



# Title: Short-term association between morbidity and daily concentrations of O3 and PM10 in the Bajío region: A time series study

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# 1. Introduction

- ▶ Air pollution is one of the main causes of death and disease worldwide. It is widely supported by scientific evidence that air pollution is the major global public health risk factor (Bodor et al. 2022). According to WHO statistics, more than 80% of urban residents in Metropolitan Areas are exposed to air quality levels which exceeds the established permissible maximum limits in the regulations. The increase of atmospheric pollution caused by the combustion of fossil fuels, transport and industry, is responsible for the increasing morbidity and mortality, especially by respiratory and circulatory diseases.
- ▶ Due to differences in size, chemical composition and concentration, some atmospheric particles are very dangerous to human body. Particulate matter penetrates deep in pulmonary system, causing adverse effects on human health, particularly on respiratory and circulatory systems (Bagherian et al. 2016). Bergmann et al. (2020) reported that the exposure to high concentrations of air pollutants such as  $PM_{10}$  and  $O_3$  is associated with both, mortality and morbidity diseases.
- ▶ The increased  $PM_{10}$  and  $PM_{2.5}$  concentrations are associated with an increased morbidity in the European Union, reducing the average life span by 8.6 months (Bodor et al. 2022).
- ▶ In addition to effects of  $PM_{10}$ , there is an increasing evidence that ozone may play a significant role in generating adverse health effects. Atmospheric ozone levels have become a growing public health concern, since  $O_3$  is a powerful oxidant.

- ▶ Epidemiological studies have reported a positive and significant correlation between ozone levels and cardiovascular mortality and morbidity in different regions of the world (Lim et al. 2019; Raza et al. 2019; Yang et al. 2018; Yin et al. 2017).
- ▶ Consequently, air pollution constitutes a significant threat to the population, particularly to population sub-groups, which can be considered as vulnerable such as children, elderly, asthmatic people or people with pre-existing conditions.
- ▶ Children are susceptible to poor air quality since their lungs are still developing (Ibrahim et al. 2021). Studies about exposure to air pollutants and health effects on children are well documented (Ab Manan et al. 2018; Cheng et al. 2021; Horne et al. 2018; Mazenq et al. 2017).
- ▶ On the other hand, older adults have increased their vulnerability to cardiovascular diseases. Therefore, it is important to get supporting evidence to develop pollution control policies in order to protect elderly.
- ▶ In this way, Time-series studies are useful to provide valuable information that can be used by decision makers and health professionals to establish new air quality standards or regulations.

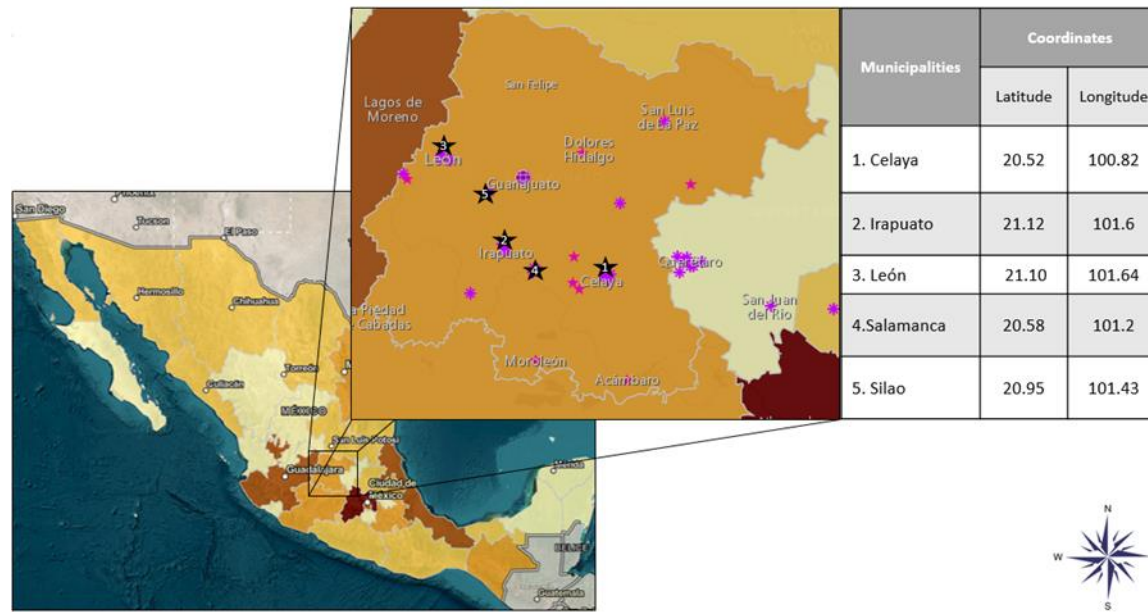
- ▶ Some epidemiological studies have been carried out in Mexico to assess the association between atmospheric pollutants and morbidity; however, excepting Mexico City, the available data and information are not enough to get a diagnosis about the prevailing situation in the remaining metropolitan areas of the country.
- ▶ Therefore, the aim of this study was to assess the association between short-term exposure to PM10 and O3 and morbidity during 2012-2015 in 5 Metropolitan Areas of the Bajío region in Guanajuato, Mexico, considering age sub-groups (0-59 years and >60 years), gender, all causes and specific cause (respiratory and circulatory diseases), seasonal trends in air quality data and meteorological variables.
- ▶ In addition, in this study, we assessed the effects derived from a hypothetical scenario in which daily mean concentration of atmospheric pollutants increases in 10%, in order to estimate the resulting association in a future scenario. Results obtained here, allowed us to quantify the number of exceedances to regulation for each pollutant, to identify in which region of the Bajío these exceedances are higher, and to identify in which areas of this region, relative risk indexes were higher, as well as the age sub –group more vulnerable.

## 2. Methodology

### 2.1 Study Area

- ▶ For this study, the municipalities of León, Silao, Irapuato, Celaya and Salamanca in the state of Guanajuato, Mexico were considered.
- ▶ These five municipalities constitute the Bajío corridor, which comprise a total of 2, 652, 893 habitants. These five municipalities constitute the Bajío corridor, which comprise a total of 2, 652, 893 habitants.
- ▶ León is the most populated city in the state of Guanajuato, and the fourth-most populated city in the country, with 1,578,626 habitants. León is part of the macro region known as Bajío, located in the Central Mexican Plateau. The main economic activity in León is shoe and leather industry, but in the last decade, automotive industry has been developed, with several industrial parks in this sector.
- ▶ Silao, has a total of 83, 352 habitants, and their main productive activities are agriculture and automotive.
- ▶ Salamanca has a population of 160, 682 habitants, being a region very industrialized, the main industries are energy, petrochemical, automotive, food and electronic.

- ▶ Celaya is an important crossroad of trade toward the Northern and Western side of the country. Has a total of 378, 143 habitants, and the main productive activities are agriculture, livestock, energy, electric, pharmaceutic, paper, chemical, steel and processed food.
- ▶ Irapuato is the second biggest municipality in Guanajuato, with 452, 090 habitants, being their main economic activities textile industry, automotive industry, and agriculture for exportation.
- ▶ Figure 2.1 Location of municipalities of the Bajío region considered in this study



Source: Own elaboration

## 2.2 Air Quality and meteorological data

- ▶ Air quality (For O<sub>3</sub> and PM<sub>10</sub>) and meteorological data (Temperature and Relative Humidity) measured by from automatic monitoring stations in Metropolitan Areas of León, Celaya, Salamanca, Silao and Irapuato were obtained from SINAICA (National System of Air Quality Information) during 2012-2015.
- ▶ Methods used to measure criteria air pollutants concentrations are standardized methods. In the case of O<sub>3</sub>, the principle of operation of the analyzer Photometry UV; whereas in the case of PM<sub>10</sub>, is Gravimetric.

## 2.3 Applicable Regulations

- ▶ Reference values to protect public health are established by Mexican Federal Government who is the responsible to monitor compliance, the reference values are published in the Mexican Official Regulations (NOM) being obligatory at a national scale. Applicable NOM's for each criteria air pollutant are presented in Table 2.1.

Table 2.1 Applicable NOM's for each criteria air pollutant

Criteria Air Pollutant	Exposure time used for the assessment	Kind of Exposure	Allowed frequency	Maximum permissible limit value	Reference (NOM)
Ozone (O <sub>3</sub> )	Hourly data (1 h)	Acute	It is not allowed	0.090 ppm	NOM-020-SSA1-2021
	Mobil average of 8 h		It is not allowed	0.065 ppm	
	Annual		Once a year	0.021 ppm	
PM <sub>10</sub>	24 h	Acute	It is not allowed	70 µg/m <sup>3</sup>	NOM-025-SSA1-2021
	Annual	Chronic	--	36 µg/m <sup>3</sup>	
	24 h			0.040 ppm	

Source: NOM-020-SSA1-2021 for Ozone (O<sub>3</sub>) and NOM-025-SSA1-2021 for PM<sub>10</sub>

- From air quality data and meteorological data set, time series for each pollutant and meteorological variable were integrated considering both, daily mean and daily maximum concentrations.
- From the reference values established for each criteria air pollutant, air quality was assessed and the exceedances were estimated. Missing data and the continuity in the records were assessed, in some cases; it was required to complete the databases for a given station.
- It was necessary to establish some criteria to include or not data in the databases:
  1. To decide which stations would be included (only values from monitoring stations showing a valid data percentage >75% were considered).
  2. If one or more stations showed missing data, to define how missing data would be imputed (to complete the database in which, despite complying with valid data percentage, missing data were isolated or intermittent, they were completed by using NIPALS approach).



## 2.4 Epidemiological Data

- ▶ Although National System of Air Quality Information (SINAICA) integrates air quality information from several cities in Mexico;
- ▶ In the case of health data, this information was obtained (hospital admissions for Bajío region) during the study period from SINAIS (National System of Health Information).
- ▶ Morbidity database from SINAIS is based in the international classification of diseases established by World Health Organization (WHO) revision CIE-10/2 considering respiratory system diseases (J00-J99) and circulatory system diseases (I00-I99). Morbidity data were assessed by hospital admission cause (all causes, respiratory and circulatory), gender (male and female), and age group (<1 year, 1-4 years, 5-59 years, 60-74 years and >75 years).

