

Distribution and Characterization of PM₁₀ in City and Valley of Mexicali, Baja California, Mexico

Miguel Canales-Rodríguez^{1*}, Margarito Quintero-Núñez¹, Benjamin Valdés-Salas¹, Walter Daessle-Heuser²

¹Departament of Environment, Institute of Engineering, Autonomous University of Baja California, Mexicali, México

²Deparment of Environmental Geosciences, Institute of Oceanological Research, Autonomous University of Baja California, Ensenada, Mexico

Email: ^{*}miguelcanales13@hotmail.com, maquinu@uabc.edu.mx, benval@uabc.edu.mx, walter@uabc.edu.mx

Received 19 December 2014; accepted 1 January 2015; published 14 January 2015

Copyright © 2015 by authors and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY). http://creativecommons.org/licenses/by/4.0/

CC ① Open Access

Abstract

The variability of the levels of atmospheric particulate matter PM_{10} and its composition is assessed in the rural and urban zones of Mexicali during fall and winter 2008-2009, using a low level volume Minivol sampler, with quartz and Teflon filters. During fall the Mexican norm was exceeded (120 µg/m³ in 24 hr) in only two occasions, while in winter it was exceeded twelve times. The predominant component in fall was geological material with 62.5% for the rural zone and 48.5% for the urban one. In winter the geological material was also predominant with 65% for the rural zone and 54.4% for the urban zone. The aim of this work is the interpretation of the variability of the atmospheric PM_{10} particulate matter at two selected zones (urban and rural of Mexicali) during fall and winter, with emphasis on the chemical composition. The results suggest that the pollution in the urban and rural zones has common sources during winter whereas in fall the pollution has different sources.

Keywords

Urban, Rural, Atmosphere, Particulate Matter

1. Introduction

The battle against air pollution began since the invention of the steam machine and with that the industrialization

*Corresponding author.

How to cite this paper: Canales-Rodríguez, M., *et al.* (2015) Distribution and Characterization of PM₁₀ in City and Valley of Mexicali, Baja California, Mexico. *Journal of Environmental Protection*, **6**, 25-33. http://dx.doi.org/10.4236/jep.2015.61004

and uncontrolled growth of the cities. The pollution problems in some cities reached a peak in 1948, when the high levels of air pollution, mainly by PM_{10} and SO_2 , affected people living in Donara, Pennsylvania, USA [1] [2]. In Mexico City, air pollution is caused by the high levels of particulate matter and ozone, especially during the cold months [3]-[5], and for this reason it is considered to be one of the most polluted cities in North America. Another region in Mexico where air pollution has caused health effects [6] is the binational region formed by the Mexicali and Imperial Valleys which are described as the most polluted by particulate matter, exhacerbing the norms by the US Environmental Protection Agency (EPA) and by the Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT) [7] [8]. It is important to comment that there has not been research on PM_{10} in the rural area of Mexicali, although work has been done in urban and suburban areas of Mexicali and Calexico, which are part of the Valleys of Mexicali and Imperial, respectively.

Particles smaller than 10 μ m (PM₁₀) are solid or liquid in nature, and are dispersed in the atmosphere, mainly with a pH > 7 and are a product of uncontrolled combustion [9]. In relation to the formation mechanism, the particles are emitted to the atmosphere (primary) or generated by chemicals reactions (secondary) [10]. These chemical reactions may consist of the interactions between precursor gases in the atmosphere to give rise to a new aerosol by adsortion or coagulation [11].

In Mexicali, Baja California an important number of human activities have aggravated the pollution problems [12], these range from the excessive use of old cars to the burning of agricultural waste at the Imperial and Mexicali Valleys. In that respect, according to measurements made in 2002 and 2006 in the region, Mexicali is rated amongst most polluted cities by PM_{10} in the country, only rivaled by the metropolitan zone of Mexico City [6] [13]. The official Mexican norm NOM-025-SSA1-1993 establishes the guidelines to evaluate the air quality of the environment, in relation to PM_{10} . It explains that the permitted value for 24 hours is 120 µm·m⁻³ and 50 µm·m⁻³ annually. Measurements in the Valley of Mexicali from 1997 to 1999, showed that the norm limits were exceeded more than 20 times as compared to 40 times between 1999 and 2008 [14].

