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Assessment study of air pollution in Amman - Jordan

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ABSTRACT

In the period from May 2014 to May 2015, air pollutants, including particulate matter (PM_{10}), sulphur dioxide (SO_2) , nitrogen dioxide (NO_2) , ozone (O_3), and carbon monoxide (CO), were measured from seven ambient air quality monitoring stations located in Amman. The locations of the measurement stations were chosen based on preliminary mapping of the city and the monitoring sites were chosen in a way that ensures a fair and comprehensive representation of anthropogenic activities throughout the city. In addition a reference station was located at the King Hussein Gardens that continuously monitor air quality in urban areas, traffic dominated sites, and industrial zones. Statistical modeling was used to research the impact of the local weather conditions. The main study results indicate that the monitoring of gas contaminants was small and the annual mean concentration within the Jordanian ambient air limit 1140/2006 except for the PM_{10}, when the annual limit laid out by Jordanian standards was exceeded and this could be due to dust and local source pollution, including motor vehicles.

Key words : *Amman, Meteorological,* PM_{10}, (SO_2), (NO_2), (O_3), *(CO).*

Introduction

Air pollution was described as the use of substances or energy that cause harm to the health of humans, living resources and ecological systems, structural damage or interference with legitimate environmental use, (WHO, 2000). Air pollution, which has a significant toxicological impact on human health and climate, is a big issue of recent decades. Pollution sources range from small cigarette units and natural causes such as volcanic activity to vast amounts of pollutants from car engines and manufacturing activities (Robinson, 2005; Habre *et al.,* 2014)

As a result of industrial activities in developed countries, air pollution is now occuring and emissions sources such as unsuitable vehicles are also rising (Chen and Kan, 2008).

The Jordanian Ministry of Environment established an air monitoring program to measure the concentrations of several compounds including Particulate matter with aerodynamic diameter $\leq$ 10 microns (PM_{10}), Carbon monoxide (CO), Sulfur dioxide (SO_2), Nitrogen dioxide (NO_2), Ozone (O_3) (Figure 1). Thus there are fixed stations that continuously monitor air quality in urban areas, traffic dominated sites, and industrial zones.

The primary objective of the study is to determine the levels for air pollutants at Amman and to compare the averages of various air pollutants with the Jordanian JS-1140/2006 per hour, daily and yearly. The goal of the research was to study the concentration of air pollutants and the meteorological effects of pollution control parameters for the behavior of pollutants in these areas (wind velocity, wind direction, temperature and relative humidity).

Methodology

Air Monitoring Sites

Amman air quality monitoring sites consist of 7 stations distributed as follows: King Hussein Gardens *(KHG)*, King Abdullah II industrial City /Sahab *(KAC)*, Marka - Mahata *(MAH)*, Northern Bus Station Tabarbour *(TAB)*, University Street Sweilrh *(UNI)*, Greater Amman Municipality (GAM) and Wadi Rimam Yarmouk Garden (TAR). The network reference station was located at the King Hussein Gardens in Amman. The locations of the measurement stations were chosen based on a preliminary mapping at the city and the monitoring sites were chosen in a way that ensures a fair and comprehensive representation of anthropogenic activities. Data obtained during the monitoring effort between May 2014 until May 2015. Figure 1 indicates the geographical locations of the monitoring stations.

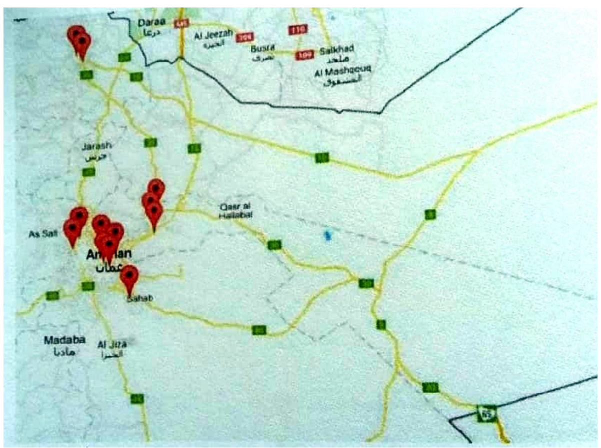

Fig. 1. Location map of the study area.

