EFFECT OF ROAD GRADE, VEHICLE SPEED AND VEHICLE TYPE ON NO_2 EMISSIONS ON URBAN ROADS IN JORDAN

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ABSTRACT
Motor vehicles emit gaseous air pollutants including sulphur dioxide, carbon monoxide (CO), carbon dioxide (CO_2) nitrogen oxides (NO_x), volatile organic compounds (VOC), and particulate matter (PM). Vehicle exhausts are confirmed as a main contributor to air pollution. The purpose of the study is intended to understanding emission rates of gases vehicle's emission in Jordan and to reveal the impact of driving conditions such as road grade, vehicle speed, number of vehicles and vehicle types in urban areas. In this study, gaseous emissions of NO_2 were measured as an indicator for other vehicle gaseous pollutant. The maximum measured emission rate for NO_2 was 0.15 ppm and the mean average emission rate for NO_2 was 0.077 ppm. Overall, our finding highlights a significant influence of road grade, speed, type and number of vehicle with the rate of NO_2 emission. The observed trends indicate there is a need for further investigation to includes other gaseous pollutant.
Keywords: vehicle emission, NO_2, traffic conditions, Jordan.

1 INTRODUCTION

Road transport is a major contributor to pollutant emissions in the Middle East and Northern Africa region (MENA). In the MENA region, vehicular transportation contribute to emission of 40% of NO_x [1]. In California, motor vehicles were responsible for 51%, of NO_x [2]. In China, vehicle emissions accounted for 36% [3]. Emissions originating from vehicle emissions have a significant impact on the atmosphere, health and the climate change [4]. Zheng et al. [3] demonstrated that vehicle emissions accounted for 67%, 36%, 39%, 36%, and 22% of CO, NO_x, VOCs, $PM_{2.5}$ and PM_{10}, respectively, in the Pearl River Delta, China. Nitrogen oxides (NO_x), comprising nitric oxide (NO) and nitrogen dioxide (NO_2), are emitted during fossil fuel combustion processes. Associations between NO_2 and adverse health effects, including mortality and morbidity, have been reported by many epidemiological studies [5], [6]. The vehicle number in Jordan has rapidly grown from 1.3 million to 1.35 million between 2014 and 2015, with around 75% of registered vehicle run on diesel (Fig. 1) [7].

In recent report, emissions of nitrogen oxides decreased by one third in the Twenty-Eight Member States of European United Countries, and 26% in the Thirty-Three Member countries of European Environment Agency [8]. Unfortunately, there is a lake of research conducted in Jordan regarding on-road emission trends [9]. Al-Hasaan et al. [10] reported emission levels of NO_2 at four monitoring sites in Amman during the period of July 1986 to June 1987.

Vehicle emissions were affected by operating modes, ambient conditions, driver behaviours, vehicle load and road grade [11]. Research studies have emphasised a significant influence road level on real-world fuel consumption and exhaust emission [12]–[14].

For test sections with positive road grade, as the gradient increases so must the engine power output to keep the vehicle at a constant speed, due to the increasing force of gravity

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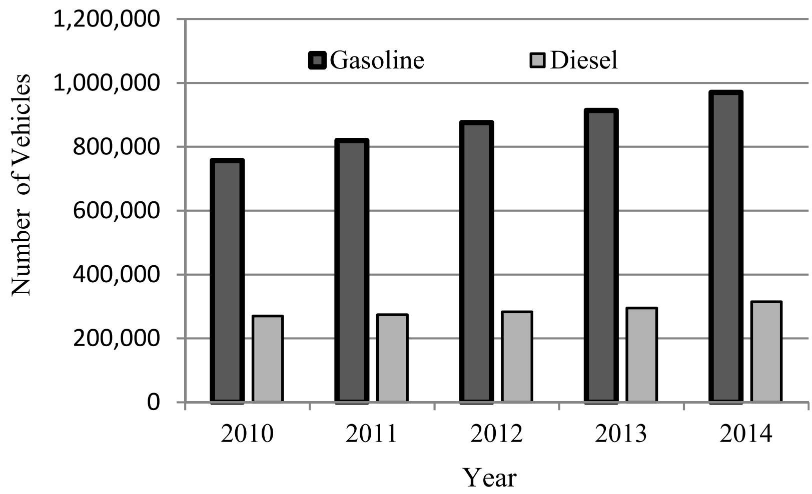

Figure 1: Number of Vehicles in Jordan between year 2010 and 2014.

opposing the motion of the vehicle. This increase in power requires greater fuel consumption resulting in increased CO_2 exhaust emission. Likewise, where a vehicle is travelling on a road with negative grade, gravity acts to accelerate the vehicle, reducing the power demand on the engine, which lowers fuel consumption and hence CO_2 emission. Zhang and Frey [14] recorded an increase in CO_2 emission of 40–90% for three light duty gasoline vehicles over sections of road with gradient 5% when compared to sections with gradient 60%, whilst Boriboonsomsin and Barth [12] measured a 15–20% rise in fuel consumption for a gasoline passenger car between a flat route and a hilly route.

