

Measurement of Ground Level Ozone at Different Locations

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Abstract: Problem statement: Ground level ozone is the most important index substance of photochemical smog. Photochemical smog is now observed in many urban and industrial centers around the world and it has become a common phenomenon in many large cities. Ozone is a most harmful pollutant for humans, in addition it plays an important role in damaging vegetation and materials. Therefore it becomes important to measure the ground level ozone at different locations especially in the center of cities. **Approach:** The ground level ozone concentration at different locations in Baghdad city was identified. Five different sites have been chosen to identify the ground level ozone concentration. Two sites were chosen as areas contained point source (power plant station) in addition to high traffic load and the other three sites were chosen as areas containing heavy traffic only (line source). The measurement focuses on spring and fall because these periods display favorable meteorology to ozone formation. **Results:** During the research period the maximum values (peaks) for ground level ozone concentration were observed in the fall: at Al-Za'afarana area 101ppb as an average, at Al-Dora 87 ppb as an average (which represent the point sources) and at line source areas 48 ppb as an average. In spring, the peaks of ozone concentration observed to be at the same height, about 50 ppb for all sites. **Conclusion:** The results show that the effect of power plant stations in forming ozone is larger than traffic load. The comparison between the ground level ozone concentrations that measured during the research period in spring and fall and the Ambient Air Quality Standards (AAQS) shows that: (1) No exceeded levels were observed in spring for all sites. (2) In the fall, the AAQS for ozone was exceeded in Al-Za'afarana area at 12: PM, 1: PM, 2: PM and 3: PM and in Al-Dora at 2: PM.

Key words: Gas Sensitive Semiconductor (GSS), Geographical Positioning System (GPS), United States Environmental Protection Agency (USEPA), Local Standard Time (LST), Ambient Air Quality Standards (AAQS)

INTRODUCTION

It has been reported that the tropospheric Ozone (O_3) is the principal index substance of photochemical smog. It has been recognized as one of the principal pollutants that degrades air quality (Eijkeren *et al.*, 2002). Ozone is unique among pollutants because it is not emitted directly into the air. Ozone is produced when the primary pollutants, nitrogen oxides NO_x and the volatile organic compounds VOCs (often called Non-Methane Hydrocarbons, (NMHC), which are referred as ozone precursors, interact under the action of sunlight. Meteorological parameters (temperature, wind speed and direction, solar radiation, humidity and boundary layer depth) highly influence the formation and dispersion of ozone. Radiation, temperature and humidity drive the chemical reactions producing ozone, while boundary layer characteristics and the absence

of wind are the factors which respectively lead to the build-up of precursors and limit their dispersion. Ozone formation/destruction indicates that the whole mechanism is particularly controlled by meteorological parameters. The concentration is varied widely from region to region, with the time of the year and the time of the day (Langyel *et al.*, 2004; Jose *et al.*, 2005; Al-Alawi *et al.*, 2008).

Both NO_x and VOCs are emitted from a large pool of sources. These sources are typically classified into four categories: area, point, mobile and biogenic. Emissions of NO_x are produced primarily by motor vehicle engines, power plants, industrial plants, boilers and burning of fossil fuels. VOCs emissions are motor vehicle emissions, gasoline vapors and chemical solvents. Biogenic Volatile Organic Compounds (BVOCs) which almost emitted from forest and marshland like terpenes and isoprene have also

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contributed to ozone formation. The impact of biogenic emissions on surface O₃ has been examined in many studies. Biogenic volatile organic compounds are a source of hydroperoxy and organic peroxy radicals, which can react with NO_x to stimulate O₃ production and react with Peroxy Acetyl Nitrate (PAN) which influence the global distribution of Nitrogen Oxides (NO_x) and thus indirectly impact O₃ production (Pfister *et al.*, 2008). The high concentration of ozone and other photochemical oxidants are observed over largest cities and metropolitan areas during warm months. Considerable levels of ozone are also found to exist over large rural regions in which ozone gets transported from large urban and industrial areas. Thus, tropospheric ozone is not merely an urban air pollution problem, but also a regional problem (Arya, 1999).

