BTEX concentrations influenced by external factors at a diesel-refuelling station in Johannesburg, South Africa

R. Moolla, C. J. Curtis & J. Knight
School of Geography, Archaeology and Environmental Studies, University of the Witwatersrand, South Africa

Abstract

Public transport systems in Johannesburg, South Africa, rely on a large number of diesel-powered buses. These buses are fuel economical and durable. However, filling station attendants, bus drivers and the public are exposed to the diesel fuel and fumes associated with them. Fuel attendants are exposed to diesel exhaust fumes, as well as emissions from fuel pumps on a daily basis, and are at risk to adverse health effects associated with inhalation of volatile organic compounds (VOCs) released. The VOCs released include benzene, toluene, ethyl-benzene and xylenes (BTEX), which have a high level of toxicity. Studies relating to the concentrations of BTEX at diesel stations are limited, as most studies focus on petrol refuelling stations. Thus, analyses of these concentrations are significant within developing countries whose transport systems rely on diesel-powered buses, and where public health measures are often less rigorously enforced. As this research falls within a larger study relating to the health impact of BTEX on fuel attendants at a diesel-refuelling bay, an initial study was undertaken to analyse the two main external factors that are influential on fluctuations of ambient concentrations. Thus, an analysis of total volume dispensed, and ambient temperature at the station, both affecting the concentrations of BTEX released, was conducted. It was established that $BTEX_{total}$ concentrations were positively correlated to the volume of diesel dispensed daily and inversely correlated to temperature. Additionally, ethylbenzene and o-xylene indicated a positive correlation with volume of fuel dispensed, while toluene and p-xylene were negatively correlated to temperature.

Keywords: benzene, toluene, ethylbenzene, xylenes, diesel, temperature.

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1 Introduction

Diesel exhaust fumes, released from motor vehicles, buses, locomotives and other motorized machinery, has three major groups of sources (i.e. mobile sources, stationary sources and stationary point sources) [1, 2]. In addition, vapours are released from diesel fuel at refuelling bays and filling-garages. These vapours include various volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs) and particulates [3–5]. However, many studies have focused on specific VOCs, namely the BTEX group (benzene, toluene, ethyl-benzene and xylenes) which are released by petrol and diesel fuels. The amount of BTEX concentrations released from the fuel can vary according to the composition and additives in the fuel, as some additives may increase benzene concentrations. In addition, the ways in which the diesel fuel is used at specific sites, such as parking or refuelling bays, can affect the concentrations, as well as ambient climatic conditions.

Epidemiological studies have shown that inhalation of fuel vapours can be hazardous to human health, specifically to fuel attendants [6–12]. BTEX in general have been shown to be associated with a range of health complications such as cardiopulmonary disease, lung, liver, and kidney diseases [6, 7, 10]. The inhalation of benzene has also been linked to adverse teratogenic effects [3, 13, 14]. In recent years diesel exhaust has been suggested as a probable human carcinogen [1, 12, 15, 16], however, very little research specifically on diesel vapour inhalation has been conducted.

BTEX concentrations and associated inhalation thereof vary due to several factors such as total fuel-dispensed, number of shifts and/or hours per shift of employees. Hein *et al.* [6] stated that exposure to fuel vapours can be markedly influenced not only by total volume of fuel dispensed by the attendants during each shift, or length of each shift, but also by changes in atmospheric temperature, ventilation and/or concentration of benzene in the fuel. However, very little literature is available on the effects of temperature and pressure, and/or total volume of fuel dispensed linked to fluctuations in concentrations of BTEX, specifically in diesel fuel. Thus, the main aim of this study was to investigate whether daily BTEX concentrations in diesel varied according to fuel dispensed in one refuelling bay, at a metropolitan bus company in Johannesburg, South Africa. In addition, the study evaluated whether atmospheric temperature also played a role in fluctuations and peaks of concentrations, at the indoor diesel-refuelling bay.

