Chapter

Particle and Carbon Monoxide Atmospheric Pollution in the City of Tepic, Nayarit, Mexico

Mario García, Héctor Ulloa, Omar García, Hermes Ramírez, Aida Fajardo, Claudia Saldaña, Sarah Messina and Yamilet Rodríguez

Abstract

Actively caring for the environment is an issue that prevails in the international debate, and our country takes part on this argument. One aspect of environmental deterioration is, with no doubt, atmospheric pollution; a constant in modern societies, which, in the attempt to find growth and development, impact the natural and urban environment they inhabit. A distinctive feature of commercial and economic exchange are the strategic cities, so-called capitals, in addition to the territories where coastal tourism predominates as an engine of regional human development. In this balance, which is far from being sustainable and fair, an exponential consumer market dominates and generates the progressive increase in the use of fossil fuels. The former being emitted into the atmosphere, in such a way that they alter chemical composition and cause harmful air quality. In addition, the territory is impacted, intoxicating the soil and water, which are the final deposit. The objective of this work is to determine the temporal behavior of atmospheric pollutants in the city of Tepic, Nayarit, Mexico and to identify the dominant pollution indicators considering the international and national context. Through the statistical analysis of the databases of particles smaller than 2.5 micrometers, particles smaller than 10 micrometers and carbon monoxide, the behaviors of these pollutants in the study area were obtained. Among the most significant results, particles smaller than 2.5 micrometers showed maximum levels outside the norm almost all year round, with values reaching 170 micrograms per cubic meter. On the other hand, the particles smaller than 10 micrometers presented satisfactory levels in their average behavior; however, the maximum concentrations remained outside the official Mexican standard. Regarding the analysis of CO, a behavior within the maximum permissible limits of protection for the population was reported; Nevertheless, by favoring the formation of tropospheric ozone, its contribution is significant, especially when the atmosphere is highly photo-reactive. This research can be used as a timely tool for mitigation of climate change, where the results contribute to the review and rethinking of public management of the environment towards sustainable development.

Keywords: air pollution, particles, carbon monoxide, Tepic, Mexico

1. Introduction

The emission of pollutants into the atmosphere has caused damage to the environment, destroying and large areas of flora and fauna, necessary for the natural balance of the planet. The use of fossil fuels raises air pollution to harmful levels for humans, favors the accumulation of greenhouse gases and destroys the ozone layer, in addition to the acid rain phenomenon that has affected Europe, Asia and North America; in fact, it is considered a significant problem in China so far in the 21st century [1–4]. The most relevant impact occurs in urban areas and industrial complexes; however, adverse effects have been observed even in distant areas [5].

Although air pollution is a cross-cutting issue that needs to be addressed in a comprehensive manner, the media discourses, being transformed into immediate solutions not for prevention and control in the long term but for mitigation, stand out. Consequently, the centralization of goods and services in the territory negatively affects the well-being of the population [6–11]. In this context, Khan et al. [12], reported that the use of renewable energy in logistics operations improves the environmental and economic state and reduces spending on public health.

The role of air quality indexes is pivotal in controlling emissions from both mobile and stationary sources. No traffic congestion problems would be observed if the use of means of transport were planned; Transportation is inefficient due to the metropolis great extension and functional segregation [6, 13]. While pollution in developed countries is due to industrialization, in most countries of Latin America and the Caribbean, it is influenced by motor vehicles [14–18].

Climate, meteorological and topographic conditions influence the pollutant concentration, transport and dispersion, as well as the magnitude of the impact on the population and its habitat [14–18]. The statistical analysis of meteorological and pollutant data makes possible to identify a relationship between local emission sources and to have a better understanding of the spatio-temporal trends of air quality indexes; whose variation depends on the distance between sources and traffic volumes [14, 19]. In addition, cities located in depressions are associated with the formation of thermal inversions, an optimal condition for the assembling of pollutants, at harmful rates, in the lower layer of the atmosphere [20]. These changes avoid the dispersion of pollutants, especially in winter.

Several studies report that the association of pollutant-meteorological variables impact human health. Therefore, incorporating atmospheric monitoring stations in cities for their evaluation and control is fully justified [19]. Another study by Tiwari et al. [21], reported that rain, wind speed, and surface temperature are the factors that control the evolution of PM10 and PM2.5 particles over Guwahati, India. Pollution levels are comparable with those obtained in other megacities and explain the effects on health in recent years.

Mexico is no stranger to environmental problems; in fact, air pollution in cities has impacted the life quality of society, as well as its health and the environment. The metropolitan area of the Valley of Mexico (**Figure 1**), Guadalajara and Monterrey are included among the metropolises that are characterized by suffering from environmental issues [22–24]. The objective of this work is to determine the spatial–temporal behavior of atmospheric pollutants in the city of Tepic, Nayarit, Mexico and define, based on the available information, the dominant pollution indicators in the area. The results can contribute to the improvement of atmospheric contingency plans, in addition to being an alternative for public management of environment aspects.

Figure 1.
Pollution in CDMX under thermal inversion scenarios. Own source (01/12/2019).

2. Case study and methodology

2.1 Description of the study area: Tepic City, Nayarit, Mexico

The state of Nayarit is located in the central western region of Mexico and has an approximate area of 27,857 km^2 that covers 1.4% of the national territory (**Figure 2**). Its geographic coordinates correspond to 23° 05′-20° 36′ north latitude and 103° 43′-105° 46′ west longitude [25–27]. It has an approximate population of 1,181,050 inhabitants [28] and it is composed of 20 municipalities, the city of Tepic being the state capital. Within its growth and development potential, tertiary and service economic activities predominate, as a consequence of its tourist and commercial explosion.

From its side, the municipality of Tepic is located in the center of the state with a land area of 1,983.3 km^2 which represents 7.25% of the state of Nayarit. It has an approximate population of 413,608 inhabitants, highlighting the towns of Tepic, Francisco I. Madero, Bellavista and Camichín de Jauja. Its geographic coordinates are 21° 51′-21° 24′ north latitude and 104° 34′-105° 05′ west longitude [26, 27, 29].

Regarding its orography, 72.5% of the land relief of the municipality corresponds to mountains, the rest is represented by hills, plains and small valleys. The mountain ranges that cross the municipality are the Neovolcanic Axis and the Sierra Madre Occidental. Its main elevations correspond to the volcanoes of Sangangüey, San Juan, Las Navajas and El Rincón hill, with altitudes of 2340, 2180, 1680 and 1600 meters above sea level, respectively.

Two main types of climate predominate; subhumid warm climate with rain in summer that affects 66.06% of the municipal geography and the subhumid semi-warm climate with rain in summer, which benefits the remaining 33.94%. Rain concentration of 91.05% is observed between the months of July and October. Average annual rainfall is 1,121 mm. In this order, **Table 1** shows monthly values of temperatures (maximum and minimum); the average temperature oscillates between 21.1° C, with north prevailing winds, with an average speed of 8 km/h [26, 27, 31].

