Chapter 6 Diurnal variation and health risk of atmospheric aromatic hydrocarbons concentrations in an urban site located in Nuevo Leon, Mexico

Capítulo 6 Variación diurna y riesgo a la salud de las concentraciones atmosféricas de hidrocarburos aromáticos en un sitio urbano localizado en Nuevo León, México

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Abstract

Diurnal variation of aromatic hydrocarbons (BTEX: benzene, toluene, ethylbenzene and p-xylene) in ambient air was determined in an urban site located in Monterrey, during North's season 2020. Samples were collected using active sampling by a vacuum pump at a controlled flow of 200 ml/min during 1.5 h, considering three sampling periods: morning (07:00 - 08:30 h), midday (14:00 - 15:30 h) and afternoon (17:30- 19:00 h). Samples were desorbed with carbon disulfide and the extracts were analyzed by gas chromatography with ionization flame detection. Ethylbenzene and p-xylene were the dominant hydrocarbons (mean concentration: 18.581 μg/m^3 and 18.039 μg/m^3, respectively). Mean values for benzene and toluene were 15.137 μg/m^3 and 15.503 μg/m^3, respectively. All BTEX showed a diurnal pattern with higher values during the afternoon. From a meteorological study (wind roses) and chimiometric analysis (principal component analysis) were identified relations among the measured variables and their possible emission sources (industrial and vehicular sources). It was carried out a health risk assessment, considering both, carcinogenic and non-carcinogenic (respiratory and cardiovascular diseases) related to BTEX inhalation founding that population in the study site could develop cancer in the lifetime by benzene inhalation.

Hydrocarbons, Chromatography, Carcinogenic, Aromatic, Benzene

Resumen

Se determinó la variación diurna de hidrocarburos aromáticos (BTEX: benceno, tolueno, etilbenceno y p-xileno) en aire ambiente de un sitio urbano ubicado en Monterrey, Nuevo León durante Nortes 2020. Las muestras fueron colectadas usando muestreo activo en tubos absorbentes empacados con carbón activado usando una bomba de vacío a flujo controlado de 200 ml/min durante 1.5 horas, considerando 3 periodos de muestreo: mañana (07:00 a 08:30 h), medido día (14:00 a 15:30 h) y tarde (17:30 a 19:00 h). Las muestras fueron desorbidas con disulfuro de carbono y los extractos fueron analizados por cromatografía de gases con detección de ionización de flama. Etilbenceno y p-xileno fueron los BTEX dominantes (concentraciones promedio: 18.581 μg/m^3 y 18.039 μg/m^3, respectivamente). Los valores promedio para benceno y tolueno fueron 15.137 μg/m^3 y 15.503 μg/m^3, respectivamente. Todos los BTEX mostraron un patrón diurno con mayores valores durante el mediodía y por la tarde. A partir de un análisis meteorológico (rosas de viento) y un análisis quimiométrico (análisis de componentes principales) se identificaron las relaciones entre las variables medidas y las posibles fuentes de emisión (fuentes industriales y vehiculares). Se llevó a cabo un análisis de riesgo a la salud por inhalación de BTEX considerando tanto riesgo carcinogénico como no carcinogénico (enfermedades cardiovasculares y respiratorias), encontrándose que la población en el sitio de estudio podría desarrollar cáncer en el tiempo de vida por inhalación de benceno a los niveles observados.

Hidrocarburos, Cromatografía, Cancerígenos, Aromáticos, Benceno

6.1 Introduction

The deterioration of air quality either by anthropogenic or natural causes, can generate negative effects on human health and ecosystems (Torres *et al*., apud Valls, 2017). Atmospheric pollution has become an issue of interest for the scientific community and population in general since that in different studies has been demonstrated that a degraded air quality is related to diverse health conditions and diseases of the cardiovascular and respiratory system, even with different kinds of cancer (Instituto Nacional de Ecología y Cambio Climático, 2020). On the other hand, several studies affirm that atmospheric pollution around the world is associated to the global warming process and its respective consequences (Zhang et al., 2012). Some factors as use of fossil fuels, operation of coal-fired power plants, the increased dependency of motor vehicles for private transport, inefficient use of energy in buildings and the use of biomass burning to cook food and for space heating, produce the called Volatile Organic Compounds (VOC's) (World Health Organization-WHO, 2014). Within this group of compounds exists a sub-group named as BTEX, that includes to benzene and its alkyl-derivatives: benzene, toluene, ethylbenzene and xylenes. These compounds can cause both carcinogenic and non-carcinogenic (cardiovascular and respiratory diseases) and they are tropospheric ozone precursors (Marć *et al*., 2014).

Lan and Binh (2012 apud IARC, 2017) indicate that benzene is highly toxic, inducer of leukemia in humans, and it has been identified as carcinogenic in humans for the International Agency for Research on Cancer. For this reason, WHO and EPA do not recommend a safe level of exposure for this compound. The rest of BTEX have adverse effects on human health and are considered as toxics of the air. For this reason, in order to evaluate air quality in given location it is important to determine the levels of concentration of these compounds in ambient air. Many cities around the world commonly monitor the levels of BTEX in ambient air, but in Mexico, even when the risks and consequences of the inhalation of these compounds are well known, neither there is an air quality standard that regulates the maximum levels in ambient air nor a continuous monitoring is carried out in the air quality stations belonging to the Mexican air quality network, excepting in Mexico City.

The general objective of this study was to evaluate the atmospheric levels of aromatic hidrocarbons (BTEX: benzene, toluene, ethylbenzene and p-xylene), their origin and their relationship with criteria pollutants, as well as their impact on health in an urban site located within the Metropolitan Area of Monterrey during the Norths season 2020. The atmospheric concentrations of BTEX were determined by gas-chromatography with ionization flame detection. The influence of the winds at the local level on the concentrations of the pollutants measured was analyzed by means of an analysis of wind roses. The probable sources of the measured pollutants were inferred from the results of the meteorological and statistical analysis (Pearson's correlation matrix and Principal Component Analysis). Finally, the health risk of BTEX was evaluated considering carcinogenic and non-carcinogenic risk (potential of development of cardiovascular and respiratory diseases).

This chapter is structured as follows: The first section provides the Introduction to the research work, Background Section (Section 6.2) gives information on the study of BTEX atmospheric registered by other researchers around the world. In Section 6.3, a background of BTEX measurements is provided, including the results of BTEX measurements in Mexico and other sites around the world, as well as the results of emissions inventory and the main sources of BTEX in the study area. Section 6.4 provides the study methodology, considering both the collection and analysis methods for the determination of BTEX by Gas Chromatography – Ionization flame Detection. A description of the method used for the meteorological analysis is also provided, which made it possible to determine the influence of local winds on the levels of the measured BTEX, as well as the identification of possible sources contributing to the levels of these pollutants. This section also provides descriptive information on the statistical tools and analysis applied to the data to determine the relationships between the measured air pollutants and the meteorological variables recorded (bi-varied and multivariate analysis: principal component analysis).

This section describes the method used for the evaluation of health risk considering both the cancer risk coefficient in the life time and the non-cancer risk coefficient (risk of contracting diseases other than cancer: cardiovascular and respiratory diseases) due to inhalation of BTEX. Section 4 shows the results of the study, the descriptive statistics of the BTEX concentrations and their diurnal variation, and the possible sources contributing to the levels of the pollutants measured and its location, based on statistical analysis and meteorological analysis. An analysis of relations between the measured BTEX is provided in order to know the relative contribution of sources to the BTEX levels and the grade of processing of air masses (photochemical age of the air masses), then benzene/toluene and ethylbenzene/p-xylene were determined. This section also shows the results of the health risk assessment for inhalation of these pollutants. Finally, section 6.6 provides the conclusions of the study, as well as the recommendations for future work.

