Journal of Urban and Environmental Engineering, v.11, n.1, p.63-72

ISSN 1982-3932
doi: 10.4090/juee.2017.v11n1.063072

Journal of Urban and Environmental Engineering

www.journal-uee.org

CORRELATION ANALYSIS OF DRIVING CONDITIONS AND ON-ROAD EMISSIONS TRENDS FOR VEHICLES

Jawad H. Al-rifai*

School of Civil Engineering, Al-Ahliyya Amman University, Amman, Jordan

Abstract: This paper presents the impact of road grade, vehicle speed, number of vehicles and vehicle type on vehicle emissions. ANOVA analyses were conducted among different driving conditions and vehicle emissions to discover the significant effects of driving conditions on measured emission rates. This study is intended to improve the understanding of vehicle emission levels in Jordan. Gas emissions in real-world driving conditions were measured by a portable emissions measurement unit over six sections of an urban road. The road grade, speed, type and number of vehicles were found to have a significant influence on the rate of gas emissions. Road grade and diesel-fueled vehicles were positively correlated with average emission rates. The average emission rates were higher at speeds ranging between 60–69 km/h than at three other speed ranges. The results of ANOVA showed a strong and consistent regression between rates of emissions measured and grade, speed and diesel vehicle parameters. The grade parameter contributed the most to the rate of emissions compared to other parameters. Gasoline vehicles contributed the least.

Keywords: Vehicle Emissons; Real World Driving Conditions; Road Grade; ANOVA Test; Jordan.

* Correspondence to: Jawad H. Al-Rifai, Tel.: 00962797960453. Email: j.rifai@yahoo.com

INTRODUCTION

The transport sector is responsible for considerable pollutants, placing direct and indirect pressure on many aspects of the environment, including humans and buildings as well as the atmosphere and ecosystems (Van Mierlo *et al.*, 2004). In recent decades, the vehicle population in Jordan has rapidly grown. In 2014, the number of registered vehicles was 1.285 million, and with an expected increase of 5 percent by 2015, that number will reach 1.35 million, with around 75% of registered vehicles using diesel. Jordanians prefer to drive their own cars due to the lack of a proper public transportation system (Obeidat, 2015).

Vehicle emissions constitute a serious environmental concern, particularly in highly populated cities. Motor vehicles emit gaseous air pollutants, including nitrogen oxides (NO_x), volatile organic compounds (VOC; a class of chemical compounds whose molecules contain carbon), carbon monoxide (CO), carbon dioxide (CO_2) and particulate matter (PM) (Sawyer *et al.*, 2000, Ban-Weiss *et al.*, 2008). In the Middle Eastern and North African (MENA) region, vehicular transportation contributes to emissions 90% CO, 80% hydrocarbon (HC), 40% NO_x and 5% sulfur dioxide (SO_2)(UNEP, 2015a). A substantial number of studies measuring real-world vehicle emissions have been conducted worldwide (Deng *et al.*, 2015, Chen *et al.*, 2007, Zheng *et al.*, 2009). In Jordan, limited research has been conducted regarding trends in on-road emissions (Al-Hasaan *et al.*,1992, Hamdi *et al.*, 2008, Al-Momani and Al-Nasser 2011). Al-Hasaan *et al.*, (1992) reported emission levels for CO, NO_2, SO_2 and PM at four monitoring sites in Amman from July 1986 to June 1987. They reported high levels of PM, CO and SO_2 in downtown Amman that exceeded accepted international criteria. Hamdi *et al.* (2008) have studied the impact of diesel on air quality in Jordan at three sites to address the issue of sulfur in diesel. They measured the concentration of NO_x, SO_2 and PM_{10}. The maximum measured values of SO_2 for downtown Amman were 0.268 parts per million (ppm). Moreover, 48 violations were recorded during the 4475 monitored hours (1.1%). No violation was recorded based on 24-h monitoring. The Jordanian Ministry of Environment has enforced a regulation for ambient air quality limits called the "Jordanian Ambient Air Quality Standards" (JS-1140/2006). A summary of these recommended standards is presented in **Table 1**. Vehicle emissions have been affected by operating modes, ambient conditions, driver behaviors, vehicle loads and road grades (Ang & Fwa, 1989, Chan *et al.*, 2004, Ko & Cho, 2006, Ntziachristos & Samaras, 2000, Zhang *et al.*, 2011).

Table 1: Summary of Relevant Jordanian Ambient Air Quality Standards (No. 1140/2206)

Air Pollutant	Average Time	Maximum Allowable Concentration in the Ambient Air
Carbon Monoxide (CO)	1 h	26 mg/kg[1]
	8 h	9 mg/kg[1]
Nitrogen Dioxide (NO_2)	1 h	0.21 mg/kg[1]
	24 h	0.08 mg/kg[1]
	1 Yr	0.05 mg/kg[2]
Sulfur Dioxide (SO_2)	1 h	0.30 mg/kg[1]
	24 h	0.14 mg/kg[2]
	1 Y	0.04 mg/kg[2]

(1) Three times within a given month in one year
(2) Once a year

Compared to gasoline engines, diesel engines emit high rates of SO_2, NO_x, CO, HC, PM_{10} and total suspended particulates (TSP)(Abu-Qudais and Kittelson, 1997) . Developed countries have reduced fuel sulfur levels to 50 or even 10 ppm, while in developing and transitional countries, the average sulfur levels are very high and may even reach 10,000 ppm. In Jordan, the maximum allowable concentration of sulfur in diesel is 5,000 ppm. This level of sulfur is much higher than it is in other Middle Eastern countries such as Saudi Arabia, Qatar, Kuwait, Oman and Bahrain, where 500 ppm is the standard (UNEP, 2015b). Jordan has not complied with the 350 ppm specification of diesel-contained sulfur mandated by the Ministry of Environment in 2004 (Hamdi *et al.*, 2008). Low-sulfur fuels are critical to lowering direct emissions of particulate matter.