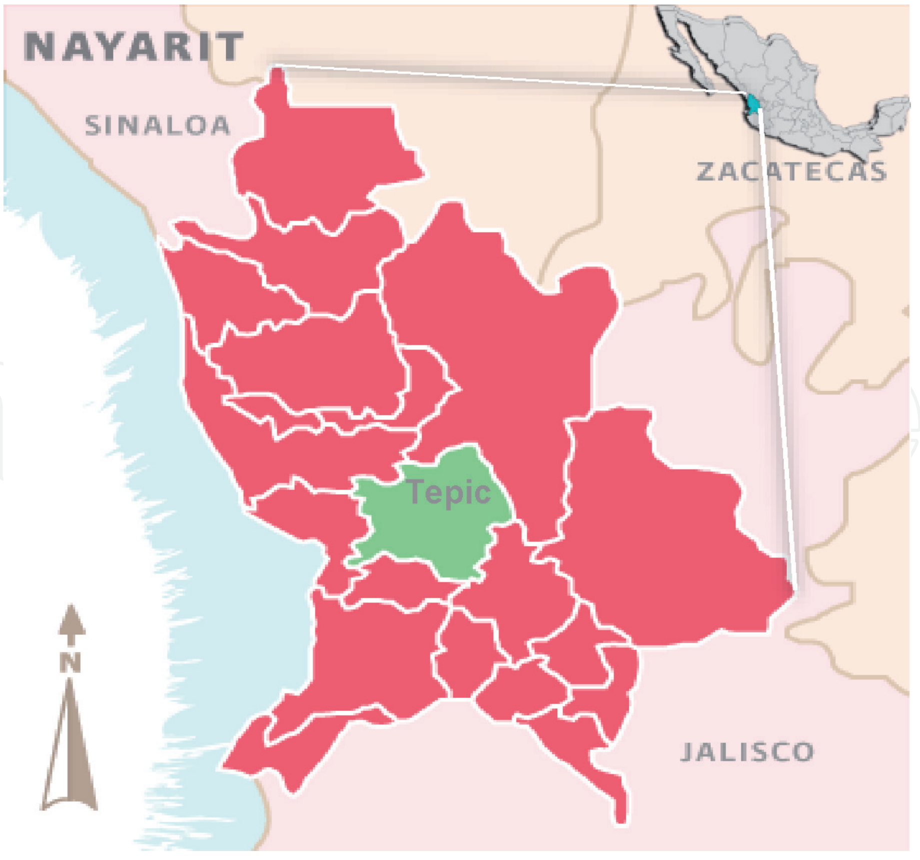

Figure 2.
Geographical location of Tepic, Nayarit, Mexico. Source: Google images.

The city of Tepic has developed around a significant vehicular complex and extraordinary industrial activity dominated by the "El Molino" sugar mill with more than a century of operations. Both sources have increased the discharge of pollutants into the atmosphere, such as total suspended particles and carbon monoxide, among others. This sugar factory, due to its magnitude and economic impact, remains within the top 10 in performance at the national level and the most important in the state of Nayarit, with the countryside, suppliers, contractors, transporters and employees, as sectors that benefit the most. In this way, Khan et al. [32], reported that trade and transport infrastructure are positively correlated with per capita income, while logistics operations are negatively associated with social and environmental problems (climate change). In addition, air pollution in the territory contributes to the generation of acid rains, water pollution and a harmful impact on human health. In this scenario, the search for better living conditions has an impact on the habitat, exceeding air quality indexes to levels that are harmful to the population.

In relation to this, Hernández [33] showed that "El Molino" is a source of atmospheric pollution. It is noteworthy that, due to its location close to the city center, due to the burning of sugarcane and its transportation, the damage to health increases 2.6 times during the harvest season.

In coincidence, the work carried out in El Salvador by Castillo and Rivera [34], reported that the sugar sector, despite its high economic and nutritional value, is a source of pollution. Accordingly, with information from 2011 to 2013, Alatorre and Llanos [35] identified that the most significant peaks in CO concentrations occur during the morning (6:00–9:00 hours), associated with low temperatures (lower temperatures, higher concentration of particles in the air) and to vehicular and industrial influence. This is proven by the fact that the most significant values were recorded in the months of December to April. Furthermore, the synergy

DOI: http://dx.doi.org/10.5772/intechopen.95579

Month	January	February	March	April	May	June	July	August	September	October	November	December
MaxTR	28	29	31	32	35	33	33	32	33	33	31	30
DMaxT	25	24	28	29	32	31	28	30	29	30	29	28
DMinT	16	15	15	17	16	22	22	22	23	21	14	12
MinTR	9	9	8	11	11	17	20	20	20	16	7	4

Maximum temperature recorded (MaxTR), Daily maximum temperature (DMaxT), Minimum temperature recorded (MinTR), Daily minimum temperature (DMinT). Temperature (°C). [30].

Table 1.
Tepic average climatic parameters.

of pollutants in Tepic can negatively impact the presence of thermal inversions (**Figure 3**). The geography and orography of the city allow this behavior to occur frequently, concentrating pollution for long periods and reaching harmful levels for the exposed population [10, 36]. Finally, other essential activities of the municipality are agriculture and livestock, followed by logging, which bring with them multifactorial problems related to air, soil and water pollution. The list is completed by an excessive generation of urban solid waste, the elimination of electronic devices (e-waste), in addition to the high stress to which sanitary landfills or open dumps are subjected [37].

2.2 Methodology

The presence of phenomena that have affected the territory over time, leads researchers, decision makers and society to search for instruments to analyze and understand the root causes of the problem. In order to apprehend reality and identify solid bases to act in the prevention and mitigation of the risk to which living beings are continuously exposed, particularly human beings. Determining the magnitude and influence of pollution indicators and rethinking control methods in cities provides an indispensable tool for the preservation of the society-nature balance. In this synergy, problems and areas of opportunity can be identified in the management of the territory.

In the first instance, information corresponding to the database of atmospheric pollutants and meteorological variables (two monitoring stations) was collected in collaboration with the Ministry of Rural Development and Environment (SEDERMA) of Nayarit. Data were selected, validated and processed with statistical methods. To choose the indicators that best describe the problem in the territory, the Official Mexican Standard (NOM) is used as reference for the criteria and their relationship with international standards (**Table 2**). The reliability and updating of data, and the spatio-temporal trends are considered as key information in the description-evaluation of the phenomenon.

2.3 Stochastic processes

Using a stochastic model, it is possible to know the future of processes that develop over time, predict the behavior of physical and atmospheric phenomena, know their evolution and culminate with decision-making considering the best solution. The time *series or temporal series* that record observations of a process as

Figure 3.
(a-b) Pollution in Tepic - thermal inversion (05/30/2016–2109,35 am) source: Own image.

Pollution indicator	World Health Organization (WHO)*		Environmental Protection Agency (EPA)*		Official Mexican Standards (NOM) - DOF (1994)	
	ppm	μg/m³	ppm	μg/m³	ppm	μg/m³
Ozone (O_3)	- 0.05 (8 h)	- 100	0.12 (1 h) 0.075 (8 h)	235 150	0.095 (1 h) 0.070 (max 1 year)	215 157
Carbon monoxide (CO)	9 (8 h) 26 (1 h)	10290 29725	9 (8 h) 35 (1 h)	10290 40000	11 (8 h)-(1/year)	12595
Nitrogen dioxide (NO_2)	0.106 (1 h) 0.023 (annual)	200 40	0.25 (1 h) 0.053 (annual)	470 100	0.21 (1 h)-(1/year) -	395 -
Sulfur dioxide (SO_2)	0.007 (24 h) 0.191 (10 min)	20 500	0.14 (24 h) 0.03 (annual)	365 80	0.11 (24 h)-(1/year) 0.03 (annual)	289 80
Breathable particulate material (PM_{10})**	—	50 (24 h) 20 (annual)	—	150 (24 h) 50 (annual)	—	75 (24 h) 40 (annual)
Fine particulate material ($PM_{2.5}$)**	—	25 (24 h) 10 (annual)	—	35 (24 h) 15 (annual)	—	45 (24 h) 12 (annual)

**[38].*
***[39]. ppm: parts per million, μg/m³: microgram/cubic meter.*

Table 2.
Air quality standards (average pollution indicators).

a function of time, are justified to predict the future based on past data, know and control the process that generates it and obtain a description of its characteristics, among others [40].

In the case of Tepic, a pollution analysis was performed using this series-based methodology using spectral analysis and correlation functions. The tool used was the Statistical Package for the Social Sciences [41]; the solution provides adequate control that provides certainty and decision opportunity. In addition, environmental indicators (**Table 3**) are instruments for monitoring through the systematic collection of data obtained and time series. Overall, the indicators, variables and indices synthetically reflect a social concern regarding the environment and are coherently inserted into the decision-making process.

In order to know the current state of air quality, SEDERMA operates the air quality monitoring network, which measures pollutants: carbon monoxide (CO), nitrogen oxides (NO_X), nitrogen dioxide (NO2), ozone (O3), sulfur dioxide (SO2) and particles smaller than 10 and 2.5 micrometers (PM10 and PM2.5). The evaluation period is 2015, with the official institution being the provider of the information. PM10, PM2.5 and CO are evaluated, which are subjected to a spatial and temporal analysis. Regarding the inclusion criteria, the hourly average concentration of the pollutants is evaluated. Data outside the consistency range, negatives, zeros, and undetected were removed. Using a map, the study area was georeferenced and the monitoring stations were located, one located to the east over the "Primary School: PRIM" and the other to the west over the "Technological Institute of Tepic: ITT" (**Figure 4**).

