



Polluting Emissions in the City of La Paz, Mexico: Emissions Inventory and Monitoring Data

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How to cite this paper: Bermudez-Contreras, A., Ivanova, A., & Martinez, J. A. (2017). Polluting Emissions in the City of La Paz, Mexico: Emissions Inventory and Monitoring Data. *Current Urban Studies*, 5, 54-67.

<https://doi.org/10.4236/cus.2017.51004>

Received: December 26, 2016

Accepted: March 5, 2017

Published: March 8, 2017

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Abstract

In the City of La Paz, Mexico, there is growing concern amongst the local population due to the uncertainty about the local air quality. To address this concern, an air pollutants emissions inventory was recently carried out as a first step to better understand air quality in La Paz. The inventory considers point, area, mobile and natural sources and it includes six major air pollutants: sulphur oxides (SO_x), nitrogen oxides (NO_x), respirable suspended particulates (RSP or PM₁₀), fine suspended particulates (FSP or PM_{2.5}), volatile organic compounds (VOC), and carbon monoxide (CO). The reference year for the inventory is 2013. This paper presents the main results of the inventory by source category. In addition, the local power utility maintains three air quality monitoring stations in the city. Data from these stations are also presented and analysed in this paper. Electricity generation and motor vehicles are the main emissions sources. The paper highlights the importance of having in place adequate emissions control systems and operations. Some recommendations for the local authorities include a ten-year air quality and emissions reduction plan that considers measures such as the imposition of statutory emission caps on power plants, implementation of renewable energies and mandatory annual roadworthiness and exhaust pipe emissions tests for on-road vehicles.

Keywords

Emissions Inventory, Air Pollutants, La Paz, Mexico

1. Introduction

The city of La Paz is the capital of the state of Baja California Sur (BCS), is the seat of the municipality with the same name and is located by the sea. For the

City of La Paz and surrounding areas, the coasts of the Sea of Cortez are of great importance for development given that the activities that support the local people include maritime trade, fishing, tourism and services. However, agricultural activities are also developed in the valleys (Ivanova Boncheva et al., 2013). The city concentrates most of the government agencies, educational institutions and health centers in the state of Baja California Sur.

The population of the city of La Paz and its actual footprint have grown rapidly in recent decades (Figure 1). The National Council of Population (CONAPO) estimates that the City of La Paz has a population of 233,559 inhabitants in 2013 (CONAPO, 2015). Population growth accelerated the challenge to achieve proper planning of urban growth and enhance sustainable development. The lack of proper planning of urban development has caused various problems including increased emissions of pollutants that affect air quality as will be discussed later. Rapid population growth has also led to a change in the surroundings of the city due primarily to the generation of waste, growth of the vehicle pool and deforestation (CONAPO, 2015; Ivanova & Gámez, 2012). Therefore, poor urban planning has caused several pollution problems and increased emissions.

In addition to motor vehicles, other sources of emissions are the two electricity generation plants that belong to the electric utility (the Federal Electricity Commission, CFE) located in the surroundings of La Paz: CCI Baja California Sur and CT Punta Prieta. The amount of electricity produced in these plants is considerably higher than the needs of La Paz, and the excess generated is intended to supply the electricity needs of other parts of the state. In turn, this is compounded by the type of inputs. The main fuel used in electricity generation in La Paz is heavy fuel oil no. 6 with high sulphur content. As a result, local air likely contains a mixture of particles and chemicals that could have serious implications on:

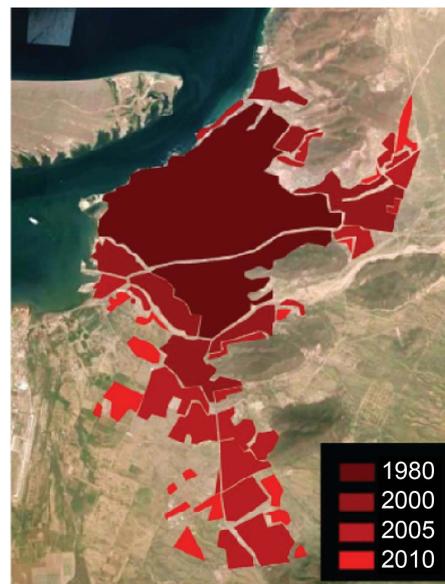


Figure 1. Growth of urban footprint of La Paz. Source: (Idom, 2014).

- The health of city inhabitants with the corresponding private and social costs (Samet, Dominici, Zeger, Schwartz, & Dockery, 2000),
- The health of nearby ecosystems, and
- The competitiveness of economic activities of La Paz (e.g., tourism).

