Analysis of Air Pollutants' Concentration in Terms of Traffic Conditions and Road Gradient in an Urban Area

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ABSTRACT

This study focuses on the impact of traffic variables; vehicular speed, traffic volume and road gradient, that have a significant impact on vehicle emissions and the corresponding quantity of air pollutants. These factors are normally addressed when devising general and detailed urban plans. Such factors are normally used to assess the adverse effects resulting from motor vehicles dominating roads and highways, including environmental hazards, such as air and noise pollution. Moreover, they identify environmental impacts of road and traffic planning. The study focuses on environmental issues that can be considered and modeled in order to be included in all generalized plans. In this study, concentrations of CO, NO, TVOCs and SO were monitored periodically at various sampling sites. The study revealed that the concentration of air pollutants showed a high correlation with traffic flow and prevailing road gradients. The concentrations of SO_2, NO_2, CO and TVOCs were highly correlated to key traffic flow parameters, such as road gradient, vehicular speed and traffic volume.

KEYWORDS: Transport, Emission, Pollutant, Gradient, Speed, Traffic volume, Road gradient.

INTRODUCTION

The emission of air pollutants from vehicular traffic on highways has become a serious concern for drivers who spend a considerable time on the road. Many cities around the world have witnessed a significant increase in air pollutants due to the increase in vehicular traffic during congestion periods. Recently, due to turmoil in the region, Amman has become home for many refugees from neighboring countries. This influx of refugees has been translated into excessive amounts of pollutants in the air.

Motor vehicles emit pollutants including nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs) and particulate matter (PM). There are a number of factors that affect these pollutants' concentrations. Zickus and Greig (2003) indicated that the pollutant concentrations depend greatly on vehicular emission rates, climate parameters and the levels of the pollutant in the background environment.

Joumard (1999) indicated that vehicular exhaust emission varies between the cruising, accelerating, decelerating and idling operational modes. Marsden et al. (2001) investigated the influence of traffic flow patterns on CO levels. Others have noted that vehicle type or size may also affect the pollutant emissions. It is an established fact that passenger cars, light-duty trucks heavy-duty trucks, and motorcycles emit pollutants in the air at different rates.

The air emission of vehicles is dependent on speed and acceleration. Some researchers opted for using

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emission factors calculated as a function of average speed. In addition, vehicle age, accumulated mileage, fuel type used, ambient weather conditions such as temperature, precipitation and wind, also affect the rate of pollutant emissions. The maintenance condition of the vehicle and the inclusion and condition of pollution control equipment can also affect the rate of pollutant emissions. Zhang et al. (2014) conducted a study on the effect of vehicle traffic on air pollution and health risks and found that congestion has a significant impact on health, while Katarzyna (2017) conducted a study on the influence of the properties of vehicle traffic on the total pollution in Poland. Shohel et al. (2017) has conducted a study on air pollution from induced traffic density after the construction of a new highway in Montreal, Canada and found that NO_2 level concentrations were reduced due to less traffic. No study has been conducted on the type of road characteristics and other functions on which this paper concentrates. Table 1 records the emission factors for light duty gasoline vehicles (LDGV) expressed as grams per hour (g/hr) and grams per minute (g/min) of idle time according to the Environmental Protection Agency (EPA).

Table 1. Light duty gasoline vehicles' emission factors formulated as (g/h) and (g/min)

Pollutant	Unit	LDGV
VOCs	g/hr	2.683
	g/min	0.045
THC	g/hr	3.163
	g/min	0.053
CO	g/hr	71.225
	g/min	1.187
NO_x	g/hr	3.515
	g/min	0.059
$PM_{2.5}$	g/hr	N/A
	g/min	N/A

Duffy et al. (1996) recorded air quality in Sydney, Australia and Rogak et al. (1998) in Canada and found that the burning of the vehicle engine gasoline or diesel is the source of the main air pollutants which are NO and CO. Noor et al. (2006) recorded PM_{10} and sulphur dioxid. Meanwhile, air pollutants like ozone and carbon monoxide are obtained through automated monitoring. Abo-Qudais (2005) and Al-Momani et al. (2015) completed statistical investigations on air pollutant emissions on highways in Jordan as a function of vehicle type.