Previous work in Mexicali showed that winter is the most critical season for air pollution [12] [15]. The major levels of air were found on the 12th and 25th of December during the Christmas festivities and the 1st of January, due to celebrations of the New Year [15]. The objective of this work is the interpretation of the variability of the atmospheric particulate matter at two selected zones (urban and rural of Mexicali) during fall and winter, with emphasis on the measurements of PM_{10} and its chemical characterization.

2. Materials and Methods

2.1. Study Site

Mexicali, is the capital of the state of Baja California with a population of 936,145 [16]. The annual average rain is 75 mm. The averaged temperature in summer is 38°C with maximum temperatures of 52°C and an annual averaged temperature of 23°C. January is the coldest month with a monthly averaged temperature of 12.7°C [17]. The predominant wind direction during the year in the fall is East-Southeast, while in the winter it is Northwest.

2.2. Sampling Sites

The work was carried out from 5 September to 5 October 2008 (fall) and from 1st to 31st January 2009 (winter). Two sampling sites were selected considering the environmental characteristics; one in the urban zone of Mexicali (32.631183°N, 115.444803°W) and the other one in the rural zone of the Valley at the Guadalupe Victoria Village (32.631183°N, 115.444803°W), located 43 km south of city (**Figure 1**). Two samplers were installed in each place: In the urban zone they at the Institute of Engineering of the Autonomous University of Baja California, based on its central position within the urban area of Mexicali where three main boulevards meet (Lazaro Cárdenas, Independencia and Benito Juárez). Whilst in the rural zone they were installed on the roof of a house surrounded by agricultural fields in the proximity of the Nuevo Leon Village, where also a meteorogical station is located.

The PM₁₀ samples were collected with a set of low volume samplers Airmetrics (5 $1 \cdot \text{min}^{-1}$) using two types of filters: 47 mm Whatman 2 µm Teflon for gravimetric analysis and of quartz for chemical analysis. The equipment was calibrated at the beginning and at the middle of the sampling process with a digital manometer.

For the gravimetric analysis, the filters were prepared in a desiccator for 24 hours and weighed using a Sartorius ME 36 microbalance, before and after the sampling in a laboratory with optimum conditions of relative hu-



Figure 1. Sampling sites located in the urban zone (Mexicali) and rural zone (Guadalupe Victoria) in the Valley of Mexicali, Baja California.

midity (30% - 40%) and an averaged temperature (20°C - 23°C). A 10% of blank filters or standards were taken for the field and the laboratory. The sampling lasted 24 hours, every other day and it was programmed to start at midnight. For the fall campaign 28 samples were taken at each site (14 Teflon and 14 quartz filters), whilst in the winter season 32 samples were taken at each site (16 Teflon and 16 quartz filters). The difference in the number of samples between fall and winter was due to the rain and the difficulty of access to the sampling site.

The study of the PM₁₀ concentrations was done considering the gravimetric information already obtained and the meteorological variables taken at the sampling site (atmospheric pressure and temperature) every 5 minutes at the meteorological station of the UABC for the urban zone and every 24 hours from the rural meteorological station. The Teflon filters were used to determine gravimetry utilizing the micro balance Sartorius ME-S-F and the concentration of chemical elements (F, Mg, Al, Si, K, Na, Ca and Cl) and to perform X Rays Dispersion Spectroscopy (EDX) coupled with a scanning electronic microscope (MEB) JEOL 6060, to identify the morphology of the samples. The latter was performed externally at the Skyworks plant in the city of Mexicali.