Monitoring Procedures

Air samples are examined using infrared fluorescence analyzer, nitrogen dioxide (NO_2) concentration using chemiluminescence analyzer to measure concentration of carbon monoxide (CO). Ultra-violent fluorescence SO_2 analysis, PM_{10} analysis made with beta-atténuation and ozone (O_3) concentrations by Thermao Model 49i, (Environment Ministry 2014 -2015). In the King Hussein Gardens station weather data are also obtained. Hourly measurement of wind speed, wind direction, temperature and relative humidity. Table 1 shows which pollutants are monitored at each station.

Statistical Analysis

According to the undisclosed data, the Royal Scientific Society (RSs) and the Ministry of Environments have both received daily mean concentrative of contaminants SO_2, NO_2, CO, O_3 and PM_{10}. The data were placed in a personal computer to be analyzed using version 18 of the SPSS Statistical Kit. Monitoring of the air pollutants and meteorological data is carried out with the Kolmogorov – Smirnov method, histogram map and Q-Q map. Most of the variables have been found to naturally be distributed.

Results and Discussion

Basic Statistics

Table 2 show the average yearly concentrations of PM_{10}, SO_2, NO_2, O_3 and CO which monitored at each station during the period from May 2014 to May 2015.

Variation of Pollutant Levels for Data Taken Daily

Sulphur dioxide (SO_2) Trend

A known toxic gas that has an effect on the respiratory system is sulphur dioxide (SO_2). Nose, mouth, and lungs become irritated and bronchitis may be caused. Concentrations of sulfur dioxide in the air can be traced primarily to combustion. If fuel with sulfur is burned, sulfur is released, such as petrol, carbon and fuel oil. Coal and high-sulfur oil must also be substituted by cleaner, less ash and less sulphur, fuels such as natural gas. (Chen *et al.,* 2007).

The Jordanian Standard allows three 1- hour average concentrations greater than 300 ppb in a 12 month period. The 24-hour average Jordanian Standard for ambient air quality is 140 ppb while the yearly average is 40 ppb. Figure 2 illustrates the yearly average SO_2 concentration for all stations. The highest regular SO_2 readings can be seen easily at MAH station.

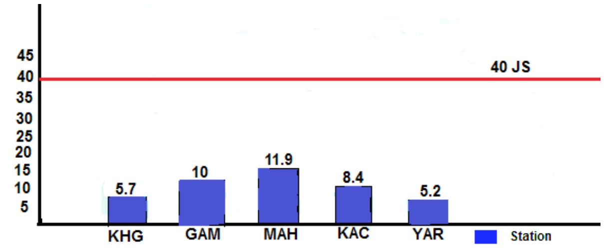

Fig. 2. SO_2 yearly average all stations

Figure 3 shows the SO_2 maximum hourly average concentrations. The figure indicates that the concentration rates have peaks which are most likely linked to growth, traffic and the environment. The statistics show that neither standard Jordanian SO_2 has been surpassed., (i.e, 1- hour average Figure 3 and for the yearly average concentration Figure 2).

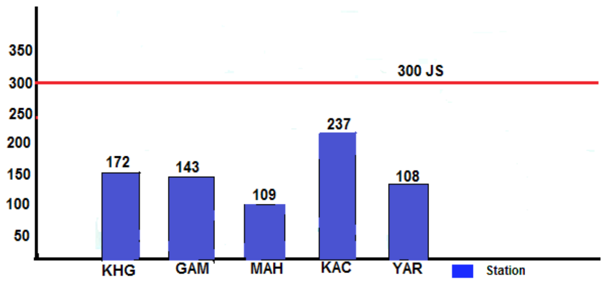

Fig. 3. SO_2 Max 1hr average all stations

Carbon Monoxide (CO) Trend

Incomplete combustion of fossil fuels is the result of carbon monoxide-petrol, fuel oil, coal and wood used in boilers, engines, oil burners, gas fires, heaters of water, solid fuel and open fires. Dangerous levels of CO will build in if fuel is not properly burned or if the rooms are poorly ventilated and the carbon monoxide cannot escape due to inadequate installation, repair or failure or damage to an equipment in operation (Allred *et al.*, 1989). Carboxyhemoglobin (COHb) concentrations below 2 percent have no human health effects, whereas levels above 40 percent are lethal. Known mechanisms of the underlying CO toxicity are hypoxia, apoptosis and ischemia (Akyol *et al.*, 2014).