Ozone is well known as strong oxidant. It has a direct effect on human, vegetation and materials. Inhalation of air mass containing 1 ppm by volume ozone causes severe irritation and headache. Ozone irritates eyes, upper respiratory system and lungs. Inhalation of ozone can sometimes cause fatal pulmonary edema which is an abnormal accumulation of fluid in lung tissue. Ozone generates free radicals in tissue. These reactive species can cause lipid peroxidation, oxidation of Sulfhydryl (-SH) groups and other destructive oxidation processes (Manahan, 2004; Palli *et al.*, 2008). Phytotoxicity of ozone is characterizing the yellow and black spots on a green leaf. Wang *et al.* (2007) show ozone effects on corn and soybeans in both quality and productivity in Linan/China. Quijano *et al.* (2009), show that phytotoxicity increased with altitude, substantial ozone injury symptoms were found at all altitudes on tobacco plants exposed to the ambient air, although, the damage was more intense in the plants at greatest altitudes. Ground level ozone may cause reduced resistance to fungi, bacteria, viruses and insects. These impacts on sensitive species may result in declines in agricultural crop. Ramo *et al.* (2006) verify that ozone (40-50 ppb) reduced the total community biomass production and the growth of three species out of seven.

Ozone has a direct effect on materials of reduction for its virtual life. Ozone attacks synthetic rubbers causing deterioration of rubber by cracking. The mechanism appears to be an attack at the double bonds in the hydrocarbon polymer used in the rubber. Some of rubber manufacturers make test to their product by the exposure to high ozone concentration they call it ageing rubber tests. Ozone also attacks the cellulose in textiles, reducing the strength of such items and changing white color of fabric to yellow (Brown *et al.*, 2001).

Because ozone has those harsh effects on both life and material, the United States Environmental Protection Agency (USEPA) considered ozone as a criteria pollutant. USEPA ozone standards have been changed according to the development of research on life requirement. To attain the ozone standard, the 3 year average of the fourth-highest daily maximum 8 h average ozone concentration measured at each monitor within an area over each year must not exceed 0.075 ppm (NRC, 2008).

In order to estimate how meteorological conditions affect the variation of ozone levels, multiple linear regression analysis was used. Multiple linear regression analysis is one of the most widely used methodologies for modeling the dependence of the response variable (predicted) on several independent variables (predictors), (Khiem *et al.*, 2010). However the multiple linear regression approach can face serious difficulties when the independent variables are correlated to each other (multicollinearity). Multicollinearity is the undesirable situation when one independent variable is a linear function of other independent variables. Multicollinearity indicating that the predictors are highly intercorrelated so that small changes in the data values may lead to large changes in the estimates of the coefficients (Paschilidou *et al.*, 2009). Abdul-Wahab *et al.* (2005) indicated that multicollinearity, or high correlation between the independent variables in a regression equation can make it difficult to correctly identify the most important contributors to a physical process. The problem can be overcome by omitting the variables that have high multicollinearity (Paschilidou *et al.*, 2009).

The aim of this research is to identify the ground level ozone concentration in Baghdad City at different locations. Five locations are chosen, Al-Dora and Al-Za'afarania sites are chosen to show the effect of the thermal power plant (as point source) and AL-Uma Park, Aden Square and AL-Mawal Square is chosen to represent line source. Statistical analysis including multiple linear regression technique was used to model the dependence of ground level ozone concentration on the meteorological parameters for Al-Dora sites.

MATERIALES AND METHODS

Site description: Baghdad is the capital of Iraq and the center of air, road and rail transport in the country. As the leading manufacturing city of Iraq, the city has numerous oil refineries, power plants, food-processing plants, tanneries and textile mills. The population of Baghdad in 2011 was approximately 7, 216, 040. Iraq's official statistical reports give the total land area as 438,446 km⁻² (169,285 sq mi). It is the largest city in

Iraq, the second largest city in the Arab World (after Cairo/Egypt) and the second largest city in Western Asia (after Tehran/Iran). The city is located on a vast plain bisected by the River Tigris. The city is located on flat terrain with no hills or other obstruction around; it is surrounded by flat uncultivated desert. Baghdad has a Subtropical Arid climate, in terms of maximum temperatures, one of the hottest cities in the world. In the summer from June to August, the average maximum temperature is as high as 44°C accompanied by blazing sunshine.

Refineries, power plants and vehicle emission that found in the city make air pollution problems and ozone formation possible.

Different sites have been chosen to estimate the ground level ozone in Baghdad City. Different measuring points at Al Dora and Al-Za'afarania Sites were chosen to show the effect of the power plant (as point source) on the formation of ground level ozone, while Aden Square, Al-Mawal Square and Al-Uma Park was chosen to represent line sources. Figure 1 and Table 1 shows the coordinates and the description of these sites.