Despite these facts, very little is known about the air people breath in La Paz and the local population is for the most part unaware of the local air quality. The only documented analyses about air quality in La Paz that made results publicly available are those based on the data collected by the National Institute for Ecology and Climate Change (NIECC) using mobile monitoring stations in 2010 and in 2014. Unfortunately, these were only short-term monitoring campaigns that lasted no more than a few weeks. Considering that prevailing winds and other meteorological variables change significantly throughout the year as do activity patterns and energy use in the city, it is very difficult to draw firm conclusions regarding air quality in La Paz from these efforts. Nevertheless, even with the limited data collected during the 2014 campaign it was found that the concentration of particulate matter surpassed Mexican regulations thresholds.

Besides NIECC's short-term campaigns, another source of information regarding air quality in La Paz was a monitoring station located in a resort near La Paz and close to one of the local power plants. This monitoring station started operation in 2009 and reported air quality parameters to NIECC. The station was in operation for a few years, reporting progressively less and less data and was finally damaged by meteorological phenomena that rendered it inoperable.

Thus, to start a systematic investigation about air quality in La Paz and start tackling the shortcoming of previous efforts in air quality monitoring in La Paz, a polluting emissions inventory was required as a first step in the process of making air quality known to local population in La Paz. To achieve the ultimate goal of deploying an open-access, real-time air quality monitoring network in La Paz, the inventory would identify the main emission sources and quantify the volume of pollutants released into the local atmosphere in La Paz. The steps involved in the development of the emissions inventory and a summary of the main findings are described in the following sections.

2. The Inventory

The first step in the study was selecting the pollutants to be inventoried. The reference for this was the so-called criteria pollutants as established in Mexican and American regulations. These pollutants can harm human health, the environment and even property. In particular, the pollutants included are nitrogen oxides, carbon monoxide, sulfur oxides, volatile organic compounds and particulate matter. The main effects of these pollutants on human health are presented in **Table 1**.

2.1. Objective

The implementation of actions, procedures and programs to maintain a minimum standard of air quality requires knowledge of the emissions in terms of

type, amount, composition and origin. For this, the objective of the study was to develop an inventory of emissions of nitrogen oxides (NO_x), sulfur oxides (SO_x), volatile organic compounds (VOCs), carbon monoxide (CO), particulate matter less than or equal aerodynamic diameter 2.5 microns (PM_{2.5}), and particulate matter less than or equal to 10 micrometers (PM₁₀) for the City of La Paz, Baja California Sur, to identify and characterize emission sources and quantify their magnitude.

2.2. Area of the Inventory

The boundaries of the study area of this emission inventory are shown in the map in **Figure 2**. In addition to the city itself, surrounding areas were included because of their influence on economic and social life of the city, as they are particularly relevant in sectors such as transport, farming and fishing activities. The total area covered by the inventory is in excess of 200,000 hectares.

Table 1. Effects of pollutants on human health (SEMARNAT, 2013).

Pollutant	Effect on human health
Nitrogen oxides	Irritation of airways. In high concentrations can cause bronchitis and pneumonia.
Sulfur oxides	Irritation of airways. In high concentrations can cause bronchitis and tracheitis.
Ozone (ground level)	Irritation of airways. In high concentrations can reduce pulmonary function, worsen asthma, inflame lung wall cells and worsen chronic pulmonary diseases.
Volatile organic compounds	Promote the formation of ground-level ozone.
Carbon monoxide	In high concentrations inhibits cellular oxygen transport. Prolonged exposure can cause lightheadedness, headaches, loss of consciousness and even death.
Particulate matter with aerodynamic diameter ≤ 2.5 microns	Worsen asthma, reduce pulmonary function, associated with diabetes development and can cause fetus size reduction.
Particulate matter with aerodynamic diameter ≤ 10 microns	Worsen asthma and cardiovascular respiratory diseases, Chronic exposure to high concentrations can cause in increased risk of morbidity and mortality.



Figure 2. Study area: La Paz and surrounding areas. Source: Google Earth.

2.3. Base Year

In the preparation of the inventory 2013 was selected as the base year. The reason for this was the availability of information. Particularly, the most recent data from electricity generation plants at the time of this work were those of 2013.

