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Short-term Effects of Air Pollution on Health in the Metropolitan Area of Guadalajara using a Time-series Approach

Rosa M. Cerón-Bretón[1*], Julia G. Cerón-Bretón[1], Reyna C. Lara-Severino[2], María L. Espinosa-Fuentes[3], Evangelina Ramírez-Lara[4], Marcela Rangel-Marrón[1], Abril Rodríguez-Guzmán[1], Martha P. Uc-Chi[1]

[1] *Facultad de Química, Universidad Autónoma del Carmen, C.P. 24180 Ciudad del Carmen, Campeche, México*
[2] *Facultad de Ciencias de la Salud, Universidad Autónoma del Carmen, C.P. 24115 Ciudad del Carmen, Campeche, México*
[3] *Centro de Ciencias de la Atmósfera, Universidad Nacional Autónoma de México, C.P. 04510 Ciudad de México, México*
[4] *Facultad de Ciencias Químicas, Universidad Autónoma de Nuevo León, C.P. 66451 San Nicolás de las Garza, Nuevo León, México*

ABSTRACT

This work have like purpose quantitative estimates of the short-term effects of air pollution on the health of residents of five municipalities of the Metropolitan Area of Guadalajara, Mexico from 2012 to 2015 using time-series approach. Air Quality was assessed for CO, NO_2, SO_2, O_3 and PM_{10}. Tlaquepaque had the highest mean concentrations for CO (0.88 ppm), NO_2 (24.55 ppb), SO_2 (0.0036 ppm) and PM_{10} (53.81 $\mu g\ m^{-3}$), whereas, Zapopan registered the highest mean value for O_3 (25.06 ppb). Only PM_{10} and Ozone exceeded the maximum permissible values established in the Mexican official standards. SO_2 presented the highest RRI values in MAG, especially for Zapopan and Tonala, for the majority of the population: 0–59 years and > 60 years. Regarding to CO, excepting Guadalajara and Tlaquepaque, associations were not significant in the most of studied municipalities. The increase of risk as percentage for NO_2 was 1.77% for 0–59 years in Guadalajara and Tlaquepaque, 1.87% by respiratory causes in Tlaquepaque, 1.73% > 60 years in Tonala, and 1.25% for 0–59 years in Zapopan. The association between daily mortality and increased O_3 levels were significant, however, values were low for all studied municipalities. Finally, regarding to PM_{10}, only Zapopan and Tonala showed statistical significance. This study cannot predict if reductions in criteria pollutants levels would have an important effect on a reduction in daily mortality, however, considering the large size of population exposed, even when observed associations were small but significant, RRI values found are of public concern.

Keywords: Relative risk index; Mortality; Megacities; Criteria air pollutants; Mexico.

INTRODUCTION

It is well known that high levels of air pollutants have short-term effects on human health, which can lead to an increase in hospital admissions or even an increase in deaths. In addition, it has been reported that these effects may appear even at levels below of the maximum allowable limits established by the air quality standards. Time-series studies with aggregated data constitute an ecological design where the aggregation unity is a period of time. These studies are indicated for research on short-term effects of air pollutants on population health, and they are focused to investigate if daily variations in air pollutants are associated to changes in health (morbidity and mortality counts). These models are frequently used in epidemiological studies and most of them report that temporal increases in air pollutants levels are associated to adverse effects on health. However, it is important to say that acute changes in air pollutants are strongly controlled by local climatic conditions known as confusion variables (Chay *et al.*, 2003). The main confusion factors are meteorological variables (temperature and relative humidity) and temporal variables (season, day of the week, warm or cold months, among others). Time-series studies of air pollution and health, estimate associations between day-to-day variations in air pollutants concentrations and day-to-day variations in adverse health outcomes. These studies constitute useful evidence in order to assess the risk of current levels of atmospheric pollution (Samat *et al.*,

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[*] Corresponding author.
Tel.: (52) 9383826514; Fax: (52) 9383826514
E-mail address: rosabreton1970@gmail.com

2000; Clancy *et al.*, 2002). Statistical modelling of time series has experienced advances in the last 15 years, and consequently standard regression methods have been replaced by semi-parametric and non-parametric approaches (Hastie and Tibshirani, 1987) as Poisson regression, which provides more flexibility in the inclusion of confusion and climatic variables. This approach allows to obtain associations between daily increases in atmospheric pollutants concentrations and daily mortality counts expressed as the percentage of increase in the mortality (relative risk coefficients). Poisson regression method considers an adjustment of the confusion variables using smooth functions and climatic variables in order to control variations in mortality time series which may not be related to changes in atmospheric pollution. Some projects around the world have provided quantitative estimates of the short-term health effects of air pollution analyzing epidemiological time-series data: APHEA Project, which considered 15 European cities (Katsouyanni *et al.*, 1996), and EMECAM Project in Spain (Ballester-Díaz *et al.*, 1999), which assessed the short-term impact of air pollution on population health in cities. Both projects considered different sociodemographic, climate and environmental situations, with 25 million and 9 million of inhabitants, respectively.

Robles *et al.* (2015) assessed the short-term effects of particulate matter on health in Temuco and Pudahuel, two urban areas classified as the most polluted cities in Latin American by World Health Organization (WHO). Mohammadi *et al.* (2016) use daily concentrations of PM_{10}, SO_2, NO_2 and O_3 to evaluate the effects on health as a result of exposure to these pollutants in Shiraz, one of seven polluted megacities in Iran. They reported that cardiovascular disease as mortality cause plays a major role in mortality due to PM_{10}, SO_2 and O_3. In this study, PM_{10} had the highest health effect on health. This agree with that reported by Hadei *et al.* (2017), where particulate matter has been implicated as the seventh leading risk factor for premature death and disability in Iran. Khaefi *et al.* (2017) estimated the association between the load of particulate matter and the prevalence of chronic obstructive pulmonary disease in Ahvaz, Iran, which has the highest PM_{10} concentration among all cities in the world, and where dust storms play an important role. They reported that during dust storms, the load of bacteria increases significantly with a detrimental effect on health not only of humans but also ecosystems.

Therefore, it is necessary to understand the sources of particulate matter and their nature, when the impact of these aerosols on health is considered, since PM_{10} levels is one of the most crucial environmental concerns. In Mexico, some studies have been carried out on the effects of air pollution in public health, but most of them have been focused to Mexico City and Metropolitan Area of the Mexico Valley, and there are not enough information about other important cities and metropolitan areas of the country as the Metropolitan Area of Guadalajara (MAG), located in Jalisco State. This region is the second most important area in Mexico with high commercial, industrial, cultural and educational activity. According to the National Council of Population (CONAPO, 2010) on areas classification, the MAG belongs to Group 1 (Metropolitan Zones with a population greater than 4 million of inhabitants). As result of its industrial and commercial development, the MAG is one of the regions in Mexico with air pollution problems and it is common that this area shows exceedances to the maximum permissible value established in the Mexican air quality regulations (SIMAJ Atmospheric Monitoring System of the Jalisco State, 2014). These high levels of air pollution may put in danger to population of MAG having as a consequence increases in mortality and hospital admissions related to atmospheric pollution.

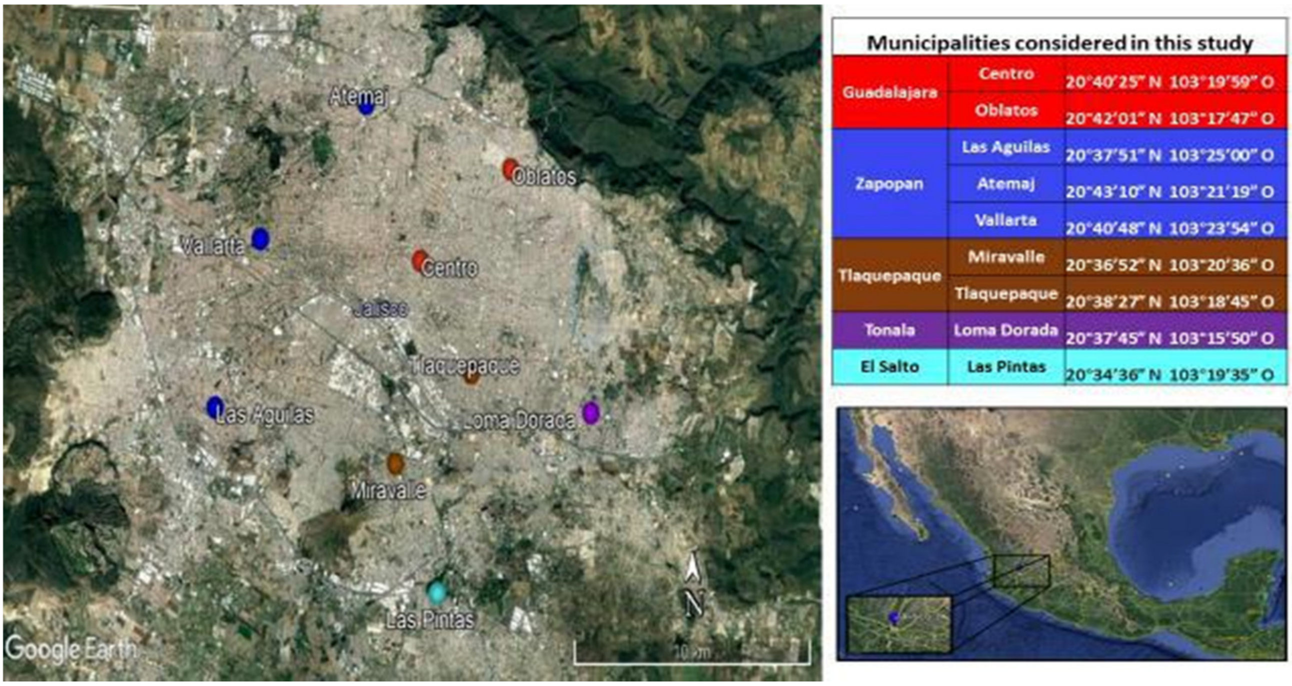
The present work have the following objectives: 1) To provide quantitative estimates of the short-term health effects (using total and cause-specific daily number of deaths) of air pollution on population health of the MAG from 2012 to 2015 using time-series approach; 2) To assess air quality and the accomplishment of the allowed maximum levels for air criteria pollutants ((carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3) and particulate matter (PM_{10})) regulated by the Mexican Air Quality Standards; and 3) To obtain a Critical Route in order to identify the most important issues that must be attended related to research and development of public policies in the association between air quality and public health. This research work includes five of nine municipalities that constitute the MAG, Jalisco, Mexico: El Salto, Guadalajara, Tlaquepaque, Tonala, and Zapopan. These grouped municipalities have a total of 4, 176, 161 inhabitants.

METHODOLOGY

Study Site Description

The MAG is the most developed center in the west zone of the country. Here resides the political and economic power of the Jalisco State, besides this area is the second largest metropolitan zone in Mexico (340 km^2). MAG is located in the central part of the Jalisco State and is officially formed by nine municipalities, of which 6 are considered as central municipalities (these municipalities have a common and continuous urbanization): Guadalajara, Zapopan, Tlaquepaque, Tonala, El Salto and Tlajomulco de Zuñiga (Fig. 1). The other three municipalities are Juanacatlan, Ixtlahuacan de los Membrillos and Zapotlanejo, which are considered as outer municipalities belonging to the MAG but they are not part of the common urbanization.

MAG is constituted as the second economic center of the country, and occupies the tenth place in Latin America. It was classified as a gamma city in 2010 and it is one of the 120 most productive cities of the world. It has an average altitude of 1570 masl. The climate of the city is temperate sub-humid with rains occurring during summer and medium humidity (ACw1). Spring is the driest and warmest season; the rainy season takes place between May and October, with storms, intense electrical activity and strong winds. During spring, days are very warm with maximums above 33°C, registering warm days even in the middle of February. During autumn and winter, the rains are reduced and give way to the sunny days and cold winds



Municipalities considered in this study		
Guadalajara	Centro	20°40′25″ N 103°19′59″ O
	Oblatos	20°42′01″ N 103°17′47″ O
Zapopan	Las Aguilas	20°37′51″ N 103°25′00″ O
	Atemaj	20°43′10″ N 103°21′19″ O
	Vallarta	20°40′48″ N 103°23′54″ O
Tlaquepaque	Miravalle	20°36′52″ N 103°20′36″ O
	Tlaquepaque	20°38′27″ N 103°18′45″ O
Tonala	Loma Dorada	20°37′45″ N 103°15′50″ O
El Salto	Las Pintas	20°34′36″ N 103°19′35″ O

Fig. 1. Study site location.

of the north. In winter, occasional frost can occur with temperatures as low as –2.5°C during cold, being common during December, January and February.

Air Pollution Measurements

Daily measurements for SO_2 (UV Fluorescence), CO (Absorption in the infrared), NO_2 (Chemiluminescence), O_3 (UV photometry), and PM_{10} (Beta radiation attenuation) were available from the air quality monitoring network of Jalisco State (SIMAJ) during the study period (from January 2012 to December 2015). Data from nine air quality monitoring stations were considered: Centro and Oblatos stations (Guadalajara), Las Aguilas, Antenas and Vallarta stations (Zapopan), Miravalle and Tlaquepaque stations (Tlaquepaque), Loma Dorada station (Tonala) and Las Pintas station (El Salto). Air criteria pollutants measurements for Tlajomulco de Zuñiga were not available, for this reason only 5 municipalities were considered in this study (El Salto, Guadalajara, Tlaquepaque, Tonala and Zapopan). All data were validated according to a specific protocol considering inclusion criteria for completeness of measurements (only monitoring stations with 75% of complete data for at least one pollutant during the study period were included). Missing values were completed using the NIPALS approach and the MCMC multiple imputation method using XLSTAT tool (https://www.xlstat.com/en/). Since the project is a study of urban air pollution effects, only urban stations that comply with standard procedures of quality assurance in their operation and performance and that belong to the National Air Quality Information System (SINAICA) were considered.

The Friedman test was used to determine if there were significant differences in mean concentrations for air criteria pollutants among different monitoring sites. The Friedman test is a nonparametric test that can be used with block designs, and the underlying assumptions are not as restrictive as an ANOVA procedure. The technique is based on the ranks of the observations within each block (sampling season or monitoring sites).

The assumptions pertaining to this study are: 1) The results within one block do not influence the results within the other blocks, and 2) within each block, the observations may be ranked according to some criteria of interest. The hypotheses to be tested are: H_o "the samples come from the same population, that is, there are no significant differences among monitoring sites", and H_1 "the samples did not come from the same population, that is, "there are significant differences among monitoring sites". This analysis was applied to concentration data set for air criteria pollutants using XLSTAT statistical software (2016.5 version). Air quality was assessed by comparison with current national standards and a two-stage statistical analysis was carried out in order to process air pollution data [descriptive statistical analysis, and a bivariate (Pearson correlation coefficients) and multivariate analysis (linear multiple regression and principal components analysis).

Data on Potential Confounders

Daily measurements for temperature and relative humidity were registered. Both meteorological parameters are considered as confusion variables. Air pollution tends to increase in periods with extremely cold temperatures and in periods with extremely hot temperatures due to excessive energy consumption. In addition, during wintertime, thermal inversions normally occur which are unfavorable to the dispersion of pollutants.

At the same time, the likelihood of deaths in susceptible population groups such as under 5 years and over 70 years is higher in periods with extreme temperatures (cold months and warm months). On the other hand, relative humidity has a negative impact on health by changing the conditions in which certain diseases develop. For this reason, a seasonality ratio (seasonal magnitude) was calculated for each pollutant and air quality information data was organized in seasonal strata (spring; summer; autumn; winter; cold months: November, December, January and February; warm months: May, June, July and august; and rest of year: March, April, September and October).

Health Data

Epidemiological data on mortality were obtained from the National Health Information System (SINAIS). This system is administered by the Ministry of Health, through the General Office of Health Information (http://www.dgis.salud.gob.mx). Databases used in the standardized format of deaths published by the SINAIS were obtained using the technological application called the Epidemiological and Statistical Subsystem of Deaths (SEED), which provides the frequency of diseases reported as basic or associated cause in the death certificates. The variables selected for the study were: year, month and day of occurrence, entity and municipality of residence, cause of death, sex and age group of the deceased. Deaths were selected only considering MAG residents, consequently deaths and diseases that occurred outside MAG were excluded. Deaths were grouped by gender and by age group (< 1 years, 1–4 years, 5–59 years, 60–74 years, and > 75 years).