Data collection: Different equipments have been used to measure both ozone concentration and meteorological parameters (temperature, wind speed, relative humidity and solar radiation). Ozone monitor S-500 from Aeroqual New Zealand Company is used to measure ozone concentration in (ppb), the sensor head for ozone monitor works on Gas Sensitive Semiconductor (GSS) principle. A portable humidity temperature meter model (HT-3015HA) from the Taiwan Lutron Company was used to measure both relative humidity and temperature. A cup anemometer model AM-4221 from Taiwan Lurton Company was used to measure wind speed in (m/Sec). Sun light intensity meter model (A1010) from MetroQ Company used to measure sunlight intensity in (Lux) and the Geographical Positioning System (GPS) is on Taiwan production with Garmin trade mark model "etrex, Vista, it has been used to define the location in term of longitude and latitude with an accuracy limit of about 5 m. All the equipments were gathered and fixed on composite aluminum bar fixed on a tripod with about 8 kg weight and 1.6 m height to simulate respiratory system intakes.

Care must be taken that no high buildings or trees present near the measuring site. Values of the daylight time period were used i.e., from 8: AM to 4: PM Local Standard Time (LST), since this documented as the most important photochemical production period.

Table 1: Measuring sites descriptions

Site	Name and location of measuring site	Code	Coordinate		Ozone source
1	Aden Square (North waste of Baghdad City)	A	N 33 21.764	E 44 20.007	Heavy traffic
2	Al Mawal Square (North waste of Baghdad City)	M	N 33 22.194	E 44 24.201	Heavy traffic
3	Al Uma Park (In the center of Baghdad City)	U	N 33 19.747	E 44 24.628	Heavy traffic
4	Al Za'afarania South east of Baghdad City, (located near South Baghdad power plant and to the North East of Al-Dora refinery)	Z1	N 33 17.692	E 44 27.265	South Baghdad power Plant and heavy traffic
		Z2	N 33 17.127	E 44 27.785	
		Z3	N 33 17.294	E 44 26.893	
		Z4			
5	Al- Dora (South of Baghdad city near the Al-Dora power plant)	D1	N 3315 50.67	E 44 2144.7	Al-Dora power plant and heavy traffic
		D2	N 33 16.077	E 44 21.87	
		D3	N 3315 22.99	E 44 2156.13	
		D4	N 331530.31	E 44 2234.66	
		D5	N 33 15.348	E 44 22.698	
		D6	N 33 15.315	E 44 22.978	
		D7	N 33 15.281	E 44 22.524	

Hourly observations for 10 days per month were recorded for each area. The measurement focus on spring (March, April and May) and fall (September, October and November), these periods display favorable meteorology to ozone formation in Baghdad City, as indicated by Kanbour *et al.* (1987) and AL-Quzweny (1990). Other researchers also indicate that these periods display favorable meteorology to ozone formation as in central Makkah, Saudi Arabia (Al-Khalaf, 2006) and in Rabia Area, Kuwait City.

RESULTS AND DISCUSSION

Al-Dora area: Al-Dora area was considered as a case study, the area was expected to be affected by the pollutants which are emitted continuously from Al-Dora Power Plant and the traffic load. Al-Dora Power Plant located in the south west of Baghdad City and to the west of Al-Dora Refinery and South Baghdad Power Plant (Fig. 1). The wind arose over a period of one full year (2008) was constructed (Fig. 2) using Wrplot V.5.9 program. The wind rose shows that the majority of the prevailing wind were from the west, therefore the measurement points were selected at different locations (D1, D2, D3, D4, D5, D6 and D7) downwind and upwind from Al-Dora Power Plant (Fig. 3). Figure 4a represents the hourly average diurnal variation of ozone concentration and corresponding meteorological parameters at spring and fall for all the locations in Al-Dora area. Figure 4a shows that:

- High ozone peak 87 ppb in 2: PM was observed in fall while a lower peak was observed in spring 50 ppb in 11: AM. In spring, the level of ozone concentration was nearly maintained constant through the daylight time, while in the fall a sharp increase in ozone concentration was observed at 2: PM



Fig. 1: Aerial photo for Baghdad city shows the measuring sites

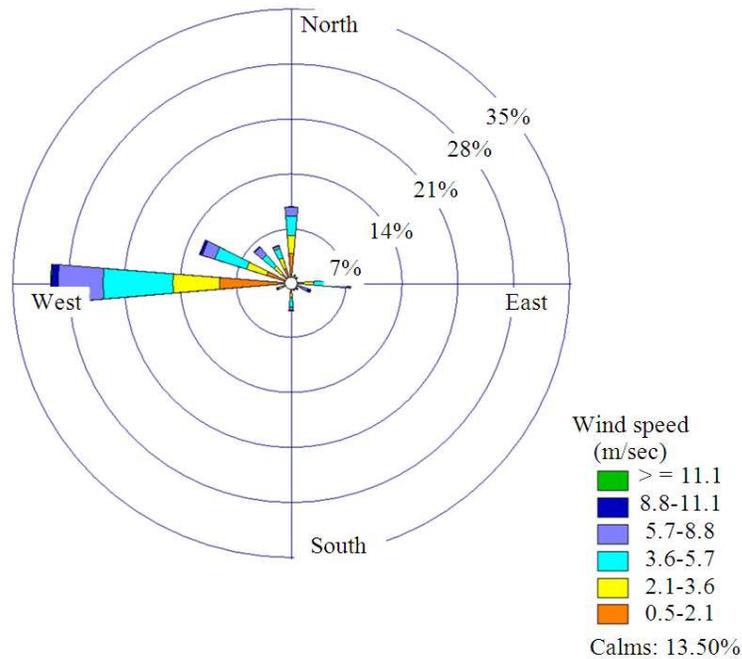


Fig. 2: Wind rose for Baghdad city one full year (2008)