The worst thing that can happen in your daily life is potentially carbon monoxide-in your house, at work, in your garage or in your vehicle. With no smell , taste or colours, good ventilation, maintaining all the equipment regularly and having completely reliable detector alarms mounted that offer both visual and audible accumulation of core to dangerous levels has become increasingly necessary in today's world of better isolation and double glazing.

The Jordanian standard allows three 1- hour average concentrations greater than 26 ppm a 12-

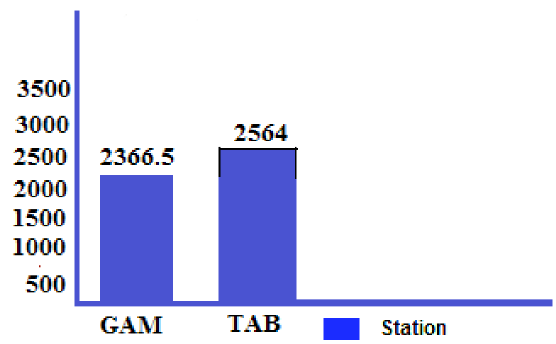

Fig. 4. CO yearly average

Table 1. Air Pollutants that are monitored at each site..

Type of station	Station Name	Short Name	O_3	CO	SO_2	NO_2	PM_{10}
Background	King Hussein Gardens	KHG	1		1	1	1
Urban	Greater Amman Municipality	GAM		1	1	1	1
Traffic	Northern Bus Station Tabarbour	TAB		1		1	1
Urban	Marka - Mahata	MAH				1	1
Traffic	University Street Sweilrh	UNI				1	1
Industrial	King Abdullah II industrial City /Sahab	KAC	1		1	1	1
Industrial	Wadi Rimam Yarmouk Garden	YAR			1	1	1

Table 2. Yearly Average concentrations for the air pollutants in each station.

Type of station	Station Name	Short Name	O_3	CO	SO_2	NO_2	PM_{10}
Background	King Hussein Gardens	KHG	39.4		5.7	12.3	57.8
Urban	Greater Amman Municipality	GAM		2367	9.9	24.5	97.7
Traffic	Northern Bus Station Tabarbour	TAB		2564		27.6	107.6
Urban	Marka - Mahata	MAH			11.9	25.7	113.3
Traffic	University Street Sweilrh	UNI				11.3	90.4
Industrial	King Abdullah II industrial City /Sahab	KAC	23.4		8.3	17.5	77.7
Industrial	Wadi Rimam Yarmouk Garden	YAR			5.2	24.6	105.2

month period. The 8 –hour average guideline is 9ppm and there is no yearly average Jordanian standard for ambient air quality. CO measured only in two stations, GAM and TAB. Figure 4 illustrates the average yearly CO concentration for each hour of the day. The highest annual CO reading in TAB relative to GAM stations can be easily seen.

Figure 5 indicates that neither station met any of the Jordanian CO criteria.