Regarding to death cause, data were divided in the following groups of causes according to the International Classification of Diseases (ICD): 1) Respiratory diseases: This group includes acute respiratory infections, pneumonia and influenza, chronic obstructive pulmonary disease and allied conditions, pneumoconiosis and other lung diseases caused by external agents, symptoms involving the respiratory system and other chest symptoms.; 2) Cardiovascular diseases: This group involves hypertensive diseases, ischemic heart and pulmonary circulation diseases, stroke, and other symptoms involving the cardiovascular system; 3) All causes: In this group, all causes besides of respiratory and cardiovascular diseases were considered.

The univariate graphical and descriptive analysis (time series, diagrams of means, descriptive statistics, and frequency diagrams) and estimation of mortality rates were performed. Once the databases of daily mortality were formed, the following analyzes were carried out for each municipality during the period 2012–2015: descriptive statistics, mean diagram, frequency distribution and time series of the daily mortality by all causes, by season, by seasonal strata (cold months, warm months, rest of the year), by age range and specific cause of death.

Estimation of the Association between Atmospheric Pollution and Daily Mortality

A preliminary analysis was carried out by multiple linear regression (MLR) and principal component analysis (PCA) in order to find associations among the studied variables (daily death counts and daily mean concentrations of air pollutants). A key aspect in PCA is the interpretation of the factors from the relation of these with the initial variables, analyzing both the sign and the magnitude of the correlations. The principal components are obtained by searching for the linear combination of the variables that maximizes the variability (Hotelling, 1933; Jolliffe, 1986) and by means of regressions using the Biplot method (Gabriel, 1971). This technique was applied to the daily average data series of mortality, pollutant criteria and meteorological variables. The principal components that contributed to the highest percentage of variability of the data were obtained and the biplot graphs (map of the axes F1 and F2) were obtained, which shows a projection of the initial variables in the factorial space. Each factor includes a series of variables that show a degree of association between them, of which only those that showed higher factor load and greater statistical significance were considered ($p < 0.10$). A basal model was obtained including all the variables studied for each cause of death for each pollutant, applying MLR, self-correlation functions between residues and cross-correlation. The variables to be included in the Poisson model were those that contributed with significant information to explain the variability of the dependent variable (daily mortality) from the PCA and MLR results. This procedure was applied considering all causes, stratified analysis (cold months, warm months), age group and specific cause (diseases of the respiratory system and circulatory system). From this preliminary modeling, an equation was obtained in order to determine the magnitude of the association between daily mortality and the variation of the average daily levels of air pollution. To carry out this regression analysis, the following variables were considered:

a) Response variables:
  - Number of deaths registered for each of the municipalities included in the study.

b) Explanatory variables:
  - Criteria Air Pollutants (quantitative explanatory variable).
  - Daily average values of SO_2, CO, NO_2, O_3 and PM_{10} for each of the municipalities included in the study.
  - Meteorological variables (quantitative explanatory variable).
  - Daily average values of temperature and relative humidity for each of the municipalities included in the study.

c) Control variables:
  - Variables of temporal control (seasonality). The control of seasonality was carried out by introducing seasonality indicator variables considering two strata: cold months and warm months.
  - Confusing variables: Relative humidity and average daily temperature (meteorological factors).

The daily mortality data series are commonly distributed according to Poisson distribution with overdispersion (the variance is greater than the mean) and usually these series shows autocorrelation. Overdispersion and autocorrelation structure are usually the consequence of exogenous factors. The Poisson regression model requires a correct specification of the conditional mean, which is why smoothing of the daily mortality time series was necessary. A Poisson regression model was constructed for each mortality series in order to explain the fluctuations of daily count of deaths with respect to explanatory and confounder variables, according to the APHEA (Katsouyanni, 1996) and the EMECAN (Ballester *et al.*, 2002) methodologies. First, a basal model was identified for each of the causes of deaths, based on possible confounding variables. Air pollution variables were entered into the preliminary model one-at-a-time and the best fitting transformations and time lags were used to construct the basal model for every pollutant.

So, temperature and relative humidity were introduced with possible transformations, which depended on the analyzed specific time-series data (possible effects of local climatic conditions). Meteorological variables may be lagged by up to 7 days. Holidays, day of the week and other unusual events were controlled, with the introduction of appropriate dummy variables. Once the basal model was obtained, we proceeded to perform the Poisson modeling. Autocorrelation was taken into account using an autoregressive model. The construction of the autoregressive Poisson regression model allows us to determine whether the response variable depends on other variables. If the independent variables have a significant effect on the response variable (for a 95% confidence interval and $p < 0.05$), this effect is evaluated by the beta coefficient (β) of each independent variable in the Poisson regression model. The generalized linear model to relate the response variable to different independent variables is constructed as follows:

$$\ln\left(E_y\right) = \beta 0 + \sum_{i=1}^{n} \beta_i x_{ij} \tag{1}$$

where, E_y is expected number of daily deaths, $\beta 0$, β_i are constants of the model and x_{ij} re the explanatory variables. After the Poisson regression, from the base model, we obtained the β values that were used to calculate the relative risk value using the following equation:

$$RRI_i = e^{\beta i} \tag{2}$$

where, $\mathrm{RRI_i}$ is the relative risk index associated to the explanatory variable i per unit of increase of this variable, and β_i is the regression coefficient associated with the explanatory variable i in the model.

Subsequently, concentration of air pollutants was increased by 10% one-at-a-time within the model and the regression parameters were obtained again (applying the Poisson distribution model), considering this increase and keeping the rest of the variables unchanged. RRI for mortality were calculated again from the β values resulting from the increase by 10%. This procedure was performed for each pollutant and for each of the municipalities considered in the study.

Mapping of the RRI's

Mapping of air quality (mean concentrations for the whole period for each air pollutants) and RRI for all-cause daily mortality associated with each air pollutant was performed using a Geographic Information System version 2.14.7 (QGIS, 2017) from vector type spatial data including geographically referenced municipalities. The information was obtained from the National Institute of Statistics, Geography and Informatics (INEGI, 2017).

RESULTS

Air Quality

Each time series for concentrations of air pollutants was analyzed by season (spring, summer, autumn and winter), for cold months (November, December, January and February) and warm months (May, June, July and August) during the period 2012–2015 for the five municipalities considered in the study. The air pollutants studied were SO_2, CO, NO_2, O_3 and PM_{10}.

Air Quality was studied for each municipality (El Salto, Guadalajara, Tlaquepaque, Tonala and Zapopan) comparing the maximum values with the maximum permissible values established in the Air Quality Mexican Standards (AQMS). Compliance and number of exceedances according to the AQMS were determined considering the latest updates of the regulations for each air criteria pollutant. Table 1 shows the mean values for the whole period, warm months and cold months for air criteria pollutants for the five municipalities considered in this study. SO_2 measurements for El Salto were not available.

Tlaquepaque showed the highest mean concentrations for CO, NO_2 and PM_{10}, whereas, Zapopan showed the highest mean levels for O_3 (Table 1).

According to the Emission Inventory for Jalisco State 2008 (SEMADET Ministry of the environment and territorial development, 2014), Industrial and fixed sources, area sources and mobile sources contribute in 0.07%, 2.14% and 97.79% of the total CO emissions, respectively. The main source contributing to the total SO_2 emissions are industries (87.72%), followed by mobile sources (11.3%) and area sources (5.98%).

Fixed and industrial sources contribute to the total PM_{10} emissions with 23.28%, source areas contribute with 65.42% and mobile sources contribute with 11.31%. The main contribution to the total NO_x emissions in Jalisco State is provided by mobile sources (63.84%), followed by natural emissions (26.55%), area sources (7.65%) and fixed and industrial sources (1.95%).

The highest mean concentrations were found during the cold months (November, December, January and February) for SO_2, CO, NO_2 and PM_{10} in all the studied municipalities (Table 1). Therefore, the seasonal magnitude (Table 2) for these pollutants was greater than 1, indicating that the highest concentrations were found during these months. Some sources of pollution, like industrial emissions, stay fairly constant throughout the year, no matter what the season. But roaring fireplaces, wood stoves, idling vehicles and intensive use of heating systems during cold months cause an increase in the emissions of particulate matter, SO_2, NO_2 and CO. During cold months, thermal inversion is common, causing a build-up of these air pollutants near the ground. During a thermal inversion, cold air is trapped near

Table 1. Mean values for air criteria pollutants (SO_2, CO, NO_2, O_3 and PM_{10}), considering the whole period, warm months and cold months for the five municipalities considered in this study.

	SO_2 (ppm)	CO (ppm)	NO_2 (ppb)	O_3 (ppb)	PM_{10} ($\mu g\ m^{-3}$)
El Salto					
Whole period	NM[a]	0.96	17.58	23.13	74.71
Cold months	NM[a]	1.44	22.43	17.54	97.72
Warm Months	NM[a]	0.68	14.78	28.61	56.81
Guadalajara					
Whole period	0.0032	0.83	21.13	22.50	44.81
Cold months	0.0041	1.11	26.56	18.60	53.93
Warm months	0.0028	0.66	18.67	26.23	40.88
Tlaquepaque					
Whole period	0.0036	0.88	24.55	19.48	53.81
Cold months	0.0039	1.18	32.63	14.44	67.36
Warm months	0.0031	0.69	19.37	23.99	44.70
Tonala					
Whole period	0.0024	0.96	22.17	20.51	44.37
Cold months	0.0027	1.23	28.49	15.69	52.46
Warm months	0.0024	0.75	17.64	25.31	38.21
Zapopan					
Whole period	0.0020	0.83	21.48	25.06	35.61
Cold months	0.0024	1.06	25.72	19.03	41.98
Warm months	0.0019	0.70	19.73	31.40	31.60

NM[a]: Non measured.

Table 2. Seasonal magnitude for the air criteria pollutants in the five municipalities considered in this study.

Municipality	Seasonal Magnitude				
	SO_2	CO	NO_2	O_3	PM_{10}
El Salto	NM[a]	2.11	1.52	0.61	1.72
Guadalajara	1.45	1.70	1.42	0.71	1.32
Tlaquepaque	1.26	1.71	1.68	0.60	1.51
Tonala	1.12	1.64	1.61	0.62	1.37
Zapopan	1.28	1.53	1.3	0.61	1.33

NM[a]: Non measured.

the ground by a layer of warm air, the warm air acts like a lid, holding these substances down. During a temperature inversion, smoke cannot rise and air pollutants can reach unhealthy levels.

On the other hand, O_3 showed the highest mean values during the warm months for all the studied sites (Table 1). This behavior can be explained, since during the summer, the intensity of the solar radiation is higher, which promotes a greater photochemical activity and therefore the atmospheric reactions of tropospheric ozone production, for this reason, O_3 showed higher values of concentration during the warm months. O_3 showed a seasonal magnitude lower than 1, indicating that the highest concentrations for this pollutant were found during the warm months.

Figs. 2–3 shows descriptive statistic for CO-SO_2, and NO_2-O_3-PM_{10}, respectively, for the five studied municipalities. CO and SO_2 showed the highest mean values in El Salto (0.96 ppm) and Tlaquepaque (0.0035 ppm), respectively (Fig. 2). The highest mean values for NO_2, O_3 and PM_{10} were registered in Tlaquepaque (24.58 ppb), Zapopan (25.66 ppb) and El Salto (75.55 $\mu g\ m^{-3}$), respectively (Fig. 3).

The Friedman test revealed that there were significant differences in mean concentrations of CO among different monitoring sites; however, a bilateral test (Nemenyi procedure) by multiple comparisons in pairs showed that mean concentrations of CO in El Salto-Tonala and Guadalajara-Zapopan were not significant. For NO_2, Friedman test showed that there were significant differences among municipalities, but Nemenyi procedure showed that there were not significant differences in NO_2 concentrations between Guadalajara-Zapopan and Tonala-Tlaquepaque. According to the Friedman test for O_3, it was found that there were significant differences among municipalities, however, applying a bilateral test (Nemenyi procedure), Tlaquepaque-Tonala-Zapopan and El Salto-Zapopan did not show significant differences in O_3 levels. The Friedman test applied to data set for PM_{10} and SO_2 revealed that there were differences among monitoring sites, but these differences there were not significant in Zapopan-Guadalajara-Tonala (Nemenyi test).

Figs. 4(a)–4(e) show the exceedances at the maximum allowable value established in the Mexican official standards on air quality. For SO_2 and CO, the limit value corresponds

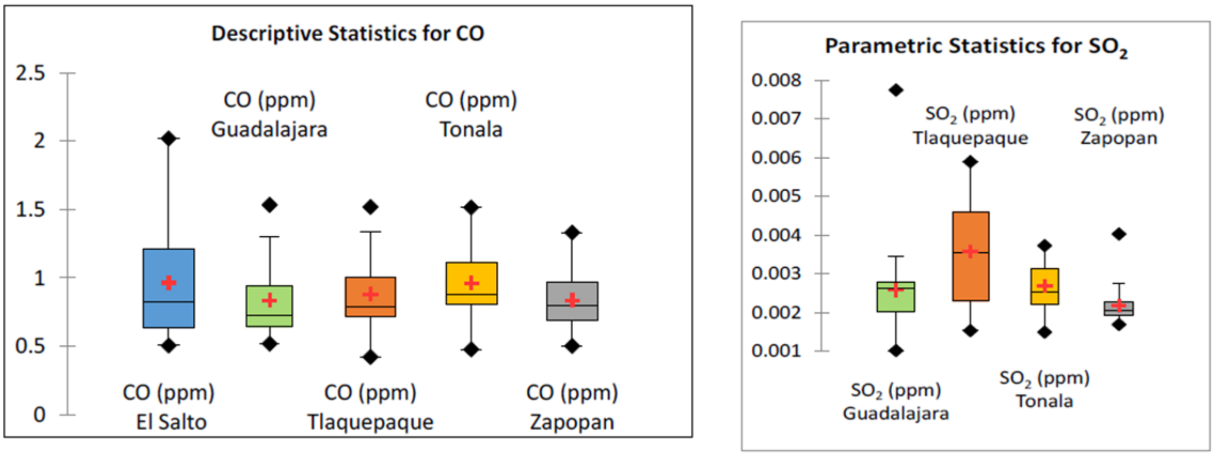


Fig. 2. Descriptive statistics for CO and SO_2 for the studied municipalities. The central horizontal bars are the medians. The lower and upper limits of the box are the first and third quartiles. Where, + is the mean value; ◆ represents maximum and minimum values; the horizontal width of the box has no statistical significance, and is only for better visualization.