2 Background

In South Africa, public transport systems rely on a large number of diesel-powered buses as they are fuel economical and durable. However, filling station attendants, bus drivers and the public are exposed to the diesel fuel and fumes associated with them. Fuel attendants are exposed on a daily basis to not only diesel exhaust fumes, but also emissions from fuel pumps. This exposure places them at particular risk to adverse health effects associated with inhalation of these BTEX, which have a high level of toxicity. There have been significant mechanisms introduced in South Africa to reduce emissions in the fuels, which include a move away from leaded petrol and high content sulphur diesel fuels. LRP (lead replacement petrol), 95-unleaded petrol, 97-unleaded petrol, and 10- and 50-ppm diesel are now the alternatives in South Africa, which are meant to have lower rates of harmful emissions. However, despite these advances, diesel fuel still poses significant risk to fuel attendants.

2.1 Site description

In this study, an indoor diesel-refuelling bay was monitored. The fuel bay is located in the hub of Johannesburg and supplies 50ppm fuel to 400 diesel-powered buses. The refuelling bay has four pumps, manned by two full time employees (with additional employees conducting various other duties in and near the bays). The refuelling bay is 30m long, with 3.5m access doors on either end of the bay. Buses are refuelled during working hours (07:00–15:30), Monday to Friday.

3 Materials and method

3.1 Sampling strategy

Continuous in situ measurements of benzene, toluene, ethyl-benzene and o- and p-xylenes were obtained using the SYNSPEC Spectras Gas Chromatography 955 VOC analyser. Ambient air was sampled at a 1.5m height, at the diesel filling pumps, measured continuously at 15 minute intervals, for the entire winter period (June, July and August). The analyser was calibrated prior to the testing period (calibration was done in the range of 0 to 18μg/m^3), and a correction factor of 2ppb and 4ppb for benzene and toluene were used, respectively [17]. Helium gas was used as a carrier gas in the GC955 analyser as it is an inert gas and thus safe at the diesel refuelling bays. The winter season provided the conditions for the GC 955 analyser to operate at its optimal, as the pilot study revealed the instrument was non-functional in hot summer temperatures, due to levels of BTEX being too high and causing errors and malfunction to the software. Additionally, the winter season experiences a prevailing high pressure system, which allows the gaseous vapours to accumulate over the site.

Additionally, a Davis weather instrument (with data logger CR10X), was mounted at a height of 2m above ground level inside the station. Temperature, pressure and humidity were recorded every 30 minutes, throughout the entire monitoring period. Temperature recordings were corrected to a ±3°C error. Fuel logs were obtained from MetroBus Pty. Ltd (which is the government owned entity that runs the bus service). Fuel logs are maintained at the site, based on fuel filled per bus (in litres), per day.

3.2 Statistical analysis

An interaction term between concentration and fuel dispensed/weather parameters/work and non-work days was included in the analysis. Daily and quarter-hourly averages of BTEX concentrations were used in order to be comparable to daily fuel dispensed and temperature records, respectively. Following the methodological approach of Keretetse *et al.* [9] the level of significance was set at 5%. Statistical analysis was undertaken with the aid of the SPSS 20.1 statistical software. Variables were tested for normality, and non-normally distributed data were analysed using non-parametric tests (viz. Wilcoxon sign rank and Spearman's correlation tests).

4 Results and discussion

4.1 The influence of fuel dispensed on daily BTEX concentrations

Figure 1 presents concentrations of the $BTEX_{total}$ concentrations obtained at the site for the duration the monitoring period, showing a statistically significant decrease of concentrations on non-workdays (F=1.953, p=0.0403). This was also apparent in a study conducted by Keretetse *et al.* [9], where a significant relationship was also found between the levels of benzene, toluene and total VOCs, and the volume of the petrol sold. However, it is notable that this was not the case in the diesel-refuelling bay in this study.