- The back ground concentration of ozone which represents the early recorded value at fall 29 ppb is much higher than the value at a spring which represents 16 ppb.
- The solar radiation (about 50 klux), temperature (about 35°C), relative humidity (about 23%) and wind speed (about 2 m sec⁻¹) throughout Al-Dora sites, in addition to low mixing height (low inversion layer) that usually observed at fall may be responsible for such higher fall ozone peak . These results coincide with those of Al-Khlaf, (2006) when he studied the influence of meteorological factors on ozone concentration at central Makkah.
- The highest peak of ozone concentration 236ppb during the research period was observed in this area at point D7 at 2:PM on 16th October 2009, the corresponding temperature was 37°C, the maximum solar radiation 72 Klux, the relative humidity 19% and the wind speeds 3.7 m/s from north direction.

Al-Za'afarania area: The measurements were located at four points (Z1, Z2, Z3 and Z4) (Fig. 5) downwind and upwind from South Baghdad Power Plant. Figure 4b represents an hourly average diurnal variation of ozone concentration and corresponding meteorological parameters at spring and fall for all the locations in Al-Za'afarania Area. From this figure it can be noticed that:

- Two ozone peaks were appearing in all locations. The peaks are nearly at the same height
- Fall represent higher average ozone peaks (90 and 101ppb) as compared with spring (50 and 55 ppb). Precursors (NO_x and VOC) from South Baghdad Power Plant and traffic load with favorable meteorological parameters in addition to low mixing height (low inversion layer) that usually observed at fall may be responsible for such higher ozone peaks
- A shift in peak time can be noticed at fall. In spring, there is a decline in ozone concentration at 12: PM while at fall the decline at 1: PM. No heavy traffic was observed at that time
- The highest concentration of ozone 153 ppb was noticed in this area at the point Z4 at 3: PM on 6th November 2009, the maximum solar radiation was 58 Klux, temperature 28°C, relative humidity 25% and wind speed 4.3 m/Sec from north direction
- Kanbour *et al.* (1987) during their research period observed that the maximum value of ozone concentration, 285 ppb was recorded at Al-Za'afarania Site in Baghdad City in October 1987.
- Almost all the meteorological data recorded at Al-Za'afarania indicate that ozone formation increase with high solar radiation (about 60 klux), high temperature (30°C) and low relative humidity

(25%). Although variable wind speed was observed but in most cases low wind speed will limit the ozone dispersion. A higher wind speed was recorded in Al- Zaafarania (3.4 m sec⁻¹ as a maximum) as compared with Al-Dora site, also there is a decline in temperature with about 5° as compared with the temperature prevails in Al-Dora site. These differences in meteorological parameters related to the nature of Al- Z'afarania area which is considered as an open area

Line source area: The measurements were located at three sites, Al-Uma Park, Aden Square and Al-Mawal Square (Fig. 6) which represent areas of high traffic load. Figure 4c shows the hourly average diurnal variation of ozone concentration and the corresponding meteorological parameters at spring and fall for the above locations. From this figure, the following points can be observed:

- No clear difference in ozone concentration between spring and fall in these areas
- Three peaks were appeared in the fall, 48ppb at 11: AM, 46ppb at 1PM and 49ppb at 4: PM, they represent the rush hours The highest ozone peak in the present research period (84 ppb) in line source areas was recorded in the Aden Square in 4: PM., on 4th November 2009
- The recorded meteorological parameters at these areas mention that the solar radiation (above 60 Klux) temperature (29°C) relative humidity (28%) and wind speed (less than 2 m sec⁻¹) are responsible for the ozone formation, in addition to NO_x and VOC that may be emitted from vehicle engines.