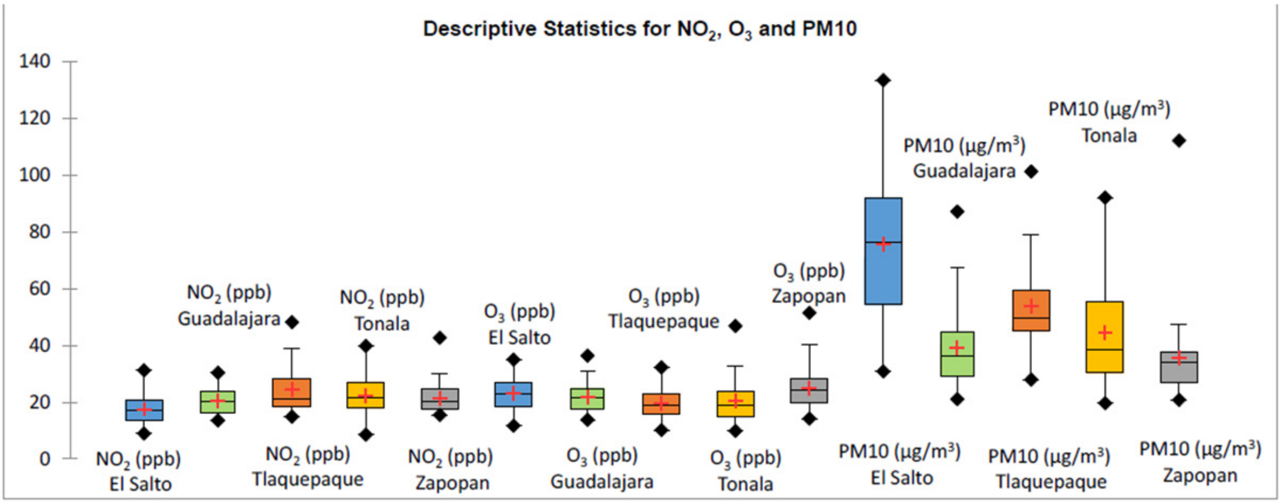


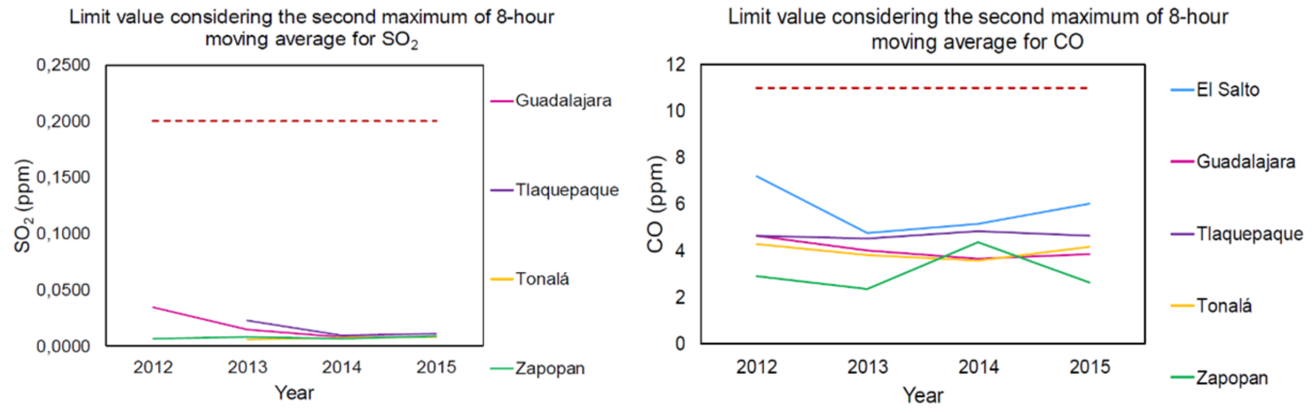
Fig. 3. Descriptive statistics for NO_2, O_3 and PM_{10} for the studied municipalities. The central horizontal bars are the medians. The lower and upper limits of the box are the first and third quartiles. Where, + is the mean value; ◆ represents maximum and minimum values; the horizontal width of the box has no statistical significance, and is only for better visualization.

to the second maximum of 8-hour moving averages (the limit value should not exceed 0.20 ppm for SO_2 and 11 ppm for CO, once a year) according to the Mexican official standards (NOM-022-SSA1-2010 for SO_2 and NOM-021-SSA1-1993 for CO). We can observe in Figs. 4(a) and 4(b) that both pollutants did not show exceedances to the permissible maximum values in atmospheric concentration established in their respective standards. For NO_2, the standard (NOM-023-SSA1-1993) establishes that the maximum limit is calculated considering the maximum average of 1 hour, which should not exceed 210 ppb. It can be observed in Fig. 4(c), that this pollutant did not show exceedances to regulated limit. For O_3, the standard (NOM-020-SSA1-2014) establishes that the limit value correspond to the second maximum of 8-hour moving averages (this value should not exceed 70 ppb, once a year).

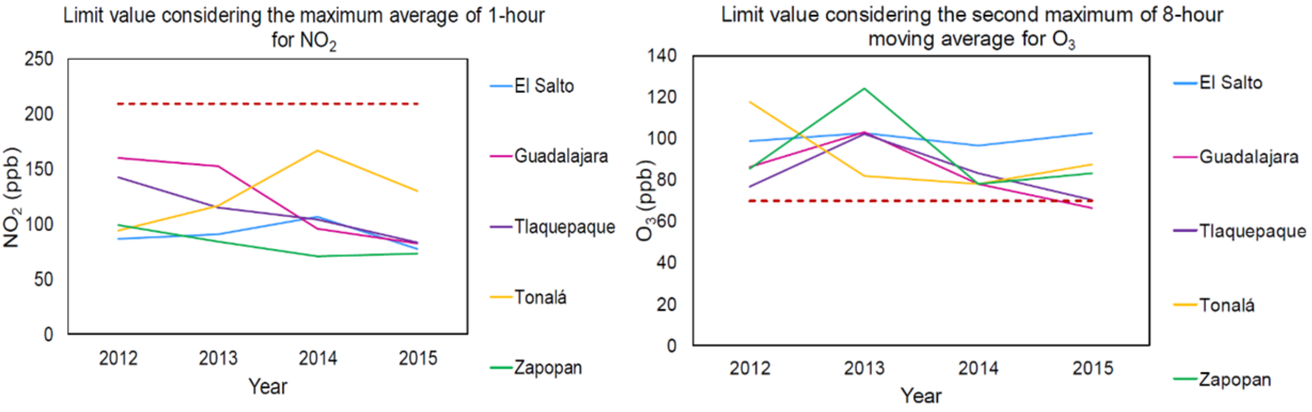
Fig. 4(d) shows that all the municipalities considered in this study exceeded the maximum allowable value established in the standard for O_3 excepting Guadalajara and Tlaquepaque during 2015. For PM_{10}, the standard (NOM-025-SSA1-2014) establishes that PM_{10} atmospheric concentration should not exceed 40 µg m^{-3} (considering average annual 24-hour averages). El Salto and Tlaquepaque exceeded the maximum permissible value established for PM_{10} during all the studied period (2012–2015) (Fig. 4(e)). Guadalajara showed exceedances to the limit value for PM_{10} during 2012 and 2014, Zapopan during 2013 and Tonala during 2012, 2013 and 2014 (Fig. 4(e)).

Figs. 5(a)–5(e) show the distribution map of the average concentrations of the criterion pollutants in the five studied municipalities as well as the exceedances to the allowable limit established in the Mexican normativity.

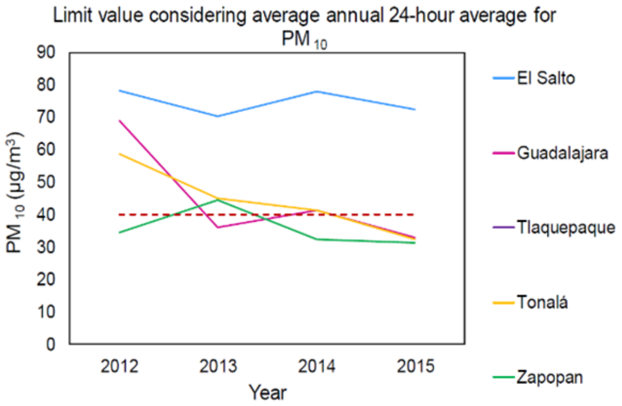
SO_2 registered higher mean concentration values in 2012 for Guadalajara, in 2013 for Tlaquepaque, in 2014 for



(a) SO_2 (b) CO



(c) NO_2 (d) O_3



(e) PM_{10}

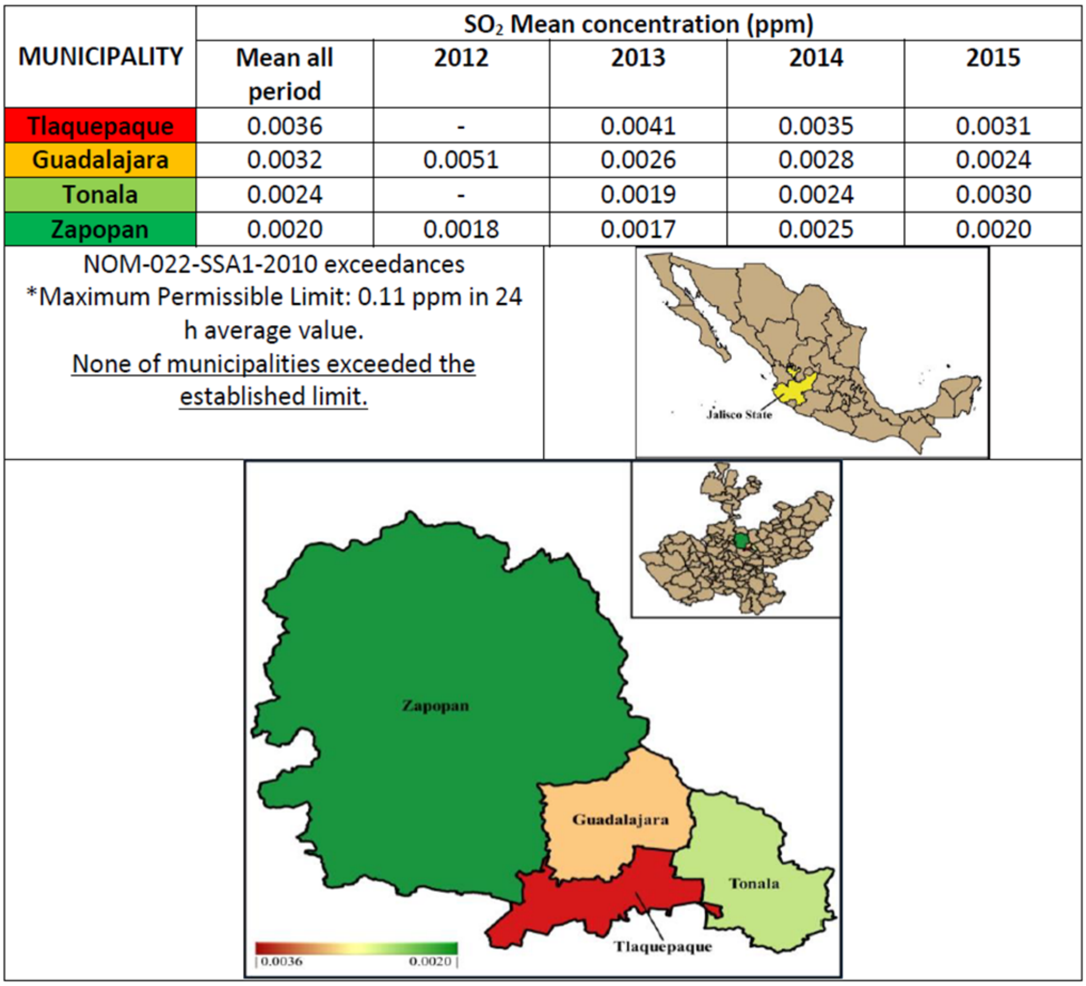
Fig. 4. Comparison of air criteria pollutants concentrations with the permissible limit values established in the Mexican official standards.

Zapopan and in 2015 for Tonala (Fig. 5(a)). El Salto and Zapopan registered the highest values of CO concentrations during 2012, whereas Tonala and Tlaquepaque registered the highest mean concentrations for this pollutant during 2014 (Fig. 5(b)).

During 2012, NO_2 registered the highest concentrations values in Tlaquepaque, Zapopan, Guadalajara and El Salto, whereas, Tonala had the highest concentrations for this pollutant during 2015 (Fig. 5(c)).

CO, NO_2 and SO_2 did not exceed the maximum permissible limits established in the Mexican standards. O_3 registered the highest mean values of concentration during 2012 in Zapopan, Guadalajara, Tonala and Tlaquepaque, whereas El Salto had the highest mean concentration for this pollutant during 2014 (Fig. 5(d)).

All the studied municipalities exceeded the limit value of concentration established in the Mexican standard for ozone, being Tonala the municipality that showed the highest number of exceedances (305 times). For PM_{10}, El Salto and Tlaquepaque showed the highest mean concentration values during 2014, Guadalajara and Tonala during 2012 and Zapopan during 2013 (Fig. 5(e)). The five municipalities



MUNICIPALITY	SO_2 Mean concentration (ppm)				
	Mean all period	2012	2013	2014	2015
🟥 Tlaquepaque	0.0036	-	0.0041	0.0035	0.0031
🟧 Guadalajara	0.0032	0.0051	0.0026	0.0028	0.0024
🟩 Tonala	0.0024	-	0.0019	0.0024	0.0030
🟩 Zapopan	0.0020	0.0018	0.0017	0.0025	0.0020

NOM-022-SSA1-2010 exceedances
*Maximum Permissible Limit: 0.11 ppm in 24 h average value.
None of municipalities exceeded the established limit.

Fig. 5(a). Distribution map of the average concentrations of SO_2 in the five studied municipalities as well as the exceedances to the allowable limit established in the Mexican normativity.

showed exceedances to the maximum permissible concentration value for PM_{10}, being El Salto, the municipality that registered the highest number of exceedances (695 times).

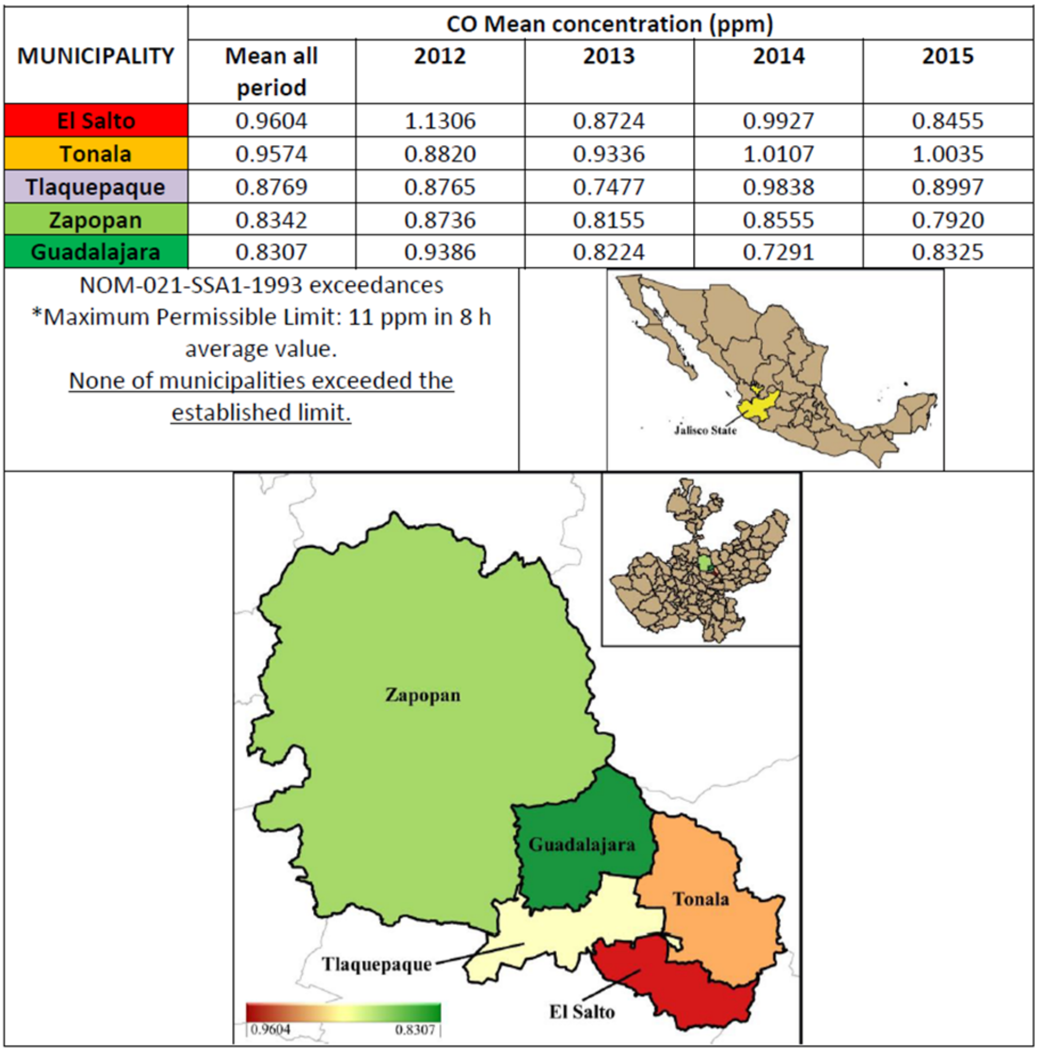
Descriptive Analysis of Epidemiological Data

Once data bases were reduced to time period and variables selected, a simple statistical analysis was applied to the epidemiological data set (mortality). Selected aspects of the mortality data for MAG during 2012–2015 are shown in Table 3 and Fig. 6. Standardized mortality rate (defined as the number of deaths of each 1000 persons by day in a specific area and adjusted by age distribution) was estimated for each municipality during 2012–2015.

The five municipalities in MAG vary in population size and mortality rate. Guadalajara and Zapopan are the most populated municipalities in MAG contributing with 40.285 and 33.51% to total population in MAG, respectively; whereas Tonala and Tlaquepaque contribute with 11.013 and 15.17% to total population. El Salto is the least populated municipality, contributing with only 0.022% of total population. From Table 3 and Figs. 6(a) and 6(b), it can be observed that, Guadalajara (10.97) and Zapopan (5.03) presented the highest mean number of daily deaths by all causes. In addition, Guadalajara showed the highest mortality rate: 2.61–2.83 (Fig. 6(c)).