6.2 Background

In recent decades, we are facing an ever-increasing energy consumption in the world due to the increase in population and the consumption of fossil fuels, nevertheless, the promotion of industries and the improvement of social welfare. This has resulted in a degradation of air quality that can be a risk to the health of the population due to the concentrations of toxic substances in the air, such as BTEX.

Some studies have been carried out around the world and in Mexico in order to know the behavior, distribution and characteristics of these compounds in ambient air. Rad and collaborators (2014) measured atmospheric BTEX by active sampling at 12 sampling points in Ahvaz, the capital city of Khuzestan province, from July to September 2012 and January to March 2013. BTEX were analyzed by chemical desorption followed by chromatography gas/flame ionization detector (GC-FID). The mean concentrations of benzene, toluene, ethylbenzene, xylenes, and BTEX were 1.78, 5.19, 0.51, 1.13, and 8.61 $\mu g \cdot m^{-3}$, respectively, and it was found that they were highly correlated. They found a clear seasonal and spatial variability in the atmospheric concentrations of BTEX at the sampling sites, showing great differences between high-traffic and residential areas and also pointed to traffic as the main source of emission of these compounds. The lowest levels of BTEX occurred during the summer due to increased solar radiation and photochemical reactions. However, the average concentrations of benzene did not exceed the European limits in any of the monitored points. Cai and collaborators (2022) studied BTEX levels in a peri-urban area in France during COVID pandemic, collecting and analyzing air samples using a fully automated online gas chromatography system (GC-FID, AirmoVOC C6–C16 Chromatotec ®, Val-deVirvée, France) at an air quality monitoring station located in the suburbs of Orleans, France. The mean concentrations of BTEX (benzene, toluene, ethylbenzene, and xylenes) before, during, and after confinement were 402 ± 143, 800 ± 378, and 851 ± 445 pptv, respectively. Their results suggested that although anomalous local anthropogenic activity can cause significant changes in BTEX concentrations, contamination levels in Orleans are primarily dependent on meteorological conditions, specifically whether the winds are coming from the Paris region. The variation in mean BTEX concentration suggested that, in addition to strength source, seasonal and diurnal variations in atmospheric BTEX in peri-urban areas are also highly dependent on meteorological conditions and photochemical activity.

In Mexico, some studies have also been carried out in order to know the levels of BTEX in the low atmosphere. Rodríguez et al. (2018) studied diurnal variation of BTEX in Tijuana, Baja California, Mexico collecting samples at intervals of 1.5 hours in different sampling periods: 7:30-9:00 a.m., 12:00-1:30 p.m., 3:00-4:30 p.m., and 6:00-7:30 p.m. and later, analyzing them by means of gas chromatography with a flame ionization detector. The highest concentrations of BTEX occurred during the morning (7:30-9:00 a.m.) and night (6:00-7:30 p.m.) periods. The average concentrations (in $\mu g\ m^{-3}$) of BTEX were 32.40, 13.28, 17.16, and 7.02, for benzene, p-xylene, toluene, and ethylbenzene, respectively. These results indicate that there should be changes in environmental policies to improve air quality in this region. The relative abundance of BTEX had the following order: benzene (32.398 $\mu g\ m^{-3}$) > p-xylene (17,155 $\mu g\ m^{-3}$) > toluene (13,277 $\mu g\ m^{-3}$) > ethylbenzene (7.023 $\mu g\ m^{-3}$). Pearson's correlation analysis and Principal Component Analysis confirmed that vehicular traffic was the main source of benzene, toluene, and p-xylene emissions, and that toluene and p-xylene may have contributed to the formation of tropospheric ozone through photochemical reactions. Ethylbenzene did not correlate with the rest of the pollutants measured, indicating that its origin probably came from a different source than the rest. Estévez et al. (2015) found a relative abundance of the BTEX in an industrial site in Orizaba Veracruz, Mexico that exhibited the following order: Benzene > Toluene> Xylenes > Ethylbenzene. The average concentrations were: 74.51 $\mu g\ m^{-3}$ for Benzene, 5.33 $\mu g\ m^{-3}$ for Toluene, 2.26 $\mu g\ m^{-3}$ for Ethylbenzene, and 3.35 $\mu g\ m^{-3}$ for p-Xylene. BTEX levels were strongly influenced by winds coming from the S and SSE where an important road, the Veracruz-Mexico highway, is located, indicating that these compounds were mainly originating from vehicular sources. The ratios T/B, X/Ebz and PCA analysis showed that B was strongly influenced by fresh vehicle emissions. The results found for B are greater than those previously observed in Europe and the United States, and the lifetime risk of cancer due to exposure to B in ambient air exceeded the acceptable levels reported by the USEPA.

Although some studies have been carried out in Mexico (Cerón *et al*., 2021; Cerón *et al*., 2015; Cerón *et al*., 2013), they are not enough, and the distribution of these compounds is currently unknown in big cities of Mexico. Thus, the Metropolitan Area of Monterrey in Nuevo Leon State, is one of the biggest population centers in the country. This Metropoli is constituted by 12 municipalities (Guadalupe, Apodaca, San Nicolás de los Garza, General Escobedo, Santa Catarina, Benito Juárez, García, San Pedro Garza García, Cadereyta Jiménez, Santiago, Salinas Victoria, El Carmen) and Monterrey city, according to the National Institute of Statistics and Geography (INEGI) is the second most populous metropolitan area in Mexico with 5,341,171 inhabitants and the second with the largest territorial extension (7657 km^2), being the 84th largest metropolitan area in the world.

According to the INEM (Criteria Pollutant Emissions Inventory) for the Metropolitan Area of Monterrey 2016, VOC emissions for these municipalities are largely due to the use and consumption of products containing volatile organic compounds. These emissions are mainly due to work in mining, the construction industry, based on electricity consumption, transportation, fossil fuel industries, industrial processes, waste management, agriculture, treatment of hazardous waste, and other anthropogenic factors. Table 6.1 shows the results for the emissions inventory 2016 for VOC's in Nuevo Leon State.

Table 6.1 Results for the emissions inventory 2016 for VOC's in Nuevo Leon State

Source distribution	Municipalities	COV's (tons/year)
Area Sources	Sabinas Hidalgo, Salinas Victoria, General Zuazua, General Zuazua, Apodaca, García, Santa Catarina, Monterrey, San Nicolás de los Garza, Pesquería, Cadereyta Jiménez, Santiago, Montemorelos, Allende, Linares, Galeana, Doctor Arroyo.	> 6,750.00 - 12,197.72
Fixed sources	Salinas Victoria, Ciénega de Flores, El Carmen, Abasolo, Apodaca, García, General Escobedo, Monterrey, Cadereyta Jiménez, Santa Catarina, Juárez, Montemorelos, Linares, Agualeguas.	> 1,155.30 - 2,060.77
Mobile Sources	Sabinas Hidalgo, Apodaca, García, San Nicolás de los Garza, Monterrey, Cadereyta Jiménez, Santa Catarina, Montemorelos, Allende, Linares, Santiago	> 3,098.94 - 7,047.72
Natural Sources	Vallecillo, Sabinas Hidalgo, Villaldama, Bustamante, General Treviño, Cerralvo, Melchor Ocampo, los Herreras, General Bravo, Doctor Coss, Los Ramones, Cadereyta Jiménez, Santa Catarina, Juárez, Montemorelos, Linares, Galeana, Aramberri, Doctor Arroyo, Mier y Noriega, Hualahuises, General Terán, El Carmen, Juárez.	> 2,088.05 - 4,881.98

Source: Inventario Nacional de Emisiones de Contaminantes Criterio 2016, INEM- SIINEM

In the 2016 emissions inventory, the municipality of Monterrey, where Obispado is located, stands out with the main contribution to VOC (Volatile Organic Compound) emissions, being the municipality with higher emissions, this is due to the contribution of area sources such as commercial and light industrial sources, poor waste management and the use of solvents. But above all, the main contaminant for the distribution of VOCs in the metropolitan area is the use of petroleum derivatives for transportation. This study is focused on determine the levels of BTEX in ambient air in Obispado, an urban site located in Monterrey municipality, during the Norths season in 2020; and evaluate the potential of health risk by inhalation of these compounds in the population of this study area.