## ▶ 2.5 Time series Analysis Design

- ▶ Time series study developed in the present research work involved the following stages:
  - ▶ Assessment of temporal variations in morbidity rate in a monthly basis for all population, by age, by gender and by specific cause and by municipality during the study period (from January 1, 2012 to December 31, 2015).
  - ▶ Assessment of temporal variations of O<sub>3</sub> and PM<sub>10</sub> in a monthly basis by municipality for the study period (from January 1, 2012 to December 31, 2015).
  - ▶ Assessment of air quality: Analysis of exceedances to reference values established as maximum permissible limits in NOM-020-SSA1-2021 for O<sub>3</sub>, and in NOM-025-SSA1-2021 for PM10.
  - ▶ Estimation of the magnitude of the association between morbidity by all causes and by specific cause, and atmospheric pollution concentrations by municipality for each population sub-group. In this stage, meteorological variables were included (temperature and relative humidity).

- ▶ *Study subject:* Hospital admissions occurring in the residents of the Bajío region during the period from January 1, 2012 to December 31, 2015.
- ▶ *Variables:*
  - ▶ Response variables: Number of monthly hospital admission during the study period by all, respiratory and circulatory causes.
  - ▶ Explanatory variables: Criteria air pollutants (quantitative explanatory variable), monthly average concentration for O<sub>3</sub> and PM<sub>10</sub> during the study period.
  - ▶ Meteorological variables (quantitative explanatory variable), monthly average values for maximum temperature, minimum temperature and relative humidity during the study period.
  - ▶ Gender (qualitative explanatory variable), number of hospital admissions by gender.
  - ▶ Age (qualitative explanatory variable), number of hospital admissions by age group.
  - ▶ Control variables (seasonality): seasons were classified as cold months (from November to February) and warm months (from May to August).
  - ▶ Confusion variables: Temperature and Relative Humidity.

- ▶ Since the hospital admission did not occur at the same time in which the study subject is exposed to a given air pollutant concentration, it is necessary to consider a certain delay time. It was estimated from cross correlations of the series (mortality vs temperature, and mortality vs relative humidity) by using Infostat software v. 2008 (Di Rienzo et al. 2008), and selecting time delays according to their significance level.
- ▶ In addition, it was required to carry out a pre-treatment of the time series, in this case, epidemiological data series were smoothed, by applying a non-parametric method (LOWESS: LOcally WEighted regression Scatterplot Smoothing); whereas in the case of air quality data, series were smoothed by using ARIMA method (Autoregressive Integrate Moving Average). The smooth procedure of time series was carried out by using statistical software XLSTAT v. 2017 (<https://www.xlstat.com/es/>).



## 2.6 Estimation of the association between morbidity by all causes and by specific cause, and criteria air pollutants concentrations for each population sub-group.

- ▶ Once, both time series, epidemiological and air quality were treated and smoothed; a Poisson model was applied to reduce Pearson residuals. It was necessary to apply a multivariate analysis to decide which variables will be added to the base model.
- ▶ A principal component analysis (ACP) and a linear regression analysis (RLM) by using XLSTAT v. 2017 were applied to data series for morbidity; criteria air pollutants and meteorological variables.
- ▶ From ACP, the principal components contributing to the major percentage of data variability were obtained, considering those showing the major load of factor and a major statistical significance. A first approach was carried out with the Poisson basal model including those variables which contributed with significant information to explain the variability of dependent variable (daily morbidity).
- ▶ *Relative Risk Index (RRI) of daily morbidity associated to atmospheric pollution.*
- ▶ To apply the Poisson model, the methodology was the same than APHEA (Katsouyanni, 1996) and EMECAN (Ballester et al., 2002) projects. This methodology is described in detail by Cerón-Bretón et al. (2018) and Ídem et al. (2021).

- ▶ Once, basal model has been established, the model is extended for each pollutant and its time delays. The construction of the auto-regressive Poisson model let to determine if the response variable depends or not on other variables.
- ▶ This effect is assessed by beta coefficient of each independent variable in the Poisson regression model. The general model to relate the response variable with different independent variables is the following:

$$\ln(E_y) = \beta_0 + \sum_{i=1}^n \beta_i x_{t,i} \quad (1)$$

Where  $E_y$  is the expected number of cases,  $\beta_0, \beta_i$  are the model constants, and  $x_{ti}$  are the explanatory variables.

- ▶ The next step is to obtain the relative risk index (RRI) from beta coefficients as follows:

$$RRI_i = e^{\beta_i} \quad (2)$$

Where, RRI is the relative risk index associated to the explanatory variable  $i$  by increment unit of this variable, and  $\beta_i$  is the regression coefficient associated to the explanatory variable  $i$  in the model.

- ▶ In this study, besides the Poisson model corresponding to the current atmospheric pollution conditions, a hypothetical scenario in which the concentration of each pollutant was increased in 10% separately was considered. In this case, again the regression parameters were obtained, a Poisson distribution was applied considering this increase and keeping the rest of variables unchanged. From obtained  $\beta_i$  values again, relative risk index was estimated for morbidity considering an increase of 10% in the magnitude of each explanatory variable. It let us to determine the effect on risk derived from a future hypothetical scenario.

### **2.7 Mapping of relative risk index for each municipality of the Bajío region in Guanajuato**

- ▶ The relative risk indexes (RRI) of daily morbidity by all causes associated to  $O_3$  and  $PM_{10}$  in the Bajío region were mapped by using a Geographic Information Systems QGIS v. 2.14.7 (QGIS, 2017).

# 3. Results

## 3.1 Air Quality

- ▶ Descriptive statistical for O<sub>3</sub> and PM<sub>10</sub> of data registered from automatic monitoring stations in León, Celaya, Silao, Irapuato, and Salamanca is shown in Tables 3.1 and 3.2. From Table 3.1 it can be observed that for all period 2012-2015, the mean concentration for O<sub>3</sub> was 26.6224 ppb, reaching a maximum concentration of 73.6725 ppb in Irapuato. León and Celaya showed the lowest mean concentrations for ozone; whereas Irapuato and Silao showed the maximum levels of O<sub>3</sub>.

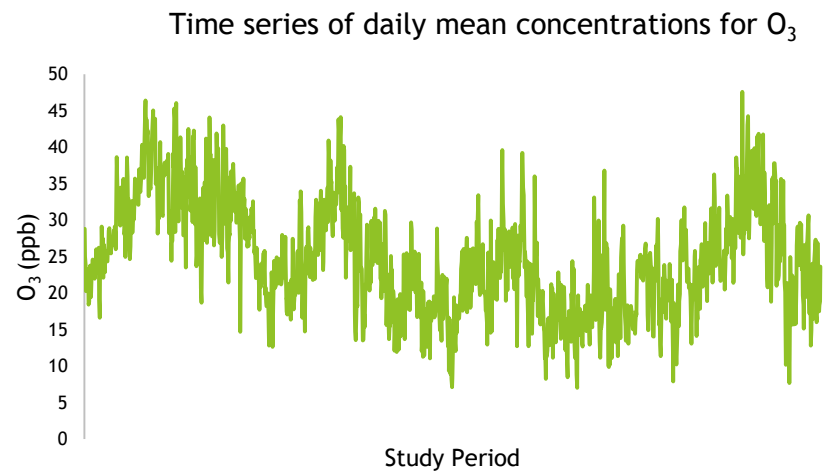
**Table 3.1** Descriptive Statistical for O<sub>3</sub> during the study period in the Bajío region

León				
Pollutant	Mean Concentration	Standard deviation	Minimum	Maximum
O <sub>3</sub> (ppb)	24.7017	7.5610	7.0235	47.5736
Celaya				
Pollutant	Mean Concentration	Standard deviation	Minimum	Maximum
O <sub>3</sub> (ppb)	25.2340	7.9457	6.5232	47.5068
Silao				
Pollutant	Mean Concentration	Standard deviation	Minimum	Maximum
O <sub>3</sub> (ppb)	28.8402	9.0672	7.5000	63.1788
Irapuato				
Pollutant	Mean Concentration	Standard deviation	Minimum	Maximum
O <sub>3</sub> (ppb)	29.0217	12.9467	5.7182	73.6725
Salamanca				
Pollutant	Mean Concentration	Standard deviation	Minimum	Maximum
O <sub>3</sub> (ppb)	25.3144	7.9857	8.7379	50.7264

Source: Own elaboration

- ▶ The highest concentrations were observed during 2012 and 2015, whereas the lowest concentrations were registered during 2014. Ozone concentrations were in general higher during the warm months in comparison with the winter season, being 22% higher than those observed during cold months.
- ▶ Time series for daily mean concentrations for  $O_3$  during the period 2012-2015 in the Bajío region, are shown in graph 3.1. It can be observed a seasonal pattern, in which, the highest values of ozone concentration occurred during the summer months whereas, the lowest concentrations occurred during winter months.

**Graph 3.1** Time-series for daily mean concentrations for Ozone during the study period in the Bajío region in Guanajuato



Source: Own elaboration



- ▶ From Table 3.2 it can be observed that for all period 2012-2015, the mean concentration for PM<sub>10</sub> was 54.1229 µg m<sup>-3</sup>, reaching a maximum concentration of 160.9764 µg m<sup>-3</sup> in the municipality of Celaya. The lowest mean concentrations were found for Silao and Irapuato; whereas the maximum values were registered in Celaya and Salamanca.