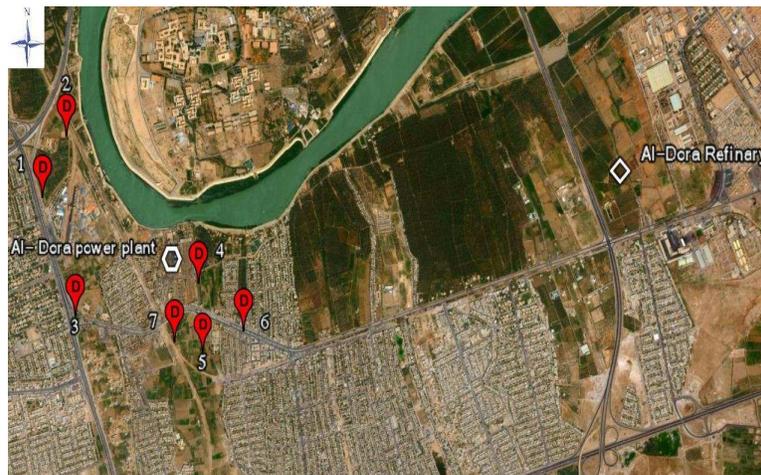


Fig. 3: Aerial photo of Al-Dora area shows the measuring sites around the power plant

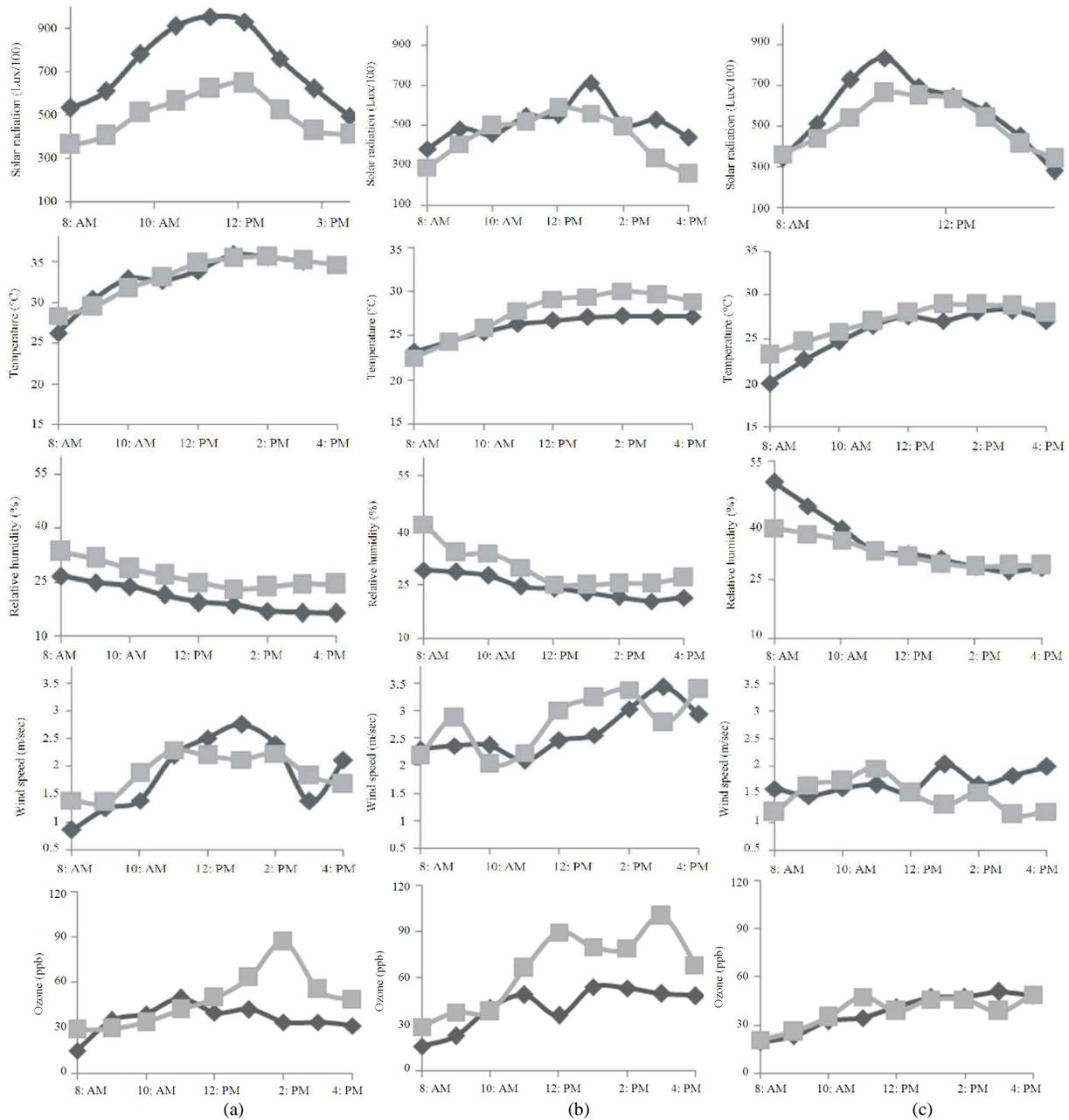


Fig. 4: Diurnal variation of meteorological parameters and ground level zone concentration during spring (black color) and fall (gray color) at (a) Al-Dora site (b) Al-Za'afarania site (c) Line source sites

