Effect of Vehicular Speed, Traffic Volume, and Road Grades on Air Pollution in Amman City (Case Study)
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Abstract

Air pollution has a global concern because of its unwilling pronounced welfare effects on human and the living beings in the world.

Lead, heavy metals, Diesel particulates, Nitrogen oxides, Photochemical oxidants (such as Ozone), NOₓ and SOₓ are considered the most major pollutants that emissions from motor vehicles exhaust.

The vehicular speed, traffic volume, and longitudinal road (vertical) grades have a great effect on vehicle emission and air pollution quantity for the same passenger trip distance.

The vehicular speed and the gradient of a road have the effect of increasing or decreasing the resistance of a vehicle to traction and thus influence emissions and fuel consumption. However, it cannot be assumed that - for example - the extra emission when travelling uphill is compensated by correspondingly reduced emission when travelling downhill. In addition gradient has different influence on the emission of air pollutants, and even fuel consumption, for light and heavy duty vehicles. While the traffic volume contributes to a vehicle delay and more time to spend on the road which leads to similar effects of the previous categories.

The research study discusses some of the environmental aspects; vehicular speed, traffic volume, and longitudinal road (vertical) grades, that have a great effect on vehicle emission and air pollution quantity for the same passenger trip distance in Amman city in Jordan as a case study, that need to be addressed when devising general and detailed urban plans. It describes the adverse effects resulting from motor vehicles dominating roads and highways, including environmental hazards such as air and noise pollution, and identifies environmental concerns to be taken into account in the 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.

Key Words: transport, emission, pollutant, gradient, heavy duty vehicles, vehicular speed, traffic volume.
INTRODUCTION

Drivers may experience an increase exposure to air pollution related to traffic and an excessive concentrations of air pollutants are easily accumulated. This can potentially have a serious effect on drivers’ health, especially when operating vehicles for a long time periods so studies on pollutant emission characteristics and influential factors of emission on the roads are important because. Motor vehicles emit nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOC) and particulate matter (PM), which constitute a major source of air pollution.

M. Zickus and A. Greig in their study of the effect of congested urban traffic flow on air pollutant concentrations indicated that the pollutant concentrations depend largely upon vehicular emission rates, meteorological parameters and the background levels of the pollutant concerned. (1)

Joumard (1999) indicated that a vehicle’s exhaust emission changes with its mode of operation, for example, whether it is cruising, accelerating, decelerating or idling. It is possible to calculate emissions based on recorded patterns of speed and acceleration cycles. However the most common approach is to use emission factors calculated as a function of average speed (2). Marsden et al. 2001 investigated the influence of traffic flow patterns on CO levels (12).

As indicated from the EPA report, there are a number of factors that affect the rate at which any vehicle emits air pollutants, whether the vehicle is being driven or is at idle (engine running, but vehicle not moving). Some of the most important factors are: vehicle type/size (passenger cars, light-duty trucks, heavy-duty trucks, motor- cycles), vehicle age and accumulated mileage, fuel used (gasoline, diesel, others), ambient weather conditions (temperature, precipitation, wind), maintenance condition of the vehicle (well maintained, in need of maintenance, presence and condition of pollution control equipment). The following table present idle emission factors for light duty fueled gasoline vehicles (LDGV) expressed as grams per hour (g/hr) and grams per minute (g/min) of idle time. (10)

Table 1. Idle emission factors for light duty fueled gasoline vehicles (LDGV) expressed as grams per hour (g/hr) and grams per minute (g/min). (10)

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Units</th>
<th>LDGV</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOC</td>
<td>g/hr</td>
<td>2.683</td>
</tr>
<tr>
<td></td>
<td>g/min</td>
<td>0.045</td>
</tr>
<tr>
<td>THC</td>
<td>g/hr</td>
<td>3.163</td>
</tr>
<tr>
<td></td>
<td>g/min</td>
<td>0.053</td>
</tr>
<tr>
<td>CO</td>
<td>g/hr</td>
<td>71.225</td>
</tr>
<tr>
<td></td>
<td>g/min</td>
<td>1.187</td>
</tr>
<tr>
<td>NOx</td>
<td>g/hr</td>
<td>3.515</td>
</tr>
<tr>
<td></td>
<td>g/min</td>
<td>0.059</td>
</tr>
<tr>
<td>PM_{2.5}</td>
<td>g/hr</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>g/min</td>
<td>N/A</td>
</tr>
<tr>
<td>PM_{10}</td>
<td>g/hr</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>g/min</td>
<td>N/A</td>
</tr>
</tbody>
</table>
The aim of this study is to describe air pollutant concentrations with respect to the road grades, vehicular speed and traffic volume. In this study, concentrations of CO, NO, TVOCs and SO were measured at various sampling sites at different period of times.