6.3 Methodology

6.3.1 Study Area Description

Figure 6.1 shows the location of the Metropolitan Area of Monterrey. Samples were collected in Obispado site, within an air quality monitoring station of the government of Nuevo Leon State. It is located within the coordinates 25°40′24″N 100°20′32″W / 25.67347222, -100.34217778. It is located at the tip of the Loma de la Chepe Vera, so called because the lands of José Vera were in its surroundings. This hill is currently known as the Cerro del Obispado and the palace is also known as the Palacio del Obispado (Figure 6.2).

Figure 6.1 Location of the metropolitan area of Monterrey

Source: INEGI (2020)

Figure 6.2 Location of Obispado sampling site

Source: Google Earth

6.3.2 Sampling Method

Ambient air samples were collected using Anasorb CSC 226-01 brand glass tubes, 70 mm long by 4.0 mm internal diameter and 6 mm external diameter, divided into two sections: 50 mg and 100 mg of activated carbon in each (Figure 6.3a), connected to a GAST-type vacuum pump operating at a controlled flow of 200 ml/min according to the Method MTA/MA-030/A92 (INSHT, 1992) (Figure 6.3.b).

Figure 6.3 Devices and equipment used for the samples collection

a) Anasorb CSC 226-01 brand activated carbon glasses

b) GAST type vacuum pump

Source: Own elaboration from pictures taken in the laboratory

Three periods of sampling were considered: morning (07:00 - 8:30 h), noon (14:00 - 15:30 h) and afternoon (17:30 - 19:00 h), with 1.5 hours of duration, from October 20 to November 18, 2020. A total of 24 samples were collected in Obispado site. At the end of each sampling, each tube was covered with plastic caps and stored in special bags to protect against of sunlight to avoid possible photochemical reactions and will later be kept refrigerated to preserve them until further analysis.

6.3.3 Analytical Method

For the determination of the BTEX, the desorption of each of the samples was carried out with 1 ml of carbon disulfide (CS_2) in amber vials of 2 ml provided with a screw cap with a rubber septa. One end of the glass tube was broken and each section of activated carbon was poured into a previously labeled vial (two vials per tube), then 1 ml of carbon disulfide (CS_2) was added. Then the vial was shaken for a period of approximately 5 minutes to ensure that the desorption was completed, and it was refrigerated for 24 hours until its analysis. Once the desorption was done, the chromatographic analysis was carried out using a TRACE GC Ultra Gas Chromatographs Thermoscientific brand equipment in splitless mode with flame ionization detector using extra dry air and ultra-high purity nitrogen as carrier gas (Figure 6.4). The capillary column used was 30 m x 0.32 mm ID, methyl fused silica type with a film thickness of 0.5 µm, the operator software used was Trace ChemStation. 1 µL of the sample was taken from the vial using a chromatographic syringe (Hamilton 10 µL, and then it was injected into the chromatography equipment previously conditioned for analysis. The chromatographic analysis was based on the MTA/MA-030/A92 method (INSHT, 1992).

Figure 6.4 TRACE GC Ultra gas chromatograph

Source: Own elaboration from pictures taken in the laboratory

For this procedure, the equipment software (Trace ChemStation) was used, which contains files of the chromatograms generated from each injection made of the calibration curves made before the analysis of the samples for each compound to be quantified, in addition to providing the times of exact retention where each compound is present.bTo perform the calculation of concentrations in ambient air using the following equations taken from MTA/MA-030/A92 Method:

$$ms = \frac{Cf+Cp-Cb}{ED-Vd} \quad (1)$$

Where:

ms = is the total amount of analyte present in the sample, in mg.

Cf = is the analyte concentration in mg/mL in the front section of the sampling tube.

Cp = is the analyte concentration in mg/mL in the back section of the sampling tube.

Cb = is the analyte concentration in mg/mL in the two blank sections.

ED = is the desorption efficiency (depends on each compound: Table 6.2).

Vd = is the volume of desorbent solution in mL.

Table 6.2 Desorption Efficiency Values (ED)

Benzene	Toluene	Ethylbenzene	pXylene
1.008	0.989	1.00	0.985

Source: Own elaboration from lab essays

To calculate C_{air}, which is the concentration of the sampled air analyte in mg/m^3, ms was calculated previously, being V, the volume of sampled air equal to 0.018m^3:

$$C_{air} = \frac{m_s}{V} \quad (2)$$

C_{ppm} is the concentration in parts per million of the contaminants in ambient air, where M is the molecular weight of each compound in g/mol, P is the atmospheric pressure of the sampling site in KPa, and T is the temperature of the site at the sampling time.

$$C_{ppm} = C_{air} \times \frac{24}{M} \times \frac{101.30}{P} \times \frac{T+273.15}{293.15} \quad (3)$$

6.3.4 BTEX ratios

The ratio of the concentrations of toluene between benzene (T/B) and Xylene and Ethylbenzene (X/E) were calculated. The purpose of calculating the T/B and X/E ratios is based on identifying the probable origin of BTEX during a given period, being able to estimate whether the emissions were originated from mobile or area sources (T/B ratio) and to determine the grade of processing of air masses (fresh or aged) (X/E ratio).

The T/B ratio has been commonly used as an indicator of emissions from vehicular traffic. Benzene and toluene are constituents of gasoline and are emitted into the atmosphere from motor vehicle exhaust. The toluene content in gasoline is 3 to 4 times higher than the benzene content (Pekey and Yilma, 2011).

Values of this ratio less than 2-3 are characteristic of vehicle emissions and have been reported in this range for many urban areas around the world (Elbir *et al*., 2007; Mugica *et al*., 2003); nevertheless, values greater than 3 may indicate that BTEX levels could be associated with sources other than vehicular sources, such as industrial facilities and area sources (evaporative emissions, automotive paint shops, food cooking processes, screen printing shops), dry cleaners, among others.The X/E ratio is commonly used as an indicator of the photochemical age of air masses at a given site (Keymeulen *et al*., 2001; Lee *et al*., 2002). This ratio is related to the atmospheric lifetime of these pollutants in the air. High values of this ratio indicate old air masses, while low values of this ratio indicate that the air masses are fresh (recent emissions). Kuntasal *et al*., (2005) used a value of 3.8 for this ratio. Fresh gasoline emissions provide values between 3.8 and 4.4 for this ratio.

6.3.5 Statistical Analysis

To identify the diurnal variation and descriptive statistics of the compounds measured in the ambient air of the city of Monterey, box plots were made which showed the mean, maximum and average of concentration for each studied compound. A bi-variate analysis was carried out in order to know the Pearson correlation coefficient and the bi-variate relation between each pair of BTEX and its grade of significance. A Principal component analysis (multivariate analysis: PCA) was applied in order to determine the relation among the studied variables using the software XLSTAT for Excel (2016 version, https://www.xlstat.com/es/). From the cosines of the variables and the factor loadings, groups of related compounds are identified, and their probable origin is inferred based on the tracer compounds present in each group of compounds. The biplot of the components that have a greater contribution to the total variability of the data is plotted.

6.3.6 Meteorological Analysis

6.3.6.1 Wind Roses Analysis

Wind speed and wind direction were examined simultaneously using a wind rose analysis. These graphics show the distribution of the direction and speed of the wind in a specific place. The wind rose model for each sampling site was made with the WRPLOT (Wind Rose Plots for Meteorological Data) software, which simulates the direction and speed of the prevailing winds in the sampling period (Software developed by Lakes Environmental, available in: https://www.weblakes.com/products/wrplot/index.html).