2.4. Emissions Categories

The inventory covered four categories: fixed or point sources, mobile sources, area sources and natural sources. Each one of these are described as follows:

1) Fixed or point sources. It refers to “any facility established in one place, that is intended to develop operations or industrial processes, commercial, services or activities that generate or may generate emissions into the atmosphere” (RLGEEPA, 2014; Art. 6, IV) including:

- The chemical, oil and petrochemical, paints and inks, automotive, pulp and paper, metal, glass, electric power generation, asbestos, cement and lime and hazardous waste treatment.
- All establishments, projects (industrial, commercial or service) activities administered by federal government agencies.
- Sources affecting the ecological balance of an adjacent state or country.

2) Mobile sources. These consist of motor vehicles with a displacement within the study area, such as private cars, trucks, motorcycles and buses for public or private use. Emissions from motor vehicles are made up of various pollutants and processes:

- Exhaustion emissions.
- Hot humid emissions.
- Evaporative emissions.
- Diurnal emissions.
- Evaporative emissions at rest.
- Evaporative emissions from refuelling.

3) Area sources. It refers to sources, establishments or activities presented scattered but in great amount, and individually do not emit into the atmosphere large quantities of chemicals, gases or particles, but in aggregate can generate significant emissions.

4) Natural sources. All those sources that emit pollutants of no direct anthropogenic origin are considered natural sources. These can be defined as biogenic or geogenic. The former include emissions of volatile organic compounds (VOC) emissions generated by crops or soil. The latter are of geological origin, such as springs, volcanoes or geysers.

2.5. Methodology for Estimating Emissions

In general, the methodology for estimating emissions uses an emission factor, which relates the released amount of a certain pollutant to an activity related to the release of such pollutant. The emission factor is given by the ratio of the amount of mass of the pollutant in question released into the atmosphere divided by a unit of measurement of the activity that generates it. Such measure-

ment unit can be, for example, the mass or volume of fuel used or the duration of operation process. In addition, the processes under study could have emissions control mechanisms in place. This is also taken into consideration in the methodology. Thus, the general equation for estimating emissions is:

$$E_i = FE_i \times A \times \left(1 - \frac{ER_i}{100}\right) \quad (1)$$

where

E_i is the emitted amount of pollutant i .

FE_i is the emission factor for pollutant i .

A is the activity data associated with the release of pollutant i .

ER_i is the efficiency of the emissions control mechanism for pollutant i .

It should be mentioned that, methodologically, the development of this work was based on various documents and resources such as the Guide for Development and Uses of Emissions Inventory (SEMARNAT, INE, & WGA, 2005), the Methodological Guide for Estimating Emissions from Fixed (SEMARNAT & INECC, 2013), the Methodological Guide for Estimating Emissions from Vehicles in Mexican Cities (SEMARNAT & INE, 2009), Technical Manuals of the Mexico Emissions Inventory Program as well as some other articles and sources.

While detailed descriptions of the specific methodologies followed to estimate the emissions of every pollutant in each category for every source fall beyond of the scope of this paper due to their significant length, it must be mentioned that fixed or point source emissions were estimated using emissions factors from the United States Environmental Protection Agency's (EPA) AP42 and WebFIRE as well as mass balances; mobile source emissions were obtained from a report by NIECC (INECC, 2014) using EPA's Motor Vehicle Emission Simulator (MOVES) and were also estimated using emissions factors from Chester & Horvath (2008) for comparison; area source emissions were obtained following the Technical Manuals of the Mexico Emissions Inventory Program (Radian International, 1997); and natural source emissions were estimated according to a personal computer version of the biogenic emissions inventory system (Pierce et al., 1991).

3. Energy Balance of La Paz

As it will be seen in the following section, energy use is largely responsible for the emission of pollutants in general. For this reason, an energy balance for the City of La Paz was also performed. The balance grouped energy use in three large categories: electricity generation, transport and heat for various purposes. Electricity generation considered the energy contained in the fuels (heavy fuel oil no. 6 and diesel oil) used in the two power plants located in La Paz (CCI Baja California Sur and CT Punta Prieta) as well as the contribution of a local solar power plant that began operations in late 2013. Similarly, the category of transport included the energy content of gasoline, LPG and diesel fuels used in the transport sector. The heat category comprised the LPG used for purposes other than transport.

In this way, the balance found a total energy use in La Paz of 25,940 TJ during 2013 with electricity generation accounting for more than 50% of this as shown in **Figure 3**. It should be noticed that not all electricity generated in La Paz is consumed locally and excess power goes to other locations in the state. Nevertheless, local ecosystems and population in La Paz and its surroundings must cope with the negative environmental and other effects derived from the whole of the electricity generated.