Variable	Definition	Indicator	Equivalences – MAQI (100)
Air pollutants (CA)	PM_{10} $PM_{2.5}$ CO	75 μg/m^3 average in 24 hours 40 μg/m^3 annual average 45 μg/m^3 average in 24 hours 12 μg/m^3 annual average 11 ppm average in 8 hours	Metropolitan air quality index (Maximum average concentrations of protection for the population: 100). [39]

Table 3.
Definition of variables and indicators.

Figure 4.
Pollutant monitoring stations (a: PRIM, B: ITT). Source: Self-elaborated.

3. Results

Within the variety of aspects that characterize the Earth's atmosphere, one of them is its dynamic character; It is not static, but significant changes are constantly taking place. Thus, due to its influence on humans, it seeks to understand in depth atmospheric phenomena and even predict their formation [42]. Pollution is influenced by the atmosphere state; if the pollutants in the air exceed their concentration in excess of that existing in a normal environment, the same atmosphere is responsible for transporting, dispersing and even transforming them.

3.1 Monthly average behavior of particles smaller than 2.5 micrometers in 2015

The official Mexican standard for particles smaller than 2.5 micrometers (PM2.5) establishes a maximum permissible limit (threshold) of 45 μg/m^3 as an average in a 24-hour interval (or 12 µg/m^3 annual average). According to the results obtained for this pollutant (PM2.5), during the month of January, a series of inconsistencies prevail. The homogeneous behavior observed is the result of the absence of information, deficiencies in the calibration and data validation stage during that month. Based on the information provided, the maximum values range between 50 and 80 µg/m^3, that is to say, unsatisfactory levels with respect to current regulations. Regarding February, it was observed that average concentrations are maintained between 25 and 45 µg/m^3 while the maximum values move in a range of 45 and 55 µg/m^3 respectively. In this order, the month of March shows a negative trend in the average data, while the maximums only in some moments of the day exceed the regulations. In the case of April, the trend in the average values is maintained, although the maximums show higher levels in relation to the previous month, reaching concentrations between 55 and 75 µg/m^3 (**Figure 5**).

On the other hand, during the month of May fluctuations are observed that keep the concentrations within the environmental regulations, both in their average and maximum levels. In June, a similar behavior to the previous month is maintained, although with a slight positive trend is its maximum peaks, however, the decrease in its average concentrations during the second half of the month due to the progressive influence of the wet period. For July, two schedules of maximum concentrations predominate; one at 4:00 p.m. and another at 6:00 p.m., reaching 60 µg/m^3. The results for the months of August, September and October remain within the standards established in the NOMs, both in their average and maximum concentrations. For this region of the country, the influence of the rainy season is noticeable, maintaining a relatively clean atmosphere. The most significant values do not exceed 25 µg/m^3 (**Figure 6**).

Finally, the months of November and December begin to experience a positive trend typical of the transition from the wet period to the dry and cold period. Average concentrations are kept within environmental regulations; however, its maximum levels range from 50 to 170 µg/m^3 (**Figure 7**), indices of air quality that are harmful to the exposed population.

The analysis of the year 2015 for PM2.5, reports maximum levels outside the norm practically throughout the year, with the exception of the wet period, where a marked decrease in concentrations is observed. Maximum average concentrations reached maximums of 170 µg/m^3 (**Figure 8**).

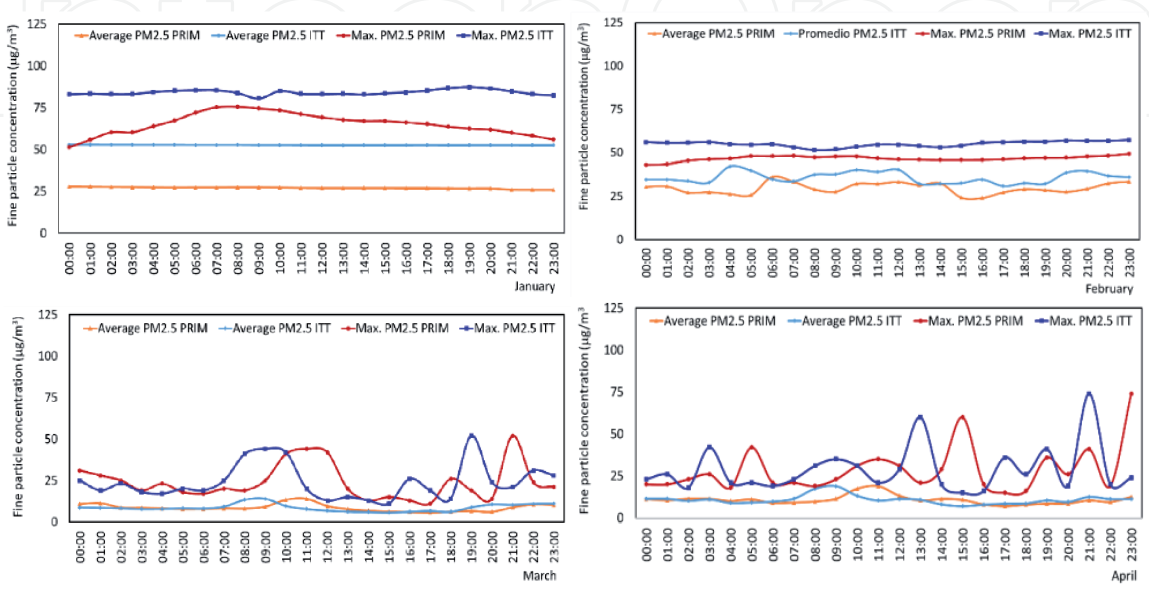

Figure 5.
(a–d) Monthly average behavior of $PM_{2.5}$ (24 h).

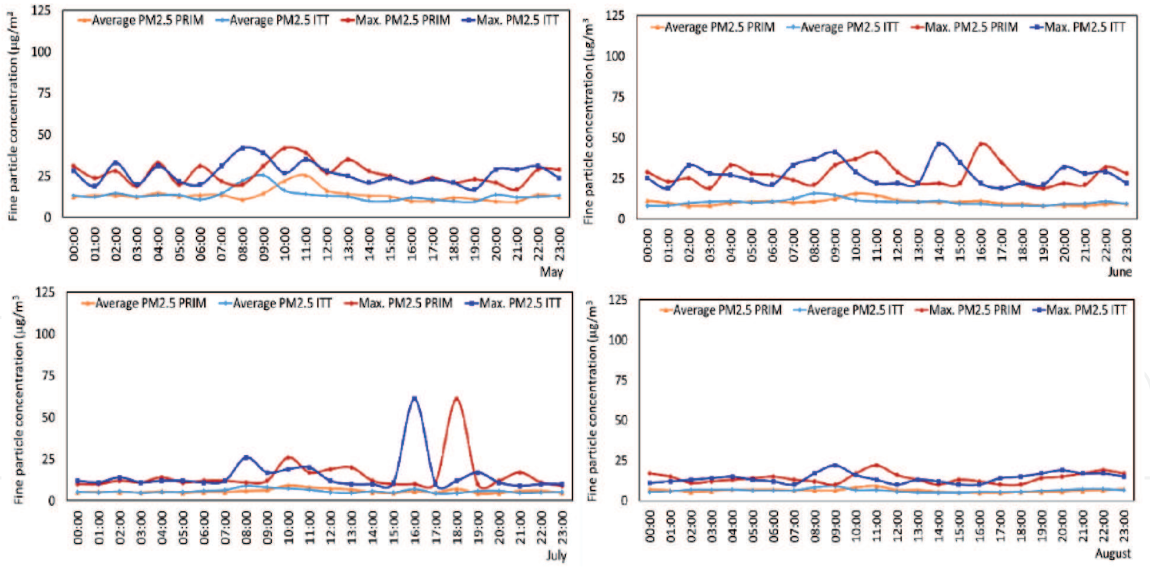

Figure 6.
(a–d) Monthly average behavior of $PM_{2.5}$ (24 h).