**Table 3.2** Descriptive Statistical for PM<sub>10</sub> during the study period in León, the Bajío region in Guanajuato

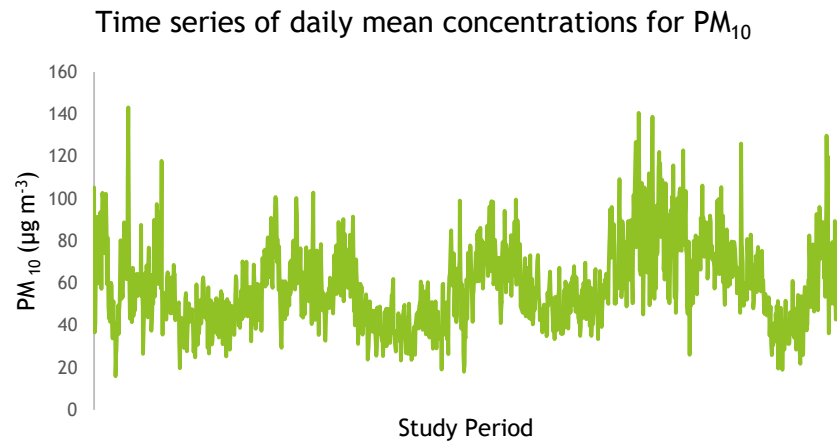
León				
Pollutant	Mean Concentration	Standard deviation	Minimum	Maximum
PM <sub>10</sub> (µg m <sup>-3</sup> )	58.8244	19.3295	15.8481	143.1591
Celaya				
Pollutant	Mean Concentration	Standard deviation	Minimum	Maximum
PM <sub>10</sub> (µg m <sup>-3</sup> )	69.1963	25.9990	18.9079	160.9764
Silao				
Pollutant	Mean Concentration	Standard deviation	Minimum	Maximum
PM <sub>10</sub> (µg m <sup>-3</sup> )	41.9583	16.3670	8.7742	104.2083
Irapuato				
Pollutant	Mean Concentration	Standard deviation	Minimum	Maximum
PM <sub>10</sub> (µg m <sup>-3</sup> )	45.5014	17.6875	8.8098	130.4270
Salamanca				
Pollutant	Mean Concentration	Standard deviation	Minimum	Maximum
PM <sub>10</sub> (µg m <sup>-3</sup> )	55.1345	19.6767	14.9325	152.6935

Source: Own elaboration

- The highest concentrations were observed during 2015, whereas the lowest concentrations were registered during 2013 and 2014. PM<sub>10</sub> concentrations were in general higher during the cold months in comparison with the summer season, being 1.29 times higher than those observed during warm months.

- ▶ Time series for daily mean concentrations for  $PM_{10}$  during the period 2012-2015 in the Bajío region are shown in graph 3.2. It can be observed a seasonal pattern, in which, the highest values of  $PM_{10}$  concentration occur during the winter months whereas, the lowest concentrations occur during the summer months.

**Graph 3.2** Time-series for daily mean concentrations for  $PM_{10}$  during the study period in the Bajío region in Guanajuato



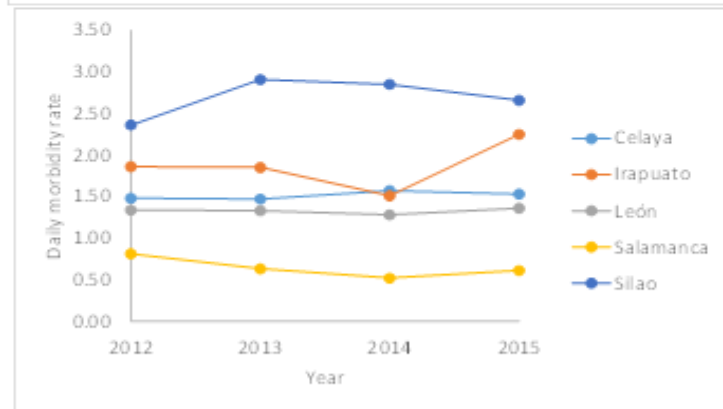
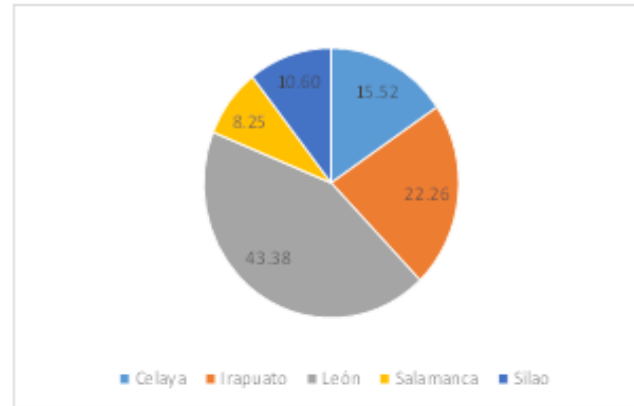
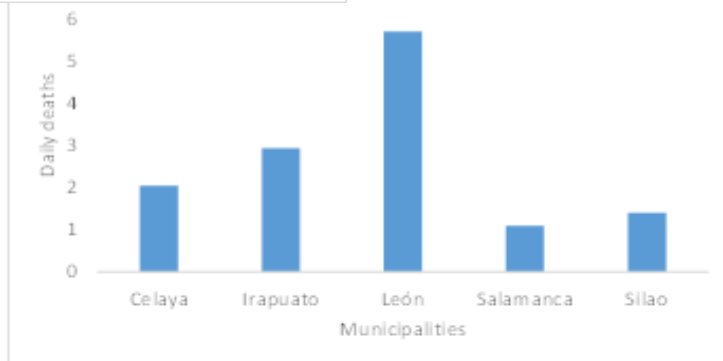
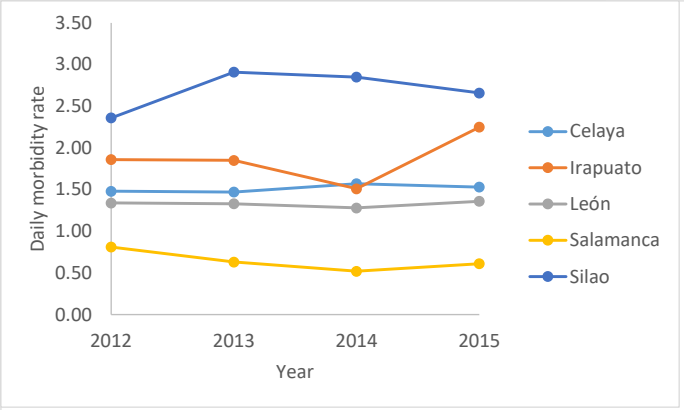
Source: Own elaboration

## 3.2 Epidemiological data

- ▶ Descriptive statistical for the 5 municipalities in the region of Bajío was estimated, it was found that León (5.73) and Irapuato (2.94) showed the highest number of hospital admissions by all causes during the study period. Salamanca (1.09) and Silao (1.40) showed the lowest.
- ▶ Morbidity rate is an epidemiological concept that refers to the number of persons which have a disease regarding to a given population and period. The total of population for each municipality was obtained from National Institute of Statistics, Geography and Informatics (INEGI). In the case of morbidity rate, the estimation considered groups of 1000 habitants.
- ▶ Silao (2.36-2.91) and Irapuato (1.51-2.25) showed the highest morbidity rate, whereas, Salamanca (1.22-1.71) showed the lowest. It is important to mention that in spite of León had the highest values of morbidity, its morbidity rate was low.
- ▶ It was found some uniformity in the results for all municipalities studied, for example, the highest values of the relative maximum for daily morbidity were found during November, December and January. In addition, it was observed a marked and evident seasonality, with the number of hospital admissions by all causes being higher during autumn and winter seasons. However, it was not observed any inter-annual trend.
- ▶ Regarding to age sub-group. It was possible to identify people between 5 and 59 years as the population group with the higher number and frequency of admissions; whereas the sub-group of 60-74 years and >75 years showed the lowest.
- ▶ In terms of gender, in León and Irapuato the number of admissions registered was similar in both, women and men. On the other hand, in Silao and Salamanca, women showed greater hospital admissions in comparison with men. Finally, in the municipality of Celaya, the number of admissions was higher in men.

considered as the specific cause of hospital admission the highest number of between 5 and 59 years, the same was observed when circulatory diseases. Regarding to the gender, in the sub-group of 5-59 years, 17.4 and 23.8% and 23.8 and 24.2% were women.

Evolution of daily morbidity during the study period in the Bajío region in Guanajuato



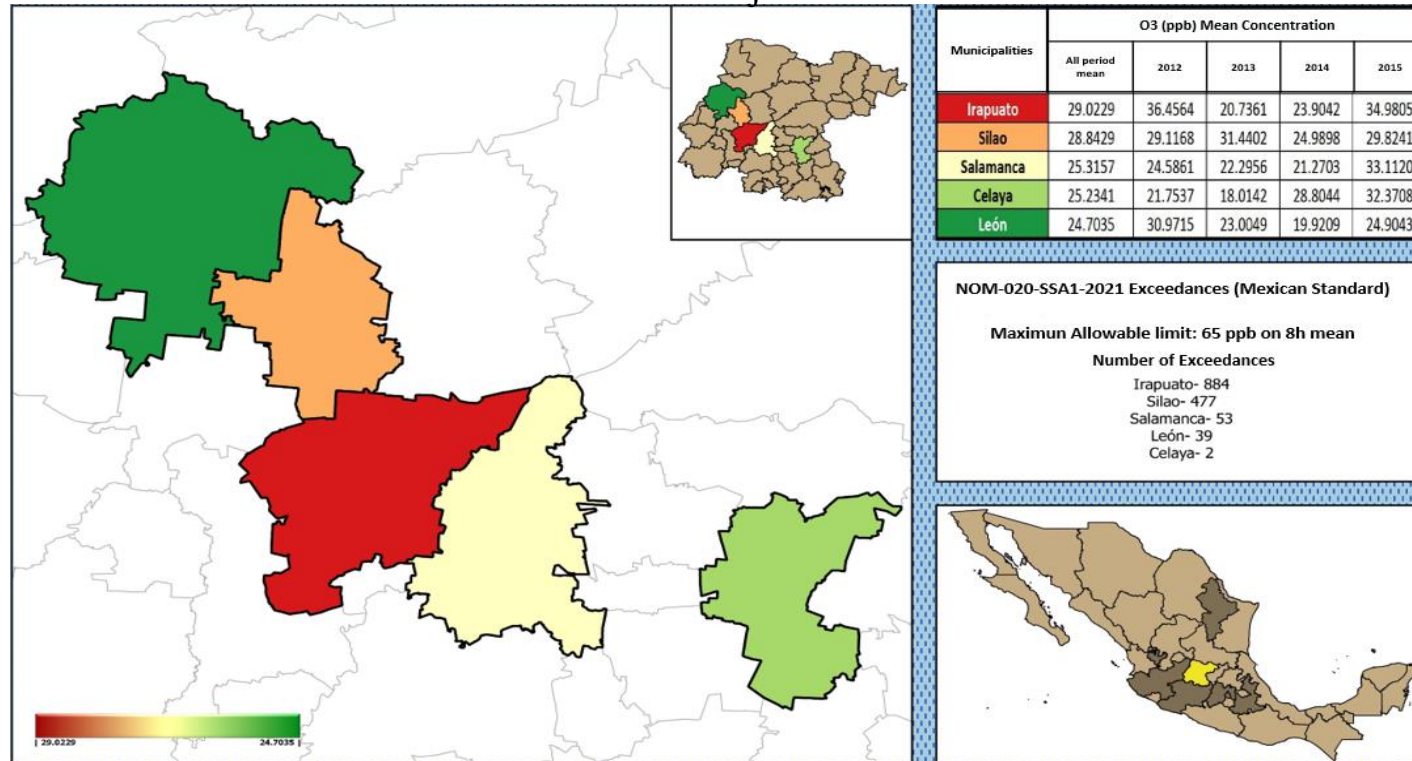
- Seasonality:**
- + autumn and winter
- Summer
- men > women**
- All causes:**
- + 5-59 years
- 0-4, 60-74 and >75 years
- Respiratory causes:**
- + 5-59 years
- 0-4, 60-74 and >75 years
- Circulatory causes:**
- + 5-59 years
- 0-4, 60-74 and >75 years

+higher morbidity values  
-lower morbidity values

### 3.3 Exceedances to reference values established by NOM's

- ▶ In Graphs 3.4 and 3.5, integrated information about the number of exceedances for O<sub>3</sub> and PM<sub>10</sub> for the Bajío region in Guanajuato is shown.
- ▶ From Graph 3.4, it can be observed that, Irapuato, Silao and Salamanca presented the highest mean concentration values for O<sub>3</sub> during the all period. However, Irapuato showed the highest number of exceedances (884) to the maximum allowable limit established by NOM-020-SSA1-2021, followed by Silao (477) and Salamanca (53), respectively. It is to say, zones located in the middle part of the Bajío presented more photochemical pollution.