Ntziachristos and Samaras [16] showed that the correlation coefficients between average emission rates of NO_x and speed were low (r^2: 0.34–0.56). de Vlieger [17] demonstrated that the emission rates of NO_x and the consumption rates of fuel increased by 10%, during rush hours compared with those of free flow conditions. The transport sector is the largest contributor to NO_x emissions, accounting for 46% of total EU-28 emissions in 2012 but the introduction of catalytic converters reduced these emissions significantly [8].

This research aims to better understanding the effect of vehicle driving conditions on NO_2 emission rates in urban area in Jordan.

2 METHODOLOGY

Jerash Road and King Abdullah bin Hussein II Road are frequently congested during rush hour and it compromises fixed road of 5.7 km route through the eastern entrance to Amman. The road was divided into different segments based on driving conditions such as traffic flow, vehicle's speed and road grade. The first segment has a slope of 6%, the second segment has a slope of 4%, the third segment has a slope of zero whereas, the last segment has a slope of –2%.

Nitrogen dioxide emissions were obtained using GrayWolf's AdvancedSense gaseous analysers. Traffic speed was measured with speed gun (Bushnell gun). Vehicle's type and speed were measured by manual count every 15 minutes during measuring emission rates at the measuring points. The vehicle's types were classified into gasoline and diesel vehicle [9].

3 RESULTS AND DISCUSSION

Emission rate for NO_2 gas measured and the frequency is shown in Fig. 2. The maximum measured emission rate for NO_2 during the rush hours was 0.15 ppm and the mean average emission rates for NO_2 was 0.08 ppm. The NO_2 emission was below the maximum allowable concentration. The result was consistent with [10]. The reported emission rate at Downtown of Amman was between 0.01 to 0.08 ppm for NO_2. The motor vehicles were the major contributor to emission of CO and NO_2 at the Downtown of Amman [10]. Deng et al. [18] reported high concentrations of NO_x greater than 30 ppm for vehicle fleet under real-world driving conditions of urban China.

There are significant correlations between road grade of 1% and NO_2 emission (Table 1). Diesel vehicles and road grade have positive correlation with emission rates (Table 1). Fig. 3 shows the average NO_2 emissions at various road levels (–2%, 4%, 0% and 6%). The emission rates of NO_2 at low level (-2%) are lower than at higher level (0%, 4% and 6%) At level of –2%, the average emission's for NO_2 decreased by 100% (Fig. 3) while smaller decreases in emissions at other levels of roads compared to 6%. Likewise, Deng et al. [18] reported that NO_2 was released at higher rates on higher road level. The amount of fuel consumption and gaseous emissions is correlated to road level due to the resistance and traction of vehicles. As the road level increases and the gravity force increases, the vehicle's engine power must be increased to keep constant vehicle's speed.

This increase in power requires greater fuel consumption resulting in increased exhaust emission. Similarly, Zhang and Frey [14] recorded an increase in CO_2 emission of 40–90% for gasoline vehicles over sections of road with gradient 5% when compared to sections with gradient 60%, and Boriboonsomsin and Barth [12] measured a 15–20% rise in fuel consumption for a gasoline passenger car between a flat route and a hilly route.

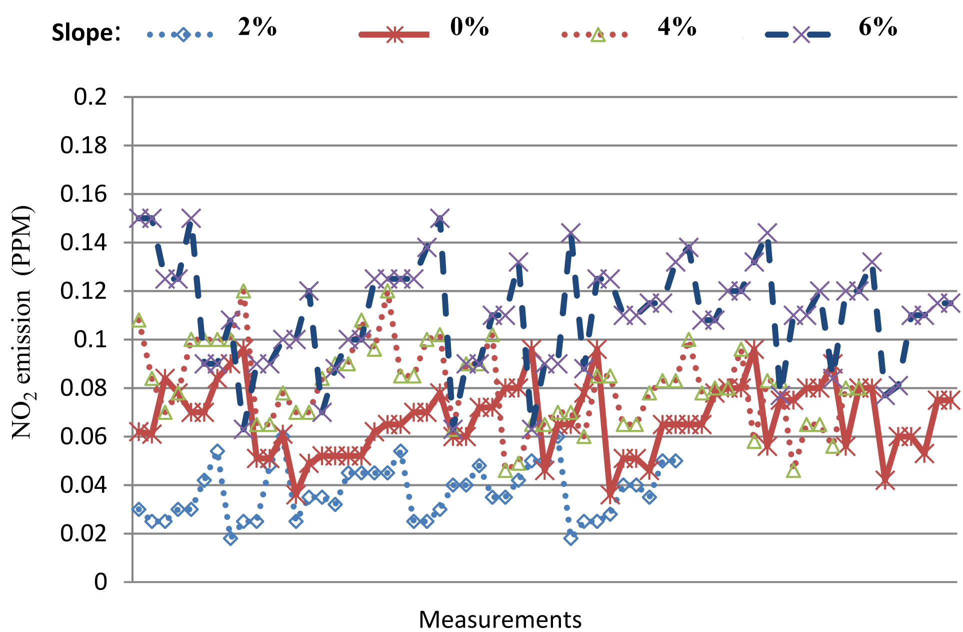

Figure 2: Frequency of measured vehicle's emission.