From Fig. 6(d), it was found that daily mortality data in MAG exhibited a strong seasonal pattern, with the higher values during the winter season (along December and January); whereas, the number of deaths decreased during the summer season. Daily mortality by all causes peaked for adults in the age range > 75 years when deaths due to all causes were considered; whereas the population subgroups corresponding to < 1 year and infants from 0 to 4 years, presented the lowest deaths number (Fig. 6(e)).

Considering gender, mortality showed higher values for women in comparison with men. From time-series and descriptive analysis, as can be observed in Fig. 6(f), a peak was identified during January for adults > 75 years, being higher death values for female gender. On the other hand, when specific-cause of death was considered, studied population exhibited maximum values in the deaths number during December and January for persons > 75 years by cardiovascular diseases, being higher for women. Considering deaths by respiratory diseases, the number of deaths was higher in persons > 75 years for female gender. However,



MUNICIPALITY	CO Mean concentration (ppm)				
	Mean all period	2012	2013	2014	2015
El Salto	0.9604	1.1306	0.8724	0.9927	0.8455
Tonala	0.9574	0.8820	0.9336	1.0107	1.0035
Tlaquepaque	0.8769	0.8765	0.7477	0.9838	0.8997
Zapopan	0.8342	0.8736	0.8155	0.8555	0.7920
Guadalajara	0.8307	0.9386	0.8224	0.7291	0.8325

NOM-021-SSA1-1993 exceedances
*Maximum Permissible Limit: 11 ppm in 8 h average value.
None of municipalities exceeded the established limit.

Fig. 5(b). Distribution map of the average concentrations of CO in the five studied municipalities as well as the exceedances to the allowable limit established in the Mexican normativity.

comparing deaths number occurred by cardiovascular causes (20,697 deaths during 2012–2015), these were twice as those registered by respiratory causes (9,366 deaths during 2012–2015) (Figs. 6(g) and 6(h)).

In this section, estimations of the magnitude of effect of criteria pollutants (SO_2, CO, NO_2, O_3, PM_{10} and $PM_{2.5}$) on mortality by all-causes are presented. In addition, to identify differential effects statistical analysis was stratified by seasonal period, age group and specific cause of death.

Effects of Air Pollution on Daily Mortality

Poisson regression was used to assess the daily mortality as a function of air pollution variables. As a first step, data analysis was applied to time series to test their scatter, identify atypical data, their normality and stationarity. Time series of epidemiological data usually show a variable variance, outliers, collinearity and nonlinear relations with some variables (temperature and humidity), that cannot be explained with parametric models.

Therefore, it was necessary to carry out a sensitivity analysis to identify the best fit to smoothed functions and to reduce residuals. LOWESS method (LOcally Weighted regression Scatterplot Smoothing) gave the best fit the mortality data by visual examination of residuals and goodness-of-fit statistics. Air quality time series were smoothed by using ARIMA (Autoregressive Integrate Moving Average), which is a rigorous technique for univariate predictions. (Box-Jenkins model) (Uriel, 1985). Confounding covariates as temperature and humidity were assessed with lags from 1 to 13 days.

Multivariate Analysis

Principal components analysis (PCA) was applied to mortality by all causes, criteria pollutants and meteorological variables time series. By using biplots graphics, those compounds contributing in a greater percentage to data variability were identified. To confirm if a given variable was related with an axis, squared cosine values were assessed.

Each factor includes a variables series that show a degree of association between them, of which only were considered those showing factor with the higher load and with a greater statistical significance, using as inclusion criteria,

MUNICIPALITY	NO_2 Mean concentration (ppb)				
	Mean all period	2012	2013	2014	2015
Tlaquepaque	24.5516	28.7215	26.4344	22.9677	20.2026
Tonala	22.1670	17.9076	22.8443	23.4036	24.5966
Zapopan	21.4793	25.5554	20.4080	20.1878	19.7894
El Salto	21.1322	24.1918	23.9307	18.6596	17.7657
Guadalajara	17.5757	20.8078	17.2947	16.0381	16.2049

NOM-023-SSA1-1993 exceedances
*Maximum Permissible Limit: 210 ppb in 1 h average value.
None of municipalities exceeded the established limit.

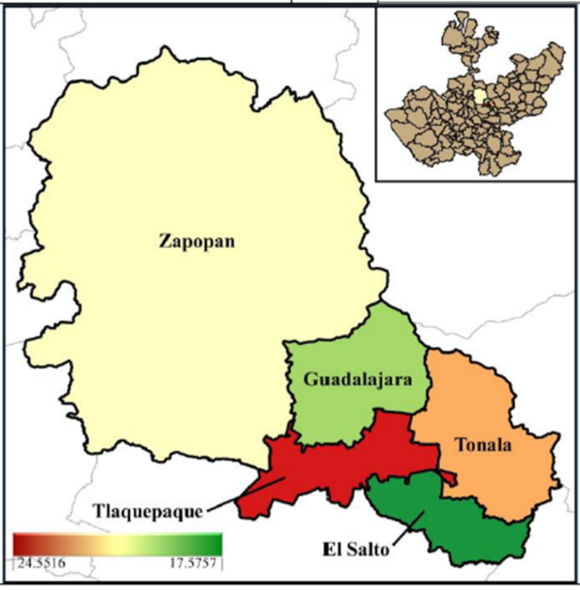


Fig. 5(c). Distribution map of the average concentrations of NO_2 in the five studied municipalities as well as the exceedances to the allowable limit established in the Mexican normativity.

the deviance from the model at $p < 0.10$. Simultaneously, a MLR) was applied to air quality and mortality data sets by all causes. In addition, auto-correlation functions and cross-correlation were assessed.

Linear multiple regression

Guadalajara and Zapopan showed the higher determination coefficients (R^2). In these municipalities, explanatory variables (SO_2, CO, NO_2, O_3, PM_{10}, Relative Humidity and Temperature) explained variations in daily mortality in 65.93% and 47.20%, respectively. (Table 4)

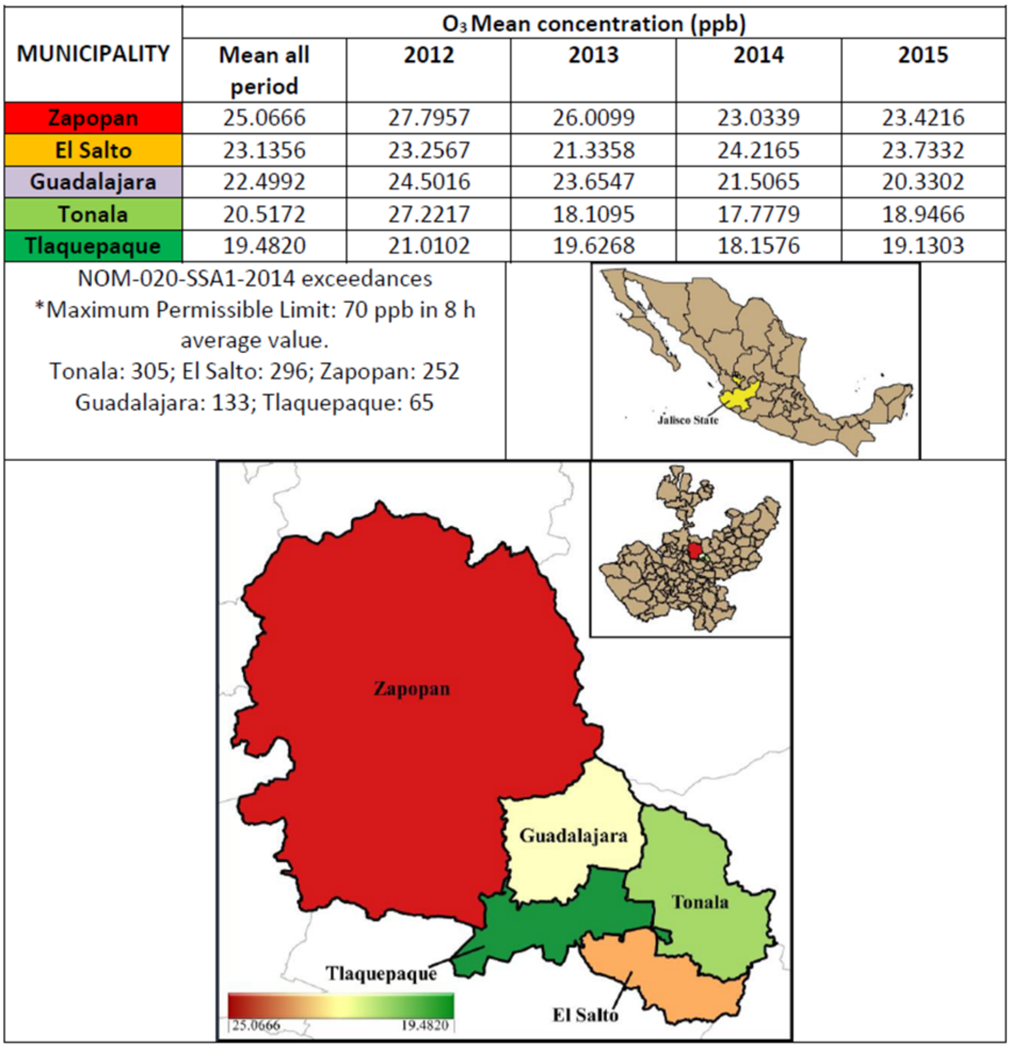
SO_2: From bi-variate analysis (Pearson correlation), only Zapopan showed a significant coefficient (0.4855). On the other hand, from MLR analysis, Guadalajara, Tlaquepaque and Zapopan municipalities presented the lowest values for Fisher tests ($F < 0.0001$), concluding that SO_2 accounts significantly to daily mortality prediction model. CO: Guadalajara (0.5176) and Tlaquepaque (0.4266) presented the highest Pearson correlation coefficients in the bi-variate analysis. From MLR analysis, Fisher tests ($F < 0.0001$) demonstrated that CO only accounts significantly to daily mortality in Guadalajara.

NO_2: In bi-variate analysis, only Tlaquepaque (0.3876) and Tonala (0.4083) showed high Pearson correlation coefficients. In MLR, from Fisher tests, only Zapopan presented the lowest values for statistical test, concluding that NO_2 only accounts significantly to daily mortality in this municipality.

O_3: From bi-variate relations it was observed that any municipality showed significant values. Only Tlaquepaque and Zapopan had the lowest values for Fisher test, therefore, it can be concluded with confidence that these municipalities explain the variability observed in mortality prediction.

PM_{10}: From Pearson correlation, it was found that Tlaquepaque (0.3322), Guadalajara (0.2702) and Zapopan (0.2937) presented the higher coefficients. On the other hand, from MLR it was observed that Zapopan was the only municipality that showed the lowest value for Fisher test, suggesting that in this municipality PM_{10} account in a significant proportion to predicted daily mortality.

Humidity: Humidity correlated significantly and negatively



MUNICIPALITY	O_3 Mean concentration (ppb)				
	Mean all period	2012	2013	2014	2015
Zapopan	25.0666	27.7957	26.0099	23.0339	23.4216
El Salto	23.1356	23.2567	21.3358	24.2165	23.7332
Guadalajara	22.4992	24.5016	23.6547	21.5065	20.3302
Tonala	20.5172	27.2217	18.1095	17.7779	18.9466
Tlaquepaque	19.4820	21.0102	19.6268	18.1576	19.1303

NOM-020-SSA1-2014 exceedances
*Maximum Permissible Limit: 70 ppb in 8 h average value.
Tonala: 305; El Salto: 296; Zapopan: 252
Guadalajara: 133; Tlaquepaque: 65

Fig. 5(d). Distribution map of the average concentrations of O_3 in the five studied municipalities as well as the exceedances to the allowable limit established in the Mexican normativity.

in the most of the municipalities, being more significant for Guadalajara (–0.4607). From MLR analysis and Fisher test, it was found that in this municipality, humidity contributes significantly to predicted daily mortality.

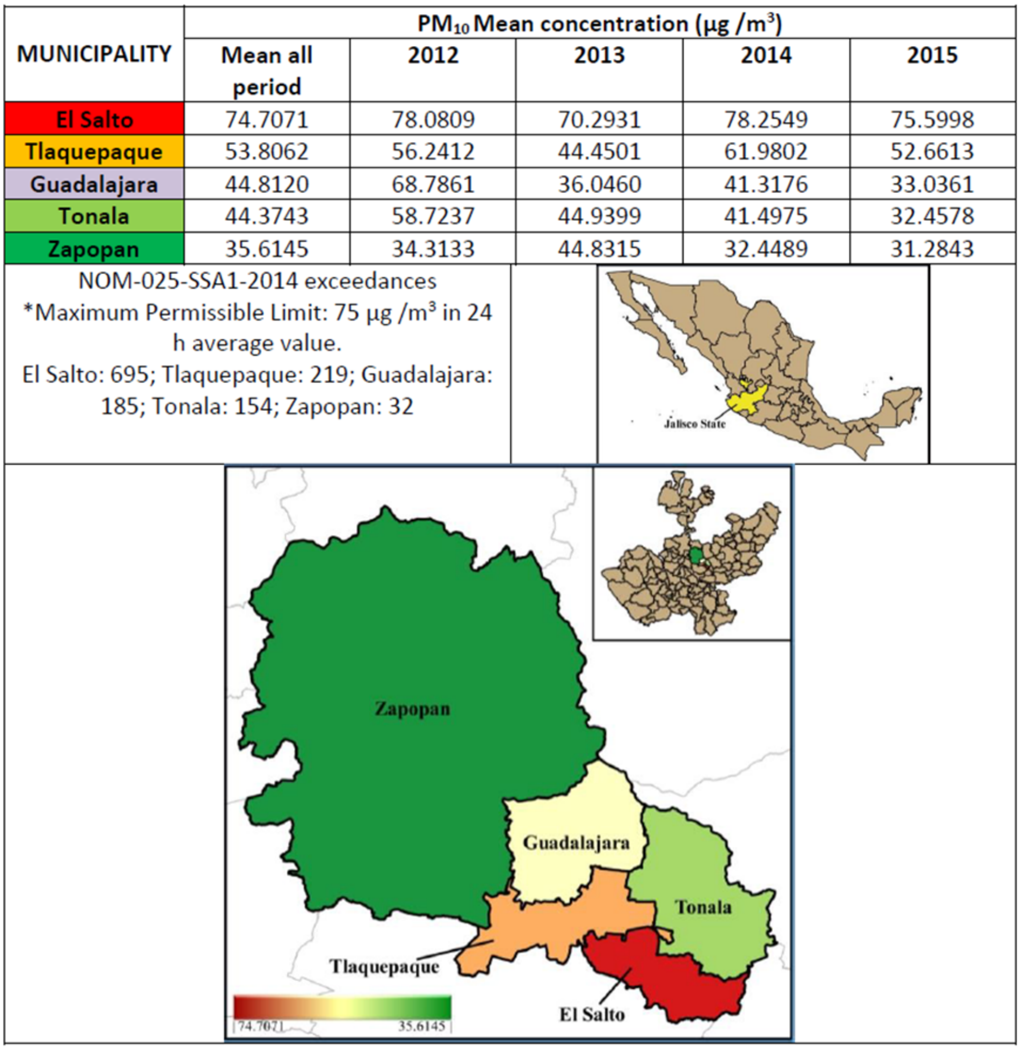
Temperature: It was found a negative and significant correlation with temperature for all municipalities studied in MAG, being more significant for Guadalajara (–0.5678). Likewise, excepting for El Salto, the rest of the municipalities presented values lower than statistical test (Fisher test), indicating that this variable contributes in a great proportion to variability observed in daily mortality predicted from model.

Principal Component Analysis (PCA)

Considering all-causes, Guadalajara and Tlaquepaque presented significant correlations between daily mortality and CO, NO_2 y PM_{10}; whereas in Zapopan, Temperature and NO_2 correlated significantly with daily mortality (Table 5). From PCA and MLR analysis, those variables that explain the variability of response variable were selected to be included into the Poisson model.