Comparison between point source, line source and AAQS: It can be noticed from the previous results that line source areas had lower peaks for ground level ozone concentration as compared with areas contained point source at fall (87 ppb for Al-Dora, 101 ppb for Al- Za'afarania and 48 ppb for line source areas). While in spring the peaks were observed to be nearly equal

(50 ppb in Al-Dora, 51 ppb at Al- Za'afarania and 51ppb at line source areas).

The comparison between ground level ozone concentration that measured during spring and fall in the areas of present research and the Ambient Air Quality Standards (AAQS) which is 75 ppb as adopted by (NRC, 2008) identify that:

- No exceeded levels were observed in spring for all sites (Fig. 7a)
- In the fall, the AAQS for ozone was exceeded in Al-Za'afarania area at 12: PM, 1: PM and 3: PM and in Al-Dora at 2: PM (Fig. 7b)

Statistical analysis:

I-Dora area (fall): In order to estimate how meteorological conditions affect the variation of ozone levels, multiple linear regression analysis was used. Table 2 shows the correlation matrix for the variables measured in Al-Dora area during the fall. The independent variables were chosen to be Solar Radiation (SR) in (Klux), temperature (Temp) in (°C), Relative Humidity (RH), Wind Speed (WS) in (m/sec), Distance (Dist) in (km), background concentration of ozone which is the Early recorded value (EOZ) in (ppb) and the dummy variables for both dates (y/m/d) and time of day. These variables were adopted by Galbally *et al.* (1986).

Linear multiple regression analysis is applied to the above values of the independent variables in order to produce a prediction model for the logarithmic transformation of the ozone concentrations $\ln [O_3]$. It is noted that the logarithmic transformation of ozone $\ln [O_3]$ is used instead of O_3 because its frequency distribution is closer to the normal and it is well known that the regression analysis works better with normal variables. The analysis of the data was carried out by using the statistical software, Statistical Package for social science, version 17 (SPSS).

The results of the analyses are presented in Table 3, where the estimated regression coefficients, their standard error, the standardized regression coefficients, the coefficients of determination R^2 , the tolerances and the variance inflation factors VIFs can be seen. Multicollinearity can be observed from Table 3. The small tolerances show that a high percentage of the variance in a given predictor can be explained by the other predictors. Also it is common practice that VIF greater than 3 is considered problematic. Thus, the high VIF values appeared in the Table are considered unacceptable.

To improve the model, the variables that have high VIF (RH, Temperature and date) can be removed from the model as shown in Table 4. The tolerance and VIF were improved and the multicollinearity was removed. Eq.1 represents the multiple regression results for the standardized values. The results show that $\ln [O_3]$ was mostly affected by wind speed, time, solar energy and in less extent by EOZ. Eq. 1 can be acceptable to explain 84% of the variation in $\ln [O_3]$ by these variables:

$$\ln [O_3] = 0.645\text{Time} + 0.239\text{SR} + 0.677\text{WS} + 0.053\text{EOZ} \quad (1)$$

$$R^2 = 0.84$$

Figure 8 illustrates the predicted and the measured values (at 10-16-2009) against the time of the day. The values appeared to fit each other closely.

Table 2: Correlation matrix for Al-Dara area during fall

	Time	Ozone	SR	RH	WS	Temp	Date	Dist	EOZ
Time	1.00	0.43	-0.15	-0.82	-0.08	0.80	0.00	0.18	0.18
Ozone	0.43	1.00	0.22	-0.36	0.69	0.33	0.38	-0.31	-0.31
SR	-0.15	0.22	1.00	-0.10	0.15	0.11	0.37	-0.21	-0.21
RH	-0.82	-0.36	-0.1	1.00	0.04	-0.98	0.29	-0.46	-0.46
WS	-0.08	0.69	0.15	0.04	1.00	-0.15	0.48	-0.50	-0.50
Temp	0.80	0.33	0.11	-0.98	-0.15	1.00	-0.36	0.55	0.55
Date	0.00	0.38	0.37	0.29	0.48	-0.36	1.00	-0.89	-0.89
Dist	0.18	-0.31	-0.21	-0.46	-0.50	0.55	-0.89	1.00	1.00
EOZ	0.18	-0.31	-0.21	-0.46	-0.50	0.55	-0.89	1.00	1.00