4. Total Emissions

Emissions from all four sources considered were estimated using the methodologies mentioned above. **Table 2** presents the totals obtained and **Figure 4** shows graphically the breakdown of the six pollutants considered in the inventory for every category in every source, including de aggregation by pollutant and by source. This is also presented schematically in the Sankey diagram of **Figure 5**. The highest volume of emissions comes from fixed sources, which are the main generators of sulphur and nitrogen oxides as well as of particulate matter.

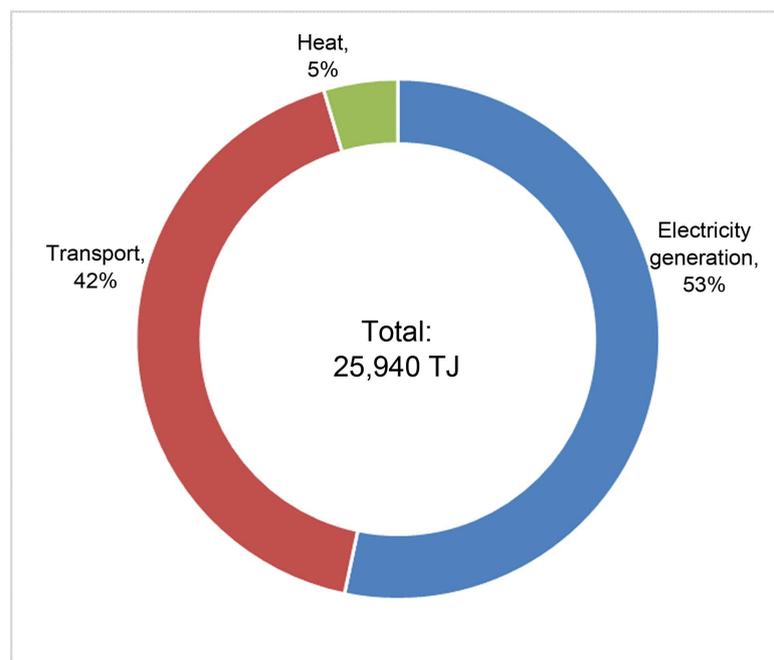


Figure 3. Energy balance summary for the City of La Paz, 2013.

Table 2. Emissions by source and by pollutant in La Paz, 2013.1 Mg equals 1000 kg.

Source	Emissions (Mg/year)						TOTAL
	SO ₂	NO _x	CO	PM10	PM2.5	COV	
Fixed	14,345	12,481	2582	839	284	16	30,546
Mobile	84	1784	12,366	45	41	813	15,133
Area	19	250	576	228	2	4170	5247
Natural	--	--	--	--	--	4455	4455
TOTAL	14,448	14,515	15,524	1005	327	10,851	56,670

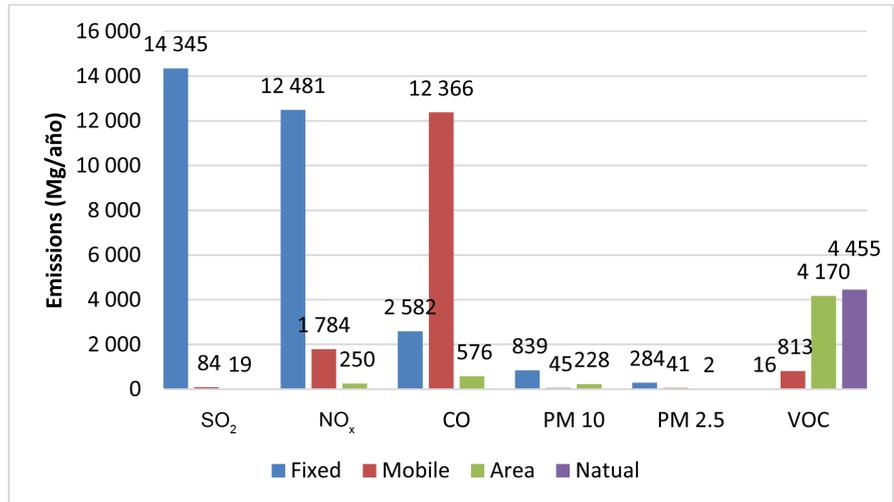


Figure 4. Emissions by source and by pollutant in La Paz, 2013.