Therefore, it is clearly established that the parameters influencing air pollutants are, among others, vehicular speed, traffic volume and road gradient. This research concentrates on the relationship between air pollutants and parameters pertaining to road characteristics and vehicular traffic composition.

MATERIALS AND METHODS

In this study, the concentration of air pollutants is examined in terms of vehicular speed, traffic volume and road gradient. The pollutants CO, NO_2, TVOCs and SO_2 are recorded at different locations for selected periods of time including peak hours. The measurements of air pollutants SO_2, NO_2, CO and TVOCs are recorded at four sampling stations as shown in Figure 1.

Figure (1): Location of pollutant sampling stations

The relevant geographical attributes of these sampling stations are shown in Table 2.

Table 2. Geographical attributes for sampling

Sampling Station	Slope (%)	Longitude	Latitude	Mean Sea Level (m)
1	0	35.8385881	32.03155514	920.7
2	5	35.8424156	32.02426216	992.8
3	7	35.8335900	32.03302000	892.6
4	9	35.8341400	32.03736000	839.7

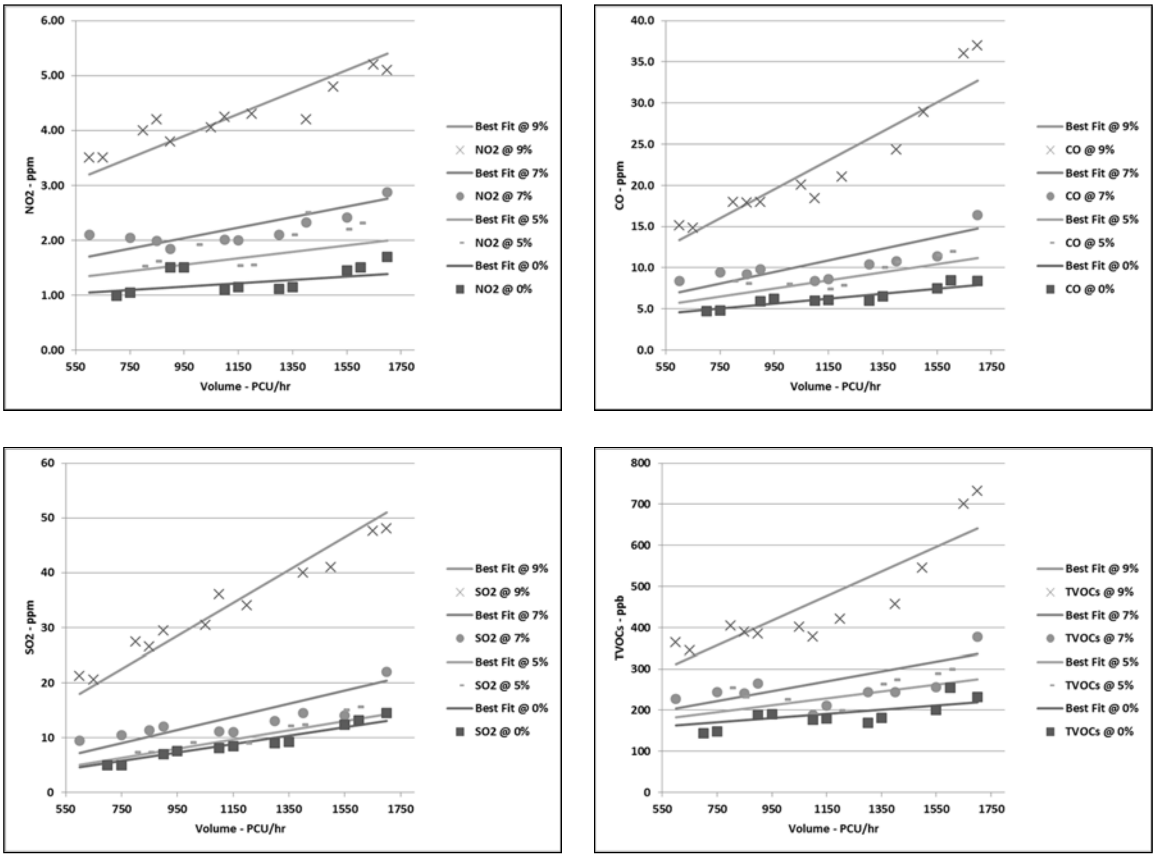

Figure (2): Pollutant concentration variations with road gradient for NO_2, CO, SO_2 and TVOCs

The emissions at a given location are normally dependent on the mean speed of travel and the road gradient. Therefore, the measurements in this research project included measurements of these important parameters. These measurements are conducted on the basis of fifteen-minute average for the traffic volume of the same locations.