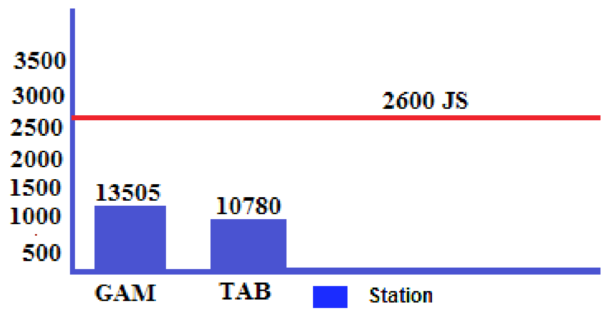

Fig. 5. CO Max. 1 hour Average in two stations

(PM_{10}) Trend

PM_{10} Particulates are inhalable aerosols with a diameter of less than 10 m; as small as the particles, they can reach the lungs, causing many health issues for people with chronic respiratory conditions like asthma or bronchitis, in particular. PM_{10} Particulates are smaller. Particles can also change immune systems and thus decrease body resilience and infection control (Sahu *et al.*, 2014 and Bentayeb *et al.*, 2013). Recent epidemiological research have also pointed that inhalable particulates could lead to high blood pressure, strokes, and lung cancer, and thereby increase annual mortality rates. The average PM_{10} for Jordan is 70 mg/m^3 per year. This year's average cap was surpassed by six out of seven stations. The Jordanian minimum is 120 µg/m^3 for 24h average PM_{10}. It must be achieved over duration of 12 months not more than three times. Regional poisoning and local soil erosion causes high PM_{10} values and during regional dust storms, all stations record very high levels of poisoning. The average reading of 24 hours PM_{10} at all stations is shown in Figure 7.

More light dust storms and pollution from local sources, such as motor vehicles, lamps and domestic heating, have contributed to high rates of PM_{10}. Events of unstable atmospheric Conditions may also lead to elevated PM_{10} levels.

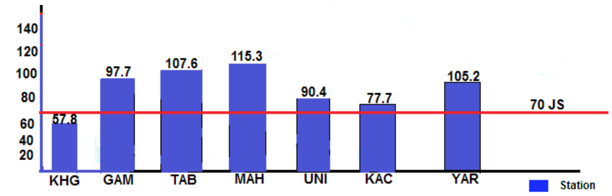

Fig. 6. PM_{10}Yearly Average in all stations

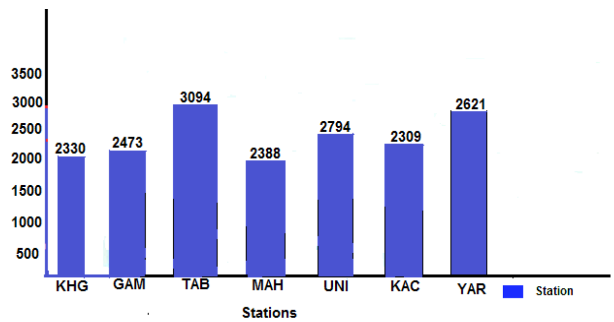

Fig. 7. PM_{10} Max. 24 hr Average in all stations

Nitrogen dioxide (NO_2) Trend

Nitrogen oxides are significant air pollutants that can increase respiratory risk (Chen *et al.*, 2007). Mainly from vehicles, they are emitted and hence air pollutants associated with traffic. Deep pulmonary irritants can cause pulmonary edema if they are deeply inhaled. Wheezing and cough are the commonest nitrogen oxides complication toxicity, but inflammation in nose, eyes or throat, vomiting,

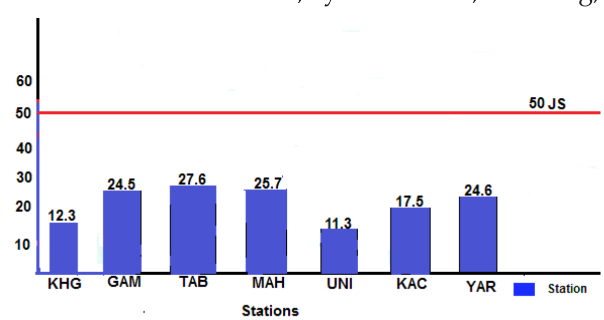

Fig. 8. NO_2 Yearly Average in all stations

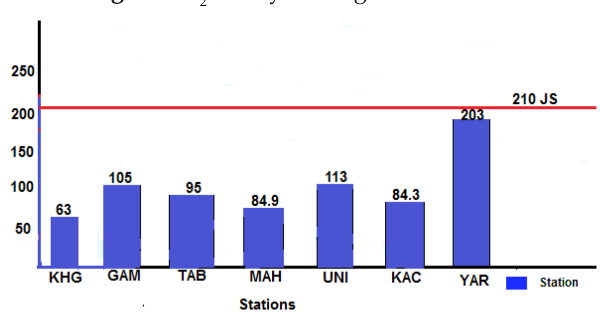

Fig. 9. NO_2 Max. 1- hr Average in all stations

chest pain, diaphoresis, pulmonary edema and fever may also happen. For another study, nitrogen oxide levels between 0.2 and 0.6 ppm are reported to be inoffensive to humans (Hesterberg *et al.*, 2009).