6.3.7 Health Risk Assessment

The carcinogenic potential of benzene is widely known (Zhang et al. 2015). The European Union recommends an annual limit of 5 μg/m^3 for benzene in ambient air and the level of minimum risk of cancer by inhalation (Minimal Risk Level: MRL) of 1 in 10,000, while the USEPA establishes a value of 4.0 ppbv for this pollutant (USEPA, 2013). In this study, we used the methodology proposed by Zhang and collaborators (2015), to determine the daily exposure (E) (USEPA, 2008), the lifetime risk of cancer (ILTCR) and the potential non-cancer risk (HQ), that is, the risk of developing diseases other than cancer (respiratory and cardiovascular diseases). The daily exposure (mg/kg per day) of an individual by inhalation can be calculated as:

$$E = \frac{C \times IRa \times Da}{BW} \quad (4)$$

Where C (mg/m^3) is the average concentration of benzene, IRa is the inhalation rate of an adult (0.83 m^3/h)[1], Da is the duration of exposure of an adult (24 h/day), and Bw is the body weight of an average adult (65 kg)[1]. The lifetime cancer risk (The Lifetime Cancer Risk: LTCR) is then calculated as:

$$LTCR = E \times SF \quad (5)$$

Where SF is the risk slope factor for toxic inhalation when the carcinogenic effect of exposure is considered linear. The proposed value by the United States Environmental Protection Agency (US EPA, 2009) of SF for benzene (0.029 mg/kg per day) was considered. The non-cancer risk of BTEX will be measured as a hazard quotient (HQ):

$$HQ = \frac{C}{RfC} \quad (6)$$

Where C is the average concentration received daily and RfC is the inhalation reference concentration proposed by the United States Environmental Protection Agency (USEPA, 2005) for each pollutant (Table 6.3).

Table 6.3 Reference concentration (RfC) used for BTEX

Reference Concentration			
Benzene	**Toluene**	**Ethylbenzene**	**p-xylene**
(mg/m^3)	(mg/m^3)	(mg/m^3)	(mg/m^3)
0.03	5	1	0.1

Source: ATSDR (2007) for benzene, US EPA (2005) for toluene, ATSDR (2010) for ethylbenzene, and US EPA (2003) for p-xylene

The accepted values proposed by EPA and WHO for LTCR (cancer risk for benzene inhalation) and for HQ (risk of non-cancer) for inhalation of BTEX are 1x 10^{-6} and 1.0, respectively. If LTCR and HQ values are higher than these reference values, indicate a probable risk in the population health.

6.4 Results

6.4.1 BTEX Concentrations

The concentrations of benzene, toluene, ethylbenzene and p-xylene (BTEX) were measured at one sampling site (Obispado) during the Norths season. Table 6.4 shows the concentrations obtained during the Norths season. Ethylbenzene and p-xylene are the compounds with the highest levels with mean concentrations of 18.333 µg/m^3 and 17.747 µg/m^3, respectively. Mean values for benzene and toluene were the following: 15.927 µg/m^3 and 14.347 µg/m^3, respectively.

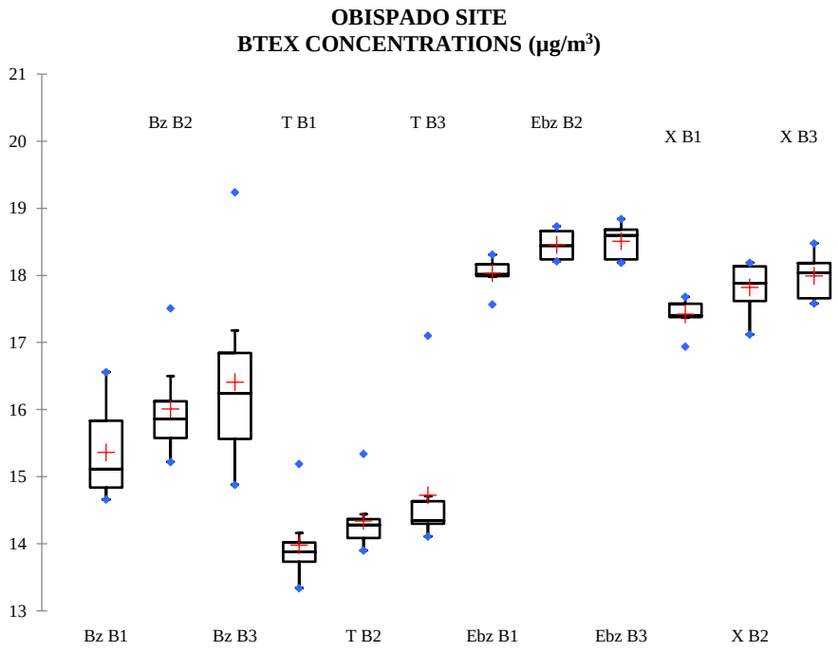
Table 6.4 Descriptive Statistics for BTEX concentrations measured in Obispado site during the Norths season. Bz: benzene; T: toluene; Ebz: ethylbenzene; X: p-xylene. B1: morning sampling period (08:00– 09:30 h); B2: midday sampling period (13:00 – 14:30 h); and B3: afternoon sampling period (17:30 – 19:00 h)

DESCRIPTIVE STATISTIC FOR BTEX CONCENTRATIONS IN OBISPADO SITE (µg/m^3)												
Parameter	**Bz B1**	**Bz B2**	**Bz B3**	**T B1**	**T B2**	**T B3**	**Ebz B1**	**Ebz B2**	**Ebz B3**	**X B1**	**X B2**	**X B3**
Minimum	14.660	15.220	14.880	13.340	13.900	14.110	17.570	18.210	18.190	16.940	17.120	17.580
Maximum	16.560	17.510	19.240	15.190	15.340	17.100	18.310	18.730	18.840	17.680	18.190	18.480
1° Quartil	14.840	15.578	15.563	13.735	14.085	14.300	17.988	18.238	18.240	17.378	17.620	17.660
Median	15.115	15.860	16.240	13.880	14.280	14.345	18.015	18.440	18.595	17.400	17.885	18.040
3° Quartil	15.833	16.125	16.843	14.018	14.365	14.635	18.168	18.660	18.683	17.578	18.133	18.185
Mean	15.363	16.010	16.410	13.980	14.338	14.723	18.034	18.456	18.509	17.423	17.824	17.995
Typical Deviation (n-1)	0.672	0.714	1.397	0.545	0.443	0.980	0.225	0.234	0.249	0.232	0.380	0.346

Source: Own elaboration from the obtained results.

Figure 6.5 shows the box plot for BTEX concentrations in Obispado site. As it can be observed, all measured BTEX showed the same diurnal pattern, showing higher mean concentration levels during the afternoon (B3 sampling period). This behavior can be explained due to the fact that during the afternoon occurs a peak on vehicular traffic originated by a higher population mobility that commuting from their workplaces to their homes, producing higher emissions of air pollutants from automobile exhaust. Ethylbenzene and p-xylene were the dominant BTEX in Obispado site.

Figure 6.5 Box plot for BTEX concentrations measured in Obispado site during the sampling period



+ are the mean values of BTEX concentrations, ♦ are the maximum and minimum values of BTEX concentrations and the edges of the box are the 1° and 3° quartiles, the box does not have a statistic mean only is represented for better visualization. Bz: benzene; T: toluene; Ebz: ethylbenzene; X: p-xylene. B1: morning sampling period (08:00– 09:30 h); B2: midday sampling period (13:00 – 14:30 h); and B3: afternoon sampling period (17:30 – 19:00 h)

Source: Own elaboration from the obtained results

A Friedman test at a significance level of $\alpha = 0.05$ was applied to the data set in order to investigate if there were significant differences among the different sampling periods along the day. The results showed that there were significant differences in BTEX concentrations among the different sampling periods, which means that the measured BTEX had a clear diurnal variation. We found that that BTEX were homogeneously distributed in the study area.