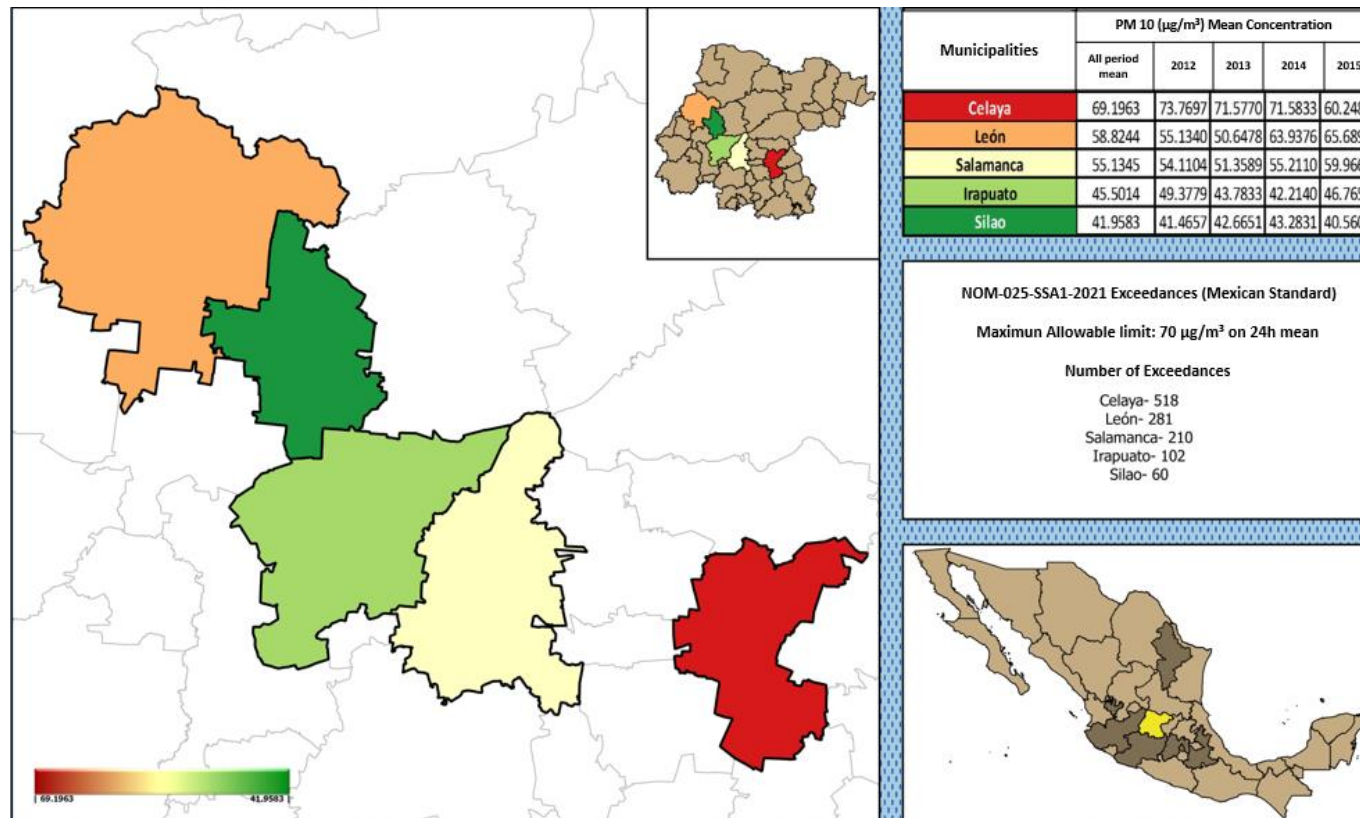
**Graph 3.4** Integrated information about the number of exceedances for O<sub>3</sub> in the Bajío region in Guanajuato



Source: Own elaboration

- From Graph 3.5, it can be observed that, Celaya, León and Salamanca presented the highest mean concentration values for PM<sub>10</sub> during the all period. All municipalities showed significant exceedances to the maximum allowable limit established by NOM-025-SSA1-2021; Celaya with 518, León with 281 and Salamanca with 210 exceedances, respectively.

**Graph 3.5** Integrated information about the number of exceedances for PM<sub>10</sub> in the Bajío region in Guanajuato



Source: Own elaboration

### 3.4 Estimation and mapping of the relative risk index (RRI) for each pollutant by municipality.

*Bi-variate analysis, multivariate analysis and multiple regression of daily mortality data with explanatory variables.*

#### ► *O<sub>3</sub>-All causes*

The association of this pollutant with daily morbidity considering bi-variate relations (Pearson coefficient) showed significant values only for Celaya and Salamanca. In the case of multiple regression analysis, the null hypothesis states that explanatory variable contributes significantly to the model, considering Fisher statistical test. If  $F < 0.0001$ , it means that the risk of assuming the null hypothesis as incorrect is lower than 0.01%. From multiple regression analysis (RLM SC Type III), Irapuato, León and Salamanca were the municipalities which showed the lowest values of the statistical test ( $F < 0.0001$ ), therefore, we can conclude that ozone variable provided significant information to the prediction model for daily morbidity.

#### ► *PM10-All causes*

The association of this pollutant with daily morbidity considering bi-variate relations (Pearson coefficient) showed significant values only for León and Irapuato. In the case of multiple regression analysis, the null hypothesis states that explanatory variable contributes significantly to the model, considering Fisher statistical test. If  $F < 0.0001$ , it means that the risk of assuming the null hypothesis as incorrect is lower than 0.01%. From multiple regression analysis (RLM SC Type III), Celaya, Irapuato and Silao, were the municipalities which showed the lowest values of the statistical test ( $F < 0.0001$ ), therefore, we can conclude that PM10 variable provided significant information to the prediction model for daily morbidity.

#### ► *O<sub>3</sub>-From 0 to 59 years*

The association of this pollutant with daily morbidity considering bi-variate relations (Pearson coefficient) showed significant values only for Celaya and Salamanca. In the case of multiple regression analysis, the null hypothesis states that explanatory variable contributes significantly to the model, considering Fisher statistical test. If  $F < 0.0001$ , it means that the risk of assuming the null hypothesis as incorrect is lower than 0.01%. From multiple regression analysis (RLM SC Type III), León, Salamanca and Celaya, were the municipalities which showed the lowest values of the statistical test ( $F < 0.0001$ ), therefore, we can conclude that ozone variable provided significant information to the prediction model for daily morbidity.

► *PM<sub>10</sub>-From 0 to 59 years*

The association of this pollutant with daily morbidity considering bi-variate relations (Pearson coefficient) showed significant values only for Irapuato, Celaya and Silao. In the case of multiple regression analysis, the null hypothesis states that explanatory variable contributes significantly to the model, considering Fisher statistical test. If  $F < 0.0001$ , it means that the risk of assuming the null hypothesis as incorrect is lower than 0.01%. From multiple regression analysis (RLM SC Type III), Celaya, Irapuato and Silao, were the municipalities which showed the lowest values of the statistical test ( $F < 0.0001$ ), therefore, we can conclude that  $PM_{10}$  variable provided significant information to the prediction model for daily morbidity.

► *O<sub>3</sub>->60 years*

The association of this pollutant with daily morbidity considering bi-variate relations (Pearson coefficient) showed significant values only for León and Silao. In the case of multiple regression analysis, the null hypothesis states that explanatory variable contributes significantly to the model, considering Fisher statistical test. If  $F < 0.0001$ , it means that the risk of assuming the null hypothesis as incorrect is lower than 0.01%. From multiple regression analysis (RLM SC Type III), León, Salamanca and Silao, were the municipalities which showed the lowest values of the statistical test ( $F < 0.0001$ ), therefore, we can conclude that ozone variable provided significant information to the prediction model for daily morbidity.

► *PM<sub>10</sub>->60 years*

The association of this pollutant with daily morbidity considering bi-variate relations (Pearson coefficient) showed significant values only for León and Salamanca. In the case of multiple regression analysis, the null hypothesis states that explanatory variable contributes significantly to the model, considering Fisher statistical test. If  $F < 0.0001$ , it means that the risk of assuming the null hypothesis as incorrect is lower than 0.01%. From multiple regression analysis (RLM SC Type III), León and Silao, were the municipalities which showed the lowest values of the statistical test ( $F < 0.0001$ ), therefore, we can conclude that  $PM_{10}$  variable provided significant information to the prediction model for daily morbidity.



► *O<sub>3</sub>- Respiratory causes*

The association of this pollutant with daily morbidity considering bi-variate relations (Pearson coefficient) showed significant values only for Salamanca, Silao and León. In the case of multiple regression analysis, the null hypothesis states that explanatory variable contributes significantly to the model, considering Fisher statistical test. If  $F < 0.0001$ , it means that the risk of assuming the null hypothesis as incorrect is lower than 0.01%. From multiple regression analysis (RLM SC Type III), Irapuato, León, Salamanca and Silao, were the municipalities which showed the lowest values of the statistical test ( $F < 0.0001$ ), therefore, we can conclude that ozone variable provided significant information to the prediction model for daily morbidity.