The Jordanian Standard allows three 1-hour average concentrations greater than 210 ppb a 12-month period. The 24-hour average Jordanian Standard for ambient air quality is 80 ppb while the yearly average is 50 ppb. Almost all stations showed results within these Jordanian Standard for ambient air quality limits (Figures 8 and 9).

Ozone (O_3) Trend

Ozone (O_3) is a colorless gas that forms the main ingredient of the atmosphere with the chemical formule O_3. The ground level as well as the upper regions of the atmosphere are known as the troposphere (Gorai and Tuluri, 2014). Ozone is a strong oxidizing agent, unlike the oxygen source that is one of the main components of air (diatomic or O_2 oxygen). O_3 causes a range of harmful effects in humans and laboratory animals in certain urban environments at concentrations (Lippmann, 1989). Ozone reacts with the biological membranes of human lungs and leaves that may damage living cells, such as those present in human lining. There have been many adverse health effects associated with Ozone exposure, such as worsening of asthma and decreased lung function.

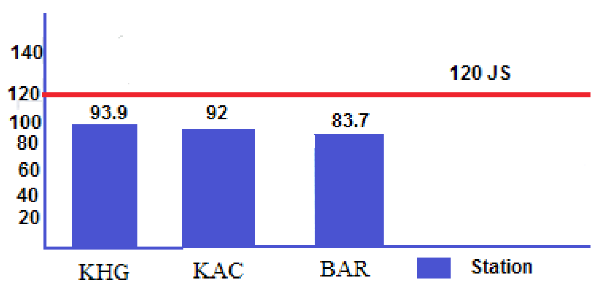

Fig. 10. Ozone Max. 1 hr average at the monitoring site

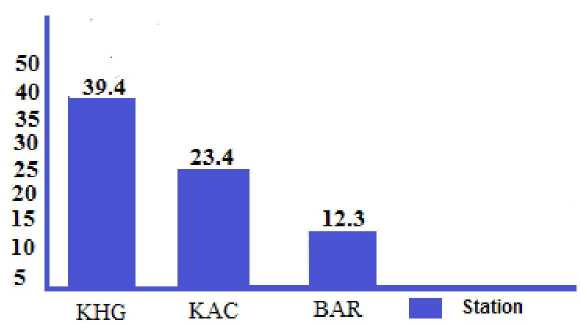

Fig. 11. Ozone Yearly Average at the monitoring site

A majority of tropospheric occurs because the presence of sunlight induces a photochemical reaction in the soil, including a nitrogen dioxide (NO_2) , carbon monoxide (CO) and volatile organic compounds (VOCs). So NO_2, CO and VOCs are recognized as precursors of ozone. The main anthropogenic sources of ozone precursors are motor vehicle exhaust, industrial emissions and chemical solvents. Although these precursors mostly arrive in urban areas, hundreds of kilometers of wind can bring NO_2, which induces ozone production in less populated areas..

The Jordanian standard ozone guidelines are 120 ppb at an average 1 hour level, 80 ppb at an 8-hour mean level, and there are no typical annual guidelines. All stations showed results within these guideline limits and there were no exceedance (Figure 10). Ozone readings are the highest recorded in the King Hussein Gardens station, (Figure 11) as it is probably picking up pollutants from the west. Highest readings are mainly during the afternoon period when ambient temperature is the highest in the day.

Meteorological parameters

Average of temperature

In August, 4.42 °C was the lowest average monthly temperature, and the maximum average monthly average temperature was 40.40 °C, averaging 21.9 °C per year. (Figure 12).