6.4.2 Meteorological parameters

Table 6.5 shows the average values for meteorological parameters, considering wind speed, wind direction, temperature, relative humidity, solar radiation and barometric pressure. It can be observed that wind blowed predominantly from ESE with an average wind speed of 11.8 m/s, showing higher values of wind speed during the midday and afternoon sampling periods.

Table 6.5 Meteorological parameters for both sampling sites. B1: morning sampling period (08:00–09:30 h); B2: midday sampling period (13:00 – 14:30 h); and B3: afternoon sampling period (17:30 – 19:00 h)

Meteorological parameters		Obispado site Wind speed m/s	Wind direction	Temperature °C	Relative Humidity %	Solar radiation W/m²	Barometric Pressure mm Hg
Sampling periods	B1	6.9	SSE	18.88	62.75	167.63	715.74
	B2	14.6	E	24.18	46.13	169.13	712.73
	B3	13.9	ESE	21.65	55.5	148.22	713.56
	Mean Value	11.8	ESE	21.57	54.79	161.66	714.01

Source: Own elaboration from the obtained results

6.4.3 Health Risk Assessment

Table 6.6 shows the average of the non-cancer risk coefficients that represent the BTEX measured in the study site for both, adult and children population. It can be seen that the non-cancer risk coefficient (HQ: Hazard Quotient) was higher for benzene, having the following behavior: benzene>p-xylene>ethylbenzene>toluene. The values found for the non-cancer risk coefficient (HQ) were below the maximum permissible limit established by the EPA and the WHO ($HQ \leq 1.0$), indicating that there is no risk of developing diseases different than cancer (respiratory and cardiovascular diseases) by inhalation of BTEX at the study site. In this study, the potential risk of non-cancer (HQ) was determined according to the methodology of Zhang (2015) and Estévez (2015).

Table 6.6 Non-cancer risk coefficients (HQ) in Obispado site during the sampling period for a) Adult population, and b) Children population

a) Non cancer risk coefficients (HQ) for Adult population	
Air Pollutant	Obispado Site
Benzene	0.536
Toluene	0.003
Ethylbenzene	0.018
p-Xylene	0.178
THQ = ΣHQ = 0.735	
b) Non cancer risk coefficients (HQ) for Children population	
Non-cancer Risk	
Air Pollutant	Obispado site
Benzene	0.5309
Toluene	0.0029
Ethylbenzene	0.0018
p-Xylene	0.1777
THQ = ΣHQ = 0.7126	

Source: Own elaboration from the obtained results

Table 6.7 shows the life-time cancer risk coefficients in children and adult population for both sampling sites due to benzene inhalation. According to WHO and EPA, the established permissible limit is (1×10^{-6}). The values obtained exceeded the maximum permissible levels almost by two orders of magnitude, therefore is a possible risk of developing cancer in the life-time due to the inhalation of benzene at the concentrations found at the study sampling site.

Table 6.7 Life-time cancer risk coefficients (LTCR) in Obispado site during the sampling period for a) Adult population, and b) Children population

a) Adult population	
Life-time Cancer Risk (LTCR)	
Air Pollutant	Obispado
Benzene	1.445×10^{-4}
b) Children population	
Life-time Cancer Risk (LTCR)	
Air Pollutant	Obispado
Benzene	2.575×10^{-4}

Source: Own elaboration from the obtained results

6.4.4 BTEX Ratios

Analysis of BTEX ratios has been used by various authors to estimate the relative contribution of pollution sources and the photochemical processing of air masses (photochemical age of air masses) containing BTEX, and it is based on the assumption that BTEX have different rates of degradation in air (Guo, *et al*., 2007). Figure 1.6 shows the box plots and descriptive statistic for the toluene-benzene (T/B) and the xylene-ethylbenzene (X/E) ratios for Obispado site, during each sampling period (B1, B2 and B3).

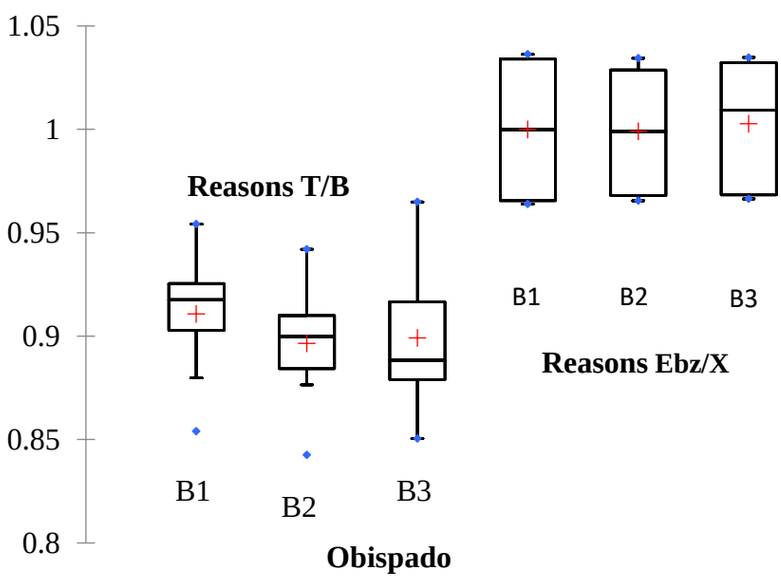
The T/B concentration ratio has been commonly used as an indicator of emissions from vehicular traffic. Benzene and toluene are constituents of gasoline and are emitted into the atmosphere from motor vehicle exhaust. The toluene content in gasoline is 3-4 times higher than the benzene content (Pekey and Yilma, 2011). Values of this T/B ratio less than 2-3 are characteristic of vehicle emissions and have been reported in this range for many urban areas around the world (Elbir *et al*., 2007; Mugica *et al*., 2002); nevertheless, while values greater than 3 may indicate that BTEX levels could be associated with sources other beyond vehicular sources such as industrial facilities and area sources (evaporative emissions, automotive paint shops, food cooking processes, screen printing shops, dry cleaners, among many others). The T/B ratio values found in this study are less than 2 and are within the typical range reported for urban sites with a strong influence of vehicle emissions. T/B ratios found in Obispado were higher during the morning sampling period (B1), when a peak of vehicular traffic occurs due to the mobility of population to their work centres and school.

The concentration ratio of p-Xylene to Ethylbenzene (X/Ebz ratio) is commonly used as an indicator of the photochemical age of air masses at a given site. A ratio of 3.6:1 (X/Ebz) has been established as a typical value of this ratio for these species (Keymeulen *et al*. 2001; Lee *et al*. 2002). This ratio is related to the atmospheric lifetime of these pollutants in the air: high values of this ratio indicate aged air masses, and low values of this ratio indicate fresh air masses (recent local type emissions). Kuntasal *et al*. (2005) used a value of 3.8 for this ratio. Fresh gasoline emissions provide values between 3.8 and 4.4 for this ratio. In the present study, the entire period registered low values of this ratio, indicating that most of the air masses in the study sites corresponded to "fresh or local emissions". The values found for this ratio (X/E) are within the typical range reported for fresh emissions with little or almost no photochemical processing, that is, emissions from primary and local sources. It can be observed in Figure 1.6 that the ratios of X/E in Obispado remained constant throughout the day, which indicates that the influence of vehicular traffic on this site is also a constant. There were no significant differences in the BTEX ratios in both study sites, which may indicate that the sources of these compounds (mainly vehicle-type emissions) are homogeneously distributed in the study area.