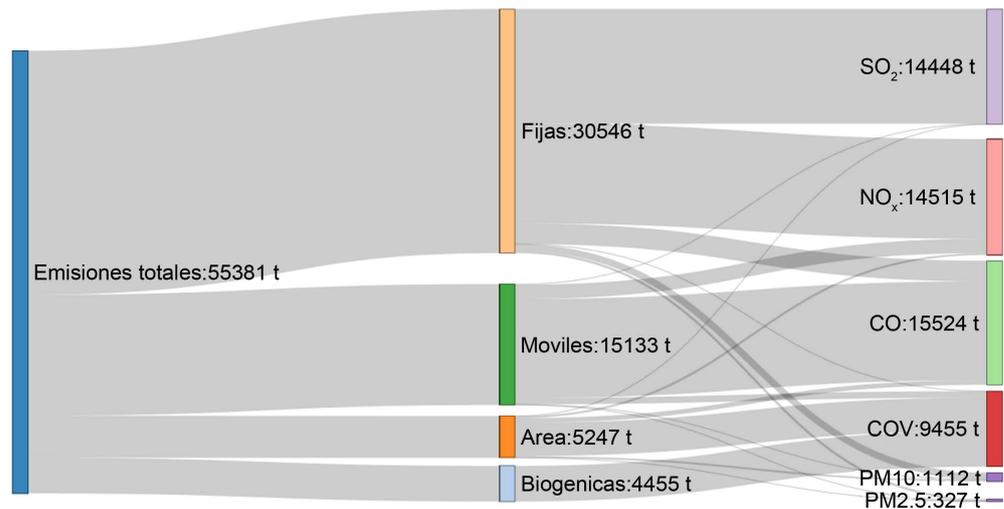


Figure 5. Sankey diagram of emissions in La Paz, 2013.

The second place in total emissions corresponds to mobile sources, where the main pollutant emitted is carbon monoxide. Nevertheless, mobile sources also emit important amounts of nitrogen oxides and volatile organic compounds. In the case of natural and area sources the main pollutant type emitted is volatile organic compounds.

One important conclusion that can be drawn from Figure 5 is that fixed sources are by far the largest combined source of pollutants followed by mobile sources. Unlike other emissions, pollutants coming from fixed and mobile sources have their origin in the consumption of a fuel, i.e., in using energy. In fact, detailed accounting of the emissions from categories of the inventory that have to do with either the direct use of energy or with enabling the use of energy (e.g., fuel storage or fuel transportation) revealed that these energy-related categories are responsible for 88% of all emissions in La Paz. Therefore, in order to approach air quality issues in La Paz energy use processes must also be addressed.

In this respect, the high electricity demand growth rate in BCS requires constant expansion of the generation capacity. Most of the new capacity built in recent years has been located in La Paz and this is expected to continue in the future. Therefore, after seeing the already high amounts of emissions coming from electricity generation and the expected electricity generation capacity growth in the future, it is of paramount importance to have in place adequate emissions control operations and mechanisms for current and future power generation units if emissions are to be kept within acceptable levels.

Likewise, poor urban planning regarding the expansion of La Paz seems to have had an impact on general transportation. For instance, **Figure 6** shows the growth of the City of La Paz between 1980 and 2010 and also the evolution of the number of vehicles in the city for the same period. In the Figure it seems that as the city grew southwards axially, the number of vehicles also grew rapidly especially between years 2000 and 2010. This can be explained at least in part as a result of the increased need for transportation for people living in the newly developed areas. The consequence for air quality is an increase in fuel consumption and therefore in emissions. It must be mentioned that the City of La Paz has a very high number of vehicles per person. In fact, it has been estimated that this number could be as high as 1.27 vehicles per person if unregistered vehicles are considered (Idom, 2014), i.e., there could be more motor vehicles than people. Considering that more than 70% of vehicles in La Paz are very old (and, therefore, inefficient) corresponding to models 2004 or older and that many lack catalytic converters, there is significant room to reduce the emissions coming from mobile sources. For instance, annual roadworthiness tests and exhaust pipe emissions tests could be made mandatory in order to obtain or keep a vehicle's registration. This would provide incentives for vehicle owners to take action to reduce polluting emissions from their vehicles.