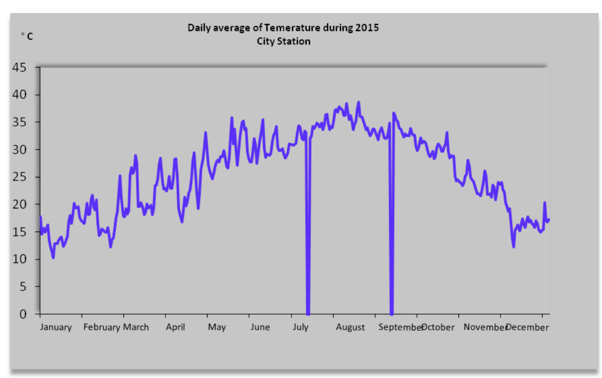

Fig. 12. Time plot for temperature.

Daily average of relative humidity

The lowest average relative humidity recorded in September is 16 percent, and the highest average relative moisture recorded in November is 92 percent and the average moisture level is 62 percent

(Figure 13). The lower the concentration of contaminants is, the more in the relative humidity. The primary explanation is that the relative humidity is a part of removing contaminants in the atmosphere and the decrease in acid rain.

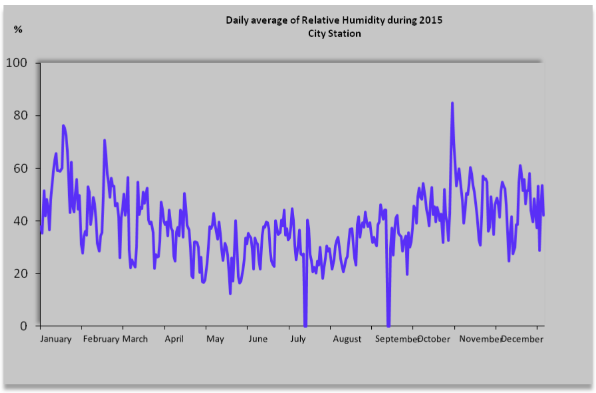

Fig. 13. Time plot for relative humidity.

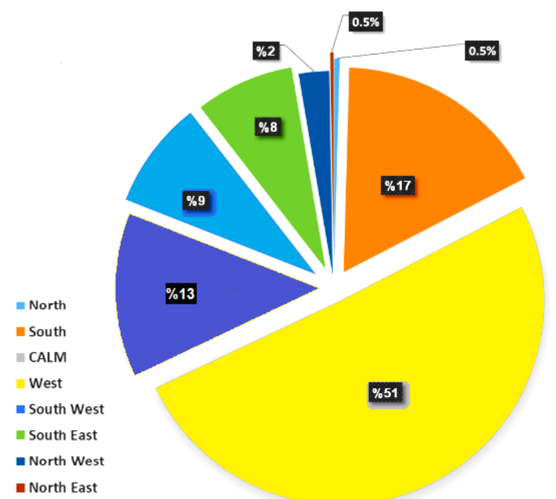

Fig. 14. Monitoring site wind direction (March 2010 – December 2015).

Daily average of wind Direction

As shown in Figure 14, wind direction at the King Hussein Gardens (Reference station) in Amman is mainly from the west.

Daily average of wind speed

Wind speed distribution from May 2015 through April 2016 is shown in Figure 15. The distance the wind travels and its concentrations in the air surrounding it also plays a crucial role in atmospheric tranquility. Daytime contaminants at high wind speeds are predicted to be transported and diluted. More than 39% of the wind blows at a speed from 0 – 2 m / s to 39% of a speed from 2 to 5 m / s. This wind blow plays a part in the fact that contaminants are more concentrated here. It is not possible to move contaminants farther away in low-speed winds.

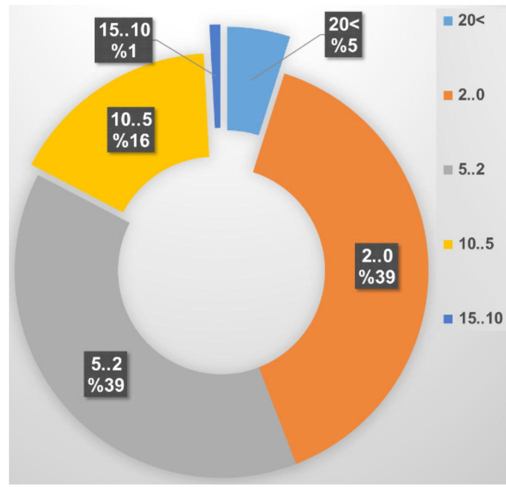

Fig. 15. Wind Speed at the monitoring site (May 2014 – May 2015).