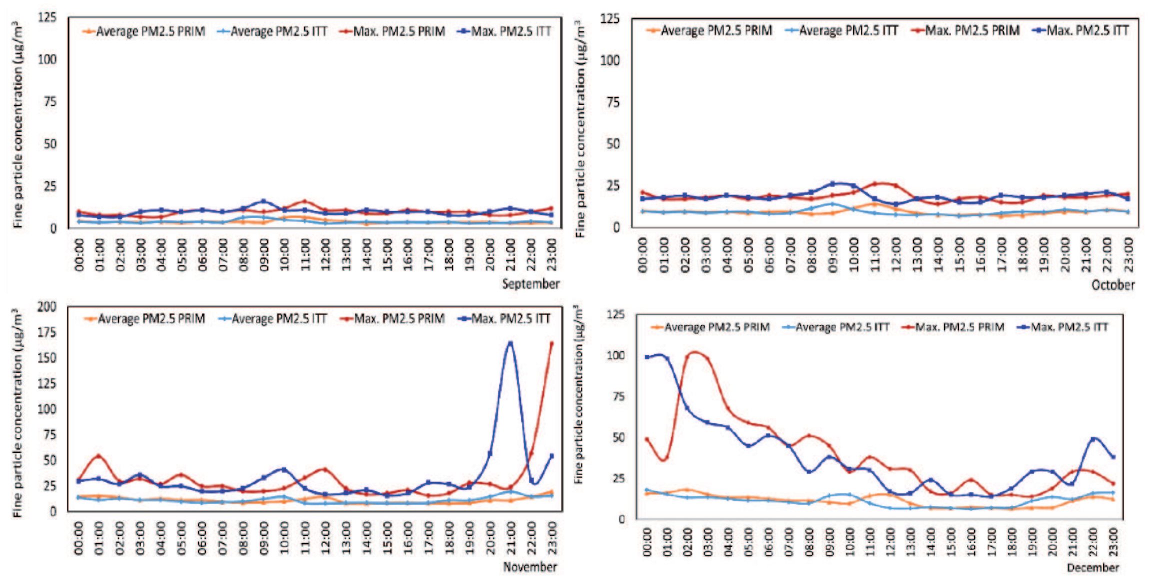

Figure 7.
(a–d) Monthly average behavior of $PM_{2.5}$ (24 h).

3.2 Monthly average behavior of particles smaller than 10 micrometers in 2015

In the case of particles smaller than 10 micrometers (PM10), current regulations define a maximum permissible limit of protection for population not being higher than 75 µg/m^3 average in 24 hours (40 µg/m^3 annual average). In a similar way to PM2.5, the average results on PM10 during the month of January report a series of inconsistencies, a consequence of the absence of reliable information, in addition to deficiencies in the calibration and validation stage of temporary data. Although maximum average concentrations are observed above the NOM (80 µg/m^3), they are not considered relevant. In relation to February, concentrations have significant fluctuations between hourly records, being more important during 5:00 and 10:00 hours; Although its average levels do not exceed the norm for this pollutant, the maximum concentrations remain outside the standards throughout the period, with peaks reaching 140 µg/m^3. During the months of March, April, May and June, concentrations within the NOM continue to be observed at their average levels, however, the maximum values for the two monitoring stations increased their maximum average

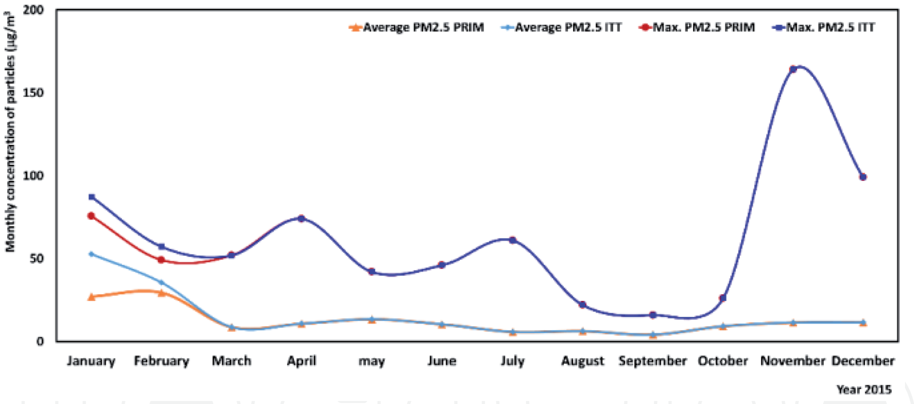

Figure 8.
Monthly average behavior of $PM_{2.5}$ for 2015.

concentrations of PM10. A common characteristic of these months is the progressive increase of pollutants starting at 7:00 a.m., remaining during the rest of the day, with maximums of up to 220 and 260 μg/m^3 (at 9:00 a.m. and 3:00 p.m.). Clearly, the maximum levels observed in the morning are related to the presence of thermal inversion, a natural phenomenon typical of the study area that contributes to the accumulation "in volume" of pollutants at air quality indices harmful to the population. On the other hand, the maximum levels in the afternoon are related to the intense productive activity of the sugar mill "el Molino" (stationary sources) and the vehicle fleet (**Figure 9**).

The continuity of the results allows us to observe that, at the end of June and the beginning of July, the negative trend is sufficiently noticeable due to the marked influence of the rainy season in the area; For this reason, the month of July perceives average concentrations within the NOM, while its maximum levels are located at the limit and slightly above 75 μg/m^3 (interval between 8:00 and 10:00 hours); this scenario remains without significant changes during the month of August. Meanwhile, September and October experience satisfactory average levels of air quality; Despite this, the maximum average concentrations define significant hourly fluctuations, highlighting the intervals from 4:00 a.m. to 10:00 a.m. for September and from 6:00 a.m. to 10:00 a.m. for October, even with a peak of extreme maximums at the beginning and end of the month (between seasons). These variations of maximum values move in a range from 75 to 180 μg/m^3. It is worth mentioning that these peaks define interactions coupled with a transition between the end of the wet period and the beginning of drier and colder periods (**Figure 10**).

Finally, the months of November and December observe critical conditions for the well-being of the population. **Figure 10** shows average concentrations of PM10 with peaks at the limit of the satisfactory threshold, while the maximum average values exceed the Mexican environmental regulations for this pollutant. PM10 levels vary between 75 and 200 μg/m^3, with higher volumes exceeding between 8: 00–12: 00 hours and 19: 00–22: 00 hours.

In addition, through the monthly analysis for 2015, satisfactory levels were observed in its average behavior; however, the average maximum concentrations remained outside the official norm; in fact, far above it. When making a comparison between the NOM and the WHO contamination standards for PM10, the maximums exceed 3.4 times the Mexican standard and 5.2 times the WHO indicators. Only the influence of the humid period in the interval from July to September, benefits the air quality in the city of Tepic, increasing again from October; the concentrations of 260 μg/m^3 during June show the magnitude of the environmental problems in the city (**Figure 11**).