Duffy et al. (1996) and Rogak et al. (1998) studied the air quality in Sydney and Canada, respectively. They similarly discovered that the main air pollution source was the burning of vehicle engine gasoline or diesel, and that NO and CO was the main air pollutants (6, 7).

Noor et al. indicated that almost of the data collected in air pollution monitoring such as PM10, Sulphur dioxide, Ozone and Carbon monoxide are obtained from automated monitoring stations due to the missing values that require special attention on analyzing the data (11).

Generally the factors affect the pollution concentration in urban highways are divided into four groups; traffic parameters, geometric design, atmospheric condition and surroundings (background) concentration. The gradient of a road, expressed as % or ratio e.g. 1 in 20, has the effect of increasing or decreasing the resistance of a vehicle to traction and thus influences emissions and fuel consumption.

The motivation for this research was to focus on the road characteristics and analyze those that might have a stronger impact on air pollution, which will cause high risks to drivers and passengers on roads.

**Methodology**

The main problem with field data in this study is the requirement of taking the traffic, air pollution and the atmospheric data in the same time. Air pollutants were monitored for several short time periods to understand the relationship between pollutant concentrations and traffic flow on roads.

The short term measurements (15-minute averages) of gaseous pollutants (SO2, NO2, CO & TVOCs) were conducted at different locations in Amman city in Jordan. The sampling positions locations were located at 1 kilometer before Sweileh tunnel, 2 kilometers before Sweileh tunnel, at Sweileh tunnel and near Nobles Hall. Air pollutants of Nitrogen dioxides; NO2, Carbon monoxides; CO and Sulphur dioxides; SO2 measurements were conducted based on Electro-chemical Cell method using portable toxic gas analyzer.

While Total Volatile Organic Compounds (TVOC’s) measurement were conducted based on Photo Ionization Detection (PID) method using portable toxic gas analyzer. Lower limits of detection for NO2, CO and SO2 are 0.02, 0.5 and 0.1 ppm, respectively, near Safoot church. All the aforementioned instruments were calibrated at multipoint before and after the experiment according to the usual routines of quality control.

Taking into consideration the gradients to be encountered on previous sections of the roads, it was decided to undertake the emission measurements for gradient classes of -
9%, 7%, 5%, and 0%, where the numbers given designate the center of the class in each case. Gradient as a function of mean speed for each period of time is needed to determine the local emission assessments.

**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 0%, 5%, 7% and 9% and as shown in figure 1.

According to the best fit line observed from the data analyzed for the NO$_2$, CO, SO$_2$, and TVOC’s gases, the results of short term measurements (15-minute averages) of gaseous pollutants (SO2, NO2, CO & TVOCs) were analyzed as shown in figure 2.
The results of short term measurements (15-minute averages) of gaseous pollutants (SO2, NO2, CO & TVOCs) best fit linear straight line of the velocity with respect to the traffic passenger car units per hour and according to road gradients 0%, 5%, 7% and 9% is drawn as shown in figure 3.

The effects of road gradient on the gaseous pollutant emission were analyzed and presented, as an example, for 1000 passenger car units (PCU/hr) as indicated in figure 4.
Figure 4. NO$_2$, CO, SO$_2$, and TVOC’s gases respectively with Road Gradient at 1000 PCU/hr volume.

The effects of road gradient on the vehicle velocity were analyzed and drawn, as an example, for 1000 passenger car units (PCU/hr) as indicated in figure 5.

Figure 5. Average Velocity Vs Road Gradient at 1000 PCU/hr volume.

From the data analysis it's observed that traffic speed and the flow in the investigated roads were highly affected with the road gradient variations. The upper parts of the curves describe how, as flows and grades increase, there is an increase in vehicle interactions and a decrease in speeds. These interactions are accompanied by an increase
in the frequency of vehicle accelerations and decelerations, and consequently also an increase in pollutant emissions.

Due to the short term measurements of the gaseous air pollutants during the day time and the uneven time periods measurements, the variation of NO\textsubscript{x} and VPH, as an example, with time in the study is following the same trends as in the literature as shown in figure 6.

![Figure 6. Variation of NO\textsubscript{x} and VPH with Time according to Joumard, 1999.(2)](image)

The results showed that vehicular speed, traffic volume, and longitudinal road (vertical) grades have a great effect on vehicle emission and air pollution quantity of SO\textsubscript{2}, NO\textsubscript{2}, CO & TVOC’s for the same passenger trip distance.

