25	3.30	196.11	2.77	62.48H	10.51L	12

IV. CONCLUSION

The results show that the monitoring site in Al Hassan Industrial Estate in Irbid exposure to high levels of suspended particles matter (PM<sub>2.5</sub>). There are multiple sources of PM<sub>2.5</sub> in Irbid city .The most prominent are natural dust from fuel burning, stationary sources, mobile sources and dust emitted from various manufacturing processes in factories located in Al Hassan Industrial City. The result prove that gas levels of sulfur dioxide (SO<sub>2</sub>) , nitrogen oxides (NO<sub>x</sub>) and carbon monoxide (CO) are within the permissible of the Jordanian standards ambient air quality limits, where as PM<sub>2.5</sub> levels exceeded the daily limit of the Jordanian Standards and this is due to Khamasin winds which become active in spring in addition to the high temperature and the lack of humidity. It has, indeed, shown that the effect of meteorological conditions are play an important roles on the concentrations

of pollutants .Both temperature and relative humidity have significant negative effects, whereas wind speed has play a significant positive effect on pollutants concentrations. The results show also that southwest, calm and northwest winds are relatively abundant, those winds amounted to 67.4%. This actually means that these winds do not disperse or reduce the emissions, rather they increase their concentration.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGMENT

The researcher would like to thank Jordanian Ministry of Environment for providing the air quality data necessary for this study.

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**Sana'a Odat** received her PhD degree in applied geology from Jordan University in 2006. She has published more than 17 papers in referred national and international journals. She has presented several articles in national and international conferences. She is now an associated professor of geology in the Department of Earth and Environmental Sciences at Yarmouk University, Irbid city, Jordan. She was the dean of Student Affairs, the vice dean of Student Affairs, the director of sports activity, an assistant dean of Student Affairs, and an assistant dean, Faculty of Science, Yarmouk University, Jordan. She has more than more than 14 years of teaching and research experience. She is a member of Jordan society for thought, dialogue and development, chairman of the Jordanian Environment Society/Irbid, Jordanian Geologist Association, Jordanian Academic Female Association and Member of the Jordanian Women's Union.