The SO_2 emissions from Jordan in 2000 were 121.3 thousand tons, a 60% increase compared to emissions in 1990. Jordan was ranked number 7 among 21 Middle Eastern and North African (MENA) countries (Hamdi *et al.*, 2008). Typical average emissions (g/kg of fuel) of the combustion processes of diesel-powered vehicles are 5–20, 0.5–5, and 1–10 for NO_2, SO_2 and PM_{10}, respectively, depending on processing and diesel specifications (Neeft *et al.*, 1996). Natural gas emissions are 2–4, 0, and 0 (g/kg of fuel) for NO_2, SO_2, and PM, respectively. These vehicles account for 75% of vehicle particulate emissions, 100% of excessive smoky vehicles, and 65% of vehicle NO_x emissions (Neeft *et al.*, 1996). All vehicles in Jordan are diesel-fueled, gasoline-fueled or hybrid; none run on natural gas.

The transport sector is the largest contributor to NO_x emissions, accounting for 46% of total EU-28 emissions in 2012, and it is a significant source of CO emissions, but the introduction of catalytic converters reduced these emissions significantly (Guerreiro *et al.*, 2014). The CO concentrations tend to vary depending on traffic patterns during the day, and the highest levels were found in urban areas during rush hour at traffic locations (Guerreiro *et al*., 2014). In a recent report, emissions of SO_X and NO_X declined by 54% and 30%, respectively, from 2003 to 2012 in the Twenty-Eight Member States of EU (EU-28) and by 36% and 26% in the Thirty-Three Member Countries of European Environment Agency (EEA-33). Furthermore, the anthropogenic emissions of Non-Methane VOC declined by 28% from 2003 to 2012 in the EU-28 and by 26% in EEA-33 countries (Guerreiro *et al*., 2014)

The objectives of this study are to measure real-world vehicle emission rates and investigate the relationship between driving conditions and pollutant emissions. Some important goals are to apply ANOVA to emission values to reveal any statistically significant effects of various parameters on emission rates. This study is intended to improve the understanding of the vehicle emission levels in Jordan. This work is the first of its kind that addresses real-world the effects of vehicle emissions on air quality in an urban area.

METHODOLOGY

Road description

A fixed route through the eastern entrance to Amman Capital was used as a test route to conduct this study (Jerash Road and King Abdullah Bin Hussein II Road). This test route—as shown in **Fig. 1**—compromises a 5.7 km route that passes through a main eastern suburb of Amman called "Sweileh," and it is one of the main arterial roads into and out of Amman. As such, it is frequently congested during rush hour. Jerash Rd consists of two lanes in each direction, and King Abdullah Bin Hussein II Road consists of three lanes in each direction. The traffic moves westward to Amman Capital in the east-bound lane and eastward to the northern part of Jordan in the west-bound lane. The east-bound lane has heavy traffic during morning peak hours, while the west-bound lane has heavy traffic during the evening hours.

To facilitate analysis at a micro-scale level, the route was divided into 5 test sections based on the grade of the road, driving conditions and traffic flow (**Fig. 1**). The first section is 550 m long and has an inclining slope of 6%, the second section is 450 m long and has an inclining slop of 6%, the third section is 550 m and has an inclining slope of 4%, the fourth section is 430 m and has an incline of nearly zero, and the last section is 600 m long and has a slightly declining slope of 2%. Motor vehicles span a wide range of sizes from gasoline-fueled automobiles and minivans, pickups, vans, and light-duty (LD) trucks and mostly diesel fueled heavy-duty (HD) trucks. In this study, vehicles were subdivided into two classes: gasoline or diesel.

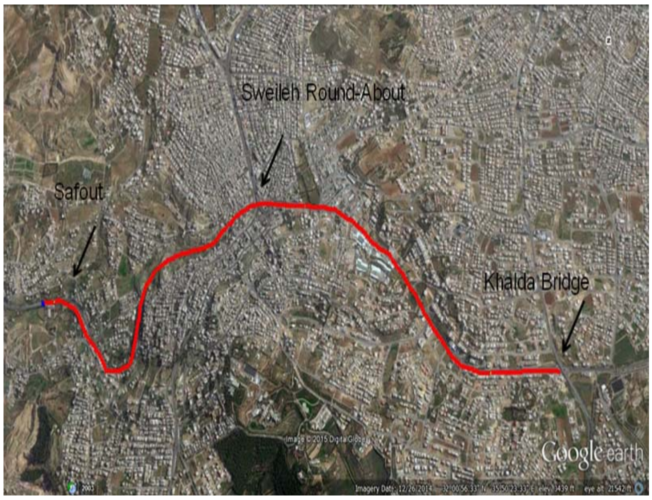

Fig. 1 Test route Jerash Rd & King Abdalla Ben Hussin II Rd

Sampling

Measurements were taken in the east-bound lane during morning peak hours (7:00–9:30) and in the west-bound lane during evening rush hours (14:30–19:00) when the traffic volumes are relatively high. Gaseous analyzers were kept at a height of approximately 1.5 m above the road level and on the right-hand side of the road. Data collected for this study include emission gases concentrations, traffic volume, type of vehicle (gasoline or diesel) and vehicle speeds. Emission gases measured are carbon monoxide (CO), nitrous dioxide (NO_2), sulfur dioxide (SO_2) and volatile organic carbons (VOCs). The data were collected for a total of 10 days between 10th and 25th November 2014. Measuring points were set along the length of the route (**Fig. 1**). The various gases were measured simultaneously.

Instruments

The AdvancedSense® system by GrayWolf, with two different probes (TG-502 and TG-501), was used to measure the various gases. Probe TG-501 measures three gases simultaneously (CO, NO_2 and SO_2) using an electrochemical gas sensor. Probe TG-502 measures TOVC using a Photo Ionization Detector (PID). The GrayWolf system has an embedded PC instrument (AdvancedSense™) for storing data and reporting. The probes were calibrated by the manufacturer on the 22nd of July 2014 and the next calibration was due on the 21st of July 2015.

Vehicular speed was measured with Bushnell's Velocity Speed Gun. Traffic volume and vehicle type manually counted every 15 minutes while measuring emission gases at the measuring points. The vehicle types were classified into gasoline- and diesel-fueled.

Although manual counting cannot separate vehicles by fuel types, an assumption was made that most passenger vehicles were gasoline-fueled, and other vehicles were diesel-fueled.

Data analysis

Data analysis was performed using PASW Statistics 18. A linear model was built using different gas concentrations as dependent variables. Residuals were assumed to be normally distributed, with a null exception. The number of vehicles, fuel type (gasoline or diesel), speed and road grade were investigated as independent variables. Pearson's correlation coefficient between dependent (emission rates) and various independent variables were conducted.