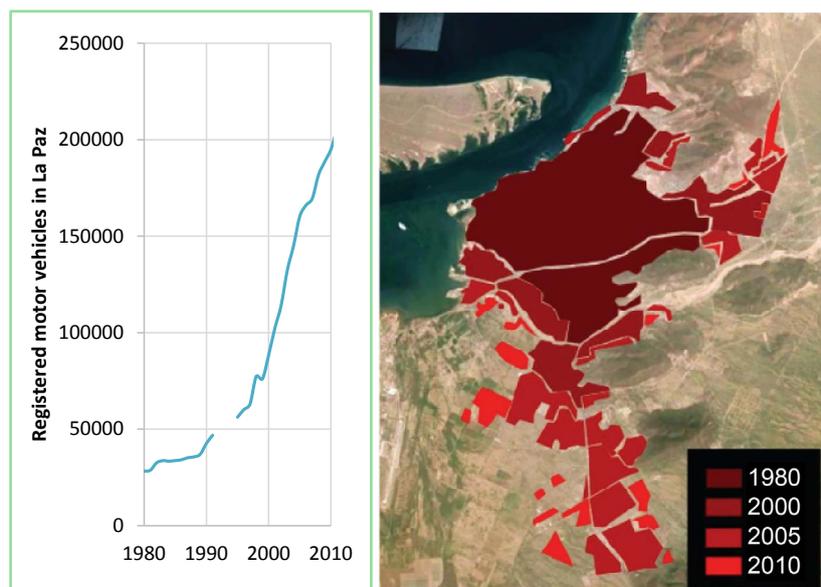


Figure 6. La Paz city surface and registered vehicle fleet. Source: left, prepared by authors based on data from (INEGI, 2016a; 2016b); right: (Idom, 2014).

5. Air Quality Monitoring

To complement the findings of the inventory, air quality monitoring data have been obtained and analysed. The data comes from three monitoring stations that belong to the local power utility CFE. These are located as shown in **Figure 7** and have been in operation since 2005. The monitoring stations sample air quality at regular intervals and generate daily averages for three pollutants, namely: sulphur and nitrogen oxides and ozone. In the case of PM10 a daily average is generated every six days as per Mexican regulations. This is appropriate to compare sulphur oxides concentrations and PM10 concentrations to maximum allowed limits established in Mexican regulations. These comparisons are presented in **Figure 8** and **Figure 9**. In addition, with the data obtained for PM10 it

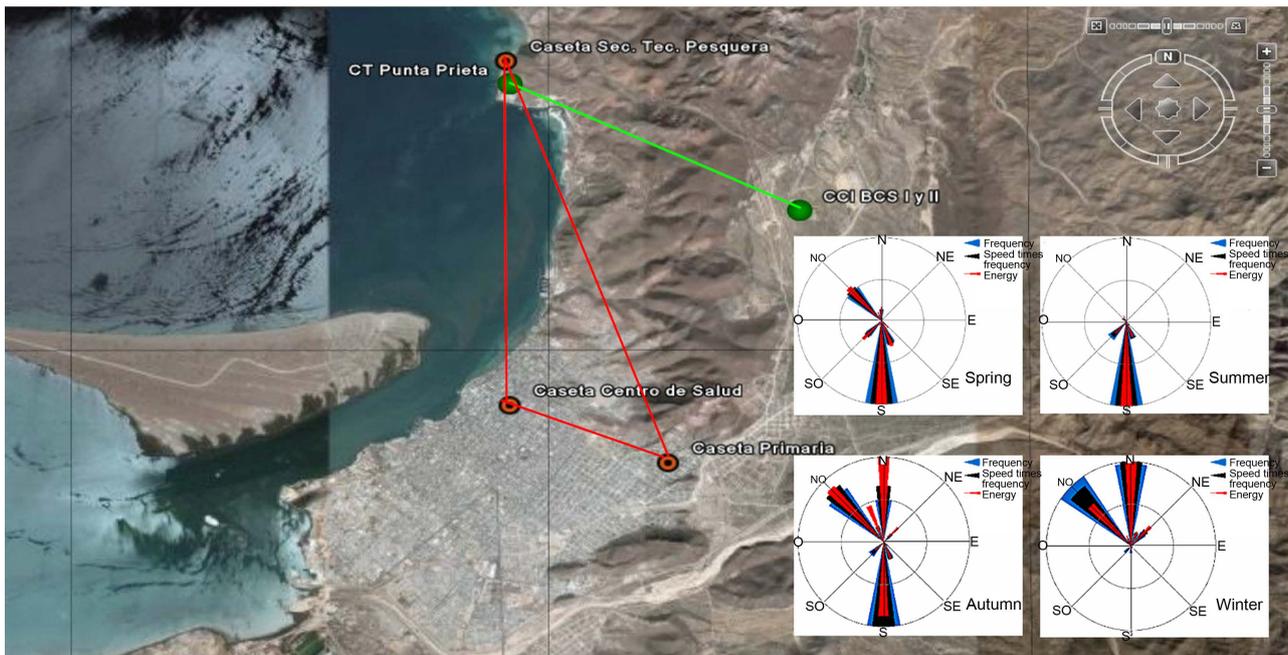


Figure 7. Location of air quality monitoring stations. Source: (CFE, 2008). Red dots correspond to monitoring stations (R1 at the top of the image, R2 directly South from R1 and R3 to the East of R2) and green dots correspond to power stations. The wind rose insets show prevailing wind directions in autumn (top left), winter (top right), spring (bottom left) and summer (bottom right).