Table 3: Linear regression analysis of Al-Dora area during fall

	Unstandardized coefficients		Standardized coefficients		Collinearity statistics	
	B	Std. Error	Beta	Tolerance	VIF	
$R^2 = 0.92$						
$R = 0.96$						
$P = 2.16E-6$						
(Constant)	5961.008	1307.837				
Time	7.399	1.267	1.430	0.061	16.355	
SR	0.030	0.007	0.579	0.216	4.626	
RH	0.280	0.060	2.044	0.019	51.550	
WS	0.647	0.062	0.973	0.428	2.339	
Temp	0.214	0.076	1.34	0.016	62.214	
Date	-0.149	0.033	-0.937	0.087	11.480	
EOZ	-0.029	0.011	-0.494	0.111	8.974	

Table 4: Linear regression analysis after improvement by removing RH, temperature and date

	Unstandardized coefficients		Standardized coefficients		Collinearity statistics	
	B	Std. Error	Beta	Tolerance	VIF	
$R^2 = 0.84$						
$R = 0.92$						
$p = 3.85 E-5$						
(Constant)	0.883	0.581				
Time	3.336	0.581	0.645	0.958	1.044	
SR	0.013	0.006	0.239	0.94	1.064	
WS	0.45	0.084	0.677	0.749	1.336	
EOZ	0.003	0.008	0.053	0.718	1.393	

Table 5: Linear regression analysis of Al-Dora area during spring

	Unstandardized coefficients		Standardized coefficients		Collinearity statistics	
	B	Std. Error	Beta	Tolerance	VIF	
$R^2 = 0.79$						
$R = 0.89$						
$p = 0.005$						
(Constant)	3.965	2.487				
Time	-0.488	1.959	-0.170	0.045	22.472	
SR	0.013	0.005	0.869	0.233	4.298	
RH	-0.049	0.050	-0.639	0.048	20.720	
WS	-0.082	0.088	-0.241	0.310	3.221	
Temp	-0.009	0.039	-0.092	0.134	7.458	
EOZ	0.023	0.012	0.692	0.151	6.644	

Table 6: Linear regression analysis after improvement by removing RH and temperature

	Unstandardized coefficients		Standardized coefficients		Collinearity statistics	
	B	Std. Error	Beta	Tolerance	VIF	
$R^2 = 0.77$						
$R = 0.87$						
$p = 0.001$						
(Constant)	1.634	0.415				
Time	1.166	0.436	0.406	0.822	1.216	
WS	-0.080	0.082	-0.236	0.326	3.005	
EOZ	0.021	0.007	0.613	0.424	2.359	
SR	0.016	0.003	1.030	0.376	2.661	



Fig. 5: Aerial photo for Al-Za'afarania area shows the measuring sits around the power plant



Fig. 6: Aerial photos for the line source area (U) Uma park (A) Aden and (M) Al-Mawal Square