RESULTS AND DISCUSSION

Levels of emissions

Measured emission rates / concentrations for each gas and their frequency are shown in **Fig. 2**. Ambient Air Quality Standards (No. 1140/2206) are enforced in Jordan. The standards set the maximum allowable concentration for the average time of 1 h, 8 h, 24 h and 1 y. A summary of the standards is presented in Appendix 1.

As shown in **Fig. 2**, the maximum measured emission rates for CO and NO_2 during the rush hour were 9 and 0.15 ppm, respectively. These measurements were below the Jordanian Ambient Air Quality Standards of 26 ppm and 0.21 ppm for CO and NO_2, respectively. The above results were consistent with those found by (Al-Hasaan *et al*., 1992). They reported that emission rates in downtown Amman were between 3 to 13 ppm for CO and 0.01 to 0.08 ppm for NO_2. They concluded that motor vehicles were the major contributors to emissions of CO and NO_2 in downtown Amman. Deng *et al*., (2015) reported high concentrations of CO (86 and 45 ppm) and NO_x (33 ppm) for mixed vehicle fleets under real-world driving conditions in urban China.

For SO_2, the maximum measured emission rate was 1 ppm, which exceeded the max 1 h of 0.3 ppm. Al-Hasaan *et al*., (1992) reported that the highest hourly SO_2 measured record was 0.19 ppm during morning rush hour from vehicles burning sulfur diesel fuels (Al-Hasaan *et al*., 1992). Hamdi *et al*.,(2008) monitored the impact of diesel on air quality in Jordan. They reported a maximum value of 0.268 ppm for SO_2 in downtown Amman and 48 (1.1%) violations during 4,475 monitoring hours, with no violation based on 24-h monitoring. No hourly or daily average excesses in NO_x were recorded from 1998–1999 in downtown Amman (Hamdi *et al*., 2008). In this study, the high measured

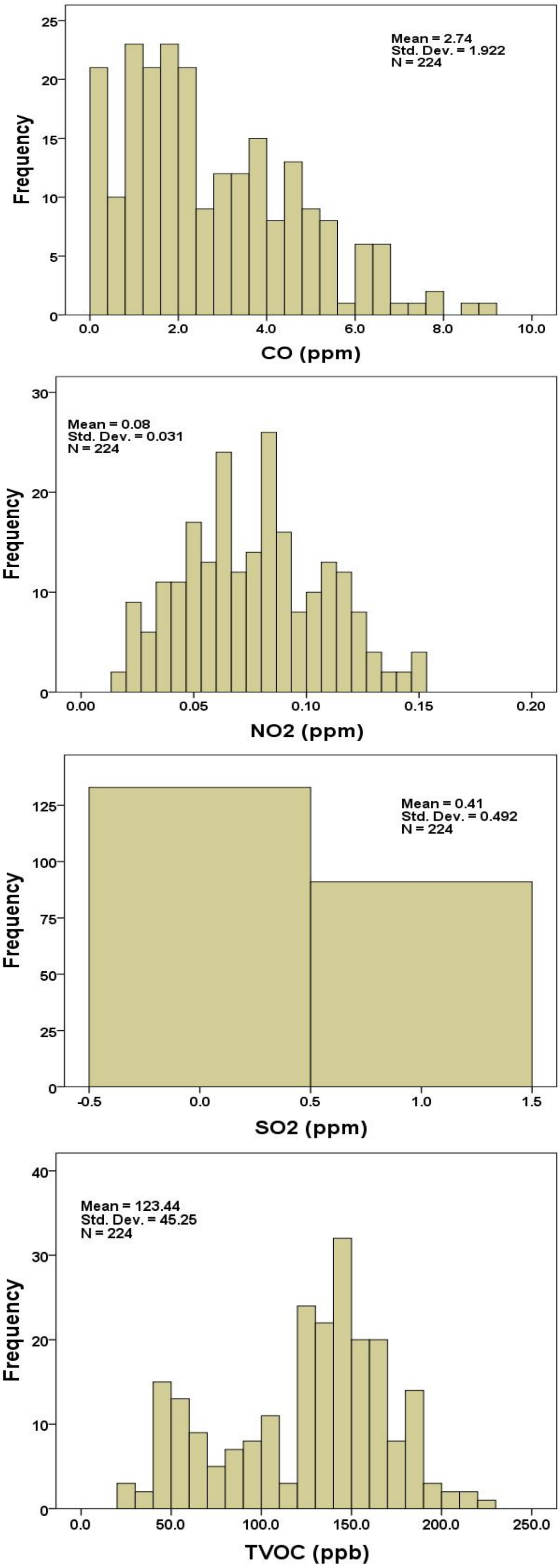

Fig. 2 Frequency of measured vehicle's emission

level of SO_2 could be related to the differences in traffic volume and other characteristics.(Sawyer *et al.*, 2000) reported that oxides from fuel-based nitrogen emissions are much greater from diesel than from gasoline mobile sources. For TVOC, the Jordanian standards set no maximum allowable concentration limit. The maximum concentration of TVOC measured was 220 ppb (parts per billion) (**Fig 2**). These results were less than those reported by other researchers.

Relation between the average emission rate and driving conditions

The average emission rate, standard deviation, and correlation between emission rates are presented in SO_2 and TVOC are 2.74 ppm, 0.077 ppm, 0.41 ppm and 123 ppb, respectively. Average emission rates and road grade are significantly correlated at 0.01 level (**Table 2**). **Figure 3** shows the average emission rates at different road grades. The emission rates at a high grade (6%) are higher than they are at lower grades (-2%, 4%, 0% and 6%). At a grade of 6%, the emission rates for NO_2, CO, SO_2 and TVOC are increased by 100%, 350%, 650% and 70%, respectively (**Fig. 3**), while smaller increases were found in emissions rates at other grade level. Similarly, Deng *et al.*, (2015) found that CO and NO_2 were emitted at higher rates on steeper slopes. Kean *et al.* (2003) reported the difference between CO emission factors both uphill and downhill at a 4% gradient.

Emissions of CO ranged from 16 to 34 g/L (100% increase) during downhill driving and from 27 to 75 g/L (200% increase) during uphill driving (Kean *et al.*, 2003). The road gradient influences the resistance and traction of vehicles, which then affects the amount of fuel consumption and vehicle emissions.