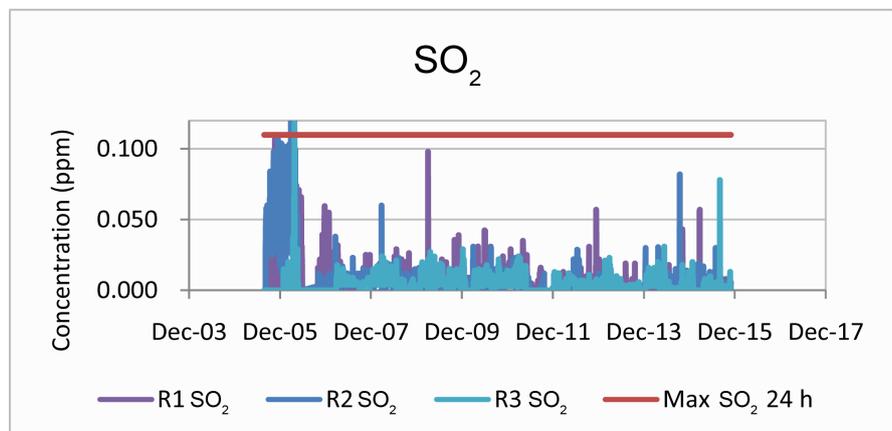


Figure 8. Monitoring data for sulphur dioxide from the three stations (R1, R2, R3).

was possible to calculate annual averages which are also subject to regulation in Mexico (see comparison in **Figure 10**).

Sulphur dioxide monitoring data are presented in **Figure 8**. As seen in the inventory results, the main emitter of this substance is electricity generation due to the high sulphur content of the fuel, which could be as high as 4%. It must be pointed out that concentration levels registered in the monitoring stations during the first year of operation often reached or exceeded the maximum allowed value but from there on, sulphur dioxide concentrations have been within acceptable values in all monitoring stations. It must also be pointed out that an emissions control system was installed in one of the power plants (CT Punta Prieta) during 2006-2007 with the objective of reducing sulphur oxides and particulate emissions by means of sulphates formation and the operation of electrostatic

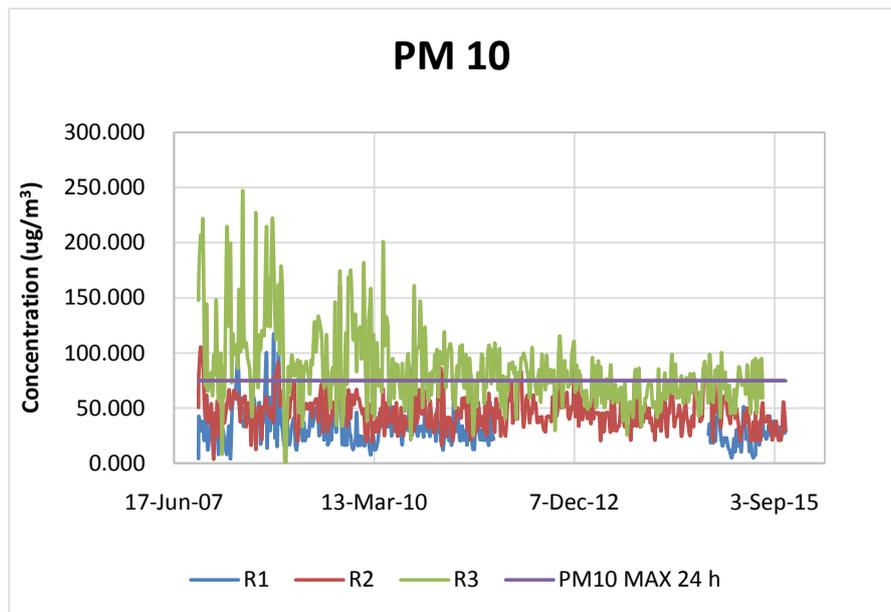


Figure 9. Monitoring data for PM10 from the three stations (R1, R2, R3).