6.4.5 Influence of meteorology on BTEX concentrations

The wind flow pattern (wind direction and wind speed) influences the removal, accumulation, transport, dispersion and transformation of pollutants in the atmosphere. The winds are related to the horizontal dynamics of the atmosphere that describes both the direction from which the air masses come and the speed and turbulence with which these air masses move containing the pollutants. Based on prevailing winds, concentration roses were constructed to study the effect of wind direction on BTEX levels measured at both study sites, considering both diurnal variation (B1: morning sampling period; B2: midday sampling period; and B3: afternoon sampling period). Figures 6.7 shows concentration-wind roses for measured BTEX in the study site.

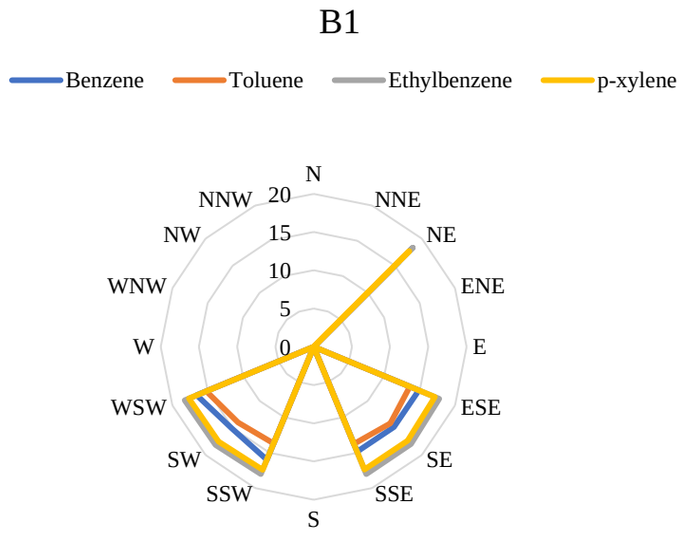
Figure 6.6 Box plot for BTEX ratios measured in Obispado site during the sampling period



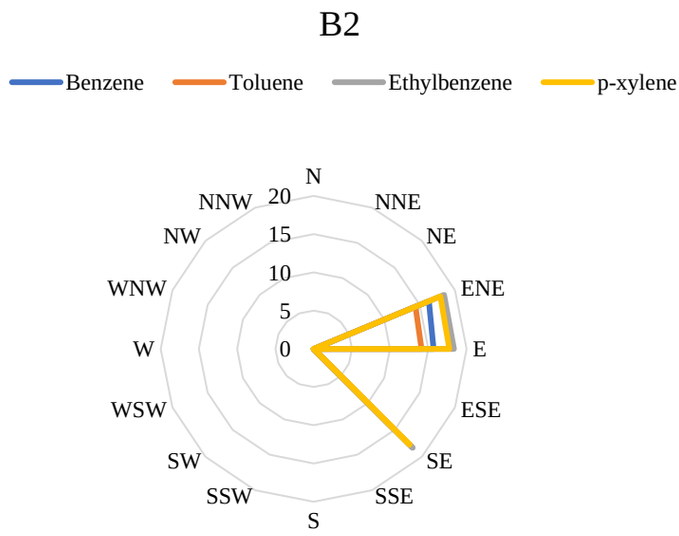
Source: Own elaboration from the obtained results

Figure 6.7 Concentration-wind roses for measured BTEX in Obispado during: a) morning sampling period (B1), b) midday sampling period (B2) and c) afternoon sampling period (B3)

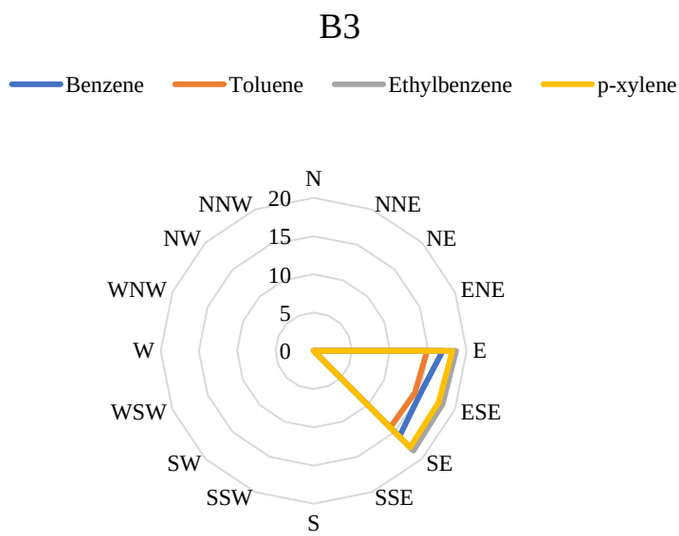
A)



B)



c)



Source: Own elaboration from the obtained results

As it can be observed in Figure 6.7, BTEX concentrations in Obispado site were higher when winds blowed from WSW, SSW, SW, SSE, ESE and NE during the B1 sampling period. During midday (B2 sampling period), BTEX concentrations were higher when winds blowed from ENE, E and SE. During the afternoon (B3 sampling period) BTEX concentrations were higher with winds blowing from E, ESE and SE. The municipalities of Juárez and Apodaca are located in these directions, as well as numerous avenues with high vehicular traffic with emissions that could have contributed to the BTEX levels measured at the study site.

6.4.6 Bi-variate and multivariate analysis

Bivariate (Pearson) and multivariate (Principal Component Analysis: PCA) statistical analysis are an useful tool to reveal more detailed information about the behavior of the pollutants studied (Polanco, 2016). Tables 6.8-6.10 show the results of the bi-variate analysis for BTEX and air criteria pollutants concentrations (CO, SO_2, O_3, NO_2, PM_{10} and $PM_{2.5}$) in Obsipado. Values in bold are different from 0 with a level of significance α=0.05. The results of the bivariate analysis for Obispado during the morning sampling (B1) are shown in Table 6.8. Benzene presented positive correlation coefficients close to linearity with ethylbenzene (0.898) and with p-xylene (0.892). Ethylbenzene presented a significant linear positive correlation with P-xylene (0.999), indicating that these compounds could have originated from common sources. Ethylbenzene and p-xylene presented a linear and significant negative correlation with $PM_{2.5}$, indicating that these hydrocarbons could have participated in photochemical reactions of secondary organic aerosol formation (SOA). Some criteria pollutants presented positive correlations close to linearity between them, such is the case of CO with $PM_{2.5}$ (0.885), with O_3 (0.717), and with SO_2 (0.798), indicating that these pollutants could have originated from emissions of vehicular sources, since CO is a tracer of combustion emissions in motor vehicles.

The correlation coefficient between CO and O_3 can be explained from the following atmospheric reactions:

- In the presence of solar radiation, CO reacts with OH to form the hydroperoxyl radical (HO_2), which leads to the formation of surface O_3 in the presence of NO_2 (Zhong *et al*., 2020).

(R1) $CO + OH + O_2 \rightarrow CO_2 + HO_2$ (7)

This radical hydroperoxyl (HO_2) reacts with NO in order to produce NO_2

(R2) $HO_2 + NO \rightarrow NO_2 + OH$ (8)

When solar radiation is intense, NO_2 undergoes photolysis in order to produce NO and atomic oxygen and this reacts with O_2 in order to produce O_3 (Ídem).