On the other hand the quartz filters were used for anions analysis (Cl⁻, NO₃⁻, SO₄²⁻) utilizing Ion Cromatography IonPac AS9-HC. The concentration of organic carbon and elemental carbon were analized using Thermal Optical Transmitance by Atomic Absortion Spectroscopy for Electrothermal Atomization using the Perkin-Elmer model 2100, at Actlabs in Ancaster, Ontario, Canada, under ISO 17025 9001:2008. Only 20 filters were analyzed for each season (10 filters from the rural zone and 10 from the urban zone).

3. Results

3.1. PM₁₀ Concentration

During the two monitoring campaigns daily averaged PM_{10} concentrations were sampled. For the fall season the following averages/ranges were obtained at each of the sampling zones: for the urban zone 54.5 µg·m⁻³ (12.1 - 131.5 µg·m⁻³) and for the rural zone 57.8 µg·m⁻³ (18.9 - 143.8 µg·m⁻³). On the other hand for the winter season the following results were obtained: from the urban zone 103.5 µg·m⁻³ (0.49 - 237.19 µg·m⁻³), for the rural zone was 118.09 µg·m⁻³ (12.72 - 285.05 µg·m⁻³).

3.2. Times Series

[15] and [18] mentioned that Teflon filters should be used to carry out the times series analysis of PM₁₀. Considering the Mexican Official Norm NOM-025-SSA1-1993 for PM₁₀ (límit of 120 μ g·m⁻³) in Figure 2, it can be seen that during fall, there was just one violation to the norm in the urban zone (131.5 μ g·m⁻³) on 5 September, and one for the rural zone (131.5 μ g·m⁻³) on 27 September.

During the fall the winds in the urban zone were predominantly blowing from East to South-West, while for the rural zone they came from the Southeast to East-Southeast (Figure 3).

In contrast to fall, in winter (**Figure 4**), in the urban zone there were 6 samples that exceeded the norm on 3, 5 and 7 January (155.1 μ g·m⁻³), 11 January (132.7 μ g·m⁻³) and 17 and 19 January (134.3 μ g·m⁻³). In the rural zone there were 6 samples: 3 January (231.83 μ g·m⁻³), 7 January (134.27 μ g·m⁻³), the 11, 13 and 15 January



Figure 3. Wind roses for the rural zone (a) and for the urban zone (b) during the fall.

with a mean of 220.6 μ g·m⁻³ and finally 160.6 μ g·m⁻³ on 31 January.

The wind direction for the urban zone was predominantly from the East-Northeast and Southeast, whilst for the rural zone it came from East-Northwest and Northeast (Figure 5).

3.3. Chemical Analyses

The chemical components were classified as geological material (GM), organic matter (OM), mineral salts (salts) elements and trace compounds (ETC), ammonium nitrate (NH_4NO_3) and ammonium sulphate ($(NH_4)_2SO_4$). The OM was estimated as 1.2 times the organic carbon, the elemental carbon (EC) as 1, the NH_4NO_3 as 1.29 times NO_3 , the (NH_4)₂SO₄ as 1.375 SO₄²⁻ and the geological material as 1.89Al + 2.14Si + 1.40Ca + 1.43Fe [12]. The trace elements were calculated as 1.65Cl.

During fall, in the rural area (**Figure 6**) the major chemical component trapped in the filters was GM with 62.5% of the total, as a product of the dust from the desert, dust re-suspension from the crop fields and the roads. The second in abundance was OM with 19.1% as a product of burning residuals like woods, residential and



Figure 4. Times series for PM₁₀ during winter.





agricultural waste. In third place is EC with 9.6% produced mainly from anthropogenic sources, like motor vehicle emissions, combustion products from brick kilns amongst others. Finally, the ETC were 3.9% magnesium and 2.5% $(NH_4)_2SO_4$ coming from fertilizers and pesticides utilized in agricultural activities.