► *PM<sub>10</sub>- Respiratory causes*

The association of this pollutant with daily morbidity considering bi-variate relations (Pearson coefficient) showed significant values only for Irapuato, León and Celaya. In the case of multiple regression analysis, the null hypothesis states that explanatory variable contributes significantly to the model, considering Fisher statistical test. If  $F < 0.0001$ , it means that the risk of assuming the null hypothesis as incorrect is lower than 0.01%. From multiple regression analysis (RLM SC Type III), Celaya, Irapuato, León, Salamanca and Silao, were the municipalities which showed the lowest values of the statistical test ( $F < 0.0001$ ), therefore, we can conclude that PM<sub>10</sub> variable provided significant information to the prediction model for daily morbidity.

► *O<sub>3</sub>- Circulatory causes*

The association of this pollutant with daily morbidity considering bi-variate relations (Pearson coefficient) showed significant values only for León and Silao. In the case of multiple regression analysis, the null hypothesis states that explanatory variable contributes significantly to the model, considering Fisher statistical test. If  $F < 0.0001$ , it means that the risk of assuming the null hypothesis as incorrect is lower than 0.01%. From multiple regression analysis (RLM SC Type III), León and Silao, were the municipalities which showed the lowest values of the statistical test ( $F < 0.0001$ ), therefore, we can conclude that ozone variable provided significant information to the prediction model for daily morbidity.

► *PM<sub>10</sub>- Circulatory causes*

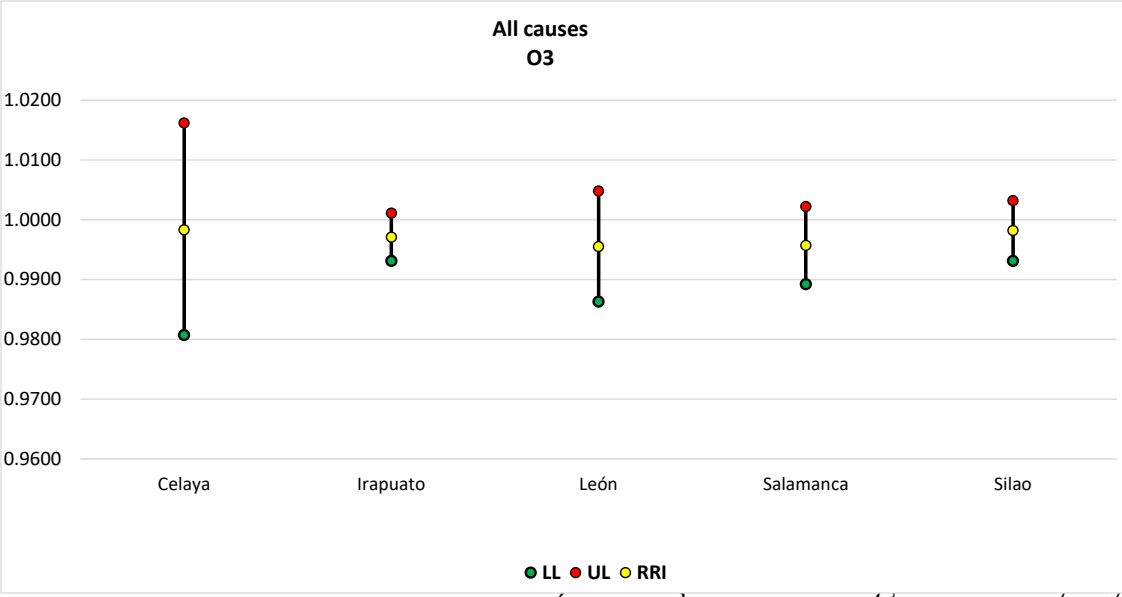
The association of this pollutant with daily morbidity considering bi-variate relations (Pearson coefficient) showed significant values only for León. In the case of multiple regression analysis, the null hypothesis states that explanatory variable contributes significantly to the model, considering Fisher statistical test. If  $F < 0.0001$ , it means that the risk of assuming the null hypothesis as incorrect is lower than 0.01%. From multiple regression analysis (RLM SC Type III), Salamanca was the only municipality which showed the lowest values of the statistical test ( $F < 0.0001$ ), therefore, we can conclude that PM<sub>10</sub> variable provided significant information to the prediction model for daily morbidity.

## *Estimation of Relative Risk Index (RRI)*

- ▶ Results for relative risk index (RRI) and the confidence interval (lower limit and upper limit) at 95% of confidence corresponding to an increase of 10% in the concentration of each pollutant are shown in Graphs 3.6-3.10 for O<sub>3</sub> and Graphs 3.11-3.15 for PM<sub>10</sub> for morbidity by all causes, age groups (0-59 years and >60 years), respiratory and circulatory causes.

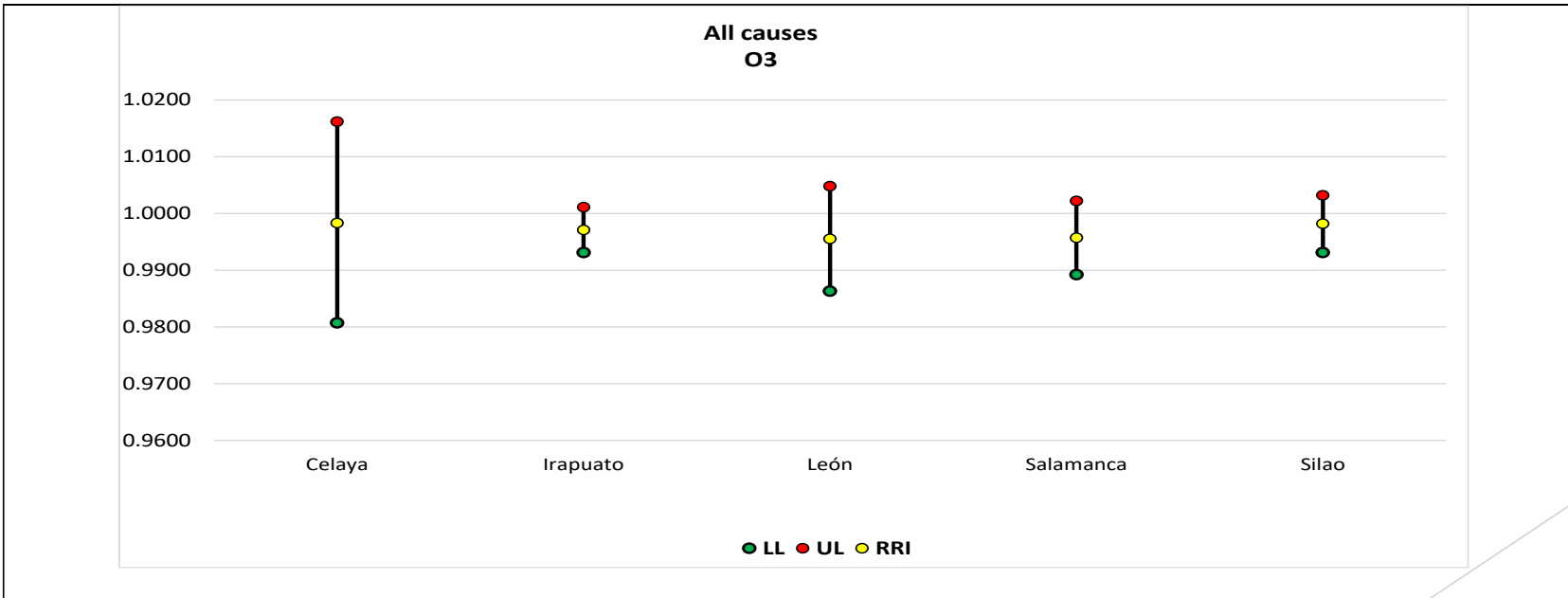
- ▶ O<sub>3</sub>

In Graphs 3.6-3.10, relative risk indexes (RRI) corresponding to an increase of 10% in daily mean ozone concentrations are shown. Celaya showed the highest significant correlations for morbidity by respiratory causes (IRR=1.0002) [IC95%: 0.9759-1.0250] during warm months. On the other hand, Silao showed the highest RRI values for morbidity by respiratory causes (IRR=1.0020) [IC95%: 0.9937-1.0104] and during the cold months [IC95%: 0.9726-1.0564] with an IRR=1.0136. The association between morbidity by all causes and ozone concentrations showed positive correlations in all municipalities, but this associations was not significant, being Celaya the highest with an IRR=0.9983 [IC95%: 0.9807-1.0162].

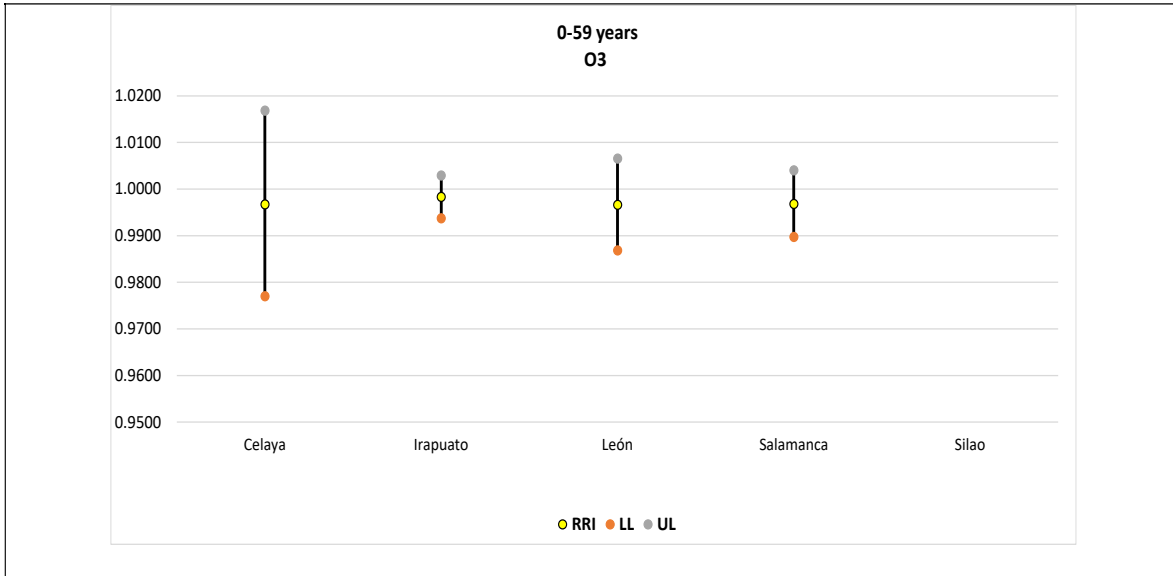


between 0 and 59 years showed correlations not so high as those observed in people between 60 and 79 years, which did not present any correlation. Finally, the highest concentrations were observed in people major than 60 years, in Salamanca, Salamanca and Silao; whereas Celaya and

the lowest concentrations were observed in Celaya and Silao. The relative risk index (RRI) and confidence interval (LL and UL) for all causes in the Bajío region in Guanajuato