(R3) $NO_2 + h\nu\ (\lambda < 420\ nm) \rightarrow NO + O$ (9)

(R4) $O + O_2 + M \rightarrow O_3 + M$ (10)

Table 6.8 Pearson correlation coefficients for the morning sampling period (B1) in Obispado

Variables	CO	NO_2	O_3	PM_{10}	$PM_{2.5}$	SO_2	Benzene	Toluene	Ethyl-benzene	p-xylene
CO	**1**	0.646	0.717	0.079	0.885	0.798	-0.910	-0.142	-0.723	-0.732
NO_2	0.646	**1**	0.903	0.074	0.218	0.695	-0.340	0.605	0.058	0.046
O_3	0.717	0.903	**1**	-0.317	0.380	0.489	-0.365	0.275	-0.098	-0.127
PM_{10}	0.079	0.074	-0.317	**1**	0.023	0.623	-0.317	0.395	-0.100	-0.052
$PM_{2.5}$	0.885	0.218	0.380	0.023	**1**	0.579	-0.948	-0.563	**-0.957**	**-0.964**
SO_2	0.798	0.695	0.489	0.623	0.579	**1**	-0.792	0.311	-0.451	-0.433
Benzene	-0.910	-0.340	-0.365	-0.317	-0.948	-0.792	**1**	0.330	0.898	0.892
Toluene	-0.142	0.605	0.275	0.395	-0.563	0.311	0.330	**1**	0.707	0.721
Ethylbenzene	-0.723	0.058	-0.098	-0.100	**-0.957**	-0.451	0.898	0.707	**1**	**0.999**
p-xylene	-0.732	0.046	-0.127	-0.052	**-0.964**	-0.433	0.892	0.721	**0.999**	**1**

Source: Own elaboration from the obtained results

During the midday sampling period (B2) (Table 6.9) significant linear correlations could be observed between CO and $PM_{2.5}$ (0.957), NO_2 and PM_{10} (0.962) and NO_2- SO_2 (0.973), indicating that these air pollutants could be originated from emissions of vehicular sources since CO is a tracer of emissions related to vehicular traffic and from high temperature combustion sources. PM_{10} and $PM_{2.5}$ showed a significant linear positive correlation (0.944), indicating that particulate matter had their origin in common sources during this study. Negative linear correlations of CO with ethylbenzene (-0.963) and p-xylene (-0.998) can be explained from the following atmospheric reactions that carry out during the midday, when solar radiation is intense and that cause the production of highly reactive OH radicals which is the main trajectory of depletion of BTEX in air:

- In the presence of solar radiation, CO reacts with OH to produce HO_2 radical, conducting to the formation of O_3 in the presence of NO_2 (Id. Ibid):

(R1) $CO + OH + O_2 \rightarrow CO_2 + HO_2$ (11)

This HO_2 radical then reacts with NO in order to produce NO_2

(R2) $HO_2 + NO \rightarrow NO_2 + OH$ (12)

Negative correlations between ethylbenzene and p-xylene with NO_2 during the midday evidence photochemical process of depletion of BTEX in ambient air in high solar radiation conditions. SO_2 showed linear positive correlations with PM_{10} and $PM_{2.5}$ (0.925 and 0.918, respectively), indicating that these particles could be originated from combustion processes that use high sulfur fuels as diesel. Toluene and Ozone showed a significant positive linear correlation (0.837), indicating that these compounds could be originated from photochemical reactions.

Table 6.9 Pearson correlation coefficients for the midday sampling period (B2) in Obispado

Variables	CO	NO_2	O_3	PM_{10}	$PM_{2.5}$	SO_2	Benzene	Toluene	Ethyl-benzene	p-xylene
CO	**1**	0.859	0.013	0.924	**0.957**	0.905	-0.151	-0.405	**-0.963**	**-0.998**
NO_2	0.859	**1**	-0.081	**0.962**	0.938	**0.973**	-0.635	-0.246	-0.722	-0.828
O_3	0.013	-0.081	**1**	-0.239	-0.207	0.128	0.108	0.837	-0.220	-0.062
PM_{10}	0.924	**0.962**	-0.239	**1**	**0.994**	0.925	-0.451	-0.483	-0.788	-0.895
$PM_{2.5}$	**0.957**	0.938	-0.207	**0.994**	**1**	0.918	-0.355	-0.504	-0.844	-0.935
SO_2	0.905	**0.973**	0.128	0.925	0.918	**1**	-0.525	-0.123	-0.826	-0.889
Benzene	-0.151	-0.635	0.108	-0.451	-0.355	-0.525	**1**	-0.196	-0.046	0.097
Toluene	-0.405	-0.246	0.837	-0.483	-0.504	-0.123	-0.196	**1**	0.276	0.380
Ethylbenzene	**-0.963**	-0.722	-0.220	-0.788	-0.844	-0.826	-0.046	0.276	**1**	**0.979**
p-xylene	**-0.998**	-0.828	-0.062	-0.895	-0.935	-0.889	0.097	0.380	**0.979**	**1**

Source: Own elaboration from the obtained results

Table 6.9 shows the bivariate statistics during the afternoon sampling (B3). Significant positive linear correlations can be observed between NO_2 and $PM_{2.5}$ (0.998) and between benzene and toluene (0.976), indicating that these compounds could have originated from common sources. Positive linear correlations can be observed that, although not significant, suggest that these compounds could have originated from common sources: CO-PM_{10} (0.860), CO-SO_2 (0.939), NO_2-PM_{10} (0.806) and SO_2-PM_{10} (0.840), indicating that the levels of these pollutants could be influenced by vehicle emissions derived from intense vehicular traffic on avenues surrounding the sampling site. Benzene-xylene (0.936), ethylbenzene-xylene (0.807) and toluene-xylene (0.837) presented correlations close to linearity, although not significant, indicating that these hydrocarbons could have originated at least partially from common sources. The negative correlations between CO with benzene, ethylbenzene and xylene indicate that in presence of high levels of CO, photochemical reactions of OH radical production occur, causing the depletion of BTEX in the study site.

Table 6.10 Pearson correlation coefficients for the afternoon sampling period (B3) in Obispado

Variables	CO	NO_2	O_3	PM_{10}	$PM_{2.5}$	SO_2	Benzene	Toluene	Ethyl-benzene	p-xylene
CO	**1**	0.548	0.713	0.860	0.596	0.939	-0.031	0.169	-0.812	-0.350
NO_2	0.548	**1**	0.919	0.806	**0.998**	0.380	-0.066	0.118	-0.682	-0.356
O_3	0.713	0.919	**1**	**0.962**	0.924	0.660	-0.362	-0.160	-0.913	-0.652
PM_{10}	0.860	0.806	**0.962**	**1**	0.826	0.840	-0.366	-0.154	**-0.973**	-0.669
$PM_{2.5}$	0.596	**0.998**	0.924	0.826	**1**	0.423	-0.040	0.150	-0.698	-0.342
SO_2	0.939	0.380	0.660	0.840	0.423	**1**	-0.324	-0.146	-0.872	-0.576
Benzene	-0.031	-0.066	-0.362	-0.366	-0.040	-0.324	**1**	**0.976**	0.551	0.936
Toluene	0.169	0.118	-0.160	-0.154	0.150	-0.146	**0.976**	**1**	0.357	0.837
Ethylbenzene	-0.812	-0.682	-0.913	**-0.973**	-0.698	-0.872	0.551	0.357	**1**	0.807
p-xylene	-0.350	-0.356	-0.652	-0.669	-0.342	-0.576	0.936	0.837	0.807	**1**

Source: Own elaboration from the obtained results

Figures 6.8-6.10 show the result of the multivariate analysis (Principal Component Analysis) among the measured variables (BTEX and air criteria pollutants). For the morning sampling period (B1), two principal components were required to explain 92.79% of the total variability of the data. The attached Table in Figure 1.8 shows the loadings of the factors representing the groups of variables that were related to each other. Group F1 included CO, $PM_{2.5}$, SO_2, Benzene, Ethylbenzene and p-xylene, indicating that the compounds in this group are related to emissions from motor vehicle exhaust. F2 group included Ozone, NO_2 and Toluene, indicating that these compounds had a high influence on photochemical activity. Finally, F3 group included only PM_{10}, indicating that this pollutant could have a different origin, probably re-suspension of dust from the quarries and companies dedicated to the manufacture of ceramic and glass products.