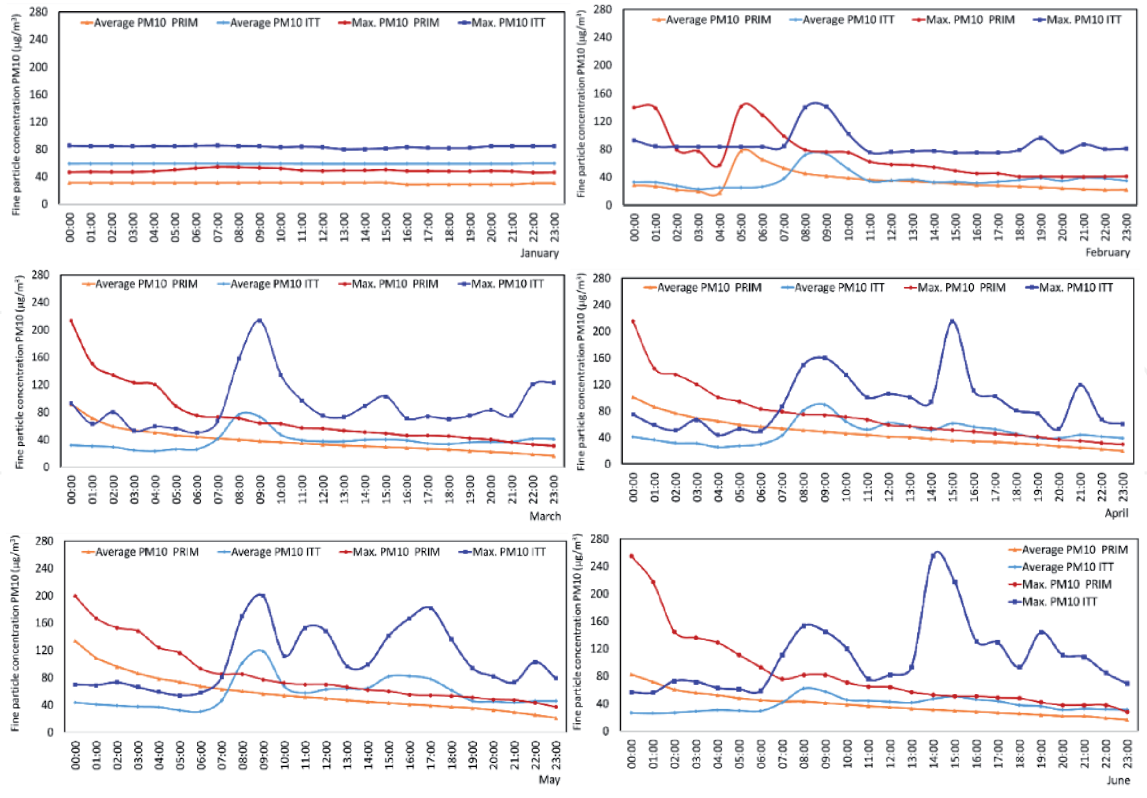

Figure 9.
(a–f) Maximum monthly average behavior of PM_{10} (24 h).

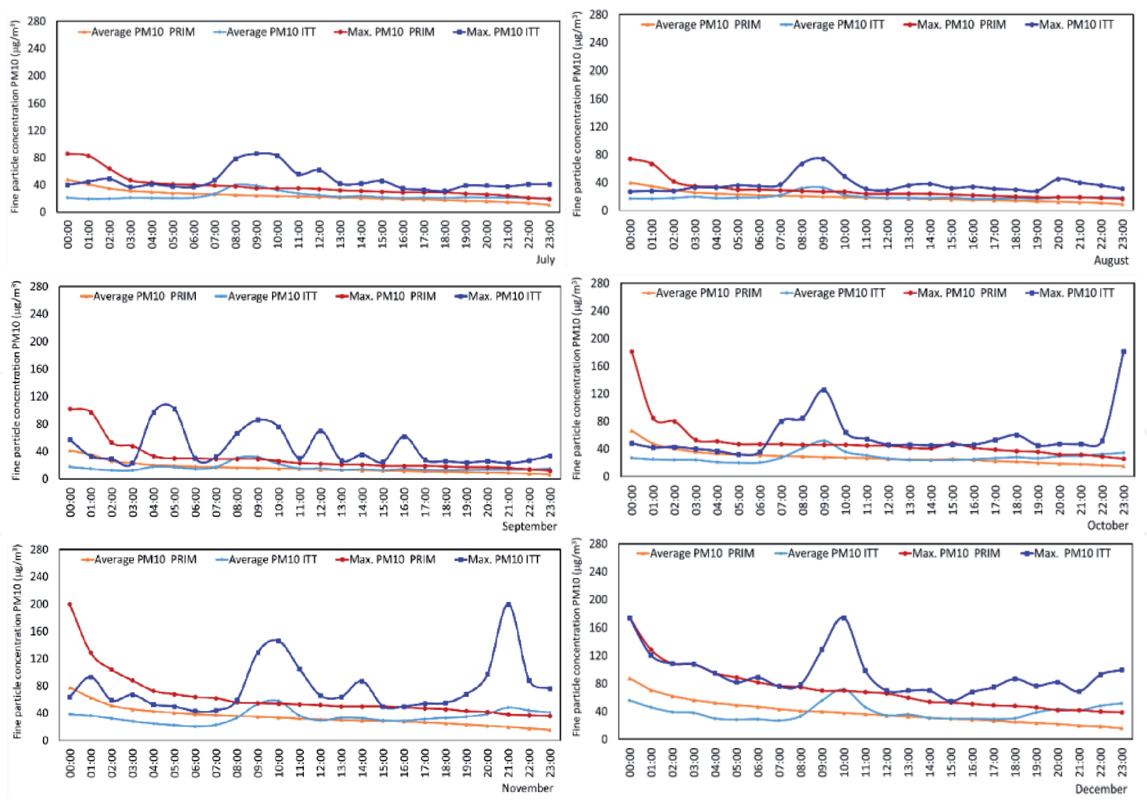

Figure 10.
(a-f) Maximum monthly average behavior of PM_{10} (24 h).

3.3 Average and maximum monthly CO behavior in 2015

Environmental researchers have verified that the tools used to determine the current state of a territory must be supported by sufficiently reliable data bases, in such a way that the results of the analysis allow the generation of strategic pollution control plans.

In this context, carbon monoxide (CO) is one of the pollutants that is emitted into the atmosphere most frequently; It is a primary gas, a product of the incomplete combustion of fossil fuels. However, its rapid ease of reacting with light (incident radiation), before raising its concentrations to out-of-standard rates, contributes to the generation of the secondary pollutant called ozone (O_3), which is a determining indicator in cities that experience smog photochemical. The NOM for pollutant CO establishes a concentration of 11 ppm as an average maximum limit of protection; this for 8 hours.

The aforementioned allows us to affirm that January, being a wet and cold month, presents maximum average concentrations outside the norm, especially during the first half of the day; while, as solar radiation increases, CO levels gradually decrease. For the month of February, only two small peaks with higher values are observed, but within the norms; this occurs in the morning and in the afternoon, –a typical behavior of the accumulation of pollutants due to the presence of thermal inversions and vehicular flow–. Regarding the months of March and April (**Figure 12**), the presence of two peaks of maximum values towards the PRIM station (center-west of the city) stands out, with values between 11 and 18 ppm (11, 00–14:00 and 11:00–15:00 hours, respectively).

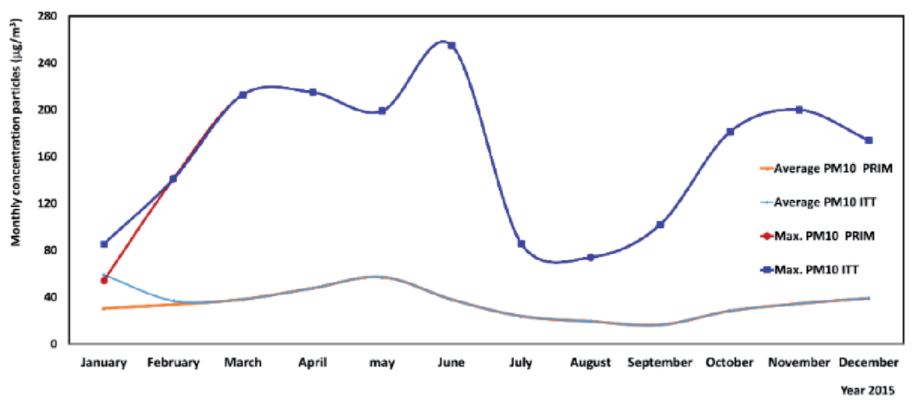

Figure 11.
Monthly average behavior of PM_{10} for 2015.