**Graph 3.7** Integrated information about relative risk index (RRI) and confidence interval (LL and UL) for O<sub>3</sub> considering the age group of 0-59 years in the Bajío region in Guanajuato



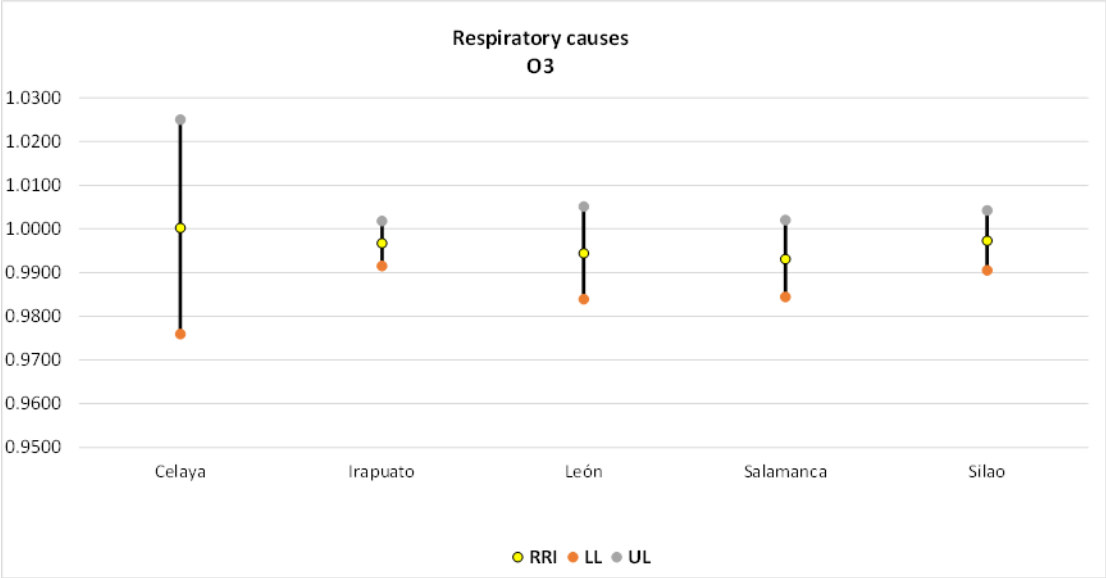
Source: Own elaboration

**Graph 3.8** Integrated information about relative risk index (RRI) and confidence interval (LL and UL) for O<sub>3</sub> considering the age group >60 years in the Bajío region in Guanajuato



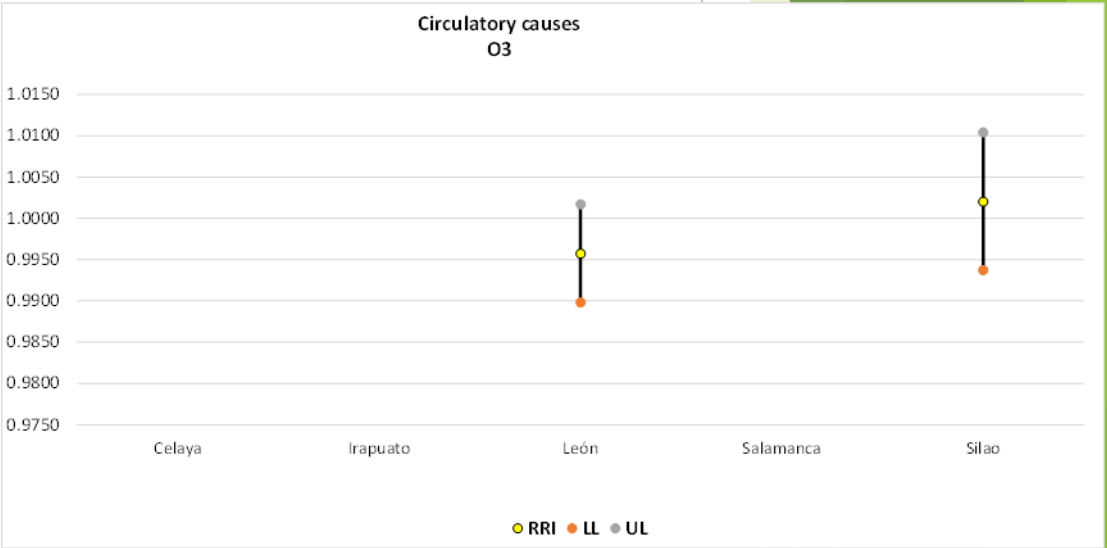
Source: Own elaboration

**Graph 3.9** Integrated information about relative risk index (RRI) and confidence interval (LL and UL) for O<sub>3</sub> considering morbidity by respiratory causes in the Bajío region in Guanajuato



Source: Own elaboration

**Graph 3.10** Integrated information about relative risk index (RRI) and confidence interval (LL and UL) for O<sub>3</sub> considering morbidity by circulatory causes in the Bajío region in Guanajuato