Estimation of Relative Risk Index

According to APHEA (Katsouyanni, 1996) and EMECAN (Ballester *et al.*, 2002) methodology, a Poisson regression was used to estimate relative risk index for daily mortality by all causes, by age group, by month (cold months, warm months and the rest of the year), and by specific cause (respiratory and cardiovascular system diseases) in each municipality of MAG during 2012–2015. In a first step, a base model was established for daily mortality, once base model was established, this model was extended for each criteria air pollutant and their lags. The second step was to obtain β values from Poisson regression (base model) to estimate the current risk index for each air pollutant. The next step was to add a relative increase of 10% to concentration for each air pollutant separately, including meteorological parameters. Poisson regression parameters were obtained for each air pollutant, considering individual increase and keeping the remainder variables unchanged. Finally, with β values obtained, RRI was estimated to assess the effect on risk index associated to an increase on air pollution levels. This procedure was done for each



MUNICIPALITY	PM_{10} Mean concentration (µg /m³)				
	Mean all period	2012	2013	2014	2015
El Salto	74.7071	78.0809	70.2931	78.2549	75.5998
Tlaquepaque	53.8062	56.2412	44.4501	61.9802	52.6613
Guadalajara	44.8120	68.7861	36.0460	41.3176	33.0361
Tonala	44.3743	58.7237	44.9399	41.4975	32.4578
Zapopan	35.6145	34.3133	44.8315	32.4489	31.2843

NOM-025-SSA1-2014 exceedances
*Maximum Permissible Limit: 75 µg /m³ in 24 h average value.
El Salto: 695; Tlaquepaque: 219; Guadalajara: 185; Tonala: 154; Zapopan: 32

Fig. 5(e). Distribution map of the average concentrations of PM_{10} in the five studied municipalities as well as the exceedances to the allowable limit established in the Mexican normativity.

Table 3. Descriptive statistical analysis of daily mortality in Metropolitan Area of Guadalajara during 2012–2015.

Municipality	Mean	Standard Deviation	Maximum Value	Minimum Value
El Salto	0.51	0.71	4.00	0.00
Guadalajara	10.97	3.72	27.00	0.00
Tlaquepaque	2.53	1.67	10.00	0.00
Tonala	1.54	1.27	7.00	0.00
Zapopan	5.03	2.37	15.00	0.00

pollutant and for each municipality. From Fig. 7, it is observed that in the case of SO_2, Zapopan showed the highest relative risk indexes for daily mortality by all causes as a result of an increase of 10% in SO_2 levels. El Salto, Guadalajara and Tlaquepaque presented uniformity in RRI for CO, in Tonala, RRI´s values were slightly lower and in Zapopan, data were not significant.

The highest RRI values for NO_2 were obtained for Tonala, however, Guadalajara and Tlaquepaque showed similar values, and Zapopan presented the lowest RRI values. In the case of O_3, mean values of RRI were uniform, but, the highest values were obtained for El Salto and Tonala. Finally, PM_{10} presented the highest RRI values for Tonala. In Table 6, RRI values for daily mortality by an increase of SO_2 levels are shown for all causes, age group and specific cause of death for each municipality in MAG during study period.

In general, El Salto did not show any statistical significance when RRI were estimated.

In Guadalajara, a 10% increase in SO_2 concentration was associated with an increase of 2.02% (by all causes), 3.05% (by age group: 0–59 years), 2.16% (by age group: > 60 years), 2.30% (by specific cause: respiratory diseases) and 2.22% (by specific cause: cardiovascular diseases) in

(a) (b)

(c) (d)

(e) (f)

(g) (h)

Fig. 6. Distribution of daily mortality and daily mortality rate in the municipalities of Metropolitan Area of Guadalajara during 2012–2015.

Table 4. Results of RLM analysis considering all causes during 2012–2015.

Criteria Pollutant	Statistical test	El Salto	Guadalajara	Tlaquepaque	Tonala	Zapopan
	RLM Determination Coefficient (R2)	0.2073	0.6593	0.3300	0.3369	0.4720
SO_2 (ppb)	Pearson Coefficient	[a]	[a]	[a]	0.2450	0.4855
	RLM Type III Pr > F	[a]	< 0.0001	< 0.0001	0.0173	< 0.0001
CO (ppb)	Pearson Coefficient	0.3368	0.5176	0.4266	0.3758	*a*
	RLM Type III Pr > F	0.0011	<0.0001	0.0045	0.0287	*a*
NO_2 (ppb)	Pearson Coefficient	[a]	0.2895	0.3876	0.4083	0.1169
	RLM Type III Pr > F	[a]	0.0009	[a]	0.0022	< 0.0001
O_3 (ppb)	Pearson Coefficient	[a]	[a]	[a]	[a]	[a]
	RLM Type III Pr > F	0.0030	[a]	<0.0001	0.0003	< 0.0001
PM_{10} ($\mu g\ m^{-3}$)	Pearson Coefficient	[a]	0.2702	0.3322	0.2125	0.2937
	RLM Type III Pr > F	[a]	0.0006	[a]	0.0006	< 0.0001
Humidity	Pearson Coefficient	–0.1920	–0.4607	–0.0939	[a]	–0.1984
	RLM Type III Pr>F	< 0.0001	< 0.0001	0.0001	[a]	< 0.0001
Temperature	Pearson Coefficient	–0.3411	–0.5678	–0.4564	–0.4304	–0.4663
	RLM Type III Pr>F	0.0044	< 0.0001	< 0.0001	< 0.0001	< 0.0001

[a] Spaces in gray indicate that there was not a significant correlation.

Table 5. Results of PCA analysis considering all causes during 2012–2015.

	El Salto	Guadalajara	Tlaquepaque	Tonala	Zapopan
Mortality	0.7565	0.6999	0.6686	0.6942	0.6877
SO_2 (ppb)	[a]	[a]	[a]	[a]	[a]
CO (ppb)	[a]	0.8130	0.8564	[a]	[a]
NO_2 (ppb)	[a]	0.7775	0.7979	[a]	0.6254
O_3 (ppb)	[a]	[a]	[a]	[a]	[a]
PM_{10} ($\mu g\ m^{-3}$)	[a]	0.6055	0.7261	[a]	[a]
Humidity	[a]	[a]	[a]	[a]	[a]
Temperature	[a]	[a]	–0.6740	[a]	–0.7354

[a] Spaces in gray indicate that factorial loads were not significant.

daily mortality. In Tlaquepaque, respiratory causes did not show statistical significance; whereas association between an increase of 10% in SO_2 levels and daily mortality presented the following values: 1.59% (by all causes), 6.49% (by age group: 0–59 years), 2.02% (by age group: > 60 years) and 0.14% (by specific cause: cardiovascular diseases). On the other hand, in Tonala, age group of 0–59 years, and specific causes (respiratory and cardiovascular) did not show statistical significance. The magnitudes of association between daily mortality and SO_2 concentration increased in 10% were 10.6% (by all causes) and 12.88% (by age group: > 60 years). Finally, in Zapopan, the association of daily mortality with SO_2 levels showed the following values: 8.65% (by all causes), 13.54% (by age group: 0–59 years), 10.23% (by age group: > 60 years) 8.21% (by specific cause: respiratory diseases) and 9.31% (by specific cause: cardiovascular diseases). From Table 7, it can be observed that, excepting by all causes (0.02%), CO did not show statistical significance in the association. However, the magnitude of the association between daily mortality and CO levels increased in 10% in Guadalajara was not significance (between 0.03 and 0.04%).

Similarly, Tlaquepaque presented RRI values relatively low (from 0.02 to 0.05%). Tonala did not presented significant values for age group of 0–59 years and respiratory causes, and in the remaining conditions, the association found was not significant. In the other hand, Zapopan did not show statistical significance when all and respiratory causes were considered, whereas for age group and cardiovascular cause, RRI values found were very low. In El Salto, association between an increase of 10% in NO_2 levels and daily mortality only showed significant values by all causes (0.24%) (Table 8).

For Guadalajara, the magnitude of this association was 0.88% (by all causes), 1.77% (by age group: 0–59 years), 0.92% (by age group: > 60 years), 1.16% (by specific cause: respiratory diseases), and 0.96% (by specific cause: cardiovascular diseases).

In Tlaquepaque, the following upper limits in RRI values were found: 0.77%, 1.77%, 0.99%, 1.87%, and 0.40% for all causes, 0–59 years, > 60 years, respiratory cause, and cardiovascular cause, respectively. In Tonala, respiratory causes did not show statistical significance; whereas found association between daily mortality and increased NO_2 levels showed the following values: 1.37%, 1.09%, 1.73% and 1.56% when all causes, age group (0–59 and > 60 years) and cardiovascular cause were considered. Finally, in Zapopan, association between an increase of 10% in NO_2 levels and daily mortality was important only when age group of 0–59 years (1.25%), respiratory cause (0.51%)

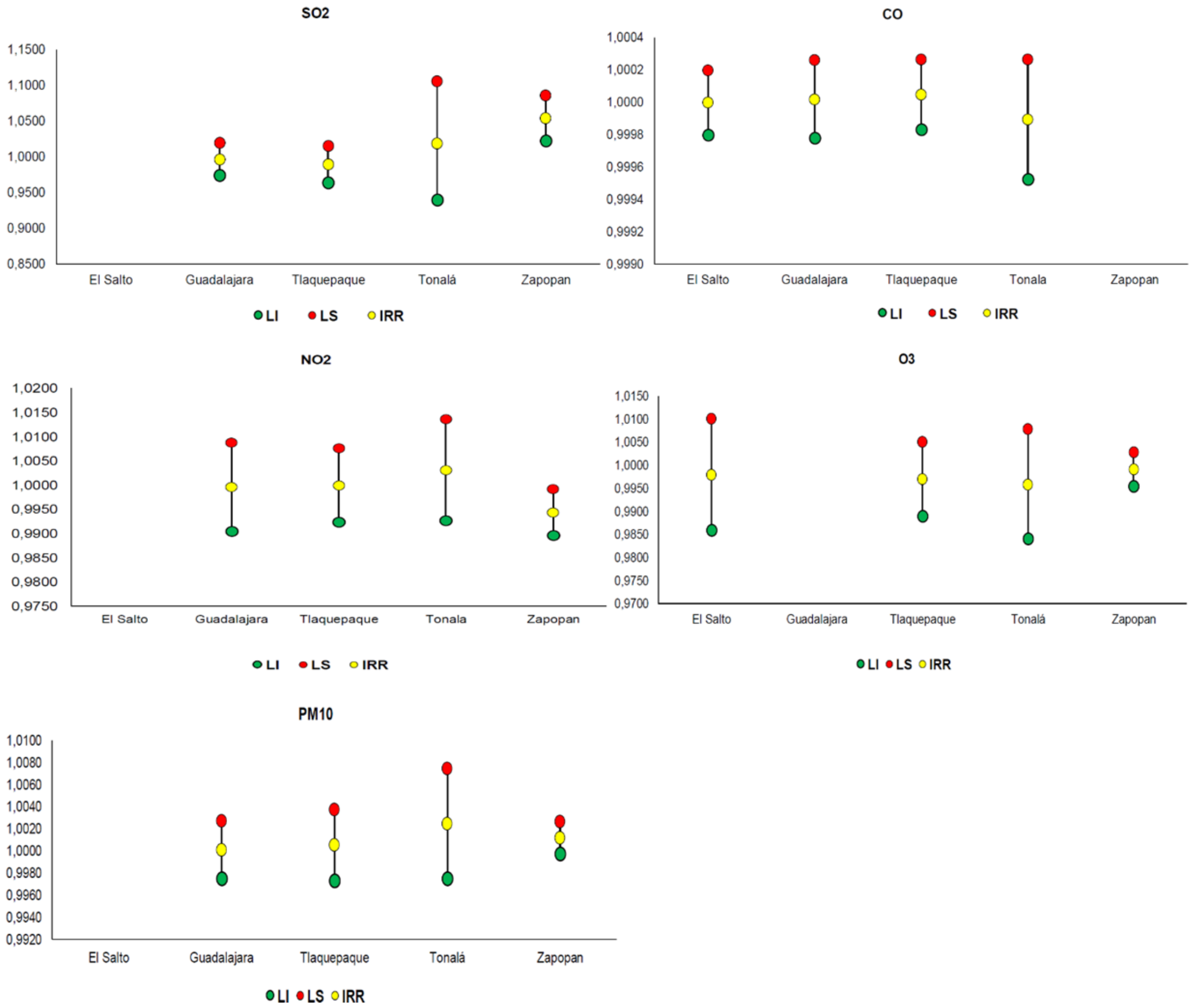


Fig. 7. Relative Risk Index (RRI) of daily mortality by all causes for MAG.

and cardiovascular cause (0.25%) were considered. In the case of O_3, the magnitudes of associations found in El Salto were 1.02% and 0.90% for all causes and >6 0 years, respectively (Table 9). On the other hand, all causes and age group of > 60 years were not significant in Guadalajara; whereas the upper limit in RRI values were 2.03%, 1.53% and 1.05% for 0-59 years, respiratory and cardiovascular causes, respectively. In Tlaquepaque, these associations presented the following values: 0.52% (by all causes), 1.41% (by age group: 0-59 years), 0.53% (by age group: > 60 years), 1.05% (by specific cause: respiratory diseases) and 1.40% (specific cause: cardiovascular diseases). In Tonala, age group did not show statistical significance; and values found for all causes and cardiovascular causes were low (0.79% and 1.19%, respectively). Finally, in the case of Zapopan, age group of > 60 years and cardiovascular causes did not show statistical significance; and values found for the remaining conditions were relatively low.

Regarding to PM_{10}, excepting cardiovascular causes, El Salto did not show any association between daily mortality and an increase of 10% in PM_{10} levels; whereas in Guadalajara and Tlaquepaque, the magnitude of these association was not important (Table 10). In addition, association between daily mortality and PM_{10} levels increased in 10% presented relative risk indexes minor than 1% for Tonala and Zapopan.

Mapping of Relative Risk Index

From spatial data of vectorial type, including estates and municipalities geo-referenced, risk indexes for daily mortality considering all causes were mapped by using a geographic information system (GIS) (QGIS v. 2.14.7) (QGIS, 2017). This information was obtained from National Institute of Statistics, Geography and Computing of Mexico (INEGI, 2017). Maps were generated for MAG including all municipalities considered. From Fig. 8(a), it can be observed that Zapopan and Tonala showed a good correlation between an increase of 10% in SO_2 levels and daily mortality, resulting in increases of 5.41% for Zapopan and 1.95% for Tonala in daily mortality.

Table 6. Rate ratios for all causes, age group (0–59 years and > 60 years) and specific cause (respiratory and cardiovascular diseases) daily mortality in relation to 10% increase in SO_2 mean Concentration for MAG during 2012–2015.

		SO_2				
		El Salto	Guadalajara	Tlaquepaque	Tonala	Zapopan
All causes	RRI	[a]	0.9971	0.9896	1.0195	1.0541
	LL	[a]	0.9744	0.9640	0.9399	1.0227
	UL	[a]	1.0202	1.0159	1.1060	1.0865
0–59 years	RRI	[a]	0.9859	1.0098	[a]	1.0448
	LL	[a]	0.9433	0.9575	[a]	0.9615
	UL	[a]	1.0305	1.0649	[a]	1.1354
> 60 years	RRI	[a]	0.9975	0.9894	1.0212	1.0570
	LL	[a]	0.9739	0.9594	0.9240	1.0135
	UL	[a]	1.0216	1.0202	1.1288	1.1023
Respiratory	RRI	[a]	0.9918	[a]	[a]	1.0224
	LL	[a]	0.9615	[a]	[a]	0.9654
	UL	[a]	1.0230	[a]	[a]	1.0821
Cardiovascular causes	RRI	[a]	0.9969	0.9707	[a]	1.0535
	LL	[a]	0.9721	0.9409	[a]	1.0154
	UL	[a]	1.0222	1.0014	[a]	1.0931

[a] Spaces in gray indicate that results were not significant. RRI: Relative Risk Index. LL: Lowed Limit. UL: Upper Limit.

Table 7. Rate ratios for all causes, age group (0–59 years and > 60 years) and specific cause (respiratory and cardiovascular diseases) daily mortality in relation to 10% increase in CO mean Concentration for MAG during 2012–2015.