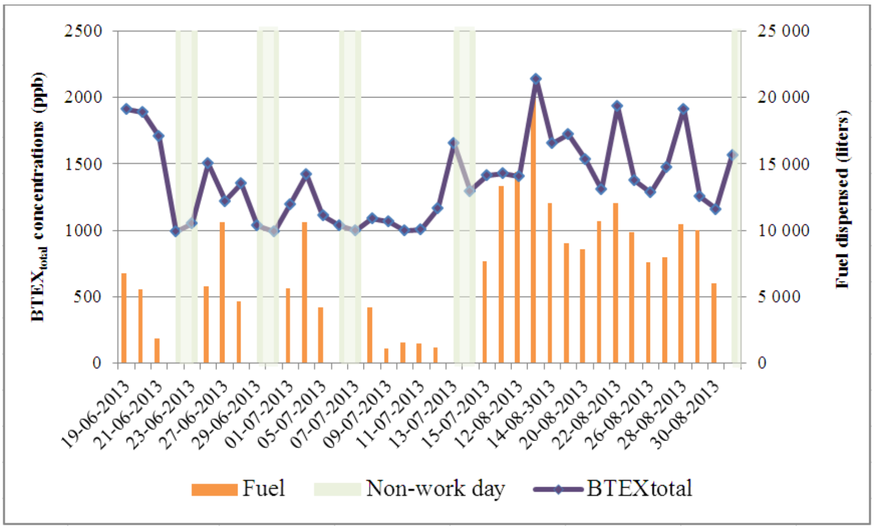

Figure 1: Daily average of ambient $BTEX_{total}$ concentrations as compared to the total volume of diesel dispensed daily at the site during the monitoring period. The shaded area indicates non-work days when the refuelling bay is closed.

Despite the trend for $BTEX_{total}$, benzene and toluene concentrations (Figure 2a, b) are not dependent on fuel consumption. This could be attributed to the fact that, according to Heeb *et al.* [18], both of these aromatic hydrocarbons can undergo prolonged photochemical decay, and this may result in increased rates of ambient benzene and toluene in diesel fuels. In addition, Rasmussen and Khalil [19] found that atmospheric benzene levels were highest during winter, which may explain the high levels recognised at the station, as the study period was during this season.

Ethylbenzene and p-Xylene on the other hand (Figure 2c, d) are positively correlated to the volume of diesel dispensed daily (p=0.478 and 0.547, respectively (Table 1)). This indicates that as volume of fuel-dispensed increases, concentrations also increase. This finding is also in line with those of other studies (e.g. Keretsetse *et al.* [9]), indicating that volume of fuel sold significantly influences ethylbenzene and xylene concentrations.

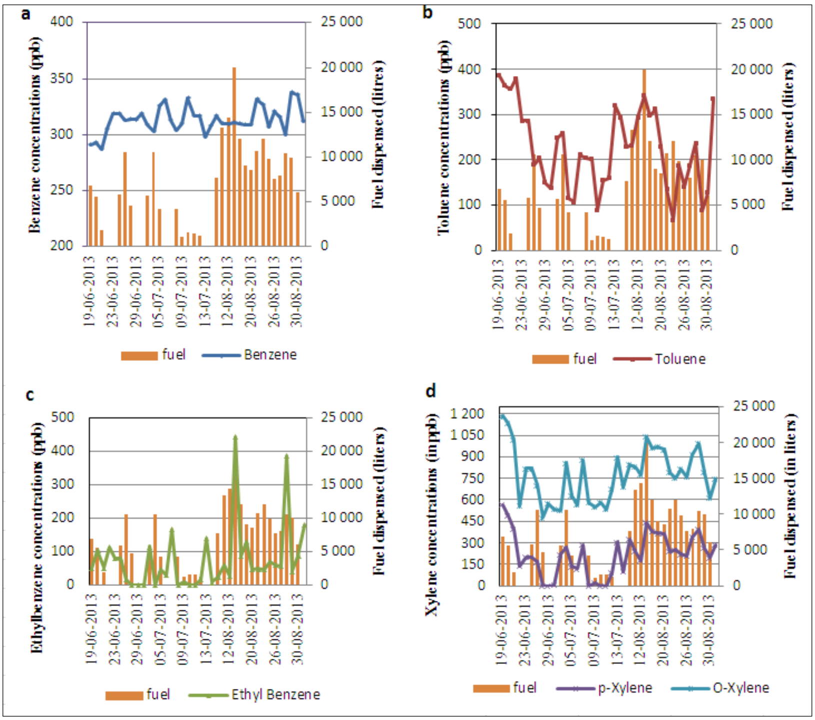

Figure 2: Ambient benzene (a), toluene (b), ethylbenzene (c) and xylene (d) concentrations as compared to fuel dispensed daily at the station, for winter (JJA) 2013.