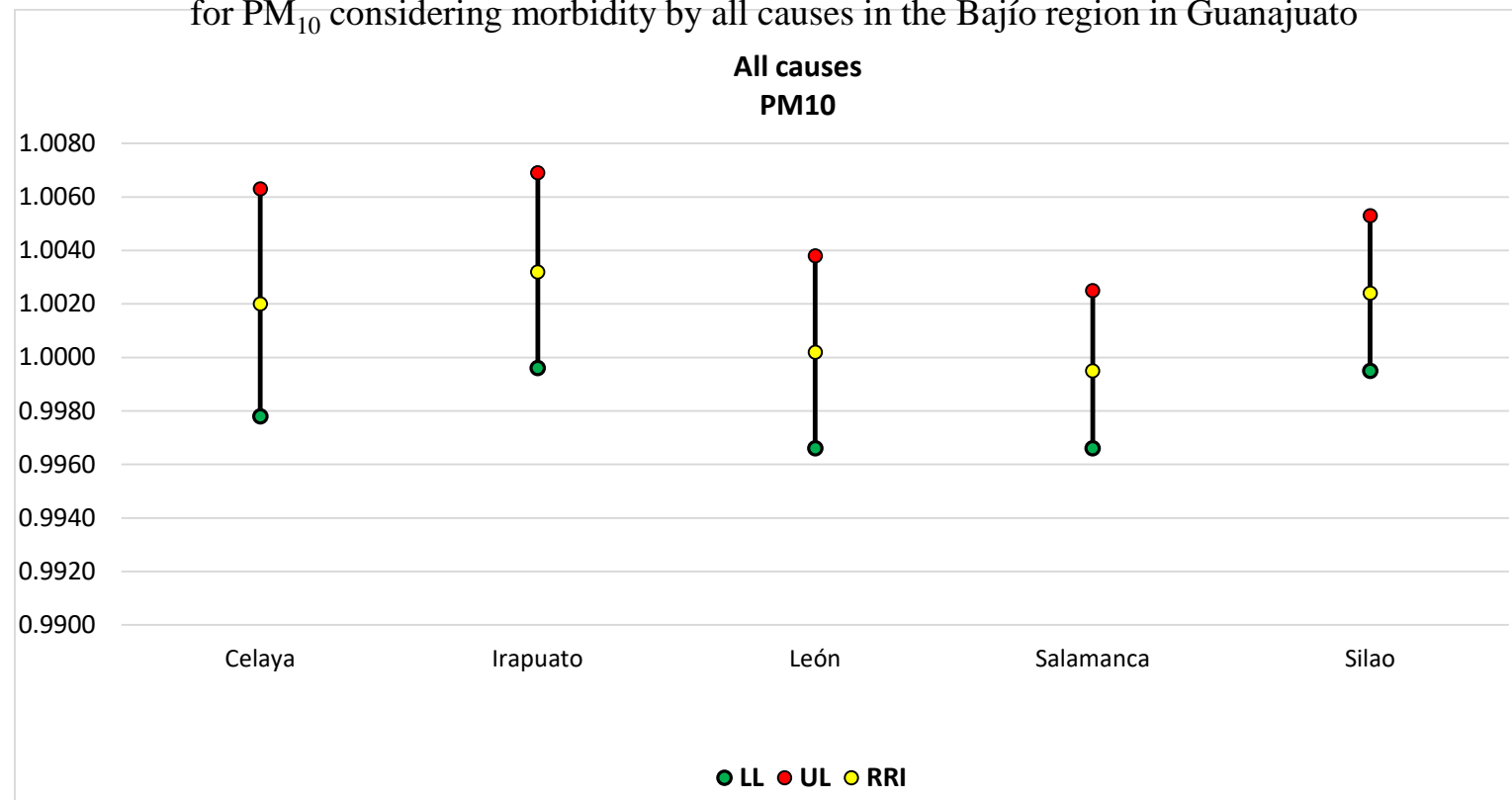


Source: Own elaboration

$PM_{10}$

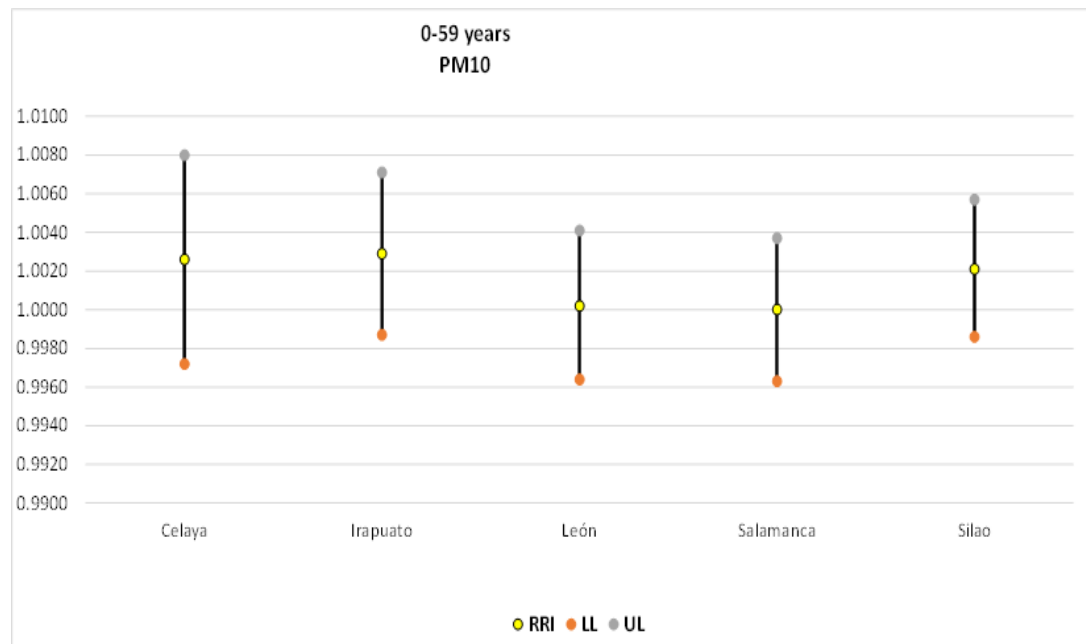
In Graphs 3.11-3.15, relative risk indexes (RRI) corresponding to an increase of 10% in daily mean  $PM_{10}$  concentrations are shown. The highest RRI values were found for Irapuato for morbidity by all causes (IRR=1.0032) [IC95%: 0.9996-1.0069]; in the age range from 0 to 59 years (IRR=1.0029) [IC95%: 0.9987-1.0071] and for morbidity by respiratory causes (IRR=1.0034) [IC95%: 0.9988-1.0081] as can be observed in graphs 3.11, 3.12 and 3.14, respectively. In addition, this municipality also showed the highest risk during the cold months [IC95%: 0.9999-1.0094] with an IRR=1.0047. The association between morbidity and  $PM_{10}$  concentrations considering people major than 60 years [IC95%: 0.9985-1.0036], and morbidity by circulatory causes [IC95%: 0.9978-1.0023] were the highest for the municipality of León with IRR values of 1.0011 and 1.0001, respectively. Silao showed the highest risk during the warm months (IRR=1.0022) [IC95%: 0.9918-1.0128].

**Graph 3.11** Integrated information about relative risk index (RRI) and confidence interval (LL and UL) for  $PM_{10}$  considering morbidity by all causes in the Bajío region in Guanajuato



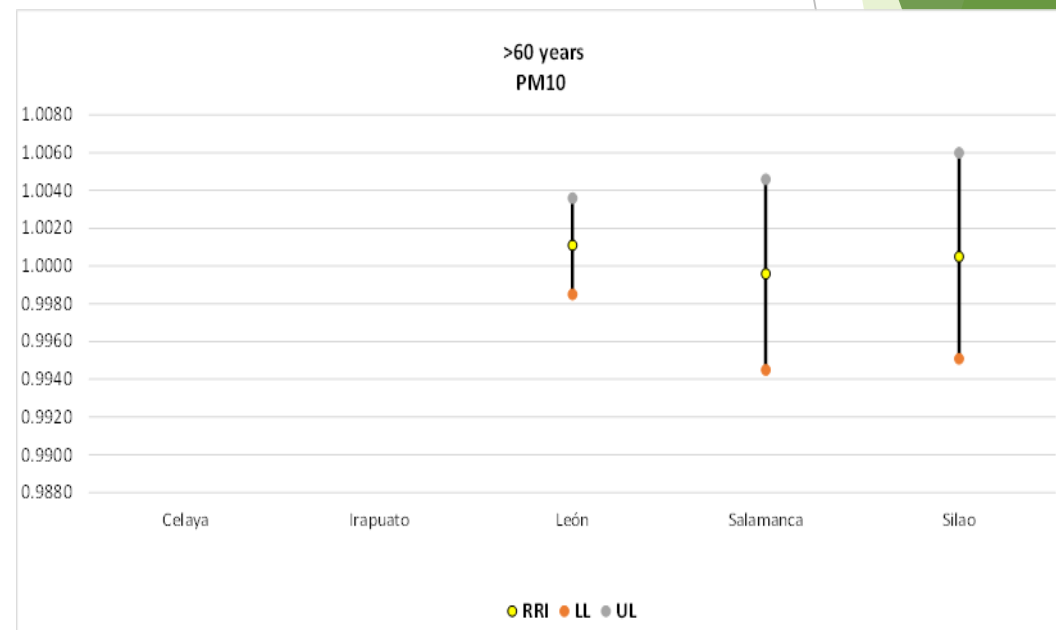
Source: Own elaboration

**Graph 3.12** Integrated information about relative risk index (RRI) and confidence interval (LL and UL) for PM<sub>10</sub> considering the age group of 0-59 years in the Bajío region in Guanajuato



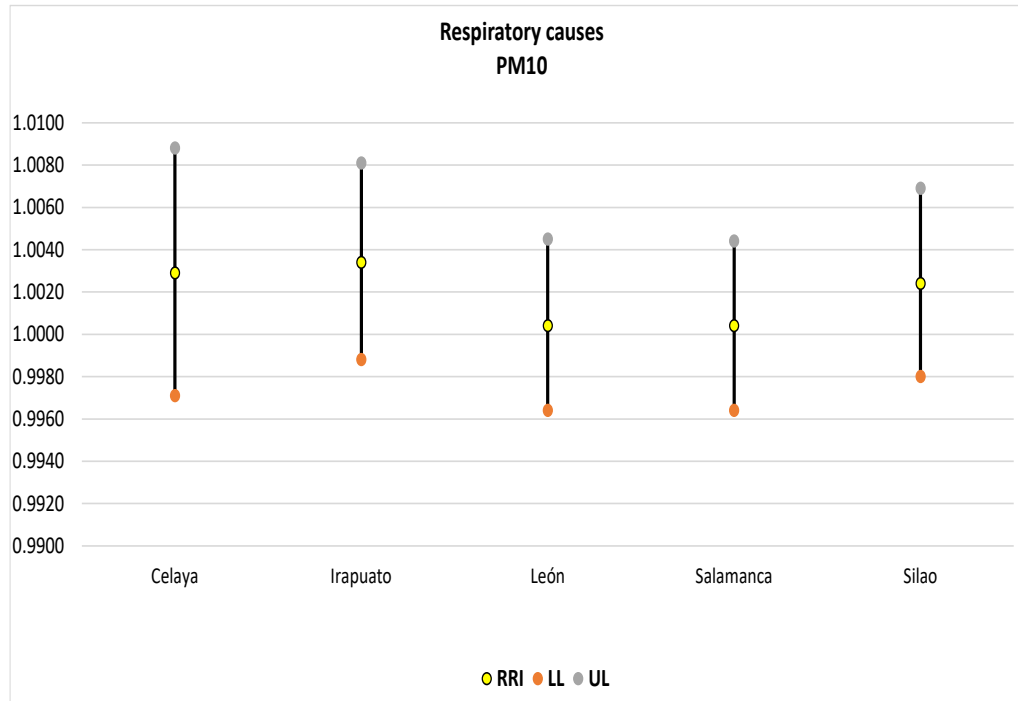
Source: Own elaboration

**Graph 3.13** Integrated information about relative risk index (RRI) and confidence interval (LL and UL) for PM<sub>10</sub> considering the age group >60 years in the Bajío region in Guanajuato



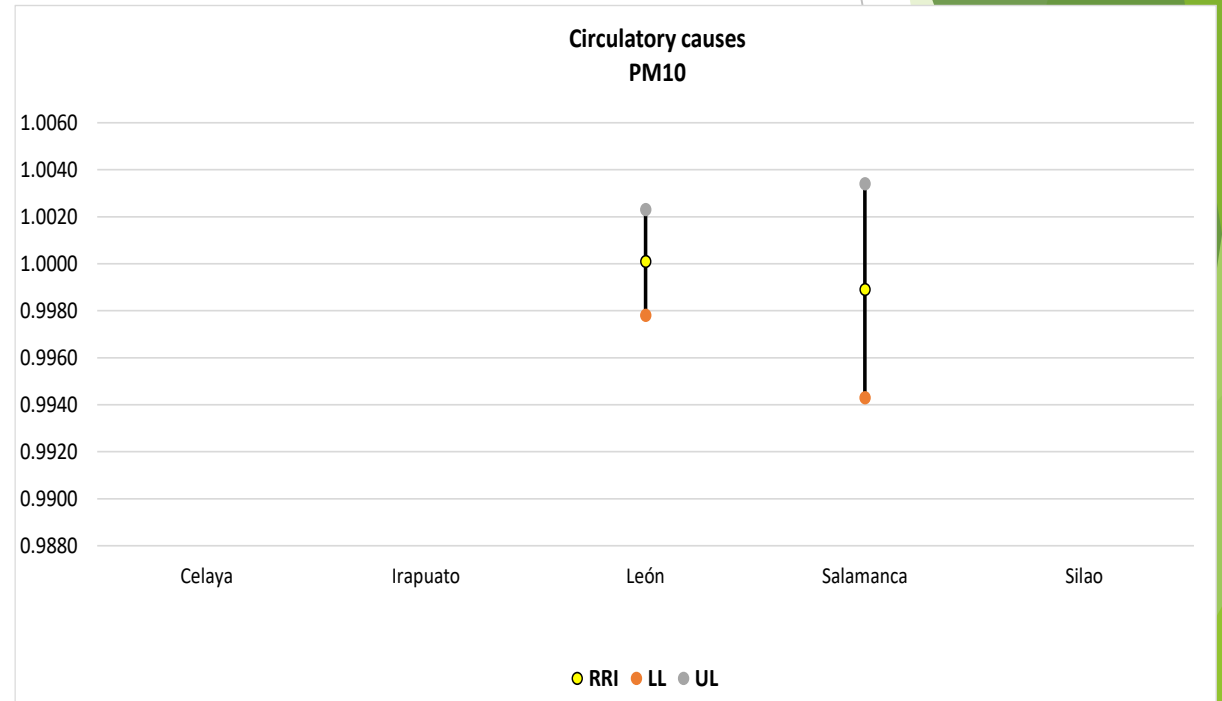
Source: Own elaboration

**Graph 3.14** Integrated information about relative risk index (RRI) and confidence interval (LL and UL) for PM<sub>10</sub> considering morbidity by respiratory causes in the Bajío region in Guanajuato



Source: Own elaboration

**Graph 3.15** Integrated information about relative risk index (RRI) and confidence interval (LL and UL) for PM<sub>10</sub> considering morbidity by circulatory causes in the Bajío region in Guanajuato