In the urban zone GM is the main component with 49.5% probably derived from unpaved or unconstructed properties in the city, road dust and sand storms from the desert. The second most abundant component is OM with 22.9% probably derived from coke burning at barbicue shops, wood burning and food cooking; in third place is EC with 11.5% as a result of combustion inefficiency of the motor cars powered by fuel or diesel, followed by the ETC with 5.3% magnesium, 5.1% (NH4)₂SO₄ and last NH₄NO₃ with 4.3% (Figure 7).

During winter an increase in OM is observed for the urban zone, but not as much for the rural zone where there is a decrease in OM. The major chemical component for the rural zone (**Figure 8**) is the GM with 65.0% as a result of the re-suspension of the desert dust followed by OM with 19.3%, due to the use of wood to warm the households and to the burning of residential waste. The EC represent 9.7%, probably produced by motor vehicles, followed by NH₄NO₃ with 2.1% and (NH₄)₂SO₄ with 1.8%. For the urban zone the main component is the GM with 54.4%, followed by OM (28.3%), EC (14.1%), ETC (1.3%) and salts (1.0%) (**Figure 9**).

M. Canales-Rodríguez et al.



Figure 6. Averaged contribution of the PM₁₀ components during fall in the rural zone.



Figure 7. Average contribution of PM components during fall in the urban zone.

3.4. Statistical Analyses

The statistical analyses were made using Statistica 7 Stat Program to verify whether there was a similarity between the source of the particulate material between the urban and the rural zones of Mexicali. By applying the "t" student test to all the data of each zone, one can assess the probability of similarities between the two sites. During winter the study sites had a very close relationship with a p value of 0.02. On the other hand during fall the p value was much higher 0.9. These results suggest that the pollution in the urban and rural areas has common sources during winter, whereas in fall the pollution is quite different.

4. Discussion

The highest values of PM₁₀ during fall were obtained in the rural zone, whilst in winter they were found in the







Figure 9. Averaged composition of PM_{10} during winter in the urban zone.

urban zone. In winter at the urban site the results mostly exceeded the guideline values of the Mexican Norm, in response to the increase of pollutants in the city during winter [15]. Already in 2000 and 2005, [19] mentioned that the cities of Mexicali, B.C. and Calexico, CA were exceeding the annual Mexican Norm for PM_{10} (50 μ g/m³), whilst in the Proaire Mexicali Report [14] an increased air pollution was reported for 2008, classifying Mexicali as one of the most polluted cities in Mexico.

In contrast to winter, the limits of the official norm for PM_{10} were exceeded only in two occasions during fall: one sample in the urban site and one in the rural site. However, 12 samples showed higher PM_{10} concentrations than the norm in both sampling sites. The explanation for this increase is that during winter, wood and residential waste is traditionally burned in December in the urban zone and throughout the season in the rural zone. [8] discussed several reasons for this increase of PM_{10} in the region based on burning of agricultural residuals, wood and residential waste, barbecue shops, unpaved and paved roads and the deficient combustion of abundant old vehicles. On the other hand, [15] mentioned that the cause for this increase in PM_{10} pollution was the use of firecrackers and wood burning. [18] determined that the pollution by PM_{10} was originated from the soil of the region, motor vehicles combustion, wood burning, industrial sources, power plants, glass processing plants and marine aerosols.

The results obtained in the present study indicate that most of the air pollution is derived from GM (48.5% - 54.4% in the city and 62.5% - 65.0% in the rural zone during fall and winter respectively). This result is similar to the one obtained previously by Chow and Watson (1997) with 55.6%, but different to that by [12], were 70.4% of GM during fall for the urban zone was reported.

The second main contributor for PM_{10} pollution was OM, with accounting for 28% in the urban zone and 18.8% in the rural zone during winter; and just 22.9% of OM for the urban zone and 19.1% for the rural zone during fall. For the rural zone [18] described that 26.1% was coming from OM similar to the present study, not much as the work by [12] where 7.6% from the urban zone was derived from OM.

The third most important component was EC with 9.6% in the rural and 11.5% in the urban zones during fall, which is similar to [12] 12.9%. However, [18] found only 2.9% EC, less to what was found in this work. On the other hand, for winter, the EC was reported at 9.7% and 14.4% for the rural and urban zones respectively.