The apparatus used for the measurements of air pollutants consisted of a toxic gas analyzer based on the electro-chemical cell method for nitrogen dioxide NO_2, while Photo Ionization Detection (PID) is used for the Total Volatile Organic Compounds TVOCs. The detection limits for NO_2, CO and SO_2 were 0.02, 0.5 and 0.1 ppm, respectively. The instruments used were calibrated for all measurements.

The volume of traffic at the time of measurement was recorded in passenger car unit per hour (PCU/h). A passenger car is counted as one PCU, while a motorcycle is counted as one half PCU. Busses and trucks are equivalent to 3 PCUs due to their large sizes.

The traffic volume is defined as the total number of vehicles crossing a point on the road during a specific time period.

RESULTS AND DISCUSSION

The best fit linear straight line is drawn with respect to the traffic passenger car units per hour and according to road gradients of 0%, 5%, 7% and 9%, as shown in Figure 2.

The effect of road gradient on the gaseous pollutant emission was analyzed. As an example, when the traffic volume is taken to be around 1000 passenger car units per hour (PCU/h), the results of short-term measurements (15-minute averages) of gaseous pollutants (SO_2, NO_2, CO and TVOCs) with respect to road gradients of 0%, 5%, 7% and 9% are shown in Figure 3. Figure 4 shows the relationship between the road gradient and the vehicle velocity for a traffic volume of around 1000 passenger car units per hour (PCU/h).

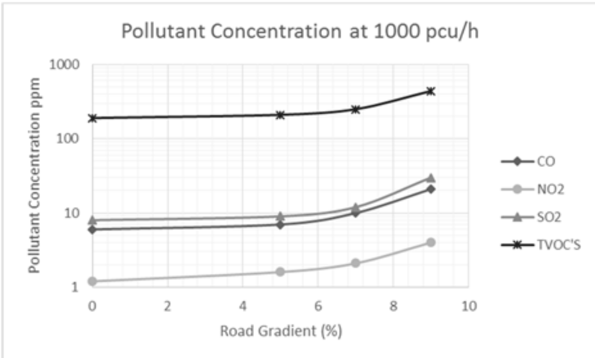

Figure (3): NO_2, CO, SO_2 and TVOCs' variations with road gradient

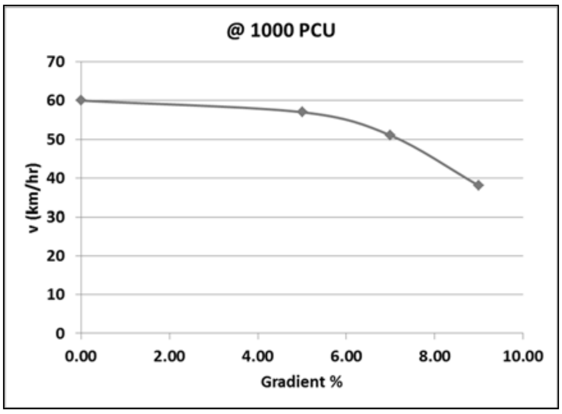

Figure (4): Velocity relationship with road gradient

It is shown that the road gradient has a high effect on the traffic speed and the traffic flow. Results show that increasing road gradient in addition to traffic flow will lead to speed decrease. Figure 5 shows the square of R values for the air pollutant concentrations of SO_2, NO_2, CO and TVOCs' concentrations while the traffic speed is indicated on the semi-log plots.