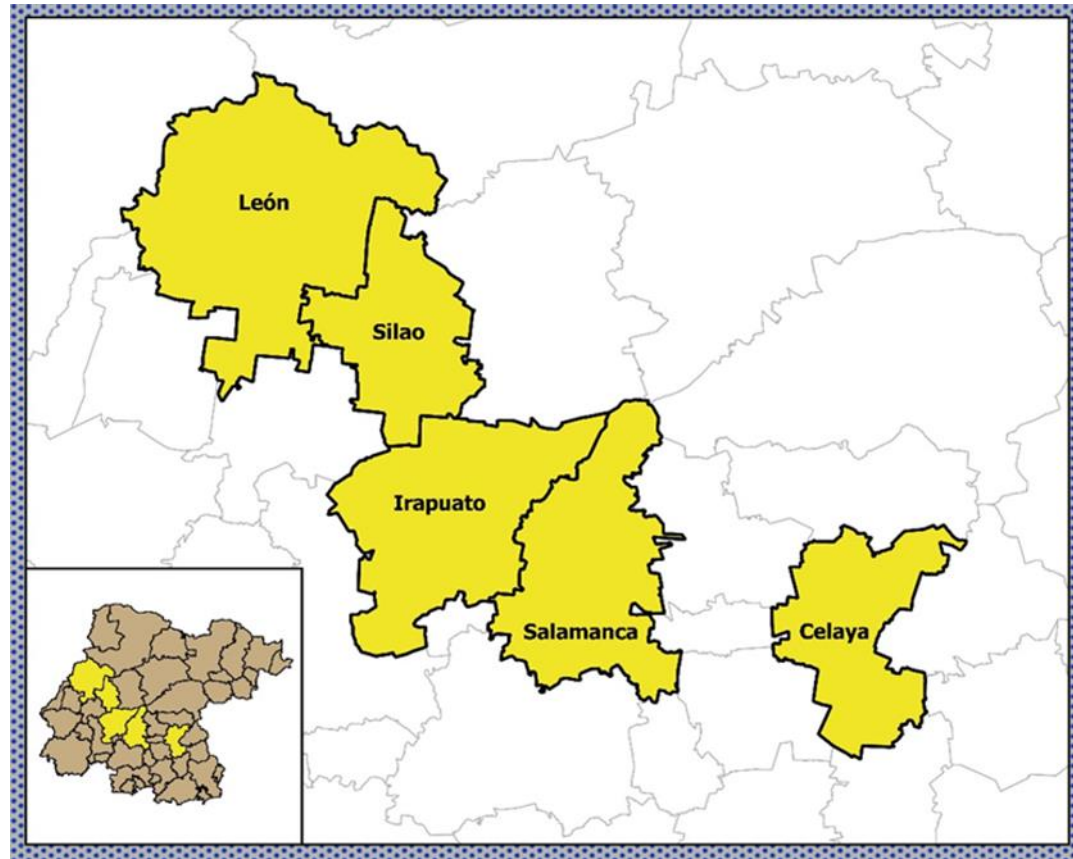


Source: Own elaboration



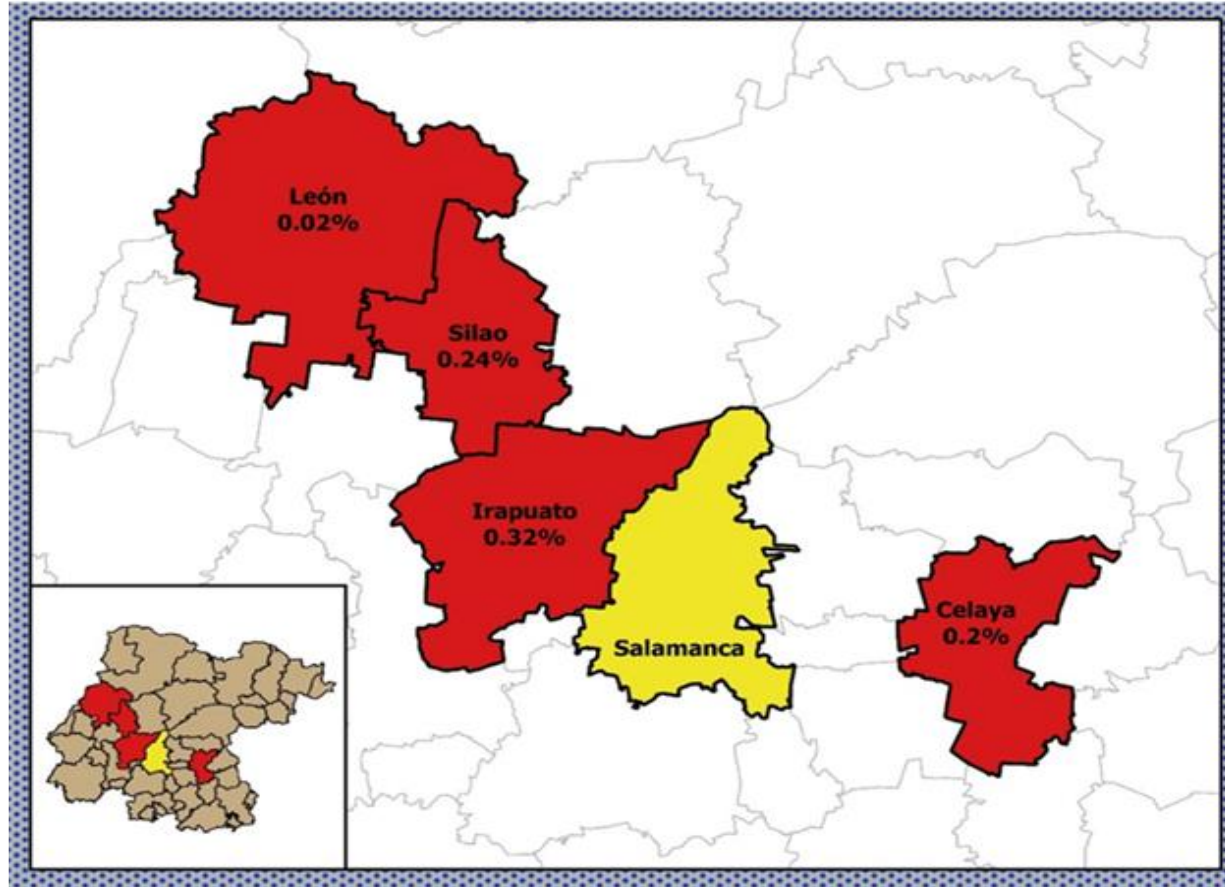
- ▶ *Integrated Mapping of Relative Risk Index for each pollutant.*
- ▶ As can be observed in Graph 3.16, an increase of 10% in the daily mean concentrations of ozone does not constitute a significant risk of morbidity in the municipalities studied, for this reason, all municipalities are in yellow, suggesting that there was a correlation, but this correlation was not significant. On the other hand, from Graph 3.17, it can be observed that because of an increase of 10% in PM<sub>10</sub> daily mean concentrations, morbidity showed an increase in Irapuato (0.32%), Silao (0.24%), Celaya (0.20%) and León (0.02%). These municipalities are in red, suggesting that there was a correlation, and this correlation was significant. In the case of Salamanca, which is presented in yellow, indicates that there was a not significant correlation.

**Graph 3.16** Integrated Mapping of Relative Risk Index (RRI) considering the hypothetical scenario in which O<sub>3</sub> concentrations increases in 10% in the Bajío region



Source: Own elaboration

**Graph 3.17** Integrated Mapping of Relative Risk Index (RRI) considering the hypothetical scenario in which  $PM_{10}$  concentrations increases in 10% in the Bajío region



Source: Own elaboration

## 4. Conclusions

- ▶ Regarding to air quality, Irapuato, Silao and Salamanca presented the highest mean concentration values for O<sub>3</sub> during the all period.
- ▶ Irapuato showed the highest number of exceedances (884) to the maximum allowable limit established by NOM-020-SSA1-2021, followed by Silao (477) and Salamanca (53), respectively.
- ▶ With respect to PM<sub>10</sub>, Celaya, León and Salamanca presented the highest mean concentration values for PM10 during the all period.
- ▶ All municipalities showed significant exceedances to the maximum allowable limit established by NOM-025-SSA1-2021; Celaya with 518, León with 281 and Salamanca with 210 exceedances, respectively. Comparing both pollutants, we can conclude that the pollution due to PM<sub>10</sub> is a hotspot in the Bajío region in comparison with pollution due to ozone.

- ▶ Silao (2.36-2.91) and Irapuato (1.51-2.25) showed the highest morbidity rate, whereas, Salamanca (1.22-1.71) showed the lowest. It is important to mention that in spite of León had the highest values of morbidity, its morbidity rate was low.
- ▶ It was found some uniformity in the results for all municipalities studied, for example, the highest values of the relative maximum for daily morbidity were found during November, December and January. In addition, it was observed a marked and evident seasonality, with the number of hospital admissions by all causes higher during autumn and winter seasons. However, it was not observed any inter-annual trend.
- ▶ Regarding to age sub-group. It was possible to identify people between 5 and 59 years as the population group with the higher number and frequency of admissions; whereas the sub-group of 60-74 years and >75 years showed the lowest. In terms of gender, in León and Irapuato the number of admissions registered was similar in both, women and men. On the other hand, in Silao and Salamanca, women showed greater hospital admissions in comparison with men. Finally, in the municipality of Celaya, the number of admissions was higher in men.

- ▶ From relative risk indexes found in this study; we can conclude that an increase of 10% in the daily mean concentrations of  $O_3$  does not constitute a significant risk of morbidity in the municipalities studied; however, the scenario was very different with respect to  $PM_{10}$ , since when  $PM_{10}$  concentrations were increased, the risk values also increased: Irapuato with 0.32%, Silao with 0.24%, Celaya with 0.20% and León with 0.02%.
- ▶ Population between 0 and 59 years was identified as the most vulnerable age subgroup, suggesting that, the habits and activities of people played an important role in the exposure to these pollutants, since, people in this group comprises economically active population and students of all ages, who develop their activities outside home just in the hours in which  $O_3$  and  $PM_{10}$  reach their peak levels as a result of industrial activity and mobile sources. Therefore, decision makers can use reported data in this work to propose or improve regulations, programs or actions focused to protect population health between 0-59 years against atmospheric pollution effects in these municipalities.

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