Table 2. Pearson Correlation coefficient between emission rates and grade, type of vehicles and speed

Emission gas	Average	Standard Deviation	Correlation coefficient: Road Grade	Gasoline Vehicle	Diesel Vehicle	Speed
CO (ppm)	2.74	1.92	0.875 [a]	-0.129	0.382 [a]	-0.452 [a]
NO_2 (ppm)	0.077	0.031	0.790 [a]	-0.66	0.449 [a]	0.388 [a]
SO_2 (ppm)	0.41	0.49	0.658 [a]	-0.013	0.307 [a]	-0.425 [a]
VOCs (ppb)	123.5	45.20	0.726 [a]	-0.21	0.419 [a]	-0.110

[a] correlation is significant at the 0.01 level (2 tailed)

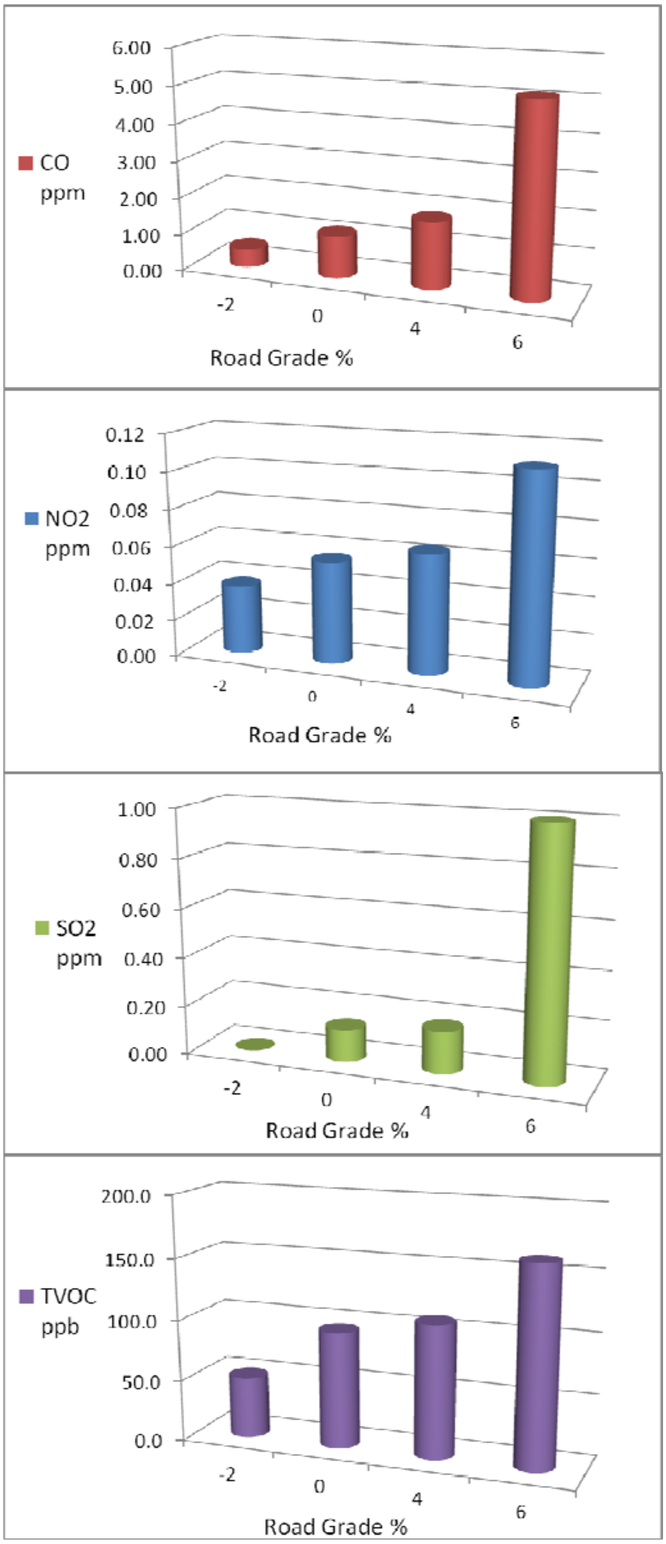

Fig. 3 Average rate emissions at various road grades

Figure 4 shows average rates of emissions at different speed intervals. The average emission rates are higher at speeds ranging between 60–69 km/h than they are at three other speed ranges. Average emission rates are significantly correlated with vehicle speed at 0.01 levels (**Table 2**). Driving at speeds ranging between 70 and 79 km/h reduces emission rates by 13% to 32%

(**Fig. 4**), while increasing vehicle speed more than 79 km/h reduces emission rates by less. This result might be due to the fact that a vehicle consumes less fuel at higher speeds compared to lower speeds. Average emission rates are significantly correlated with diesel-fueled vehicles at 0.01 levels (**Table 2**). Diesel-fueled vehicles are positively correlated with average emission rates (**Table 2**). Conversely, gasoline-fueled vehicles do not significantly influence average emission rates.

Relation between the average emission rate and number of vehicles

Table 2 shows the average emission rates with the number of vehicles. Average emission rates are significantly correlated with the number of diesel vehicles at 0.01 levels (**Table 2**). Abu Qudais & Kittelson (1997) reported that diesel engines emitted high emissions of SO_2, NO_x, CO, HC, PM_{10} and total suspended particulates (TSP) compared to gasoline engines. On the other hand, average emission rates are not significantly correlated with the number of gasoline vehicles at 0.01 levels (**Table 2**).