		CO				
		El Salto	Guadalajara	Tlaquepaque	Tonala	Zapopan
All causes	RRI	1.0000	1.0000	1.0001	0.9999	[a]
	LL	0.9998	0.9998	0.9998	0.9995	[a]
	UL	1.0002	1.0003	1.0003	1.0003	[a]
0–59 years	RRI	[a]	1.0000	1.0001	[a]	1.0001
	LL	[a]	0.9995	0.9996	[a]	0.9996
	UL	[a]	1.0004	1.0005	[a]	1.0005
> 60 years	RRI	[a]	1.0000	1.0000	0.9999	1.0001
	LL	[a]	0.9998	0.9997	0.9995	0.9999
	UL	[a]	1.0003	1.0002	1.0003	1.0003
Respiratory causes	RRI	[a]	1.0001	0.9999	[a]	[a]
	LL	[a]	0.9998	0.9995	[a]	[a]
	UL	[a]	1.0004	1.0003	[a]	[a]
Cardiovascular causes	RRI	[a]	1.0000	1.0002	0.9998	1.0000
	LL	[a]	0.9998	1.0000	0.9994	0.9999
	UL	[a]	1.0003	1.0004	1.0003	1.0002

[a] Spaces in gray indicate that results were not significant. RRI: Relative Risk Index. LL: Lower Limit. UL: Upper Limit.

These relative risk indexes were too high in comparison with other criteria pollutants. SO_2 data were not available for El Salto, whereas, in Guadalajara and Tlaquepaque, this pollutant did not correlate and the associated relative risk found was not significant. In Zapopan, an increase of 10% in CO levels did not correlate with daily mortality; whereas Tonala presented correlation but without relative risk. On the other hand, in El Salto, Guadalajara and Tlaquepaque increased CO levels were well correlated with daily mortality, however, the relative risk indexes found were relatively low in comparison with SO_2 (Fig. 8(b)).

Regarding to NO_2, El Salto did not show a correlation; whereas, Zapopan, Guadalajara and Tlaquepaque had a good correlation, but RRI found were not significant. Only Tonala showed both, a good correlation between increased NO_2 levels and daily deaths, and significant relative risk indexes (Fig. 8(c)).

Regarding to ozone, Guadalajara and Tlaquepaque did not show a good correlation between daily mortality and an increase of 10% in O_3 concentrations. In the other hand, Zapopan and El Salto, although they showed a good correlation, when Poisson regression was applied, RRI obtained were not statistically significant. From all municipalities in MAG, only Tonala showed a significant effect on daily mortality as a result of increased O_3 levels (Fig. 8(d)).

In Fig. 8(e), it can be observed that estimated RRI obtained for Guadalajara and Tlaquepaque were much smaller than that found for Zapopan and Tonala, whereas in El Salto, increased PM_{10} levels did not correlate with

Table 8. Rate ratios for all causes, age group (0–59 years and > 60 years) and specific cause (respiratory and cardiovascular diseases) daily mortality in relation to 10% increase in NO_2 mean Concentration for MAG during 2012–2015.

		NO_2				
		El Salto	Guadalajara	Tlaquepaque	Tonala	Zapopan
All causes	RRI	^{a}	0.9996	1.0000	1.0032	0.9944
	LL	^{a}	0.9905	0.9924	0.9927	0.9896
	UL	^{a}	1.0088	1.0077	1.0137	0.9992
0–59 years	RRI	1.0020	1.0004	1.0009	0.9977	0.9975
	LL	0.9804	0.9834	0.9844	0.9847	0.9827
	UL	1.0024	1.0177	1.0177	1.0109	1.0125
> 60 years	RRI	^{a}	0.9997	1.0008	1.0050	0.9907
	LL	^{a}	0.9902	0.9918	0.9928	0.9835
	UL	^{a}	1.0092	1.0099	1.0173	0.9978
Respiratory causes	RRI	^{a}	0.9986	1.0038	^{a}	0.9960
	LL	^{a}	0.9857	0.9891	^{a}	0.9870
	UL	^{a}	1.0116	1.0187	^{a}	1.0051
Cardiovascular causes	RRI	^{a}	0.9995	0.9948	1.0032	0.9958
	LL	^{a}	0.9895	0.9856	0.9909	0.9892
	UL	^{a}	1.0096	1.0040	1.0156	1.0025

^{a} Spaces in gray indicate that results were not significant. RRI: Relative Risk Index. LL: Lowed Limit. UL: Upper Limit.

Table 9. Rate ratios for all causes, age group (0–59 years and > 60 years) and specific cause (respiratory and cardiovascular diseases) daily mortality in relation to 10% increase in O3 mean Concentration for MAG during 2012–2015.

		O_3				
		El Salto	Guadalajara	Tlaquepaque	Tonala	Zapopan
All causes	RRI	0.9980	^{a}	0.9971	0.9959	0.9992
	LL	0.9860	^{a}	0.9890	0.9841	0.9955
	UL	1.0102	^{a}	1.0052	1.0079	1.0030
0–59 years	RRI	^{a}	1.0018	0.9975	^{a}	0.9974
	LL	^{a}	0.9837	0.9811	^{a}	0.9887
	UL	^{a}	1.0203	1.0141	^{a}	1.0062
> 60 years	RRI	0.9967	^{a}	0.9959	^{a}	^{a}
	LL	0.9846	^{a}	0.9866	^{a}	^{a}
	UL	1.0090	^{a}	1.0053	^{a}	^{a}
Respiratory causes	RRI	^{a}	1.0016	0.9955	0.9925	0.9968
	LL	^{a}	0.9880	0.9808	0.9771	0.9901
	UL	^{a}	1.0153	1.0105	1.0081	1.0034
Cardiovascular causes	RRI	^{a}	1.0000	1.0042	0.9978	^{a}
	LL	^{a}	0.9896	0.9945	0.9839	^{a}
	UL	^{a}	1.0105	1.0140	1.0119	^{a}

daily mortality. However, it is important to note that excepting El Salto, in all municipalities studied in MAG, the effect of PM_{10} in mortality was not only well correlated but also had significant RRI values.

Comparison with Other Epidemiological Studies

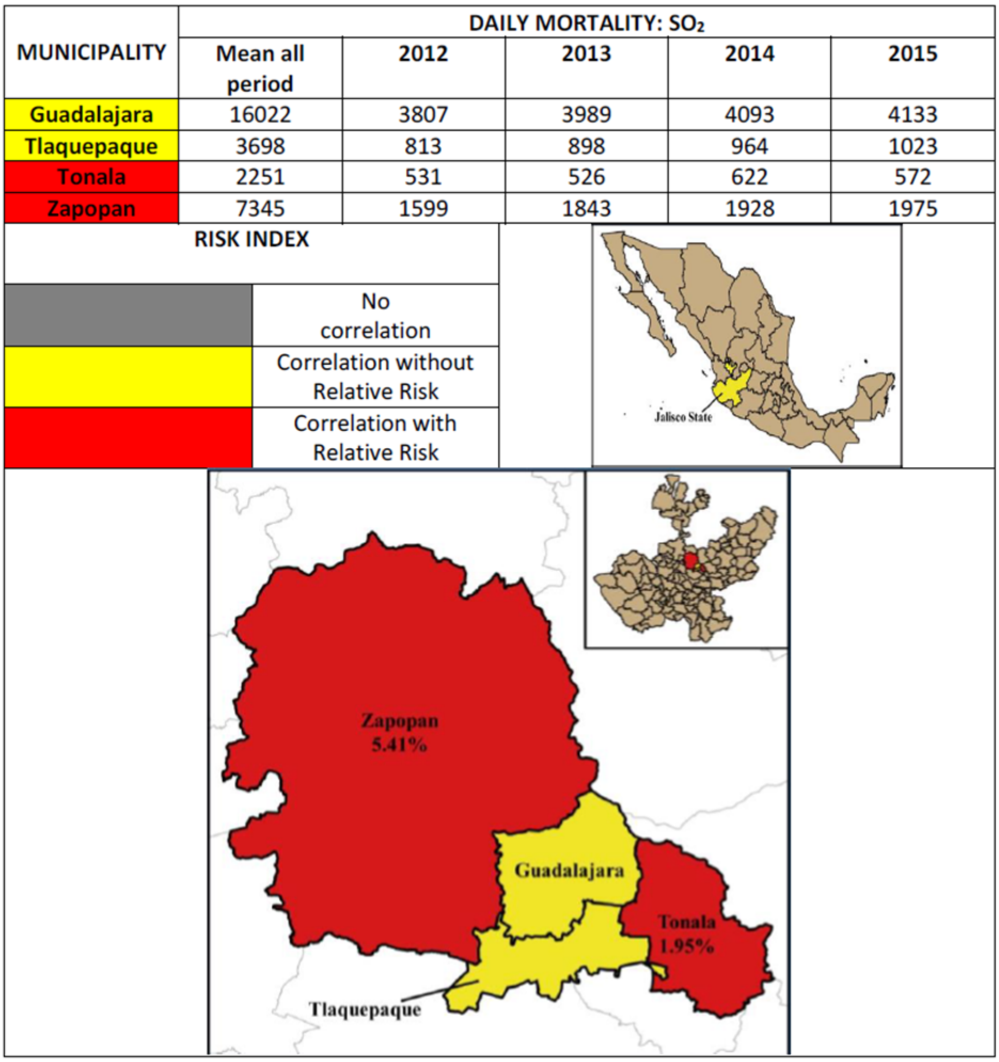
From Table 11, that RRI values obtained for the different municipalities of MAG were lower than those reported in other cities around the world. Tonala (by all causes) and Zapopan (by all causes and by cardiovascular and respiratory causes) presented the highest RRI values. RRI and 95% IC values found in Tonala and Zapopan were even higher than those reported for Athens (Toloumi *et al.*, 1994), Barcelona (Sunyer *et al.*, 1996), Zaragoza (Arribas-Monzón *et al.*, 2001) and thirteen more Spanish Cities (Ballester *et al.*, 2003). However, the magnitude of the association between an increase of 10% in SO_2 levels on daily mortality estimated for Zapopan was comparable to those reported for Tehran (Hadei *et al.*, 2017) and for Lyon (Zmirou *et al.*, 1996), considering all causes, and specific cause (respiratory and cardiovascular), indicating that the relative risk is significant. In the other hand, in the case of CO, RRI and 95% IC values estimated for municipalities of MAG were significantly lower than those reported for 13 Spanish Cities (Ballester *et al.*, 2003), European (Stieb *et al.*, 2002) and Italian Cities (Biggeri *et al.*, 2001); suggesting that the current relative risk associated to increased CO levels in 10% is not a problem in the municipalities of MAG (Table 12).

From Table 13, it can be observed that excepting Tonala, all municipalities studied in MAG did not present significant values for RRI. In the case of Tonala, RRI and 95% IC values found were lower than those reported in

Table 10. Rate ratios for all causes, age group (0–59 years and > 60 years) and specific cause (respiratory and cardiovascular diseases) daily mortality in relation to 10% increase in PM_{10} mean Concentration for MAG during 2012–2015.

		PM_{10}				
		El Salto	Guadalajara	Tlaquepaque	Tonala	Zapopan
All causes	RRI	[a]	1.0001	1.0006	1.0025	1.0012
	LL	[a]	0.9975	0.9974	0.9975	0.9998
	UL	[a]	1.0028	1.0038	1.0075	1.0027
0–59 years	RRI	[a]	1.0014	0.9997	[a]	[a]
	LL	[a]	0.9967	0.9929	[a]	[a]
	UL	[a]	1.0062	1.0066	[a]	[a]
> 60 years	RRI	[a]	1.0000	1.0011	[a]	1.0013
	LL	[a]	0.9973	0.9975	[a]	0.9997
	UL	[a]	1.0028	1.0048	[a]	1.0030
Respiratory causes	RRI	[a]	[a]	1.0018	[a]	1.0021
	LL	[a]	[a]	0.9962	[a]	0.9996
	UL	[a]	[a]	1.0074	[a]	1.0046
Cardiovascular causes	RRI	0.9998	1.0002	[a]	1.0029	1.0000
	LL	0.9972	0.9973	[a]	0.9973	0.9982
	UL	1.0024	1.0031	[a]	1.0085	1.0018

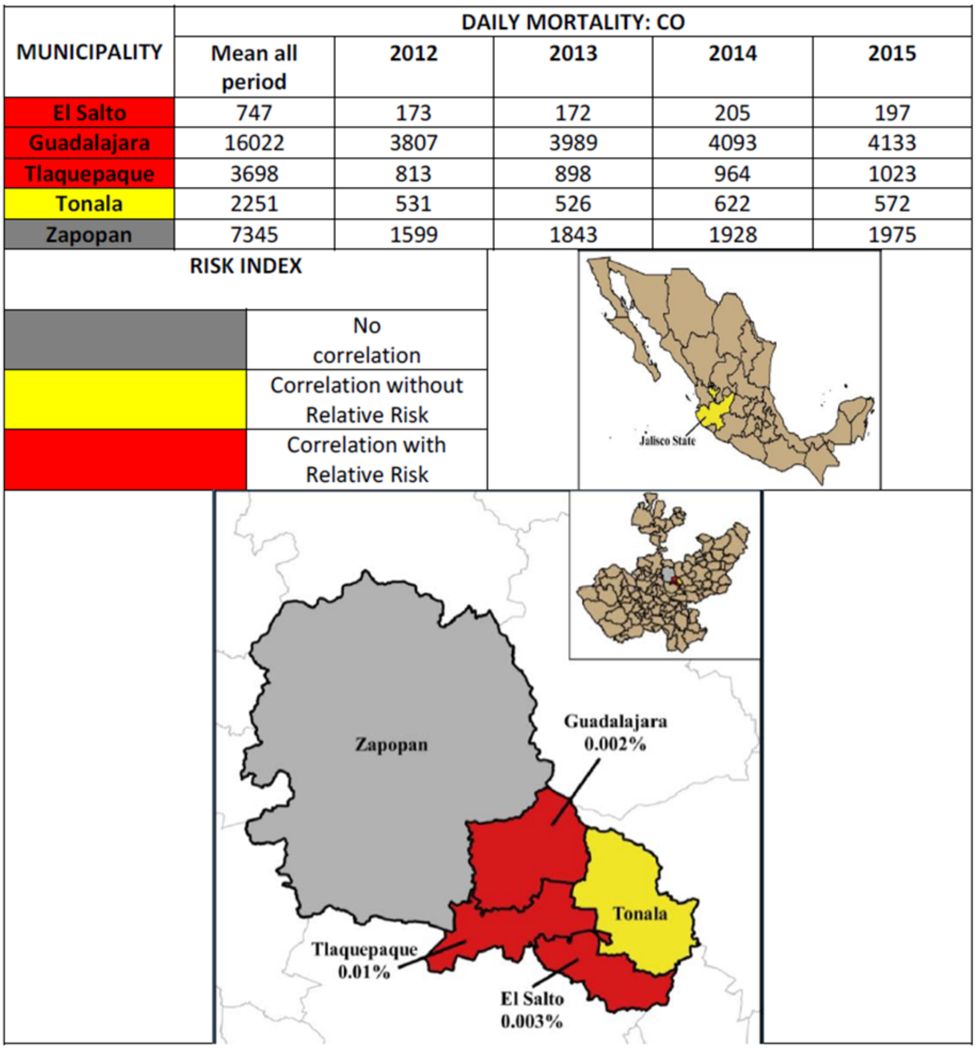
[a] Spaces in gray indicate that results were not significant. RRI: Relative Risk Index. LL: Lowed Limit. UL: Upper Limit.



MUNICIPALITY	DAILY MORTALITY: SO_2				
	Mean all period	2012	2013	2014	2015
🟨 Guadalajara	16022	3807	3989	4093	4133
🟨 Tlaquepaque	3698	813	898	964	1023
🟥 Tonala	2251	531	526	622	572
🟥 Zapopan	7345	1599	1843	1928	1975

RISK INDEX	
⬛	No correlation
🟨	Correlation without Relative Risk
🟥	Correlation with Relative Risk

Fig. 8(a). Relative Risk Index Map of daily mortality for SO_2 by all causes during 2012–2015 in MAG.