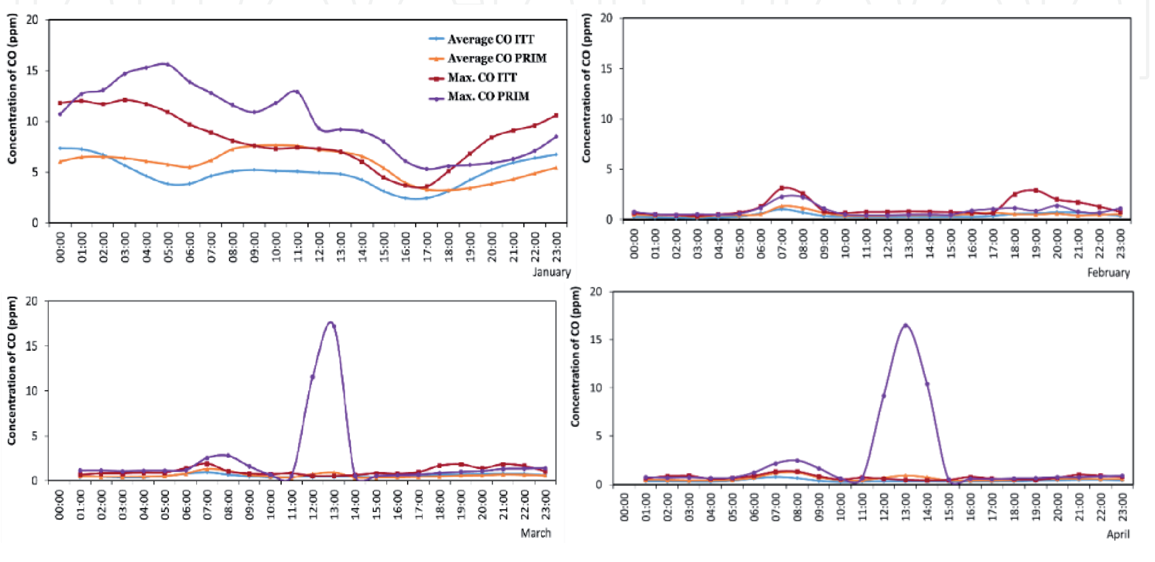

Figure 12.
(a–d) Average behavior and monthly maximum of CO (24 h).

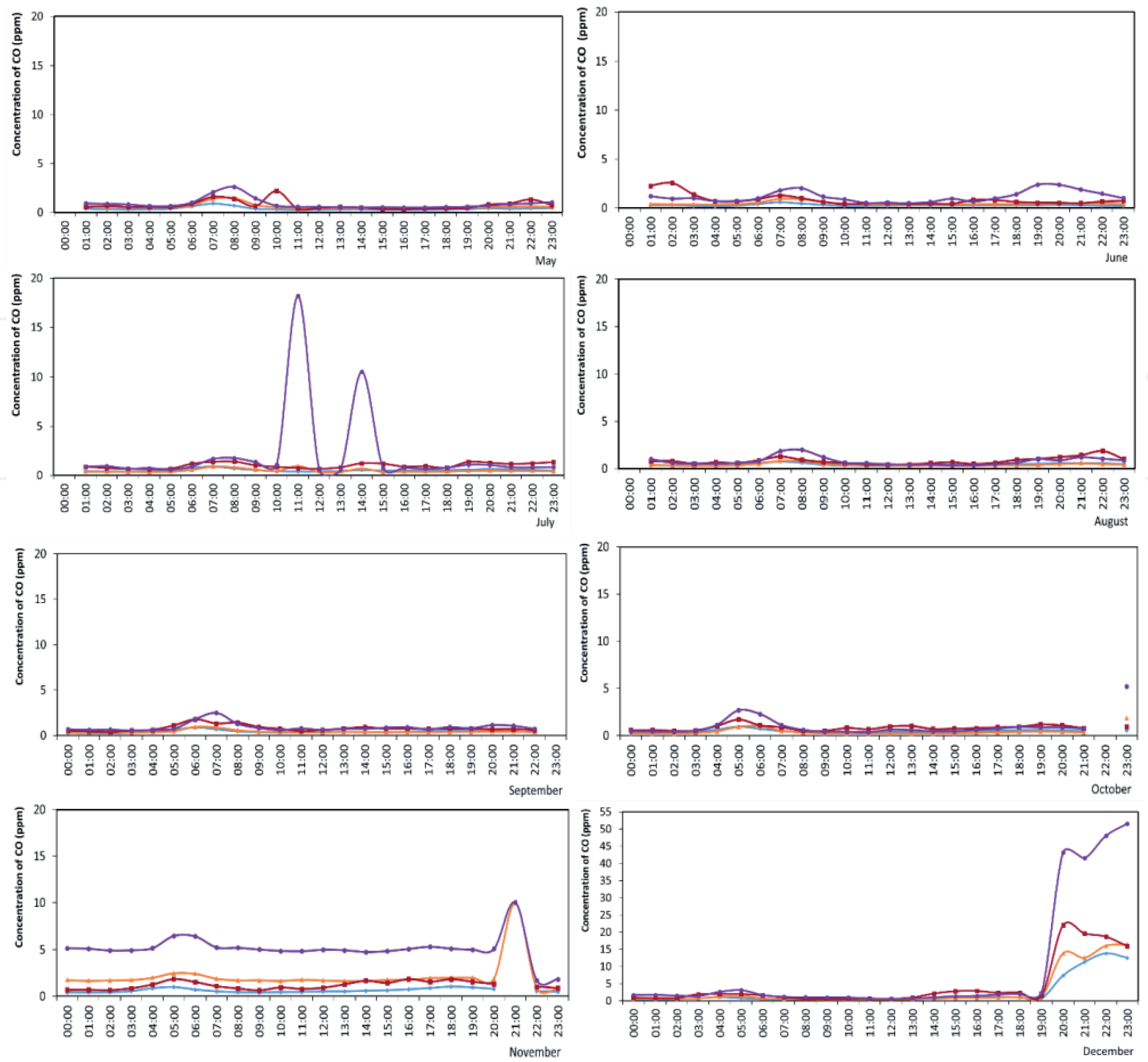

Figure 13.
(a–h) Average behavior and monthly maximum of CO (24 h).

On the other hand, in the interval from May to October, all the months present a behavior within the satisfactory standards, except July, which maintain concentration peaks outside the norm between 10:00 and 12:00 hours, with values 18 ppm. The month of November maintains its average levels in a satisfactory range, while the maximum averages are located at the limit in the evening hours (8:00 p.m. and 10:00 p.m.). Finally, December reports concentrations outside the NOM, especially at their maximum averages; this is observed at the end of the day, with values ranging between 11 and 52 ppm. This month contributes to a worrying scenario for the health of the exposed population (**Figure 13**).

Overall, CO keeps a behavior within the established regulations, however, by favoring the formation of tropospheric ozone, its contribution is significant especially when the atmosphere is highly photo-reactive.

4. Discussion and conclusions

The emission of pollutants into the atmosphere and local immission, in addition to the generation of waste in strategic cities, alter the habitat, the quality of life of the population and compromise sustainable urban development. The city of Tepic has prospered around a significant vehicle complex and extraordinary industrial activity, a scenario that produces air pollution. In Tepic a vehicular congestion prevails caused by inefficient transportation (public and private); it is a city that is gaining in extension and functional segregation. These factors contribute to the increase in the concentration of pollutants, which, added to the sugar mills (regional axis for development), represent a constant source of contamination and latent risk to the health of the population.

The sugar mill "el Molino" in its beginnings was an industry founded on the periphery of the city, however, the absence of uncontrolled real estate development plans, was propitiating a segregated growth in the surroundings, to such a degree that the synergy -city- industry- strengthened in deterioration of air quality, impacting on the most vulnerable age groups. In the work of Hernández [33], it was reported that damage to health increased 2.6 times in the harvest season, sugarcane burning and transportation, mainly the total suspended particles and CO; For its part, in the present study these levels rose to 3.7 times for PM2.5 and 3.4 times for PM10 with respect to the NOM (6.8 and 5.2 times for the WHO indicators).

It is observed that the diurnal patterns vary between seasonal periods (dry and wet period). The volumes and type of pollutants are significant for each place and region; in addition, the distances between sources and types of traffic are other aspects to consider.

Although it was not possible to determine the type of thermal inversion that occurs in the city, it is evident that it influences the concentration of pollutants, especially during the early hours and in the morning. Jang et al., [14]; Amarillo and Carreras [23] mention that cities located in depressions are associated with the formation of strong thermal inversions, an optimal condition for the accumulation of pollution in the lower atmosphere. In this context, the city of Tepic is located within a semi-closed valley, an ideal natural physical obstacle for pollutants to accumulate and prevent their dispersion, especially in the winter period. The geography and relief of the city contribute so that the anomaly of the temperature with the height, occurs frequently, concentrating the indices of air quality to levels not satisfactory for the population and, in the periods of greater cooling of the surface [43].