The percentage of salts reported in this study (1.7% in the rural zone and 1.0% in the urban zone) is slightly lower to the 3.4% reported by [18] and similar to 1.7% found by [12] during fall and winter.

The main component found in the present research is GM, similar to what [18] and [12] reported, in relation to particulate matters levels, which are present specifically in the winter season. Concerning wind directions during our sampling they are similar to those found by [12] and [15]. However, these authors suggested that there is border transport of particulate matter and the present work found that the pollution sources are common for the rural and urban zones.

5. Conclusions

The urban and rural zones of Mexicali do not have a satisfactory air quality during fall less so during winter. The main reason for this is different for each zone. During fall the PM_{10} pollution is mainly produced by GM from the barren agricultural soil being condition for production, from the unpaved roads and the re-suspension of dust from paved streets in the urban zone. During winter the PM_{10} derived from GM was greater than in fall.

The OM is originated from wood burning in the urban zone and agricultural residual burnings in the rural zone. The pollution from anthropogenic sources is related to motor vehicles, although during fall it is s lower, especially in the urban zone.

It is important to mention that the PM_{10} concentrations associated to the urban zone is related to the close vecinity of two major avenues (Benito Juarez and Lazaro Cardenas) where hundreds of cars are driven every day, This particular setting within the city could have contributed to the increase of PM_{10} generated by the car vehicles combustion and/or from the resuspension of street dust generated by the cars passing by, besides the dust generated in the surrounding urban zone. In the rural zone however, there were other contributors of PM_{10} , such as unpaved roads, burning of agricultural residuals and brick kilns.

Based on these results and the statistical analysis, it is emphasized that the pollution in the urban and rural areas has common sources during winter whereas in fall the pollution is quite different.

The current investigation does not support the idea of transborder transport of particulate matter as it has been shown by [15] and [18] in their research work.

These results are similar to those of [18] for the urban zone of Mexicali. This is explained in terms of the years past by where the chemical composition of the particulate matter of the region has been diversified, although the pollution has not been reduced, moving from a natural pollution associated to the region to another one caused anthropogenically, increasing OM (fossil) and EC (motor vehicles).

Acknowledgements

We acknowledge the Mexican Council for Science and Technology CONACYT for the financial support. Many thanks to E. Dávalos (UABC) and E. Colima (CONAGUA). Also to L. Quintero for her support in installing the samplers at the Guadalupe Victoria Village and to the Institute of Engineering at UABC for the use of its infrastructure.