4.2 The influence of temperature on hourly BTEX concentrations

A significant result in this study was that $BTEX_{total}$ concentrations were negatively correlated (p=-0.555) to temperature for the entire monitoring period (Table 1). This can be clearly seen in Figure 3, where daily ambient $BTEX_{total}$ concentrations and ambient temperature variations are compared. However, if the findings are

Table 1: Correlation between BTEX concentrations and the influential factors considered. (r indicates the linear correlation coefficient between two variables, and p indicates the level of significance).

VOC	n	Volume of diesel sold		Temperature	
		r	*p*	r	*p*
Benzene	96	0.113	0.113	0.197	0.197
Toluene	96	0.045	0.045	0.013	-0.816[b]
Ethylbenzen e	96	0.478	0.478[a]	0.250	-0.221
o-Xylene	96	0.139	0.139	0.390	-0.670[b]
p-Xylene	96	0.547	0.547[a]	0.656	-0.007
$BTEX_{total}$	96	0.553	0.553 [a]	0.456	-0.555[b]

[a]Positive significance
[b]Negative significance

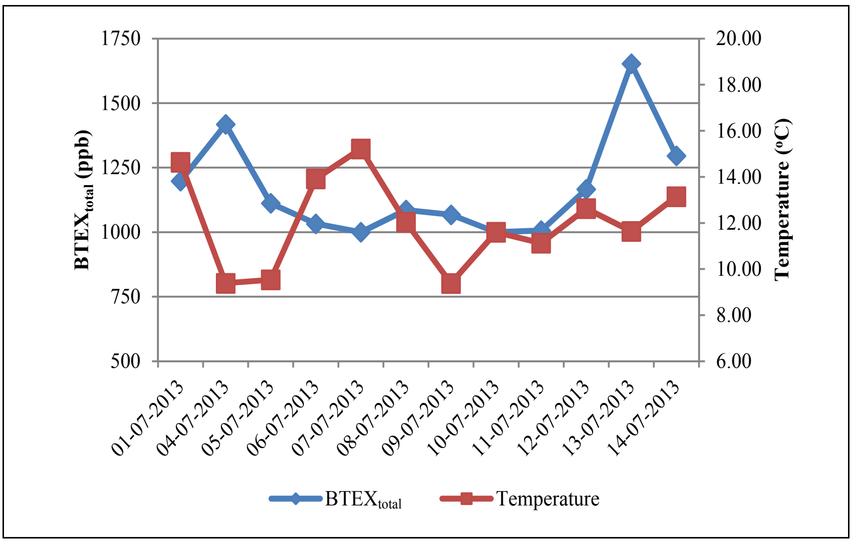

Figure 3: Daily ambient $BTEX_{total}$ concentrations as compared to ambient temperature at the station during a two-week period in the winter season.

evaluated against the study conducted by Keretsetse *et al.* [9], temperature was positively correlated to BTEX concentrations. One reason for this could be that diesel and petrol emissions may react differently to fluctuations in temperature, and thus, concentrations of diesel are negatively correlated to temperature.

This is further illustrated when hourly concentrations are contrasted to hourly temperature changes, on a typical winter's day (Figure 4). However, the fluctuations noted may be attributed to a time lag offset in the data, as well as indicative that other factors may be involved (such as humidity, wind and/or atmospheric pressure).