The results obtained show high air pollution at specific times, which can motivate local authorities to implement new criteria, create public policies, methodologies and innovate in mobility tasks, among others.

The current air quality monitoring stations are overwhelmed by the size of the city; It is suggested to incorporate three stations and distribute them in a homogeneous way in such a way that between the five they cover a greater coverage radius and a more comprehensive analysis. One element that can contribute to the evaluation of contamination by stationary sources is the assessment of the level of influence of the mill "El Molino" through the measurements "in situ" of the pollutants analyzed in this work (PM10, PM2.5, and CO, among others). The scaffolding must be laid for the configuration of an air quality monitoring network, supported by short and medium-term plans, where continuous monitoring is maintained on the databases obtained. This is useful in joint decision-making by the integrating axis Government and society [12]. It should be noted that various studies report an association between pollutants-meteorological variables and human health [32]; therefore, incorporating a mesh of five atmospheric monitoring stations in Tepic is fully justified [17], in addition, it will allow a comprehensive assessment of contamination and generate control mechanisms, as well as viable strategies for decision-making.

Tepic is a region that has the opportunity to progress under the objectives or characteristics pursued by sustainable development. Although it is true that there is an industrial productive sector that strengthens local economic development, it is possible to progress taking care of the local habitat, without compromising future generations and without risking the health of the vulnerable population [12].

The participation of the health sector and the Ministry of the Environment of Nayarit (SEMANAY) is significant in the sense of keeping track of cases of acute respiratory diseases in the different seasons of the year, and specifically, at the harvest season.

The study of pollutants in the air has great relevance to design strategies based on prediction, prevention, mitigation and resilience in the habitat. In agreement with Khan et al. [12], the present results can be a useful tool for the formulation of public policies and their implementation towards sustainable economic growth. Thus, the city of Tepic plays a key role in the state's economy and "el mill" is a central axis of the territory because the strategic lines that largely support the family economy converge there.

The continuous analysis of the CO pollutant for a longer period of time can favor the integral obtaining of plans and strategies for the control of emissions in the atmosphere of Tepic. Daytime patterns vary seasonally, weekly, and spatially depending on the distance between sources and volumes of traffic [14, 19].

Alatorre and Llanos [35] conducted a study on air pollution in the city of Tepic, reporting that there was no monitoring of air quality in the area; There was only one monitoring unit, but its operation was not optimal (constant interruptions in measurements). Emphasis is placed on the lack of dissemination of information, a situation that leads to high vulnerability in areas that lack it. That is, it is not disclosed or available to users. Through SEMANAY and with the information from 2011 to 2013, they identified that the most significant peaks in CO concentrations occur during the morning (6:00–9:00 am). They associated this with low temperatures (lower temperatures, higher concentration of particles in the air) and vehicular influence in this period of time (entry to schools and work). According to the National Institute of Ecology, the metropolitan area of Guadalajara with its 4.5 million inhabitants approximately, registers CO concentrations at an average of 10 ppm, while in Tepic (with an eighth of this population) levels have been observed by above 8 ppm. This is an indication that the proportion of contamination per inhabitant in Tepic is high.

It should be remembered that the sugar mill "El Molino" due to its historical impact and its economic importance represents an essential axis of local and regional development; However, despite being recognized as respectful of the environment and occupying the first place in the control of emissions of gases and solids released into the atmosphere, it is a constant source of air pollution and represents a risk to the health of the population [33]. Finally, although a period of one year is a short time for the analysis of air pollution, this diagnosis observes trends for PM10 and PM2.5; results that allow knowing the evolution of pollution in the short term and timely informing the population about its status in real time.

Author details

Mario García[1]*, Héctor Ulloa[1], Omar García[1], Hermes Ramírez[1], Aida Fajardo[1], Claudia Saldaña[2], Sarah Messina[2] and Yamilet Rodríguez[2]

1 Universidad de Guadalajara, México

2 Universidad Autónoma de Nayarit, México

*Address all correspondence to: megarcia@astro.iam.udg.mx

References

[1] Zhang, G., et al. Acid rain in Jiangsu province, eastern China: Tempo-spatial variations features and analysis, Atmospheric Pollution Research; 2017, http://dx.doi.org/10.1016/j.apr.2017.02.001.

[2] Dong, L., Dong, H., Fujita, T., Geng, Y., Fujii, M., 2015. Cost-effectiveness analysis of China's Sulfur dioxide control strategy at the regional level: regional disparity, inequity, and future challenges. J. Clean. Prod. 90, 345e359.

[3] Huang, L., Yang, J., Zhang, G. Chemistry and source identification of wet precipitation in a rural watershed of subtropical China. Chin. J. Geochem. 2012: 31 (4), 347e354.

[4] Chen, L., Heerink, N., van den Berg, M. Energy consumption in rural China: a household model for three villages in Jiangxi Province. Ecol. Econ. 2006: 58 (2), 407-420.

[5] Sans R. y Ribas J. Ingeniería ambiental. Contaminación y tratamientos. Ed. alfaomega marcombo. (1999). Pp. 148.

[6] Hajizadeh, Y., et al. Trends of BTEX in the central urban area of Iran: A preliminary study of photochemical ozone pollution and health risk assessment, Atmospheric Pollution Research (2017), http://dx.doi.org/10.1016/j.apr.2017.09.005.

[7] da Silva, D.B.N., Martins, E.M., Correa, S.M. Role of carbonyls and aromatics in the formation of tropospheric ozone in Rio de Janeiro, Brazil. Environ. Monit. Assess. 2016: 188, 1e13.

[8] Fard, R.F., Naddafi, K., Yunesian, M., Nodehi, R.N., Dehghani, M.H., Hassanvand, M.S. The assessment of health impacts and external costs of natural gas-fired power plant of Qom. Environ. Sci. Pollut. Res. 2016: 23, 20922e20936.

[9] Mario García, Héctor Ulloa, Hermes Ramírez, Miguel Fuentes, Silvia Arias, Martha Espinosa. Comportamiento de los vientos dominantes y su influencia en la contaminación atmosférica en la zona metropolitana de Guadalajara, Jalisco, México. Revista Iberoamericana de Ciencias. Vol. 1 No. 2. Pp:97-116. URL http://www.reibci.org/publicados/2014/julio/2200120.pdf.

[10] García Mario. Tesis Doctoral "Contaminación del aire en las Ciudades: La Zona Metropolitana de Guadalajara (2001-2010), hacia un modelo de prevención y mitigación. Jalisco, México. CONACYT/Universidad de Guadalajara. Pp. 321. 2013.

[11] Yu Zhang, Syed Abdul Rehman Khan, Anil Kumar, Hêriş Golpîra, Arshian Sharif. Is tourism really affected by logistical operations and environmental degradation? An empirical study from the perspective of Thailand. Journal of Cleaner Production. 2019, Vol. 227: 158-166. https://doi.org/10.1016/j.jclepro.2019.04.164.

[12] Syed Abdul Rehman Khan, Yu Zhang, Anil Kumar, Edmundas Zavadskas, Dalia Streimikiene. Measuring the impact of renewable energy, public healthexpenditure, logistics, and environmental performance on sustainable economic growth. Sustainable Development. 2020; Vol. 28: 833-843. https://doi.org/10.1002/sd.2034.

[13] Atkinson, R. Atmospheric chemistry of VOCs and NO x. Atmos. Environ. 2000: 34, 2063e2101

[14] Eunhwa Jang*, Woogon Do, Geehyeong Park, Minkyeong Kim, Eunchul Yoo. Spatial and temporal

variation of urban air pollutants and their concentrations in relation to meteorological conditions at four sites in Busan, South Korea. 2017: Vol.8, No.1, Pp: 89-100. https://doi.org/10.1016/j.apr.2016.07.009.

[15] Whiteman, C.D., Hoch, S.W., Horel, J.D., Charland, A. Relationship between particulate air pollution and meteorological variables in Utah's Salt Lake Valley. Atmos. Environ. 2014: 94, 742e753.