The bi-plot attached in Figure 6.8 also shows the relationships between the measured variables, and it can be observed that benzene, ethylbenzene and p-xylene are in the same quadrant, indicating that these compounds could have originated from common sources. In the quadrant located on the left side of the bi-plot, it can observed that NO_2 and Ozone are very close to each other, so it can be inferred that these compounds were influenced by photochemical activity. SO_2, CO, and $PM_{2.5}$ showed proximity to each other as well as vectors with the same intensity, indicating that these compounds were influenced by vehicular combustion sources.

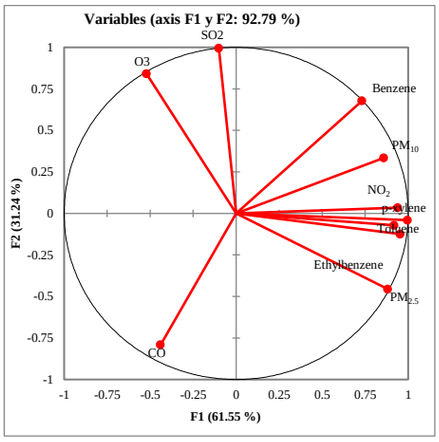
Figure 6.9 shows the results of the multivariate analysis with the loadings of the factors found. Two principal components were required to explain 86.48 % of the variability in the data. Group F1 showed higher factor loadings for CO, NO_2, PM_{10}, $PM_{2.5}$, SO_2, ethylbenzene and p-xylene, indicating that concentrations of these compounds were influenced by vehicle emissions. F2 group presented higher factor loadings for ozone and toluene, indicating that these compounds were influenced by photochemical activity. Finally, F3 group included only benzene, indicating that this hydrocarbon could have had a different source than the rest of the BTEX.

Figure 6.10 shows the results of the multivariate analysis for the afternoon sampling period in Obispado. Two principal components (F1 and F2) were required to explain 83.21% of the total variability of the data. F1 group showed higher values of factor loadings for CO, NO_2, O_3, PM_{10}, $PM_{2.5}$, ethylbenzene and p-xylene, indicating that all these compounds were influenced by vehicle emissions and photochemical activity, while F2 group included with higher factor loadings to benzene and toluene, likely originating from area sources such as solvent use, paints and coatings, biomass burning, and petrochemical industry.

Figure 6.8 Principal Component Analysis for the measured variables during the morning sampling period (B1) in Obispado

	F1	F2	F3
CO	0.193	**0.626**	0.181
NO_2	**0.884**	0.001	0.115
O_3	0.271	**0.706**	0.023
PM_{10}	**0.738**	0.112	0.150
$PM_{2.5}$	**0.777**	0.208	0.015
SO_2	0.010	**0.989**	0.000
Benzene	**0.536**	0.459	0.005
Toluene	**0.993**	0.002	0.005
Ethylbenzene	**0.911**	0.015	0.074
p-xylene	**0.843**	0.005	0.152

The values in bold correspond for each variable to the factor for which the squared cosine is the highest

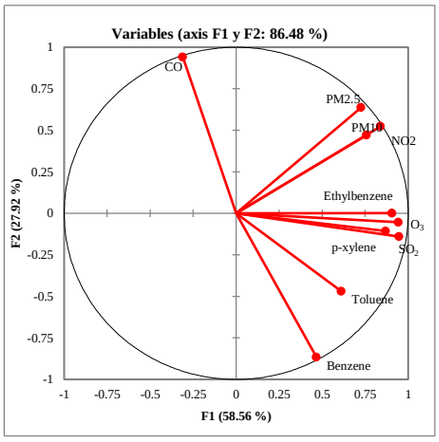


Source: Own elaboration from the obtained results

Figure 6.9 Principal Component Analysis for the measured variables during the midday sampling period (B2) in Obispado

	F1	F2	F3
CO	0.096	**0.887**	0.017
NO_2	**0.574**	0.221	0.205
O_3	**0.889**	0.003	0.108
PM_{10}	**0.705**	0.274	0.021
$PM_{2.5}$	**0.528**	0.405	0.067
SO_2	**0.897**	0.020	0.083
Benzene	0.218	**0.751**	0.031
Toluene	0.373	0.220	**0.407**
Ethylbenzene	**0.821**	0.000	0.179
p-xylene	**0.755**	0.011	0.234

The values in bold correspond for each variable to the factor for which the squared cosine is the highest.

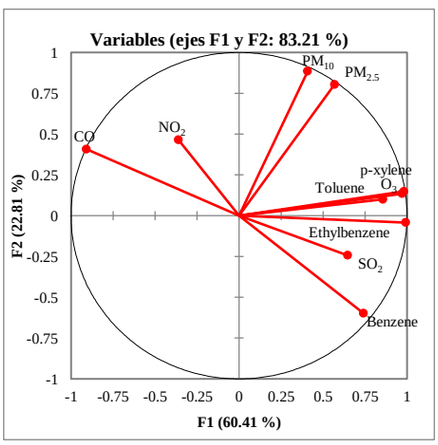


Source: Own elaboration from the obtained results

Figure 6.10 Principal Component Analysis for the measured variables during the afternoon sampling period (B3) in Obispado

	F1	F2	F3
CO	**0.826**	0.166	0.008
NO_2	0.130	0.216	**0.654**
O_3	**0.734**	0.010	0.256
PM_{10}	0.167	**0.783**	0.049
$PM_{2.5}$	0.323	**0.646**	0.031
SO_2	0.418	0.059	**0.522**
Benzene	**0.550**	0.358	0.092
Toluene	**0.944**	0.018	0.038
Ethylbenzene	**0.984**	0.002	0.014
p-xylene	**0.965**	0.022	0.013

The values in bold correspond for each variable to the factor for which the squared cosine is the highest.



Source: Own elaboration from the obtained results

6.5 Conclusions

Levels of BTEX in Obispado were influenced by vehicle-type emissions and by photochemical activity. Nevertheless, the concentration levels of benzene found in the study site constitute a risk of contracting cancer in a lifetime, with possible harmful effects, especially in children. The toluene/benzene concentration ratio showed a strong influence from mobile sources (automotive exhaust emissions) and was within the range reported for other urban cities.

The ratio of Xylene/Ethylbenzene concentrations indicated that the air masses in the study site were "fresh" or originated from local emissions, which is an indicator of vehicle traffic emissions, since these compounds are constituents of gasoline and are emitted into the atmosphere from motor vehicle exhaust.

BTEX levels showed a clear diurnal pattern at the study sites with higher concentrations between noon (B2) and afternoon (B3) sampling periods. The meteorological analysis indicated that emissions were transported from Juarez and Apodaca municipalities. It should be noted that in these municipalities there are important avenues that cross the Monterrey metropolitan area from east to west and that register a large influx of vehicles most of the time. The influence of carbon monoxide (CO) on BTEX levels was evident, probably through photochemical reactions producing hydroxyl radicals, which are the main oxidants of BTEX in the troposphere. However, negative correlations were observed between atmospheric particles and BTEX, indicating the participation of these hydrocarbons in the formation of secondary organic aerosols is important in the study site. That is, the role of BTEX was more important in the formation of aerosols than in the formation of tropospheric ozone.

The results from this study can help to establish a basis for knowing the distribution of BTEX and its behavior in one urban site located in the metropolitan area of Monterrey, as well as its relationships with other criteria pollutants. Nevertheless, it is recommended in future works to sample at more points located in other municipalities belonging to the metropolitan area of Monterrey to have more information on the spatial behavior and distribution of BTEX sources. This study provided preliminary information on the levels of BTEX in the measured site that will allow have information in order to design a program to improve air quality in the city and/or implementation of measures or control policies of emission sources of these pollutants in a future.

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