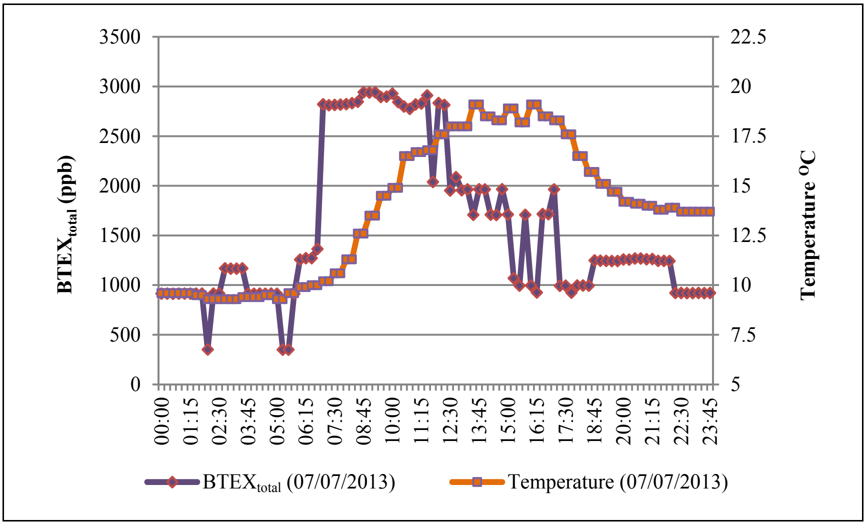

Figure 4: Hourly ambient BTEX$_{total}$ and ambient temperature variations on a single average winter's day during July.

Toluene and o-xylene observe the same behavioural pattern of a negative correlation to temperature (Table 1). A noteworthy finding was that benzene concentrations were not affected by fuel dispensed (Figure 2a) or changes in temperature. However, it was found that peaks in concentrations were closely related to the timing of sunrise daily (06:30–06:45), and this inevitably influenced the BTEX$_{total}$ concentrations to peak at sunrise (Figure 4).

Further investigation into this phenomenon is imperative, as studies have shown that relative humidity, atmospheric pressure and/or wind speed, besides temperature, may contribute to fluctuations in concentrations of diesel emissions from fuel and fumes.

5 Conclusions

BTEX$_{total}$ concentrations at a diesel refuelling bay in Johannesburg, South Africa, have been noted to have a positive correlation with volume of diesel dispensed daily. Additionally BTEX$_{total}$ indicated to be negatively correlated to temperature changes (thus when atmospheric temperature decreases, BTEX$_{total}$ concentrations increase). This finding is noteworthy, as previous research indicated that total

BTEX concentrations are positively correlated to both volume of fuel (petrol) dispensed and temperature. Benzene concentrations were noted to be neither related to temperature or volume of diesel dispensed, which could be linked to the chemical properties of the benzene vapours. Despite benzene not being significantly related to external factors, p-xylene and ethylbenzene both showed positive correlations to volume of fuel dispensed, while toluene and o-xylene showed a negative relationship with temperature. However, other factors besides total volume of diesel dispensed and temperature (such as wind speed, relative humidity and/or atmospheric pressure) may play a role in the fluctuations of BTEX concentrations, and further evaluation in the future is imperative. In addition, due to the high levels of $BTEX_{total}$ concentrations noted at the refuelling bay, it is essential to analyse the health risk exposure of employees in the near future.

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References

[1] Stayner, L., Dankovic, D., Smith, R., and Steenland, K., “Predicted lung cancer risk among miners exposed to diesel exhaust particles,” American Journal of Industrial Medicine, vol. 34, no. 3, pp. 207–219, 1998.

[2] US Department of Health and Human Services. Public Health Service, National Toxicology Program, “Report on Carcinogens, 12th edition,” 2011.

[3] Ferreira, S. L., dos Santos, A. M., de Souza, G. R., and Polito, W. L., “Analysis of the emissions of volatile organic compounds from the compression ignition engine fueled by diesel–biodiesel blend and diesel oil using gas chromatography,” Energy, vol. 33, no. 12, pp. 1801–1806, Dec. 2008.

[4] Fujita, E. M., Campbell, D. E., Zielinska, B., Arnott, W. P., and Chow, J. C., “Concentrations of air toxics in motor vehicle-dominated environments.,” Res Rep Health Eff Inst, no. 156, Feb. 2011.