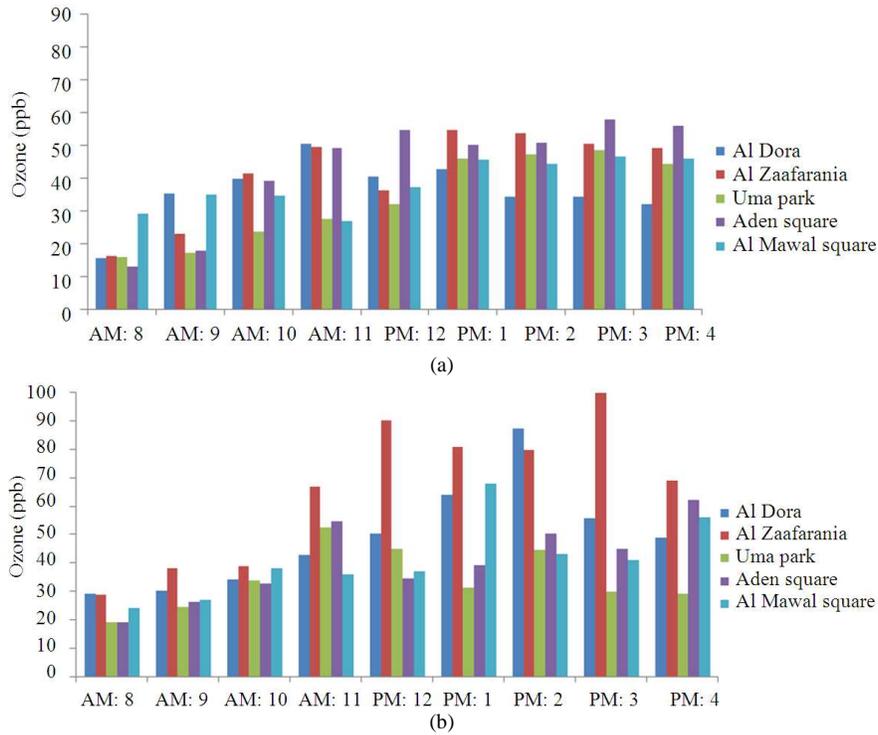


Fig. 7: Comparison between measured values and AAQS (a) Spring (b) fall

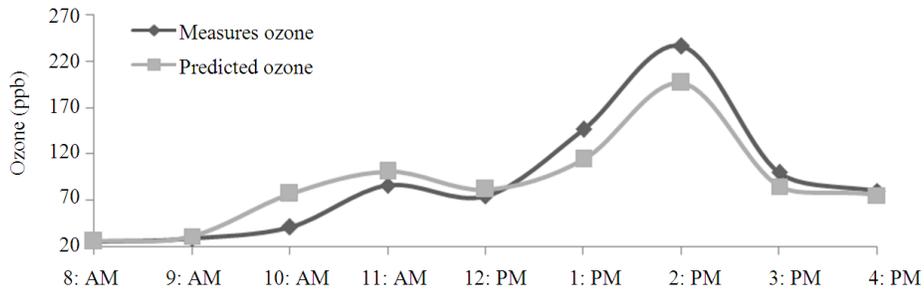


Fig. 8: Predicted and measured values of ground level ozone concentration according to the time of day (fall 16-10-2009)

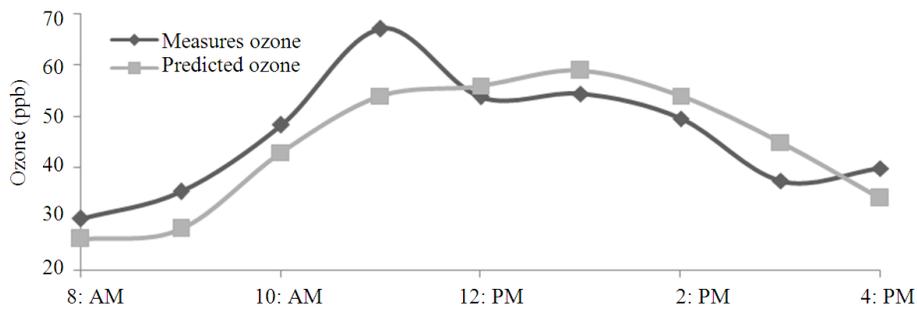


Fig. 9: Predicted and measured values of ground level ozone concentration according to the time of day (spring 4-3-2009)

Al-Dora Area (spring): Table 5 and 6 show the linear regression analysis for spring at Al-Dora Area before and after the improvement. Eq.2 represents the results for the standardized values. Ln [O₃] was affected by SR, EOZ and Time positively and affected by WS negatively. Equation 2 can be acceptable to explain 77% of the variation in Ln[O₃]:

$$\text{Ln [O}_3\text{]} = 0.406 \text{ Time} - 0.236 \text{ WS} + 0.613 \text{ EOZ} + 1.03 \text{ SR} \quad (2)$$

$$R^2 = 0.77$$

Figure 9 shows the predicted and measured values of ground level ozone concentration according to the time of day in spring (3-4-2009). The deviation between the predicted and the measured values is due to other predictor (independent variables) as: wind direction, mixing height pressure and the ozone precursors as NO₂, NO, CO, SO₂ and VOCs, which are not considered in this study.

CONCLUSION

The following conclusions can be considered for the present research:

- The highest ground level ozone concentration was found during fall in all sites, the peaks of ozone concentration appeared clearly in the fall as compared with spring
- The highest average peak of ground level ozone concentration was found during fall in Al-Za'afarania area, 101 ppb in 3: PM. This probably due to the precursors (NO_x and VOC) that emitted from South Baghdad Power Plant, the traffic load, the favorable meteorological parameters, the low mixing height (low inversion layer) that usually observed in the fall, in addition to the effect of al-Dora Refinery
- It was found that no clear variation in ozone concentration between spring and fall in line source areas
- The area contained point source represent higher ozone peaks as compared with areas contained line source only in the fall, while in spring the peaks were observed to be approximately equal
- Ozone formation was enhanced by high solar radiation (about 60 Klux), high temperature (30°C), low relative humidity (25%) and low wind speed (less than 2 m sec⁻¹)
- AAQS for ozone was exceeded in Al- Za'afarania areas at 12: PM, 1: PM and 3: PM and in Al-Dora at 2: PM in the fall
- The best prediction equation (R² = 0.84) that shows the dependence of ozone concentration on the predictors in Al-Dora area was obtained in fall by using multiple linear regression analysis

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