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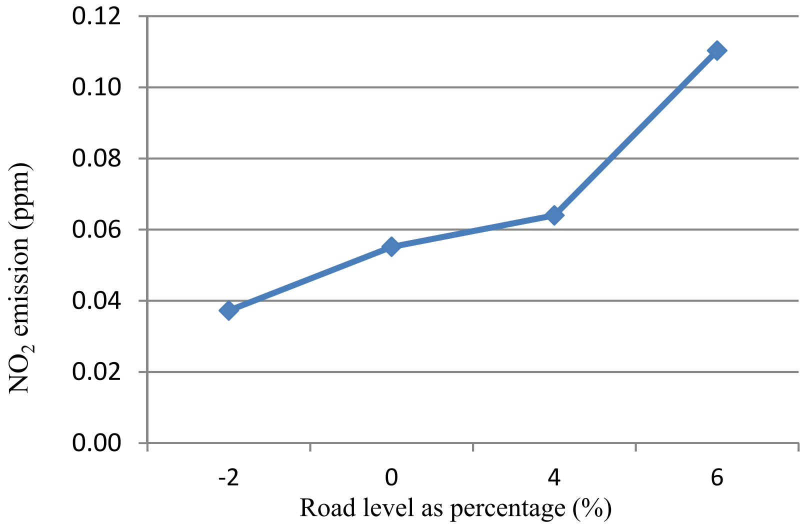

Figure 3: Average rate emission of NO_2 at various road grades.

Table 1: Relationship between vehicle emission and road level, and vehicles type and speed.

Emission gas (ppm)	Average	Standard Deviation	Correlation coefficient			
			Road Level	Gasoline Vehicle	Diesel Vehicle	Speed
NO_2	0.08	0.03	0.8**	-0.7	0.4**	0.4**

** Pearson correlation is significant at the 0.01 level (2 tailed).

Fig. 4 Shows different rate of emissions at various speed segments. The emissions decrease significantly with increasing the vehicle's speed (Table 1). Driving at high speed reduces emission rates by 13% to 32% (Fig. 4), this could be as a result of reduction in fuel consumption with increasing speed. Ntziachristos and Samaras [16] showed that the correlation coefficients between average emission rates of NO_x and speed were low (r^2: 0.34–0.56). de Vlieger et al. [17] demonstrated that the emission rates of NO_x and the consumption rates of fuel increased by 10%, during rush hours compared with those of free flow conditions.

There are significant correlations between average emission rates and diesel vehicles (Table 1). Diesel vehicles have positive correlation with the average emission rates (Table 1), while gasoline vehicle has no significant effect increasing in emission rates of NO_2.

4 CONCLUSION

The maximum measured emission rates for NO_2 was 0.2 ppm. The emission was below the maximum allowable concentration according to the Jordanian Standards. There were significant correlations between average emission rates and road level, vehicle's speed and diesel vehicles. The emission rates increase with increasing the road level and driving at low speed, while gasoline vehicle had no significant influence on increasing NO_2 emission compared to diesel vehicle.

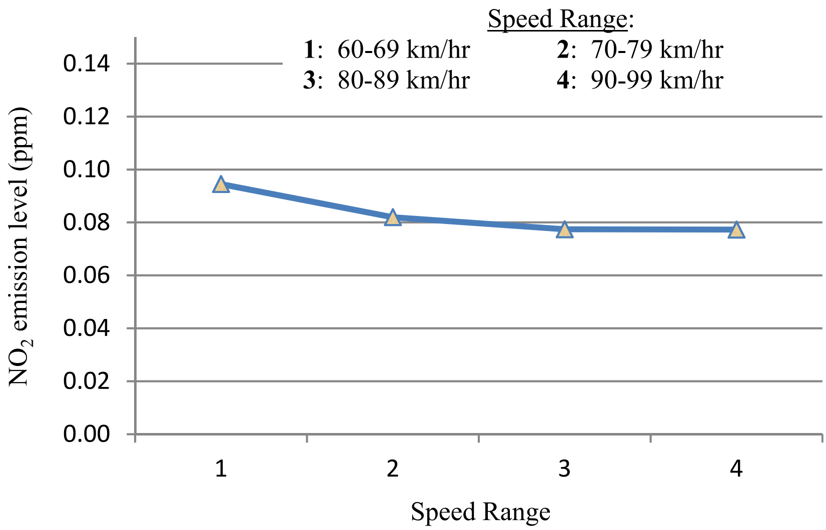

Figure 4: Average rate emissions of NO_2 at vehicle speeds.

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