Combined effect of both road-grade and speed-range parameters on emission rates

The effect of both road grade and vehicle speed on emission rates are shown in **Fig. 5**. The emission rates at higher grades (6%) are higher than they are at lower grades (4%, 0 and -2%) with decreasing vehicle speeds. This result is obvious for NO_2, CO and TVOC. Similarly, as grade levels decrease in conjunction with high vehicle speed, the rate of emissions decreased (**Fig. 5**). This result indicates that grade increases and vehicle speed decreases are strongly and consistently correlated with the average emission rate. Similarly, Deng *et al.*, (2015) found that CO and NO_x emissions are dependent on the road gradient and vehicle speed. Emissions increased with an increasing road gradient and decreased with vehicle speed (Deng *et al.*, 2015). At high road grades, vehicles need more fuel; thus, they produce more pollutants. Deng *et al.* (2015) found that the differences in traffic characteristics and vehicle emission standards greatly affect CO vehicle emissions.(Chang *et al.*, 2009) found that the emission rates of NO_x, CO, and SO_2 at upslope are twice what they are at downslope. Deng *et al.*,(2015) reported that CO emissions decreased by 50% when the average rates vehicle speed increased from 10 to 40 km/h. On the other hand, Qu et al. (2015) found that emission for CO, NOx and hydrocarbons (HC) at high speed (40 km/h) and during acceleration were higher than they were in other driving modes (low speed/acceleration, high speed/deceleration and low speed/deceleration).

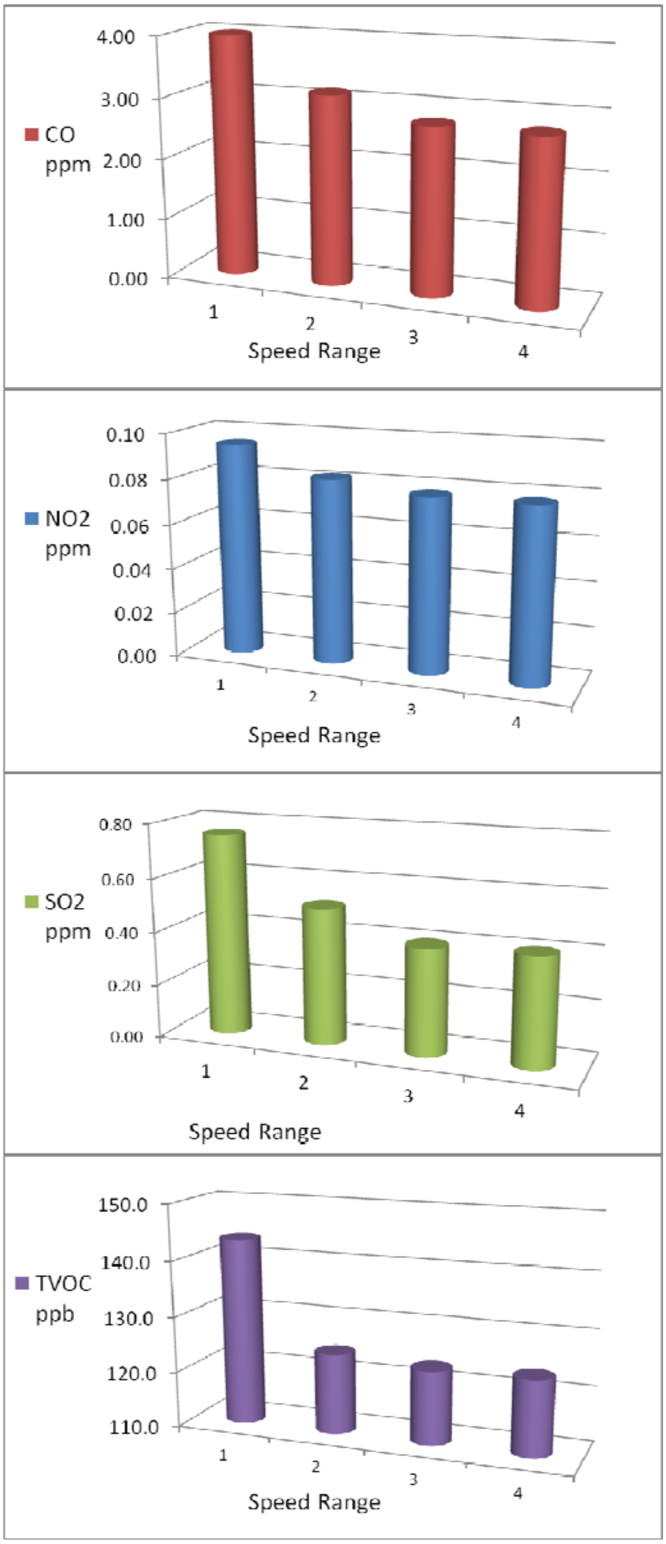

Fig. 4 Average rate emissions at vehicle speeds

Combined effect of both road grade and number of vehicles on emission rates

Box-plots are shown in **Figs**. **6** and **7** to quantify the combined effect of road grade and vehicle number on emission rates. The emission rates at high grade (6%)