MUNICIPALITY	DAILY MORTALITY: CO				
	Mean all period	2012	2013	2014	2015
El Salto	747	173	172	205	197
Guadalajara	16022	3807	3989	4093	4133
Tlaquepaque	3698	813	898	964	1023
Tonala	2251	531	526	622	572
Zapopan	7345	1599	1843	1928	1975

RISK INDEX	
⬛	No correlation
🟨	Correlation without Relative Risk
🟥	Correlation with Relative Risk

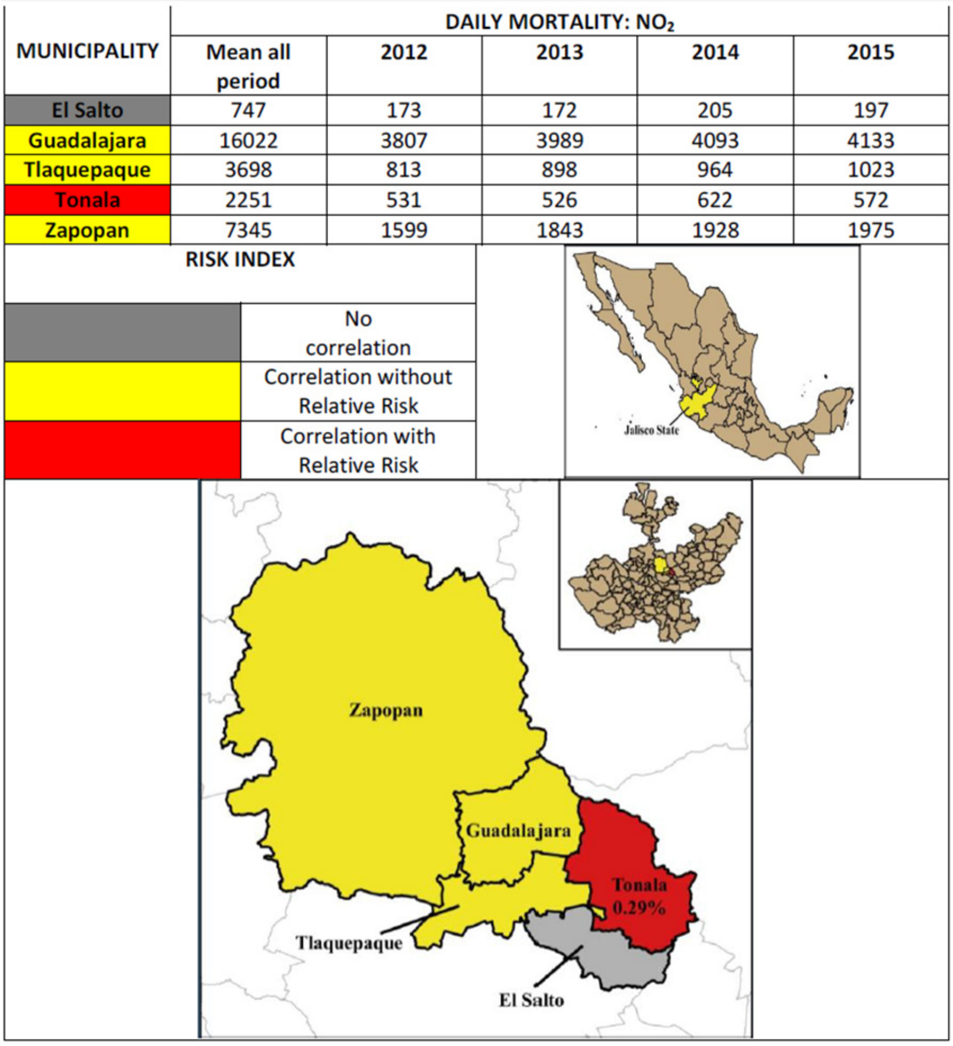
Fig. 8(b). Relative Risk Index Map of daily mortality for CO by all causes during 2012–2015 in MAG.

6 European Cities (Toloumi *et al.*, 1997), Italian Cities (Biggeri *et al.*, 2001) and Barcelona (Sunyer *et al.*, 1996); and considerably lower than Sao Paulo (Saldiva *et al.*, 1994). In the other hand, the magnitude of the association between daily mortality and an increase of 10% in NO_2 levels was comparable to those found in 13 Spanish Cities (Ballester *et al.*, 2003), Tehran (Hadei *et al.*, 2017), Paris (Quenel *et al.*, 1999) and some European Cities (Stieb *et al.*, 2002). Regarding to Ozone, from Table 14, it is possible to observe that only Guadalajara showed a relative risk high, since the rest of the municipalities did not have significant values. Comparing RRI and 95% IC values found in Guadalajara with those obtained in other cities of the world, relative risk found in Guadalajara was lower than 4 European cities (Toloumi *et al.*, 1997) and Tehran, Iran (Hadei *et al.*, 2017) and considerably lower than Barcelona (Sunyer *et al.*, 1996). The magnitude of the association between increased ozone levels in 10% and daily mortality obtained for Guadalajara was comparable to 8 cities in United States of America (Bell *et al.*, 2005).

Finally, regarding to PM_{10}, it was found that excepting El Salto, in all municipalities studied in MAG PM_{10} levels were well correlated with daily mortality, presenting significant RRI values, and being higher in Tonala. RRI and 95% IC values found in all municipalities in MAG were lower than those reported for European Cities (Dockery and Pope, 1994), some cities in United States of America (Dockery and Pope, 1994), Barcelona (Sunyer *et al.*, 1996), Lyon (Zmirou *et al.*, 1996), Temuco, Chile (Robles et al, 2015) and 13 Spanish cities (Ballester *et al.*, 2003); and considerably lower than values registered in Valencia (Ballester *et al.*, 2002) and some European cities (Laden *et al.*, 2006). The magnitude of the association between PM_{10} levels increased in 10% and daily mortality estimated for Tonala was comparable to some cities in London and United States of America (Ostro *et al.*, 1993), Athens (Toloumi *et al.*, 1994), Pudahuel in Chile (Robles *et al.*, 2015), and Tehran in Iran (Hadei *et al.*, 2017) (Table 15).

CONCLUSION

All measured air criteria pollutants showed a seasonal behavior. Higher temperatures and solar radiation intensities



MUNICIPALITY	DAILY MORTALITY: NO_2				
	Mean all period	2012	2013	2014	2015
⬛ El Salto	747	173	172	205	197
🟨 Guadalajara	16022	3807	3989	4093	4133
🟨 Tlaquepaque	3698	813	898	964	1023
🟥 Tonala	2251	531	526	622	572
🟨 Zapopan	7345	1599	1843	1928	1975

RISK INDEX

⬛	No correlation
🟨	Correlation without Relative Risk
🟥	Correlation with Relative Risk

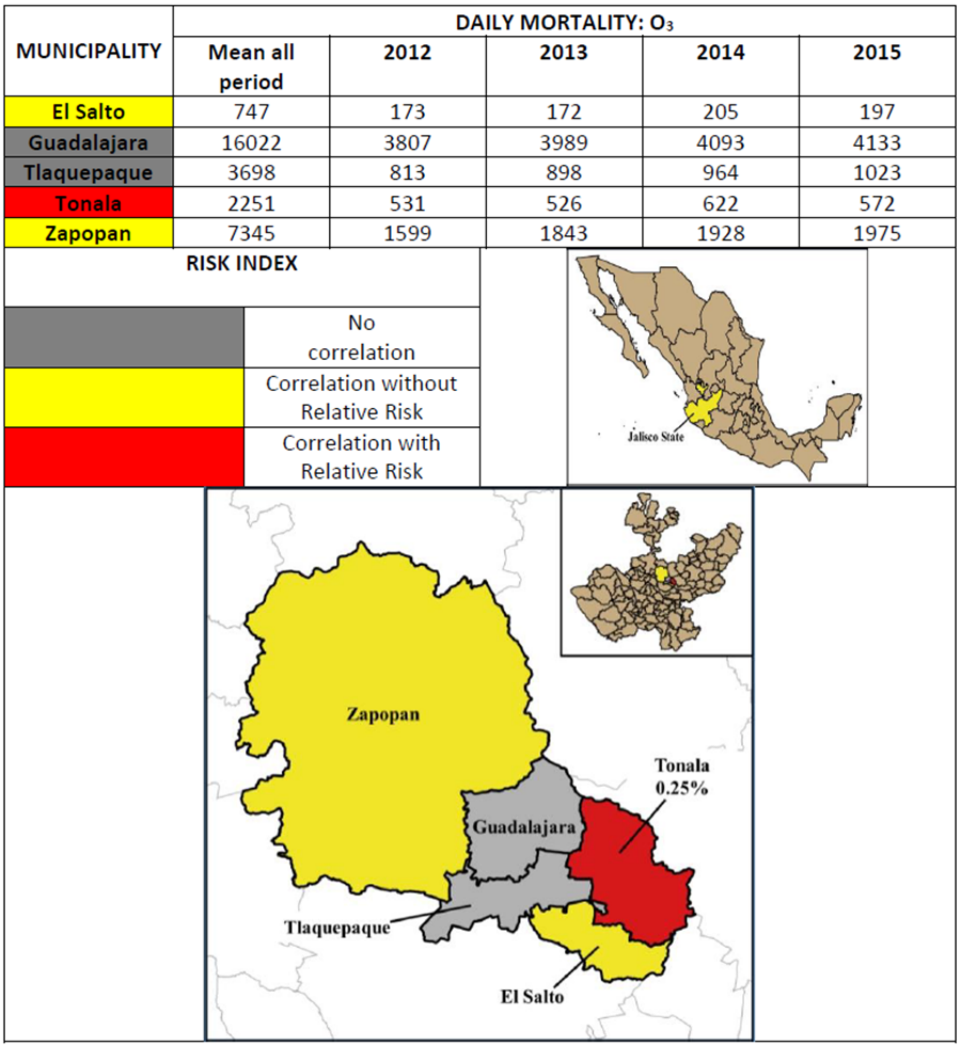
Fig. 8(c). Relative Risk Index Map of daily mortality for NO_2 by all causes during 2012–2015 in MAG.

during warm months influenced on the ozone levels, whereas, PM_{10}, NO_2, SO_2 and CO were influenced by thermal inversions occurring during cold months resulting in higher concentrations of these pollutants during this period.

Tlaquepaque registered the highest mean concentrations values for SO_2, PM_{10}, NO_2 and CO, whereas, Zapopan had the highest mean levels of O_3 during the study period. Comparing with the maximum permissible values established in the Mexican official standards on air quality, only O_3 (Tonala: 305 times) and PM_{10} (El Salto: 695 times) showed exceedances to the limit values.

Analysis of 2012–2015 daily mortality statistics in MAG showed an increase in deaths number when criteria pollutants were increased in 10% on the same day and on the thirteen previous days. In general, excepting for SO_2, the magnitude of the effect associated to an increase of air pollutants on daily mortality was small but statistically significant in all municipalities of MAG. In the case of El Salto, this municipality has a small population size in comparison with the other municipalities in MAG. It could explain the lack of significance at this level of analysis, however, the lack of effects must be considered. From MLR analysis, it was found that criteria pollutants explained daily mortality in 65.93% for Guadalajara, and in 47.20% for Zapopan. Consequently, stronger associations were observed in Guadalajara and Zapopan, which are the most populated municipalities and present the highest mortality rates in MAG. In the case of Tonala, it is a zone with a great industrial development, it could explain the strong association found. It is important to note that, unlike expected, in spite of Guadalajara is the most populated municipality in MAG, excepting for O_3, RRI values were not high in comparison with the other municipalities.

SO_2 presented the highest RRI values in MAG, especially for Zapopan and Tonala for the majority of the population, since the age subgroups that presented the highest values were 0–59 years (13.54%) and > 60 years (10.23%). This could be important given the large exposed population. These values were comparable to those reported for European cities and some sites in United States of America. Regarding to CO, excepting Guadalajara and Tlaquepaque, associations were not significant in the most of studied municipalities. In spite of associations in Guadalajara and Tlaquepaque were statistically significant,



MUNICIPALITY	DAILY MORTALITY: O_3				
	Mean all period	2012	2013	2014	2015
El Salto	747	173	172	205	197
Guadalajara	16022	3807	3989	4093	4133
Tlaquepaque	3698	813	898	964	1023
Tonala	2251	531	526	622	572
Zapopan	7345	1599	1843	1928	1975

RISK INDEX	
▨	No correlation
🟨	Correlation without Relative Risk
🟥	Correlation with Relative Risk

Fig. 8(d). Relative Risk Index Map of daily mortality for O_3 by all causes during 2012–2015 in MAG.

their magnitude was low, suggesting that the current levels of CO in MAG did not have any effect on daily mortality until this moment.

In the case of NO_2, this pollutant was also related to daily mortality. The increase of risk as percentage resulting from an increase of 10% in NO_2 levels was 1.77% for age subgroup of 0-59 years in Guadalajara and Tlaquepaque, 1.87% by respiratory causes in Tlaquepaque, 1.73% for age subgroup of > 60 years for Tonala, and 1.25% for 0–59 years for Zapopan. Although values are significant, they were considerably lower than those found for SO_2. Excepting Zapopan, the association between daily mortality and increased O_3 levels was significant for all studied municipalities. The magnitude of this association was low when an increase of 10% in O_3 concentrations was considered, resulting in an increase of risk as percentage of 1.02% by all causes in El Salto, 2.03% in age group of 0–59 years for Guadalajara, 1.41 and 1.40% in age group of 0–59 years and by cardiovascular diseases in Tlaquepaque, and 1.19% by respiratory causes in Tonala.

Finally, regarding to PM_{10}, only Zapopan and Tonala showed statistically significant RRI values. However, considering that Zapopan is a large urban zone and Tonala is an important industrial area, with a different mixture of pollutants, the confounding effect of particulate matter may be stronger. Therefore, it is necessary to take in account that composition of air ambient in large urban areas is extremely complex over time and space.

This complexity and variability of mixtures in which different pollutants coexist in megacities as MAG also makes difficult to assess isolated effects for each criteria pollutant. Synergic effects must be assessed, since the total risk levels posed by several pollutants could be higher than average risk acceptance levels (Cheng *et al.*, 2018). The nature and sources of particulate matter must be considered when association between daily mortality and PM_{10} levelsis assessed. There is an important implication in relation with the size and chemical composition of the particles, but, monitoring, control, strategies and regulations play an important role in this type of studies (Robles *et al.*, 2017).

In addition, the differences in magnitude and precision of RRI for criteria pollutants could result from variations in measurement quality for each pollutant. In particular,

MUNICIPALITY	DAILY MORTALITY: PM_{10}				
	Mean all period	2012	2013	2014	2015
El Salto	747	173	172	205	197
Guadalajara	16022	3807	3989	4093	4133
Tlaquepaque	3698	813	898	964	1023
Tonala	2251	531	526	622	572
Zapopan	7345	1599	1843	1928	1975

RISK INDEX	
◼	No correlation
🟨	Correlation without Relative Risk
🟥	Correlation with Relative Risk

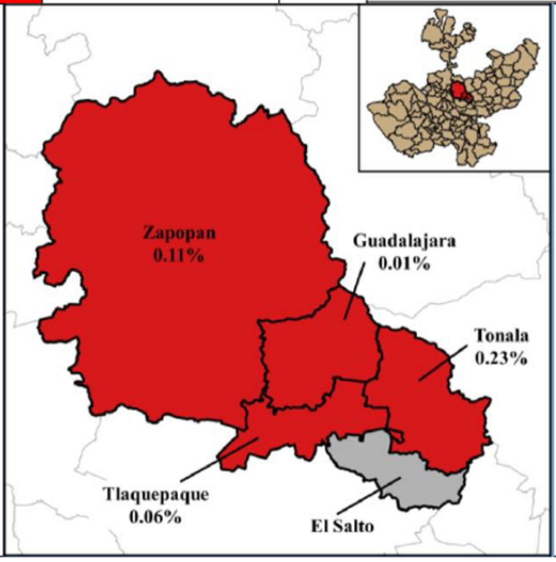


Fig. 8(e). Relative Risk Index Map of daily mortality for PM_{10} by all causes during 2012–2015 in MAG.

estimations more precise of particulate matter could lead to stronger spatial correlations and better results. Behavioral changes during the study period were not assessed due to lack of data.

Unlike other sites in mid-latitudes, since temperature in Mexico is moderate, extremes values almost never occur, therefore only minimum temperature showed an effect on daily mortality. In general, all studied municipalities in MAG presented an inverse association between temperature values and daily mortality, with lag effects between 1 and 13 days. Secular trends in mortality also can be attributed to influenza epidemics (Loomis *et al.*, 1996), however, information about possible epidemic effects were not available.

This study could not predict if reductions in criteria pollutants levels would have an important effect on a reduction in daily mortality, however, considering the large size of population exposed, even when observed associations were small but significant, RRI values found are of public concern. This study provides a basic support to policy makers and efforts to control the current air pollution levels in MAG, especially with respect to SO_2. Important considerations are discussed below.