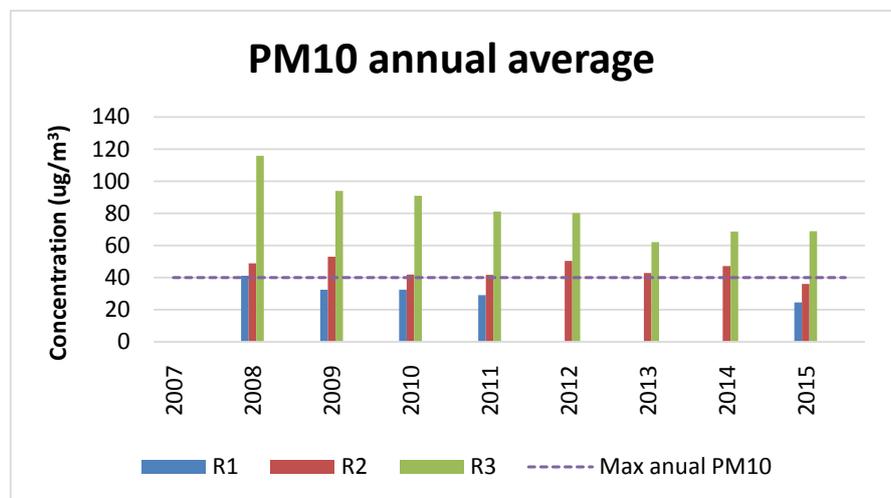


Figure 10. PM10 annual averages for all monitoring stations.

precipitators. This seems to have a good correlation with the sudden drop in sulphur dioxide concentrations observed in **Figure 8**.

The concentration levels of PM₁₀ since October 2007 are shown in **Figure 9**. It is immediately noticeable here that the maximum allowed concentration is highly and frequently surpassed in monitoring station 3 (R3), sometimes exceeded in station 2 (R2) and never in station 1 (R1). This suggests that the main sources of PM₁₀ at the point of registration by the monitoring stations could be different from power stations despite fixed sources being the main PM₁₀ generators as identified in the inventory. Rather, another source of PM₁₀ could be responsible for the high levels observed at the monitoring stations. This could be local traffic and other activities in the vicinity of monitoring stations R2 and R3. This also suggests that the dynamics of the air shed in La Paz must be further studied.

Finally, PM₁₀ annual averages are presented in **Figure 10**. These averages are related to chronic exposure. Here it is observed that, with the exception of 2015, the maximum allowed level has been surpassed every year in stations 2 (R2) and 3 (R3) which are the two urban stations. Therefore, it is of paramount importance that the source of these emissions be identified and that emissions control systems be put in place to protect public health as PM₁₀ aggravates for instance asthma and cardiovascular respiratory diseases.

6. Concluding Remarks

A polluting emissions inventory was recently completed for the City of La Paz as a first step to systematically approach the lack of information about air quality. The inventory results consist of emissions estimations (i.e., they are not actual measurements) for various pollutants affecting air quality and human health. While the results from the inventory yield total amounts of pollutants emitted and cannot be compared to maximum concentration values set in the air quality regulations, they are nevertheless an important first step that allows the identification of pollutant types, amounts and their sources.

The emissions inventory found that the pollutants emitted to the atmosphere larger quantities in La Paz, Mexico are carbon monoxide, sulphur dioxide and nitrogen oxides. Electricity generation and the exaggerated number of motor vehicles per capita are the main emissions sources. Data from air quality monitoring stations suggest that the implementation of the emissions control system in the CT Punta Prieta, one of the two power stations located in La Paz, had an important effect in reducing sulphur dioxide emissions. On the other hand, while electricity generation is also the main emitter of particulate matter, monitoring data trends suggests that PM₁₀ may have a different origin at least in the proximity of the monitoring stations. With PM₁₀ concentration levels recurrently found above maximum allowed values, it is very important to identify the additional sources of PM₁₀ emissions in urban areas in order to protect public health. To address this and other air quality concerns, local authorities could design and implement an air quality and emissions reduction plan up to 2026 (i.e.,

ten years). The plan could include measures such as the imposition of statutory emission caps on power plants, implementation of renewable energies and mandatory annual roadworthiness and exhaust pipe emissions tests for on-road vehicles. The State Government has already begun the application to obtain support from the Federal Government to establish measures that enhance air quality and to acquire air quality monitoring equipment so that local air quality can be assessed against current regulations and actions taken to ensure emissions are kept within acceptable levels to protect public health in the City of La Paz.

In this way, the emissions inventory will provide useful information for decision makers and politicians in the formulation of plans and programs to improve air quality. Additionally, the inventory results in combination with monitoring data will be valuable assets in the following steps of the design and implementation of an open-access, real-time air quality monitoring network in the City of La Paz. Such network will help to ensure that pollution levels are kept within acceptable limits as well as to raise awareness about air quality and its impact on public health amongst the local population.

Acknowledgements

The emissions inventory for La Paz was financially supported by the International Community Foundation through project grant INV-EX/173.

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