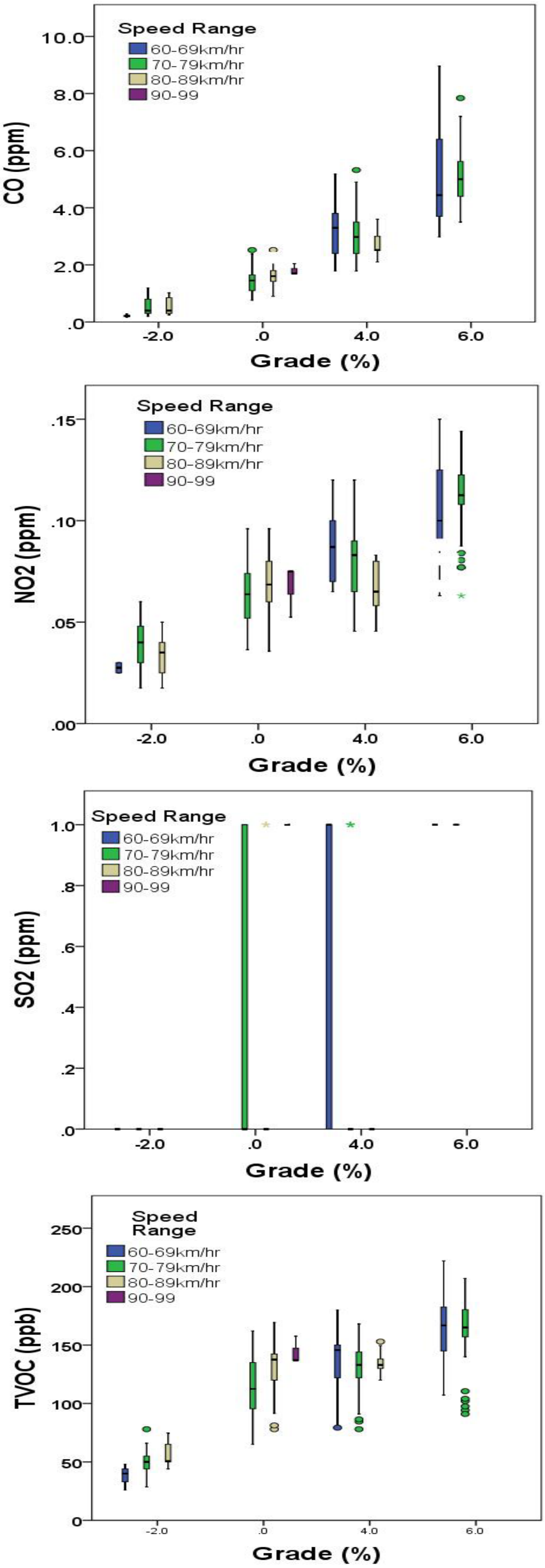

Fig. 5 Effect of both road grade and speed range on emission rates

are higher than they are at lower grades (4%, 0 and -2%) as they number of vehicles increases (Figs. 6 and 7). Average emissions of NO_2, SO_2 and TVOC increased significantly (99% confidence level) as the number of diesel vehicles increased (Fig. 6), but average emission rates were not significantly different than the number of gasoline vehicles (Fig 7). This result is because diesel engines emit high emissions of SO_2, NO_x, CO, O_3, HC, as well as high total suspended particulates (TSP) and particulate matters (PM_{10}) compared to gasoline engines (Abu-Qudais & Kittelson, 1997). Deng et al., (2015) found that diesel-fueled vehicles emit more NO_x than gasoline-fueled vehicles. Therefore, the rate of emissions significantly increases as road grade and number of diesel vehicles increase.

Trend of emission rates and ANOVA

An ANOVA was applied to emission values to reveal any statistically significant effects of the various parameters measured on emission rates. The R square, error of the estimate of standard deviation and standardized correlation are shown in **Table 3**. The results of the ANOVA showed that there is strong and consistent regression between rate of emission trend of CO with grade, speed and diesel vehicle parameters ($r^2 = 0.86$). This relation is strongly positive with grade and diesel vehicle but negative with speed. This result indicates that CO emissions increase as grade and number of diesel vehicles increases but decrease as speed increases. Emission rates for NO_2 and TVOC have moderate strength regression ($r^2 = 0.76$ & 0.67), while the SO_2 emission rate has a weak regression ($r^2 = 0.5$). The grade parameter contributes the most to rate of emission compared to other parameters, as shown in the standardized coefficient of **Table 3**. Gasoline vehicles contribute slightly to the rate of emissions. As previously mentioned, this parameter is not correlated with various emission rates.

According to Huo *et al.* (2012), standards for vehicle emissions have played a significant role in reducing vehicle emissions of individual vehicles. Therefore, more stringent emission standards, such as Euro IV for the entire country and Euro V/VI for mega-cities, should be introduced as quickly as possible, especially as the number of vehicles is growing dramatically. Furthermore, identification and restriction is equally important to reducing vehicle emissions. Super emitting vehicles—old or high-mileage taxis—could contribute significantly to total emissions because their emission factors are much higher than those of other vehicles (Huo *et al.*, 2012). According to Huo *et al.* (2012) , super emitters could contribute 59–74% to CO emissions, 71–82% to HC emissions, and 51–58% to NO_x emissions.

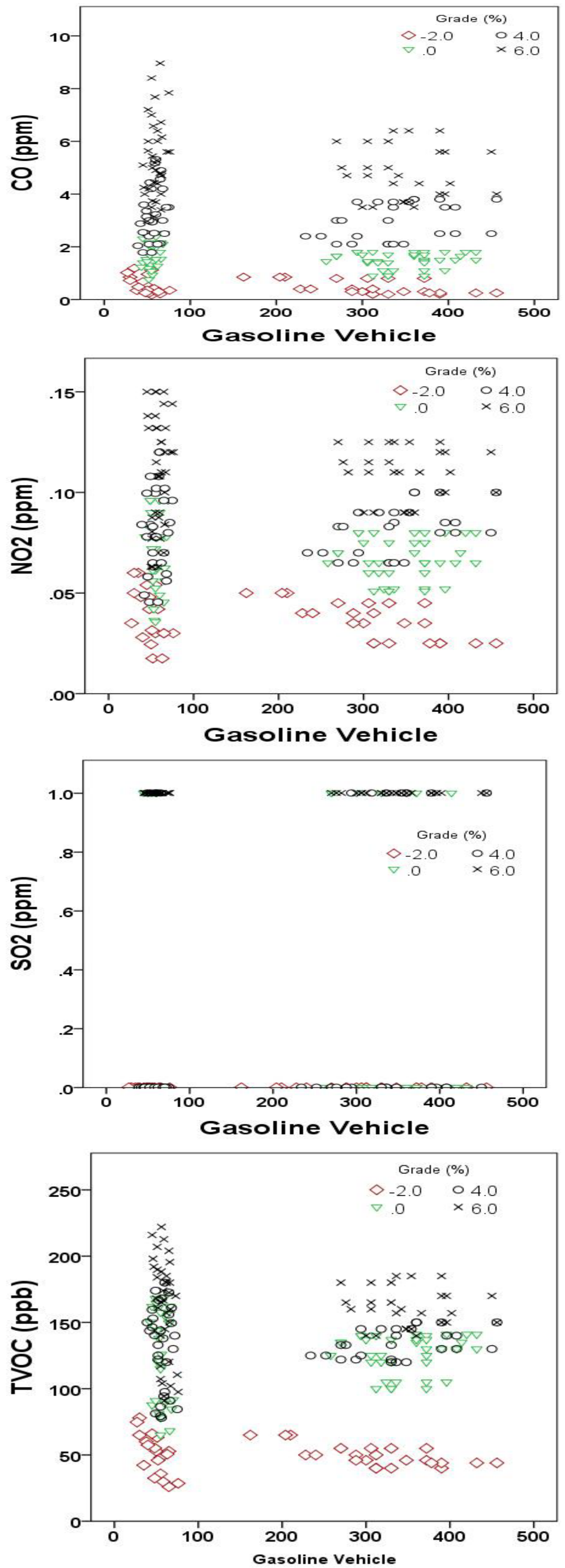

Fig. 6 Combined effect of number of gasoline vehicles and speed on emission rates