Nature of the study: Ecological studies of time series as this approach only allows to assess the acute impact of air pollution. It is not possible to distinguish between deaths that have simply been advanced a few days or months, and those that constitute an important lost in years of life (harvesting effect). To assess the long-term impact of exposition to air pollutants, cohort studies are more appropriate. In the case of ozone, in spite of this pollutant presented a greater number of exceedances to air quality standard, associations with daily mortality were not significant and their magnitudes were low. It suggests that the effects of O_3 observed on health occur in a long-term, therefore, it is recommended that, for future studies, the analysis of the effects associated with this pollutant be assessed in a long-term by using cohort studies.

Epidemiological data register: An aspect that may constitute a problem is generated by population mobility, since some deaths of residents could occur outside MAG, or some non-residents deaths could occur in MAG. This problem was solved to filtering information by using interactive data query system of INEGI by residence municipality.

Table 11. Comparison of RRI for daily mortality by an increase of 10 % in SO_2 concentrations found in this study with those reported by other authors.

Site	Author	RRI	95% IC	Cause
Guadalajara	This study	0.9971	0.9744–1.0202	All causes
		0.9918	0.9615–1.0230	Respiratory causes
		0.9969	0.9721–1.0222	Cardiovascular causes
Tlaquepaque	This study	0.9866	0.9640–1.0159	All causes
		0.9707	0.9409–1.0014	Cardiovascular causes
Tonala	This study	1.0195	0.9399–1.1060	All causes
Zapopan	This study	1.0541	1.0227–1.0865	All causes
		1.0224	0.9654–1.0821	Respiratory causes
		1.0535	1.0154–1.0931	Cardiovascular causes
Athens, Greece	Toloumi *et al.* (1994)	1.0126	1.0091–1.0161	All causes (Winter season)
		1.0053	1.0011–1.0117	All causes (Summer season)
Barcelona, Spain	Sunyer *et al.* (1996)	1.014	1.0030–1.025	All causes (Winter season)
		1.0096	1.0021–1.0172	All causes (Summer season)
		1.0138	1.0068–1.0208	Respiratory diseases (Winter season)
		1.0076	1.0040–1.0192	Cardiovascular diseases (Winter season)
		1.0131	1.0026–1.0230	Respiratory diseases (Summer season)
		1.0218	1.0038–1.0406	Cardiovascular diseases (Summer season)
Lyon, France	Zmirou *et al.* (1996)	1.045	1.0080–1.086	All causes
		1.090	1.041–1.144	Respiratory diseases
		1.041	1.010–1.070	Cardiovascular diseases
13 Spanish Cities	Ballester *et al.* (2003)	1.005	1.001–1.010	All causes
		1.006	1.001–1.020	Respiratory diseases
		1.020	1.0030–1.020	Cardiovascular diseases
Zaragoza, Spain	Arribas-Monzón *et al.* (2001)	1.018	1.001–1.036	Cardiovascular diseases

Table 12. Comparison of RRI for daily mortality by an increase of 10% in CO concentrations found in this study with those reported by other authors.

Site	Author	RRI	95% IC	Cause
El Salto	This Study	1.0000	0.9998–1.0002	All causes
Guadalajara	This Study	1.0000	0.9998–1.0003	All causes
		1.0000	0.9995–1.0004	0–59 years
		1.0000	0.9998–1.0003	> 60 years
		1.0001	0.9998–1.0004	Respiratory diseases
		1.0000	0.9998–1.0003	Cardiovascular diseases
Tlaquepaque	This Study	1.0001	0.9998–1.0003	All causes
		1.0001	0.9996–1.0005	0–59 years
		1.0000	0.9997–1.0002	> 60 years
		0.9999	0.9995–1.0003	Respiratory diseases
		1.0002	1.0000–1.0004	Cardiovascular diseases
Tonala	This Study	0.9999	0.9995–1.0003	All causes
		0.9999	0.9995–1.0003	> 60 years
		0.9998	0.9994–1.0003	Cardiovascular diseases
Zapopan	This Study	1.0001	0.0006–1.0005	0–59 years
		1.0001	0.9999–1.0003	> 60 years
		1.0000	0.9999–1.0002	Cardiovascular diseases
13 Spanish Cities	Ballester *et al.* (2003)	1.0150	1.0050–1.0260	All causes
		1.0320	1.0140–1.0510	Respiratory diseases
		1.0230	1.0130–1.0320	Cardiovascular diseases
Italian Cities	Biggeri *et al.* (2001)	1.0140	1.0100–1.0180	All causes
		1.0340	1.0150–1.0530	Respiratory diseases
		1.0180	1.0120–1.0240	Cardiovascular diseases
European Cities	Stieb *et al.* (2002)	1.0140	1.0090–1.0180	All causes
		1.0190	1.0080–1.0300	Respiratory diseases
		1.057	1.0370–1.0780	Cardiovascular diseases

Table 13. Comparison of RRI for daily mortality by an increase of 10% in NO_2 concentrations found in this study with those reported by other authors.

Site	Author	RRI	95% IC	Cause
El Salto	This Study	1.0020	0.9804–1.0024	0–59 years
Guadalajara	This Study	0.9996	0.9905–1.0088	All causes
		1.0004	0.9834–1.0177	0–59 years
		0.9997	0.9902–1.0092	> 60 years
		0.9986	0.9857–1.0116	Respiratory diseases
		0.9995	0.9895–1.0096	Cardiovascular diseases
Tlaquepaque	This Study	1.0000	0.99245–1.0077	All causes
		1.0009	0.9844–1.0177	0–59 years
		1.0008	0.9918–1.0099	> 60 years
		1.0038	0.9891–1.0187	Respiratory diseases
		0.9948	0.9856–1.0040	Cardiovascular diseases
Tonala	This Study	1.0032	0.9927–1.0137	All causes
		0.9977	0.9847–1.0109	0–59 years
		1.0050	0.9928–1.0173	> 60 years
		1.0032	0.9909–1.0156	Cardiovascular diseases
Zapopan	This Study	0.9944	0.9896–0.9992	All causes
		0.9975	0.9827–1.0125	0–59 years
		0.9907	0.9835–0.9978	> 60 years
		0.9966	0.9870–1.0051	Respiratory diseases
		0.9958	0.9892–1.0025	Cardiovascular diseases
6 European Cities	Toloumi *et al.* (1997)	1.0130	1.0091–1.0180	All causes
Barcelona	Sunyer *et al.* (1996)	1.0340	1.0130–1.0550	All causes (all year)
		1.0260	0.9950–1.0580	All causes (Winter)
		1.0400	1.0130–1.0680	All causes (Summer)
		1.0380	1.0090–1.0680	Cardiovascular diseases (all year)
		0.9990	0.9570–1.0430	Cardiovascular diseases (Winter)
		1.0690	1.0300–1.1100	Cardiovascular diseases (Summer)
		1.0260	0.9660–1.0890	Respiratory diseases (all year)
		0.9960	0.9080–1.0940	Respiratory diseases (Winter)
		1.0470	0.9700–1.1300	Respiratory diseases (Summer)
13 Spanish Cities	Ballester *et al.* (2003)	1.0060	1.0030–1.0080	All causes
		1.0120	1.0030–1.0210	Respiratory diseases
		1.0080	1.0030–1.0160	Cardiovascular diseases
Paris	Quenel *et al.* (1999)	1.0080	1.0040–1.0110	All causes
		1.0080	1.0040–1.0210	Respiratory diseases
		1.0090	1.0030–1.0160	Cardiovascular diseases
Italian Cities	Biggeri *et al.* (2001)	1.0120	1.0080–1.0150	All causes
		1.0200	1.0060–1.0350	Respiratory diseases
		1.0150	1.0100–1.0200	Cardiovascular diseases
European Cities	Stieb *et al.* (2002)	1.0060	1.0050–1.0070	All causes
		1.0140	1.0070–1.0210	Respiratory diseases
		1.0070	1.0050–1.0090	Cardiovascular diseases
Sao Paulo, Brazil Children population	Saldiva *et al.* (1994)	1.3000	1.1700–1.4300	Respiratory diseases

Air quality data register: About quantity and quality of atmospheric pollution indexes, the data of interest are not absolute values of air pollutants, but rather their fluctuations along a time period.

Effect of population characteristics and seasonally on estimation of the magnitude of association between air pollution and mortality: It was found a positive relationship between atmospheric pollution and mortality in a short-term, suggesting that the current atmospheric levels could have an effect on the number of early deaths. In spite of the magnitude of these associations were relative low, their implications on public heath are important, considering the size of exposed population and the need to establish effective control measures. In addition, the variability of obtained parameters from fitted regression models depends on the population size and the extension of the study period. With respect to the first, the number of habitants between municipalities in this study varied considerably, for this reason, estimations tended to be unstable as they are disaggregated by specific cause.

Table 14. Comparison of RRI for daily mortality by an increase of 10% in O_3 concentrations found in this study with those reported by other authors.

Site	Author	RRI	95% IC	Cause
El Salto	This Study	0.9980	0.9860–1.0102	All causes
		0.9967	0.9846–1.0090	> 60 years
Guadalajara	This Study	1.0018	0.9837–1.0203	0–59 years
		1.0016	0.9880–1.0153	Respiratory diseases
		1.0000	0.9896–1.0105	Cardiovascular diseases
Tlaquepaque	This Study	0.9971	0.9890–1.0052	All causes
		0.9975	0.9811–1.0141	0–59 years
		0.9959	0.9866–1.0053	> 60 years
		0.9955	0.9808–1.0105	Respiratory diseases
		1.0042	0.9945–1.0140	Cardiovascular diseases
Tonala	This Study	0.9959	0.9841–1.0079	All causes
		0.9925	0.9771–1.0081	Respiratory diseases
		0.9978	0.9839–1.0119	Cardiovascular diseases
Zapopan	This Study	0.9992	0.9955–1.0030	All causes
		0.9974	0.9887–1.0062	0–59 years
		0.9968	0.9901–1.0034	Respiratory diseases
4 European Cities (APHEIS Project)	Toloumi *et al.* (1997)	1.0230	1.0140–1.0330	All causes
Barcelona, Spain	Sunyer *et al.* (1996)	1.0480	1.0120–1.0800	All causes (all year)
		1.0260	0.9650–1.0910	All causes (Winter)
		1.0580	1.0170–1.1010	All causes (Summer)
		1.0580	1.0090–1.1111	Cardiovascular diseases (all year)
		0.9992	0.9110–1.079	Cardiovascular diseases (Winter)
		1.0880	1.0280–1.1520	Cardiovascular diseases (Summer)
		1.07100	0.9620–1.1920	Respiratory diseases (all year)
		1.1400	0.9240–1.4060	Respiratory diseases (Winter)
		1.0500	0.9270–1.1880	Respiratory diseases (Summer)
8 Cities in United States of America	Bell *et al.* (2005)	1.0087	1.0055–1.0118	All causes

Regarding to the latter aspect, data availability reduced the study period to 4 years, being more difficult to find results with statistical significance and resulting in association magnitudes relatively low. However, considering the level of information updating, it could be an advantage, since the assessment of the impact of atmospheric pollution on mortality is closer to the current conditions, making it more representative.

Study Area: Low temperatures typical of winter season at the first hours in the morning are associated to thermal inversion conditions that depending on topography of the site, could condition the dispersion of pollutants. In the case of dispersion occur at low levels in the atmosphere, could result in an increase of pollutants concentrations at ground level, causing the delayed effect of pollutants on health and mortality of exposed population.

Exposition measurement: SO_2, CO, PM_{10} and $PM_{2.5}$ showed a greater association with daily mortality in this study, despite the fact that the largest exceedances were present for ozone. This can be explained because of temporality of peaks in ozone concentration reduces the exposition time to this pollutant to just a few hours of the day, when radiation intensity is high and photochemical activity is intense (midday). In addition, this exposition period matches office and school hours when the most of population is developing their activities in intramural.

Threshold values for atmospheric pollution: Even when air quality standards are being met, population health could be in risk, since exposition levels are greater than those recommended by World Health Organization (WHO). Mexican standard for NO2 (NOM-023-SSA1-1993) establish as a reference value of 0.21 ppm (395 µg m^{-3}) as maximum mean concentration in one hour, almost twice the value recommended by WHO of 200 µg m^{-3} as mean concentration in one hour (WHO, 2006). In the case of SO_2, NOM-022-SSA1-2010 propose a limit value of 288 µg m^{-3} in 24 hours, approximately ten times the value established by WHO (20 µg m^{-3} as mean concentration in 24 hours). In the other hand, in the case of particulate matter, Mexican standard (NOM-025-SSA1-2014) establishes 75 µg m^{-3} and 45 µg m^{-3} as mean concentration in 24 hours for PM_{10} and $PM_{2.5}$, respectively; whereas, WHO recommends 50 µg m^{-3} and 25 µg m^{-3}. This might explain why the levels of these pollutants did not exceed reference values of air quality standards but showed significant associations with daily mortality.

Future Works Recommendations

Air Quality: It is necessary to expand the monitoring infrastructure where it is insufficient, and in those zones

Table 15. Comparison of RRI for daily mortality by an increase of 10 % in PM_{10} concentrations found in this study with those reported by other authors.

Site	Author	RRI	95% IC	Cause
El Salto	This Study	0.9998	0.9972–1.0024	Cardiovascular diseases
Guadalajara	This Study	1.0001	0.9975–1.0028	All causes
		1.0014	0.9967–1.0062	0–59 years
		1.0000	0.9973–1.0028	> 60 years
Tlaquepaque	This Study	1.0002	0.9973–1.0031	Cardiovascular diseases
		1.0006	0.9974–1.0038	All causes
		0.9997	0.9929–1.0066	0–59 years
		1.0011	0.9975–1.0048	> 60 years
		1.0018	0.9962–1.0074	Respiratory diseases
Tonala	This Study	1.0025	0.9975–1.0075	All causes
		1.0029	0.9973–1.0085	Cardiovascular diseases
Zapopan	This Study	1.0012	0.9998–1.0027	All causes
		1.0013	0.9997–1.0030	> 60 years
		1.0021	0.9996–1.0046	Respiratory diseases
		1.0000	0.9982–1.0018	Cardiovascular diseases
Cities in London and United States of America	Ostro (1993)	1.0096	1.0063–1.0130	All causes
European Cities	Dockery and Pope (1994)	1.0100	1.0070–1.0160	All causes
Athens	Toloumi *et al.* (1994)	1.0050	1.0030–1.0070	All causes
Barcelona	Sunyer *et al.* (1996)	1.0068	1.0028–1.0107	All causes
Valencia	Ballester *et al.* (2002)	1.0090	1.0030–1.1500	All causes
Cities in United States of America	Dockery and Pope (1994)	1.0140	1.0080–1.0180	Cardiovascular diseases
Barcelona	Sunyer *et al.* (1996)	1.0089	1.0036–1.0114	Cardiovascular diseases
Valencia	Ballester *et al.* (2002)	1.0130	1.0030–1.0230	Cardiovascular diseases
Cities in United States of America	Dockery and Pope (1994)	1.0340	1.0150–1.0370	Respiratory diseases
Lyon	Zmirou *et al.* (1996)	1.0050	1.0000–1.0170	Respiratory diseases
13 Spanish Cities	Ballester *et al.* (2003)	1.0060	1.0020–1.0150	All causes
		1.0120	1.0050–1.0800	Cardiovascular diseases
		1.0130	1.0010–1.0260	Respiratory diseases
European Cities	Laden *et al.* (2006)	1.1600	1.0700–1.2600	All causes
		1.2700	0.9600–1.6900	Lung Cancer
		1.2800	1.1300–1.4400	Cardiovascular diseases
Pudahuel, Chile	Robles *et al.* (2015)	1.0086	1.0007–1.0165	Cardiorespiratory diseases
Temuco, Chile	Robles *et al.* (2015)	1.0126	1.0004–1.0250	Cardiorespiratory diseases
Tehran, Iran	Hadei *et al.* (2017)	1.006	1.004–1.008	All causes

where there are enough monitoring stations, it is necessary that those responsible define the classification with respect to their representativeness, assessing their distribution to assure that obtained data be representative of air quality at an urban scale.

Health: Information about air pollution and its impact on health is often sub estimated since between 18 and 30% of total population do not have a health insurance, and is not being included in statistics. Relative information about criteria pollutants and their effects on health is not adequately communicated, therefore, the most of population do not know neither the risks to health associated to these pollutants nor protection measures to be implemented.

Finally, regarding to decision makers in health matter, another aspect must be considered, for example, to assess the way in which pollutants and health indexes are related, to investigate the duration of this relationship along time, to assess if this association can be attributed to a simply advance in death date (harvesting effect) or if this association stays with the time, which would be an indicator of significant and sustained impact.

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