The correlation of climate variables with air pollutants

If there is a relationship between air pollutants and basic meteorological parameters, correlation analysis is deployed. As in Table 3.

The following comments are derived from the findings presented in Table 3./

Temperature has strong negative relationship with RH%, weak negative relationship with NO_2 and CO, moderate positive relationship with wind Speed and wind Direction, week positive relationship with SO_2 and PM_{10} and strong positive relationship with O_3.

RH% has a strong adverse temperature and PM_{10} relationship, a moderate negative O_3 relationship and a low negative with SO_2, Co and NO_2 relationship. However, the relationship with wind speed is moderately positive.

Wind Speed has weak negative relationship with SO_2 and CO, moderate negative relationship with NO_2 and moderate positive relationship with temperature, wind direction, RH% and O_3.

SO_2 has weak negative relationship with Wind Speed, Wind Direction, RH%, and O_3, and low temperature positive relations, moderate $PM_{10,}$ NO_2 and CO positive relationship.

Table 3. Correlation between air pollutants and meteorological parameters.

O_3	PM_{10}	CO	NO_2	SO_2	Wind Direction	Wind Speed	RH%	Temperature	
0.69	0.035	-0.12	-0.14	0.19	0.33	0.39	-0.62	1.000	Temperature
-0.32	-0.59	-0.008	-0.014	-0.12	-0.12	0.31	1.00	-0.62	RH%
0.38	-0.64	-0.021	-0.21	-0.07	0.33	1.000	0.31	0.39	Wind Speed
0.33	-0.007	-0.05	-0.04	-0.1	1.00	0.33	-0.12	0.33	Wind Direction
-0.09	0.34	0.24	0.25	1.00	-0.1	-0.07	-0.12	0.19	SO_2
-0.25	- 0.012	0.62	1.00	0.25	-0.04	-0.21	0.014	-0.014	NO_2
-0.12	0.49	1.00	0.62	0.24	-0.05	-0.021	-0.008	-0.12	CO
-0.32	1.000	0.49	- 0.012	0.34	-0.007	-0.64	-0.59	0.035	PM_{10}
1.00	-0.32	-0.12	-0.25	-0.09	0.33	0.38	-0.32	0.69	O_3

O_3 has strong negative relationship with PM_{10}, weak negative relationship with SO_2 and CO, moderate negative relationship with PM_{10}, RH% and NO_2, moderate positive with wind speed and wind direction, and highly positive temperature relationships.

CO has low negative with temperature, wind speed, wind direction, RH% and O_3 relationship, moderate positive with SO_2, high positive relationship with NO_2 and PM_{10}.

The relationship between NO_2 and temperature, wind, and PM_{10}, low and negative whereas the relation with SO_2, and RH% weak and positive, NO_2 has a clear positive relationship with CO.

PM_{10} has low negative with wind direction and NO_2 relationships, moderate negative O_3 relationships, moderate positive with CO and SO_2 relations, strong negative with RH% and wind speed.

Conclusion

Results indicate that, in contrast to Jordan's 1140-2006 environmental standard, Amman is relatively decent for the entire year. The monitored pollutants: CO, SO_2 , NO_2 and O_3 were generally within the current Jordanian standard guideline limits; however PM_{10} concentrations in most sites exceeded the standard.The results of this study indicate that the SO_2, CO, PM_{10}, NO_2 and O_3 variability patterns are well related to parameters of meteorological conditions.

The high levels of PM_{10} were leading to regional dust and local abrasion. Since wind direction in Amman is mostly from the west, it is realized that pollution levels in measurement stations in the center of Amman are higher as they include air pollution emitted from the various activities in the cities (industry, domestic heating and motor vehicles).

Acknowledgment

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Disclaimer

The opinions and conclusions stated in this paper are those of the authors and do not necessarily represent those of the Jordanian Ministry of Environment, or any of the organizations associated with the measurements of air quality parameters. Any reference to trade names does not constitute an endorsement of the product.

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