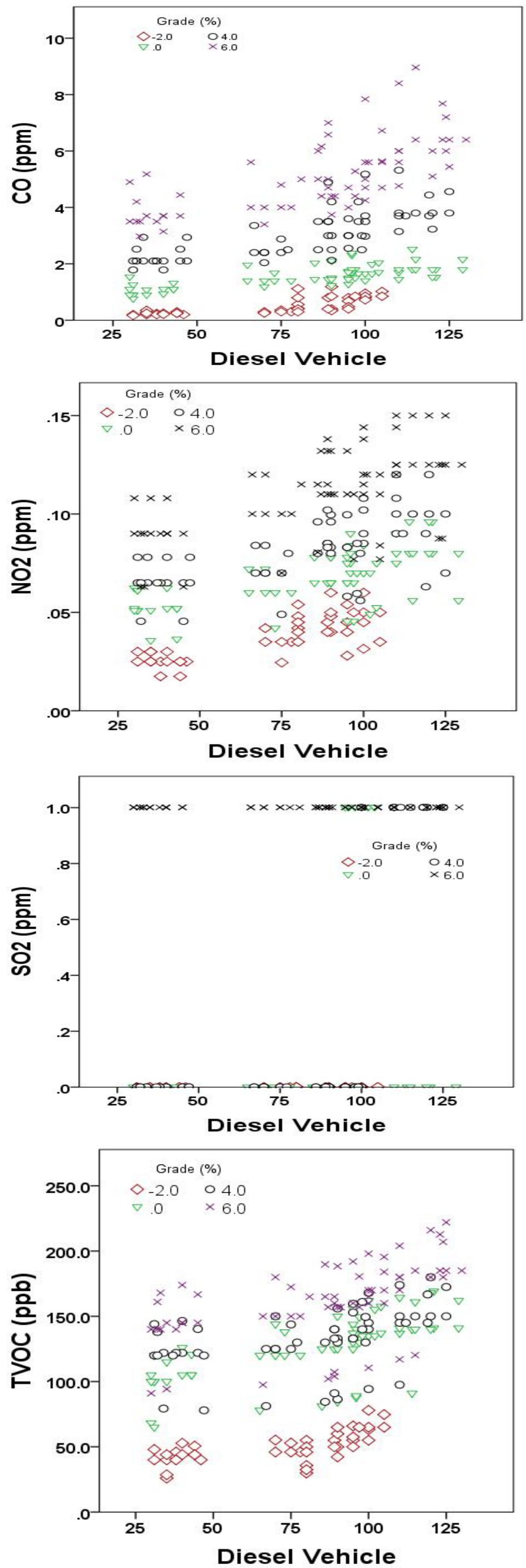

Fig. 7 Combined effect of number of diesel vehicles and speed on emission rates

Table 3. ANOVA test between emission rates and grade, type of vehicles and speed

Emission gas	R square	Standard error of the estimate	ANOVA			Standardized coefficient			
			Mean of Square	F	Sig	Road Grade	Gasoline Vehicle	Diesel Vehicle	Speed
CO(ppm)	0.859	0.732	176.68	329.823	0.000	0.791	-0.062	0.296	-0.100
NO_2 (ppm)	0.766	0.015	0.040	177.428	0.000	0.710	-0.006	-0.372	-0.088
SO_2 (ppm)	0.515	0.347	6.909	57.519	0.000	0.540	0.045	0.258	-0.193
TVOC(ppb)	0.688	25.593	78287.46	119.521	0.000	0.804	0.011	0.308	0.241

The issue of vehicle pollution is becoming more serious and complicated, and addressing the issue relies on multiple effective measures, which should be based on extensive emission measurements and comprehensive modeling studies. Accumulations of fundamental vehicle emission factors and modeling methodologies have improved over the last few decades. Simulating vehicle emissions accurately in magnitude and distribution will be of great significance to regional and global air quality and climate (Huo *et al*., 2012). To obtain reliable and representative data, a far greater number of measurements should be conducted more extensively across Jordan, research that will require widespread and sustained efforts from the government and the academic communities both domestically and internationally. To the knowledge of the author, this work is the first conducted in the MENA region to address real-world emission rates of vehicles.

CONCLUSION

The maximum measured emission rates for CO and NO_2 were 26 ppm and 0.21 ppm. These emissions were below the maximum allowable concentrations for the average time of 1 h (max 1 h) according to the Jordanian Standards. For SO_2, the maximum measured emission rate was 1 ppm, which exceeded the Max 1 h of 0.3 ppm. For TVOC, the maximum measured concentration of TVOC measured was 220 ppb, with no maximum allowable concentration limit in the Jordanian standards.

Average emission rates were significantly correlated with road grade, speed of vehicles and diesel-fueled vehicles at 0.01 level. At grade of 6%, the emission rates for NO_2, CO, SO_2 and TVOC increased by 100%, 350%, 650% and 70%, respectively. The average emission rates were higher at speed ranges between 60–69 km/h than they were at three other speed ranges. Driving at speeds ranging between 70 and 79 km/h reduced emission rates by 13% to 32%, while increasing vehicle speed more than 79 km/h reduced emission rates less. On the other hand, gasoline-fueled vehicles had no significant influence on average emission rates.

Results of ANOVA showed strong and consistent regression between the rate of emissions of CO with grade, speed and diesel vehicle parameters (r^2 =0.86). This relation was strongly positive with grade and diesel vehicle but negative with speed. Emission rates for NO_2 and TVOC had a moderate strength regression (r^2 =0.76 and 0.67), while SO_2 emission rate had a weak regression (r^2 =0.5). Grade parameter contributed the most to rate of emissions compared to other parameters, while gasoline vehicles contributed only slightly to the rate of emissions.

Acknowledgment The author would like to thank Philadelphia University for funding this research.

REFERENCES

Abu-Qudais, M. & Kittelson, D.B. (1997) Experimental and theoretical study of particulate re-entrainment from the combustion chamber walls of a diesel engine. *Proc. Institution Mechan. Engrs. Part D: J. Autom. Engng.* **211**(1), 49-57. doi: 10.1243/0954407971526218.