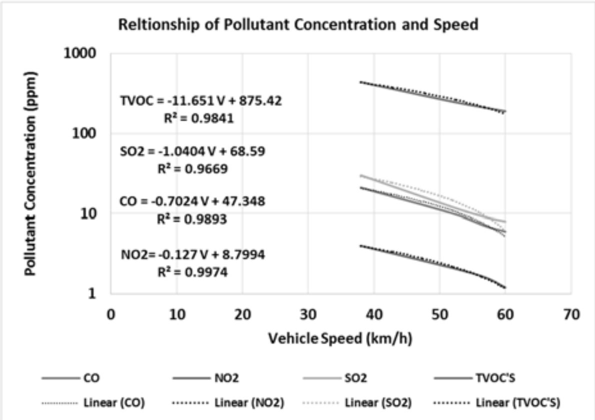

Figure (5): Pollutant concentrations and vehicle speed

The increase of pollutant emissions of vehicles is correlated to the vehicle frequency in acceleration and deceleration. The variation of the gaseous air pollutants with time was recorded for a short period of time, which made the time not uniformly distributed, where, for example, the variation of NO_x and VPH in this study followed the same result cited by Joumard (1999). It was clearly noted that vehicular speed, traffic volume and road gradient have a great effect on vehicle emission and air pollution quantity of SO_2, NO_2, CO and TVOCs for the same passenger trip distance. The average pollutant rate per gradient can be defined as given in the following equation:

APR/G = (Emissions at 10%/Emissions at 0%) (1)

where,

APR/G: the average pollutant rate per gradient which is used as an estimated linear average of pollutant concentration per unit gradient percentage. Table 3 shows the APR/G values for the concentrations of SO_2, NO_2, CO and TVOCs by using Equation 1.

Table 3. Summary of APR/G results for Pollutant emissions

Pollutant	APR/G
SO_2	3.1
NO_2	2.8
CO	2.5
TVOCs	5.2

The difference in SO_2 concentrations at different gradients is large, since busses and trucks are not prohibited from travelling on roads and these heavy-duty vehicles have higher SO_2 emissions. Furthermore, the ratio of NO_2 concentrations at different grades was about 2.8, while for CO_2 it was 2.5. It is concluded that NO_2 and CO concentrations were all affected by different gradients and traffic flows with a higher nitrogen dioxide for a higher gradient. After analyzing the relationship between air quality and traffic flow data at different gradients using linear regression, it is obvious that pollutant concentrations increase with an increase in gradient.

Based on the estimated relationships of SO_2, NO_2, CO and TVOCs' concentrations with traffic variables, several distinctive effects of traffic flow on air pollutant concentrations on streets can be identified. Under high-gradient traffic flow conditions, where traffic speeds are less than 50 km/h, higher rates of pollutant concentrations were noticed. The result is similar to those indicated in the literature. Higher speeds also result in decreasing SO_2, NO_2, CO and TVOCs' concentration levels up to 60 km/h. It was also observed that for measurements taken at relatively high gradient locations, the traffic speed was significantly lower, resulting in lower traffic volumes and consequently in higher concentrations of gas pollutant levels.

In summary, this study has shown that traffic flow patterns significantly influence air pollution concentrations and that their effect differs under different gradients and traffic volumes. These effects should be taken into account for uncertainty analysis as well as for the development of confidence limits of pollution dispersion models and for designing effective air quality improvement programs.

CONCLUSIONS

In this study, the characteristics of air pollutants under different traffic flow conditions and different road gradients were analyzed; SO_2, NO_2, CO and TVOCs' concentrations were measured under prevailing traffic conditions. The ratios of SO_2, NO_2, CO and TVOCs' concentrations for different road gradients were between 2.5 and 5.2.

The air pollutant concentrations had a high correlation with traffic flow and road gradient. R-square values as well as relationships between SO_2, NO_2, CO and TVOC's concentrations and traffic speed are indicated on the plots in Figure 5.

It is concluded that the pollutant concentrations decrease with speed up to 60 km/h, while higher concentrations have been noticed with increasing gradient under the same traffic flow. This research project had introduced the average pollutant rate per gradient parameter. The values obtained are very much reflective of local conditions which are not typical when compared with other sampling locations in other recent studies by other researchers. Therefore, comparisons with other research studies may lack validity.

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