[5] Tsai, J.-H., Chang, S.-Y., and Chiang, H.-L., “Volatile organic compounds from the exhaust of light-duty diesel vehicles,” Atmospheric Environment, vol. 61, pp. 499–506, Dec. 2012.

[6] Hein, R., Aung, B. T., Lwin, O., and Zaidi, S. H., “Assessment of occupational benzene exposure in petrol filling stations at Rangoon,” Annals of Occupational Hygiene, vol. 33, no. 1, pp. 133–136, 1989.

[7] Das, M., Bhargava, S. K., Kumar, A., Khan, A., Bharti, R. S., Pangtey, B. S., Rao, G. S., and Pandya, K. P., “An investigation of environmental impact on health of workers at retail petrol pumps,” Annals of Occupational Hygiene, vol. 35, no. 3, pp. 347–352, 1991.

[8] Carvalho-Oliveira, R., "Diesel emissions significantly influence composition and mutagenicity of ambient particles: a case study in São Paulo, Brazil," Environmental Research, vol. 98, no. 1, pp. 1–7, May 2005.
[9] Keretetse, G. S., Laubscher, P. J., Du Plessis, J. L., Pretorius, P. J., Van Der Westhuizen, F. H., Van Deventer, E., Van Dyk, E., Eloff, F. C., Van Aarde, M. N., and Du Plessis, L. H., "DNA Damage and Repair Detected by The Comet Assay in Lymphocytes of African Petrol Attendants: A Pilot Study," Annals of Occupational Hygiene, vol. 52, no. 7, pp. 653–662, Aug. 2008.
[10] Udonwa, N. E., Uko, E. K., Ikpeme, B. M., Ibanga, I. A., and Okon, B. O., "Exposure of Petrol Station Attendants and Auto Mechanics to Premium Motor Sprit Fumes in Calabar, Nigeria," Journal of Environmental and Public Health, vol. 2009, pp. 1–5, 2009.
[11] Rekhadevi, P. V., Rahman, M. F., Mahboob, M., and Grover, P., "Genotoxicity in Filling Station Attendants Exposed to Petroleum Hydrocarbons," Annals of Occupational Hygiene, vol. 54, no. 8, pp. 944–954, Nov. 2010.
[12] World Health Organisation, "IARC: Diesel Engine Exhaust Carcinogenic," in IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Lyon, France, 2012, vol. Volume 105, Press release 213.
[13] Askari, K., Pollard, S., Great Britain, and Environment Agency, The UK approach for evaluating human health risks from petroleum hydrocarbons in soils. Bristol: Environment Agency, 2005.
[14] Pinedo, J., Ibáñeza, R., and Irabiena, Á. "Risk Assessment of Total Petroleum Hydrocarbons (TPHs) Fractions," Chemical Engineering, vol. 28, 2012.
[15] Tang, S., Frank, B. P., Lanni, T., Rideout, G., Meyer, N., and Beregszaszy, C., "Unregulated Emissions from a Heavy-Duty Diesel Engine with Various Fuels and Emission Control Systems," Environmental Science & Technology, vol. 41, no. 14, pp. 5037–5043, Jul. 2007.
[16] United States, "Diesel Particulate Matter," 2011. [Online]. Available: http://www.epa.gov/region1/eco/airtox/diesel.html. [Accessed: 25-Jun-2014].
[17] Synspec, Manual for the Syntech Spectras GC955 series 400, 600 and 800 single/double. De Deimten 1, 9747 AV Groningen, Nederland, 2013.
[18] Norbert V. Heeb, Anna-Maria Forss, Christian Bach, Stefan Reimann, Alex Herzog, and Hans W. Jäckle, "A comparison of benzene, toluene and C2-benzenes mixing ratios in automotive exhaust and in the suburban atmosphere during the introduction of catalytic converter technology to the Swiss Car Fleet," Atmospheric Environment, vol. 34, pp. 3103–3116, 2000.
[19] Rasmussen, R. A. and Khalil, M. A. K., "Atmospheric benzene and toluene," Geophysical Research Letters, vol. 10, no. 11, pp. 1096–1099, 1983.