References

- Lacasaña, N.M., Aguilar, G.C. and Romieu, I. (1999) Evolución de la contaminación del aire e impacto de los programas de control en tres mega-ciudades de América Latina. Salud Pública de México, 41, 203-215. http://dx.doi.org/10.1590/S0036-36341999000300008
- Molina, G.A. (2013) Contaminantes atmosféricos primarios. In: *Curso básico de toxicología ambiental*, Albert, Limusa, México D.F., 43-70.
- Borja, A.V.H. (2000) Estudios Ecológicos. Salud pública de México, 42, 533-538. http://dx.doi.org/10.1590/S0036-3634200000600010
- [4] Chow, J.C., Watson, J.G., Edgerton, S.A. and Vega, E. (2001) Chemical Composition of PM_{2.5} and PM₁₀ in México City during Winter 1997. *Science of the Total Environment*, **287**, 177-201. http://dx.doi.org/10.1016/S0048-9697(01)00982-2
- [5] Covarrubias, P.C.A.L. (2003) Región metropolitana: Propuesta de solución a la descontaminación. Urbano, 6, 26-31.
- [6] Reyna, C.M.A., Quintero, N.M., Collins, K. and Vildósola, R.R.L. (2003) Análisis de la relación del PM₁₀ con las enfermedades respiratorias en la población urbana de Mexicali, Baja California: Un estudio de series de tiempo. *Revista Mexicana de Ingeniería Biomédica*, 24, 116-125.
- [7] Meza, L.M., Quintero, N.M., García, C.O.R. and Ramírez J. (2009) Estimación de Factores de Emisión de PM₁₀ y PM_{2.5}, en Vías Urbanas en Mexicali, Baja California, México. *Información Tecnológica*, 21, 45-56.
- [8] Kelly, K.E., Jaramillo, I.C., Quintero, N.M., Wagner, D.A., Collins, K. and Meuzelaar, H.L. (2010) Low-Wind/High Particulate Matter Episodes in the Calexico/Mexicali Region. *Journal of the Air and Waste Management Association*, 60, 1476-1486. <u>http://dx.doi.org/10.3155/1047-3289.60.12.1476</u>
- [9] Quijano, P.A., Quijano, V.M.J. and Henao, M.J.A. (2010) Caracterización fisicoquímica del material particulado fracción respirable PM_{2.5} en Pamplona Norte de Santander, Colombia. *Bistua: Revista de la Facultad de Ciencias Básicas*, 8, 1-20.
- [10] Tzintzun, C.M.G., Rojas, B.L. and Fernández, B.A. (2005) Las partículas suspendidas en tres grandes ciudades mexicanas. *Gaceta Ecológica*, **74**, 15-28.
- [11] Warneck, P. (1988) Chemistry of the Natural Atmosphere. International Geophysics Series, 41, 757.
- [12] Chow, J.C., Watson, J.G., Green, M.C., Lowelthal, D.H., Bates, B., Oslund, W. and Torres, G. (2000) Cross Border Transport and Spatial Variability of Suspended Particles in Mexicali and California's Imperial Valley. *Atmospheric Environment*, 34, 1833-1843. <u>http://dx.doi.org/10.1016/S1352-2310(99)00282-4</u>
- [13] Zuk, M.G. and Rojas, T.L. (2007) Tercer almanaque de datos y tendencia de la calidad del aire en 9 ciudades Mexicanas. SEMARNAT and INE, México.
- [14] SPA, SEMARNAT and ECOLOGÍA (2011) Pro-Aire Mexicali 2011-2020. Programa para mejorar la calidad del aire en Mexicali 2011-2020. Secretaría de Medio Ambiente y Recursos Naturales, Mexicali.
- [15] Mendoza, D.A. and Pardo, C.E. (2005) Niveles de PM_{2.5} y su composición química en la atmósfera de Mexicali, BC durante el otoño de 2004. V simposio de contaminación atmosférica, Iztapalapa, 19-21 June 2005, 55-59.
- [16] INEGI (2010) México en cifras: Información nacional, por entidad federativa y municipios. http://www.inegi.org.mx/default.aspx Enero del 2013.
- [17] García, C.O.R., Jáuregui, O.E., Toudert, D. and Tejeda, M.A. (2007) Detection of the Urban Heat Island in Mexicali, B.
 C. México and Its Relationship with Land Use. *Atmósfera*, 20, 111-131.
- [18] Chow, J.C. and Watson, J.G. (1997) Imperial Valley/Mexicali Cross Border PM₁₀ Transport Study, DRI Document No. 8623.2d1.
- [19] Quintero, N.M. and Vega, R.A. (2006) Estudio comparativo de tendencias de la calidad del aire de la ciudad de Mexicali (1997-2004). In: *Contaminación y medio ambiente en Baja California*, UABC, Margarito Quintero-Nuñez, Porrúa, Mexicali, 40-46.



Scientific Research Publishing (SCIRP) is one of the largest Open Access journal publishers. It is currently publishing more than 200 open access, online, peer-reviewed journals covering a wide range of academic disciplines. SCIRP serves the worldwide academic communities and contributes to the progress and application of science with its publication.

Other selected journals from SCIRP are listed as below. Submit your manuscript to us via either submit@scirp.org or Online Submission Portal.



 \checkmark