Al-Hasaan, A.A., Dann, T. F., Brunet, P. F. (1992) Air Pollution Monitoring in Amman, Jordan. *J. Air Waste Manag. Assoc.***42** (6), 814-816. doi: 10.1080/10473289.1992.10467034.

Al-Momani, T.M. & Al-Nasser, A.D. (2011) Emission Rate of Gases Emitted from Private Gasoline Vehicles in Irbid-Jordan. *Jordan. J. Civil Engng.* **5**(15), 287-301.

Ang, B.W., & Fwa, T.F. (1989) A study on the fuel-consumption characteristics of public buses. *Energy,* **14**(12), 797-803. doi: 10.1016/0360-5442(89)90033-9

Ban-Weiss, G.A., McLaughlin, J.P., Harley, R.A., Lunden, M.M., Kirchstetter, T.W., Kean, A.J., Strawa, A.W., Stevenson, E.D., Kendall, G.R. (2008) Long-term changes in emissions of nitrogen oxides and particulate matter from on-road gasoline and diesel vehicles. *Atmos. Environ.* **42**(2), 220-232. doi: 10.1016/j.atmosenv.2007.09.049

Chan, T.L., Ning, Z., Leung, C.W., Cheung, C.S., Hung, W.T., Dong, G. (2004) On-road remote sensing of petrol vehicle emissions measurement and emission factors estimation in Hong Kong. *Atmos. Environ.* **38**(14), 2055-2066. doi: 10.1016/j.atmosenv.2004.01.031

Chang, S.-C., Lin, T.-H., Lee, C.-T. (2009) On-road emission factors from light-duty vehicles measured in Hsuehshan Tunnel (12.9 km), the longest tunnel in Asia. *Environ. Monit. Assess.* **153**(1-4), 187-200. doi: 10.1007/s10661-008-0348-9

Chen, C., Huang, C., Jing, Q., Wang, H., Pan, H., Li, L., Zhao, J., Dai, Y., Huang, H., Schipper, L., Streets, D.G. (2007) On-road emission characteristics of heavy-duty diesel vehicles in Shanghai. *Atmos. Environ.* **41**(26), 5334-5344. doi: 10.1016/j.atmosenv.2007.02.037

Deng, Y., Chen, C., Li, Q., Hu, Q., Yuan, H., Li, J., Li, Y. (2015) Measurements of real-world vehicle CO and NOx fleet average emissions in urban tunnels of two cities in China. *Atmos. Environ.*122:417-426. doi: 10.1016/j.atmosenv.2015.08.036.

Guerreiro, C., F. de Leeuw, Valentin, Foltescu, and J. Horálek. 2014. Air quality in Europe — 2014 report. Luxembourg.

Hamdi, M. R, A. Bdour, and Z. Tarawneh. 2008. Diesel Quality in Jordan: Impacts of Vehicular and Industrial Emissions on Urban Air Quality. *Environm. Engng. Sci.* **25**(9), 1333-1344. doi: 10.1089/ees.2007.0234

Huo, H., Yao, Z., Zhang, Y., Shen, X., Zhang, Q., Ding, Y., He, K. (2012) On-board measurements of emissions from light-duty gasoline vehicles in three mega-cities of China. *Atmos. Environ.* **49**:371-377. doi: 10.1016/j.atmosenv.2011.11.005

Kean, J., Harley, R. A., Kendall, G.R. (2003) Effects of Vehicle Speed and Engine Load on Motor Vehicle Emissions. *Environ. Sci. & Techn.* **37**(17), 3739-3746. doi: 10.1021/es0263588

Ko, Y.W. & Cho, C.H. (2006) Characterization of large fleets of vehicle exhaust emissions in middle Taiwan by remote sensing. *Sci. Total Enviro.* **354**(1), 75-82. doi: 10.1016/j.scitotenv. 2005.05.040

Neeft, J. P. A., M. Makkee, and J. A. Moulijn. 1996. Diesel particulate emission control. *Fuel Processing Techn.* **47**(1), 1-69. doi: 10.1016/0378-3820(96)01002-8

Ntziachristos, L. & Samaras, Z. (2000) Speed-dependent representative emission factors for catalyst passenger cars and influencing parameters. *Atmos. Environ.* **34**(27), 4611-4619. doi: 10.1016/S1352-2310(00)00180-1

Obeidat, O. 2015. Number of private cars estimated to rise to 1.35m'. The Jordan Times.com. Accessed in: 10/13/2015.

Qu, L., Li, M., Chen, D., Lu, K., Jin, T., Xu, X. (2015) Multivariate analysis between driving condition and vehicle emission for light duty gasoline vehicles during rush hours. *Atmos. Environ.* **110**:103-110. doi: 10.1016/j.atmosenv.2015.03.038

Sawyer, R.F., Harley R.A., Cadle S.H., Norbeck J.M., Slott, R., Bravo, H.A. (2000) Mobile sources critical review: 1998 NARSTO assessment. *Atmospheric Environment* **34**(12–14), 2161-2181. doi: 10.1016/S1352-2310(99)00463-X

UNEP (2015a) Air Quality and Atmospheric Pollution In The Arab Region. In, ed UNEP. Available in: http://www.un.org/esa/sustdev/csd/csd14/escwaRIM_bp1.pdf.

UNEP (2015b) Middle East, North Africa & West Asia Diesel Sulphur Matrix. UNEP.

Van Mierlo, J., Timmermans, J.-M., Maggetto, G., Van den Bossche, P., Meyer, S., Hecq, W., Govaerts, L., Verlaak, J. (2004) Environmental rating of vehicles with different alternative fuels and drive trains: a comparison of two approaches. *Transportation Res. Part D: Transp. Environ.* **9**(5),387-399. doi: 10.1016/j.trd.2004.08.005

Zhang, K., Batterman, S., Dion, F. (2011) Vehicle emissions in congestion: Comparison of work zone, rush hour and free-flow conditions. *Atmos. Environ.* **45**(11), 1929-1939. doi: 10.1016/j.atmosenv.2011.01.030

Zheng, J., Zhang, L., Che, W., Zheng, Z., Yin, S. (2009) A highly resolved temporal and spatial air pollutant emission inventory for the Pearl River Delta region, China and its uncertainty assessment. *Atmos. Environ.* **43**(32), 5112-5122. doi: 10.1016/j.atmosenv.2009.04.060