The maximum ratios of SO\textsubscript{2}, NO\textsubscript{2}, CO & TVOC’s concentrations of different grades; i.e. emission at 9\% grade divided by the emission at 0\% grade for the same PCU of a vehicle, are indicated in table 2.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Ratio</th>
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<tbody>
<tr>
<td>SO\textsubscript{2}</td>
<td>3.1</td>
</tr>
<tr>
<td>NO\textsubscript{2}</td>
<td>2.9</td>
</tr>
<tr>
<td>CO</td>
<td>2.5</td>
</tr>
<tr>
<td>TVOC’s</td>
<td>5.2</td>
</tr>
</tbody>
</table>

The difference in the SO\textsubscript{2} concentrations at different grades is large since buses and trucks are not prohibited from travelling on roads and these heavy-duty vehicles have high SO\textsubscript{2} emissions.

Nitrogen oxides (NO\textsubscript{x} and NO\textsubscript{2x}) is also an important air pollutant from mobile sources. In general, NO emissions in an engine exhaust typically consist of 85–95\% NO and 5–15\% NO\textsubscript{2x} (Soltic and Weilenmann, 2003). The results are similar to the study of Soltic and Weilenmann (2003).

Furthermore, the ratios of NO\textsubscript{2} concentrations at different grades were about 2.9. It is obvious that the NO\textsubscript{2} concentrations were highly emitted on high grades. Additionally,
the concentration distribution was affected by the traffic flow and showed that the NO\textsubscript{2} and CO concentrations were all affected for different grades.

After analyzing the relationship between air quality and traffic flow data at different grades with a linear regression, it is obvious that the pollutant concentrations increase with an increase in grade. The R-square value, square of relative coefficient, of the relationships between SO\textsubscript{2}, NO\textsubscript{2}, CO & TVOC’s concentrations and traffic flow were about: 0.84, 0.81, 0.87, and 0.92 respectively. It is seen that traffic flow has a high impact on SO\textsubscript{2}, NO\textsubscript{2}, CO & TVOC’s concentrations.

Based on the estimated relationships between SO\textsubscript{2}, NO\textsubscript{2}, CO & TVOC’s concentrations with traffic variables several distinctive effects of traffic flow on air pollutant concentrations in a streets can be identified. Under high grades traffic flow conditions (traffic speed < 50 km/h) higher rate of pollutant concentrations is noticed. The result is similar to those indicated in the literature. Higher speeds also result in higher SO\textsubscript{2}, NO\textsubscript{2}, CO & TVOC’s concentrations levels. Under higher grades (traffic speed <50 km/h) lower traffic volume travelling at the same speed result in higher concentration gases levels.

In summary, this study has shown that traffic flow patterns significantly influence air pollution concentrations and their effect differs under different grade traffic flow. These affects should be taken into account for uncertainty analysis and the development of the confidence limits of pollution dispersion models and for designing an effective air-quality improvement program. For explicit emission rate simulations microscopic traffic simulation models have to be used. (8)

**Conclusion and Results**

In this study, the characteristics of air pollutants under different traffic flow conditions and different road grades were analyzed; SO\textsubscript{2}, NO\textsubscript{2}, CO & TVOC’s concentrations were measured with traffic variables. The ratios of SO\textsubscript{2}, NO\textsubscript{2}, CO & TVOC’s concentrations different road grades were 2.5- 5.2 showing the influence of grade effects.

The air pollutant concentrations had a high correlation with traffic flow and road grades. The R-square value, square of relative coefficient, of the relationships between SO\textsubscript{2}, NO\textsubscript{2}, CO & TVOC’s concentrations and traffic flow were about: 0.84, 0.81, 0.87, and 0.92 respectively. It is seen that traffic flow has a high impact on SO\textsubscript{2}, NO\textsubscript{2}, CO & TVOC’s concentrations.

The maximum ratios of SO\textsubscript{2}, NO\textsubscript{2}, CO & TVOC’s concentrations of different grades; i.e. emission at 9% grade divided by the emission at 0% grade for the same PCU of a vehicle were about 3, 2.9, 2.5, and 5.2 or the spatial concentration is 33%, 32%, 27% and 58% for each grade increase on roads.

These results are important since gaseous air pollutants combines easily more than oxygen with the hemoglobin in blood and reduces the content of oxygen in the blood of exposed drivers. Therefore, the health risk is elevated due to the long exposure time of drivers in the high grades.
References

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