[16] Guttikunda, S.K., Gurjar, B.R. Role of meteorology in seasonality of air pollution in megacity Delhi, India. Environ. Monit. Assess. 2012: 184, 3199e3211.

[17] Colette, A., Granier, C., Hodnebrog, Ø., Jakobs, H., Maurizi, A., Nyiri, A., Bessagnet, B., D'Angiola, A., D'Isidoro, M., Gauss, M., Meleux, F., Memmesheimer, M., Mieville, A., Rouïl, L., Russo, F., Solberg, S., Stordal, F., Tampieri, F. Air quality trends in Europe over the past decade: a first multi-model assessment. Atmos. Chem. Phys. 2011: 11, 11657e11678.

[18] Simioni D. Contaminación atmosférica y conciencia ciudadana. *Comisión Económica para América Latina y el caribe (CEPAL).* ONU. Santiago de Chile. 2003. Pp. 278.

[19] Amarillo, Ana Carolina; Carreras, Hebe Alejandra. Quantifying the influence of meteorological variables on particle-bound PAHs in urban environments; Elsevier; Atmospheric Pollution Research; 7; 4; 2-2016; 597-602. https://doi.org/10.1016/j.apr.2016.02.006

[20] G Castejón Porcel, D Espín Sánchez, V Ruiz Álvarez, R García Marín, ... Runoff Water as A Resource in the Campo de Cartagena (Region of Murcia): Current Possibilities for Use and Benefits. Water 2018: 10 (4), Pp: 25.

[21] Tiwari, S., Dumka, U. C., Gautam, A. S., Kaskaoutis, D. G., Srivastava, A. K., Bisht, D. S., ... Solmon, F. Assessment of PM2.5 and PM10 over Guwahati in Brahmaputra River Valley: Temporal evolution, source apportionment and meteorological dependence. Atmospheric Pollution Research, 2017. Vol. 8, no 1, pág. 13-28. https://doi.org/10.1016/j.apr.2016.07.008.

[22] Instituto Nacional de Ecología y Cambio Climático (INECC). Informes de los estudios e investigaciones durante el periodo 2013-2018. Contaminación y Salud Ambiental. https://www.gob.mx/inecc. (2018) Consultation date: July, 2020.

[23] Amarillo, AC, Mateos, AC & Carreras, H. Distribución en origen de hidrocarburos aromáticos policíclicos ligados a PM 10 por factorización de matriz positiva en la ciudad de Córdoba, Argentina. Arch Environ Contam Toxicol 72, 380-390 (2017). https://doi.org/10.1007/s00244-017-0384-y

[24] Ramirez-Sanchez HU, Meulenert-PeñaAR,Garcia-GuadalupeME, Garcia-Concepción FO, Alcala-Gutierrez J and Ulloa-Godínez HH. The Influence of Air Pollutants on the Acute Respiratory Diseases in Children in the Urban Area of Guadalajara, Air Quality-Models and Applications. Dragana Popovic. InTech. (2011) http://www.intechopen.com/books/air-quality-models-and-applications. ISBN: 978-953-307-307-1.

[25] Instituto Nacional de Estadística, Geografía e Informática (INEGI). México en cifras/Nayarit. www.beta.inegi.org.mx/app/areasgeograficas/?ag=18. Consultation date: July,2018.

[26] Aguilar L. Cultura política y participación electoral en elecciones locales de la ciudad de Tepic, Nayarit. Universidad Autónoma de Nayarit.

Maestría en Desarrollo Económico Local. Tesis de Grado. 2010: Pp:268. http://www.uan.edu.mx/es/maestria-en-desarrollo-economico-local.

[27] Aguilar L. El miedo, la frustración y la indiferencia electoral y política en la ciudad de Tepic, Nayarit, 2011. Jalisco, México. Universidad de Guadalajara. Tesis de Grado. Pp:146. http://www.eumed.net/libros-gratis/2013a/1332/index.htm. 2012.

[28] Instituto Nacional de Estadística, Geografía e Informática (INEGI). Distribución de la población. Población total en viviendas particulares habitadas (número de personas), 2015. www.beta.inegi.org.mx/app/areasgeograficas/?ag=18. Consultation date: July 2018.

[29] Instituto Nacional de Estadística, Geografía e Informática (INEGI). Espacio y datos de México. División territorial. www.beta.inegi.org.mx/app/mapa/espacioydatos. Consultation date: July 2018.

[30] http://www.esacademic.com/dic.nsf/eswiki/1137532#sel=. Parámetros climáticos promedio de Tepic. Wunderground Weather, Tepic, Nayarit, México. Consultation date: July 2018.

[31] Enciclopedia de los municipios y delegaciones de México. Estado de Nayarit. Tepic/clima. www.inafed.gob.mx/work/enciclopedia/EMM18nayarit/. Consultation date: December, 2019.

[32] Syed Abdul Rehman Khan, Arshian Sharif, Hêriş Golpîra, Anil Kumar. A green ideology in Asian emerging economies: From environmental policy and sustainable development. Sustainable Development. 2019; Vol. 27: 1063-1075. https://doi.org/10.1002/sd.1958.

[33] Hernández Mojarro, E. E. (2008). Tesina. Contaminación ambiental causada por la quema de la caña de azúcar (Sacharum officinarum L.). Xalisco, Nayarit, México: El autor. Instituto Nacional de Estadística y Geografía. (2010). INEGI. Retrieved June, 2013, de www.inegi.gob.mx.

[34] Castillo A., Rivera D. Diagnóstico de las emisiones atmosféricas generadas por los ingenios azucareros de El Salvador. El Salvador, Centro América. *Tesis de licenciatura en Química y Farmacia de la Universidad de El Salvador*, 2004.

[35] Alatorre A. & Llanos M. Contaminación Atmosférica en Tepic, Nayarit, México. Educateconciencia, 2014: 4(4): 36-47. ISSN: 2007-6347. http://tecnocientifica.com.mx/educateconciencia/index.php/revistaeducate/article/view/297.

[36] Ramírez, H., Andrade, M., González, M., Celis, A. Contaminantes atmosféricos y su correlación con infecciones agudas de las vías respiratorias en niños de Guadalajara, Jalisco. Salud Pública de México. 2006: Vol. 48, Núm. 005. Pp. 385-394.

[37] Saldaña Durán, Claudia E.; Nájera González, Oyolsi. Identificación de sitios con potencial para la disposición final de residuos sólidos urbanos en el Municipio de Tepic, Nayarit, México. Revista Internacional de Contaminación Ambiental, V. 35, P. 69-77, 2019. http://Dx.Doi.Org/10.20937/Rica.2019.35.Esp02.07.

[38] Mihelcic J, Zimmerman J. Ingeniería Ambiental: Fundamentos, Sustentabilidad, Diseño. Alfaomega. México, 2012; pp. 720. ISBN: 978-607-707-317-8.

[39] Diario Oficial de la Federación (DOF) 2014. Norma Oficial Mexicana NOM-025-SSA1-2014, Salud ambiental. Valores límite permisibles para la concentración de partículas suspendidas

PM_{10} y $PM_{2.5}$ en el aire. Secretaria de Salud. http://siga.jalisco.gob.mx/aire/Normas.html.

[40] Justin A. Daniels. Advances in Environmental Research, Vol. 64. Nova Science Publishers, Inc. New York. Chapter 3: David Espín-Sánchez, Carmelo Conesa-García and Gregorio Castejón-Porcel. Temperature Inversions Due to Warm Air Advections at Low Levels: Significant Thermal Contrasts in the Vega Media of the Segura River (Southeast Spain). 2018: 139-177. ISSN: 2158-5717.Available from: https://www.researchgate.net/publication/.

[41] Statistical Package for the Social Sciences (SPSS), https://www.ibm.com/mx-es/analytics/spss-statistics-software. Consultation date: July, 2020.

[42] Strauss, W., Contaminación del aire: causas, efectos y soluciones. 2a Ed. México. Trillas. 2012: 208 p. ISBN: 978-607-17-0634-8.

[43] Global Forcast System GFS (2020). Numerical prediction models. Virtual soundings. https://www.tropicaltidbits.com/analysis/models/. Consultation date: December 2020.