IMPACT OF COVID-19 PANDEMIC ON N AND S ATMOSPHERIC DEPOSITION FLUXES IN A MEGACITY IN THE NORTH EAST OF MEXICO

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ABSTRACT

During 2020–2021, the COVID-19 pandemic resulted in a lockdown in many countries around the world. This work assessed the impact of the restrictions to economical and industrial activities, and population mobility on N and S atmospheric deposition fluxes in the Metropolitan Zone of Monterrey (MZM). Trends of atmospheric deposition fluxes were analyzed and compared during two periods. The first period before pandemic from 27 February 2017 to 15 October 2018; the second one, from 20 October 2020 to 5 May 2021. Both periods including two climatic seasons (dry and rainy) and considering the same sampling points along MZM. Passive collectors of throughfall deposition (hydrologic flux of ions to floor contained within a solution) were used to estimate concentrations for SO_4^{2-} and NO_3–. From a meteorological analysis, by using back-air masses trajectories and wind roses, the influence on transport and deposition of pollutants was assessed. The results showed that the change rates of N and S before and during the lockdown ranged from 63%–67% and 90% for N and S, respectively. The response of S was more sensitive to the lockdown than N. Since, during pandemic, industrial and vehicular emissions, and forest fires were reduced; it had a positive impact on atmospheric deposition. However, besides the lockdown due to COVID-19, the observed changes in spatial and temporal deposition patterns also could be attributed to meteorological conditions associated to the sampling season, particularly to precipitation patterns. Mean atmospheric deposition fluxes for N and S for the two studied periods were compared with critical load values established for sensitive ecosystems in Europe. Exceedances to critical load values before pandemic were significant higher than those found for the period during pandemic, suggesting that the lockdown improved the air quality in MZM.

Keywords: COVID-19, nitrogen, sulphur, atmospheric deposition, Monterrey.

1 INTRODUCTION

Atmospheric deposition is the main process to transfer materials (particles and gases) from the atmosphere to terrestrial surface; this process can occur by two ways: wet deposition and dry deposition. Wet deposition is a process in which atmospheric pollutants are incorporated to rain drops and transferred to the terrestrial surface by precipitation, mainly in the form of rain, snow or fog. Dry deposition depends on the type of component (gas or particle), whose deposition occurs on the terrestrial surface in the absence of precipitation [1]. Inputs of acidity by deposition to aquatic and terrestrial ecosystems have gained considerable public and scientific interests [2]. Dry and wet deposition contribute to the biogeochemistry cycle, and can explain nutrient inputs to the ecosystems [3].

Total emissions of N and S in Mexico have increased since 1980. In spite of S emissions have been reduced as a result of the implementation of new regulations and changes in the

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composition of fuels, deposition rate of N in comparison with those reported for S have increased significantly [4]. Saturation phenomena of N constitutes a threat for natural resources and ecosystems. Besides, the effects of N deposition on water quality constitute a concern due to some diseases of human health are associated to high levels of nitrates. In the other hand, the high deposition of S cause severe damages to forests, sulfur dioxide cause damages when its derivative sulfite is absorbed faster than receptors are detoxified. In spite of their importance, N and S atmospheric deposition is not considered as a criteria pollutant, and therefore, standardized sampling devices and reference values or regulations are not available. Regarding this, critical loads can be used as a valuable tool by decision makers to establish public policies focused to protect aquatic and terrestrial ecosystems in polluted regions. However, the establishment and application of critical loads requires accurate measurements of N and S deposition [5]. In Mexico, there are some individual stations of specific research groups measuring the major components in wet deposition, but they are limited and are not enough to calibrate empirical models, to monitor status, trends and exceedances to critical loads. Therefore, cost-effective sampling devices which integrate wet and dry deposition are required for the understanding of the distribution and effects of N and S deposition on ecosystems. Regarding this, throughfall deposition is widely used to estimate atmospheric deposition inputs to ecosystems, since it includes both, wet and dry deposition, and it is a non-expensive collector [6].

The comprehension of deposition mechanisms of N and S and their interactive effects is primordial not only to aspects related to deposition patterns at regional scale, but also to national and global scale. However, these patterns can be affected by changes in human activities, regarding this, it is expected that several atmospheric pollutants showed levels significantly lower during the COVID-19 pandemic as a result of restrictions in human activities in comparison with the observed patterns before the pandemic. Therefore, this work had as objective to study the spatial and temporal patterns of N and S atmospheric deposition in Metropolitan Zone of Monterrey (MZM) during two periods, the first occurring before COVID-19 pandemic (2017–2018), and the second occurring during the COVID-19 pandemic (2020–2021). Both results were compared to assess the effect of the restrictions on population mobility and industrial activities on atmospheric deposition patterns.

2 STUDY AREA

MZM is located at the north east of Mexico, grouping a total of 5,341,171 inhabitants, and it is considered as the second Metropolitan Area in Mexico, after Metropolitan Zone of Mexico Valley. In Fig. 1, 10 sampling sites selected for the installation of passive sampler are presented, their location is the same of atmospheric monitoring stations of Atmospheric Monitoring System of Nuevo León (SIMA). Sampling sites were grouped considering their land use as follows: industrial sites 1,3 and 5; urban sites 2,4,7,8,9 and 10; rural site 6.

3 METHODOLOGY

3.1 Sampling

Sampling was carried out in MZM considering two periods. The first one, occurring before COVID-19 pandemic from 27 February 2017 to 15 October 2018; the second one, occurring during the COVID-19 pandemic from 20 October 2020 to 5 May 2021. Both periods including two climatic seasons (dry and rainy) and considering the same sampling points along MZM. To measure wet and dry deposition fluxes is very complex and expensive, for this reason, throughfall collectors constitute a good choice to obtain reliable estimations of

SITE	NAME	SOIL TYPE
1	APODACA	INDUSTRIAL
2	SAN PEDRO	URBAN
3	SAN BERNABÉ	INDUSTRIAL
4	JUÁREZ	URBAN
5	SANTA CATARINA	INDUSTRIAL
6	GARCÍA	RURAL
7	OBISPADO	URBAN
8	SAN NICÓLAS	URBAN
9	LA PASTORA	URBAN
10	ESCOBEDO	URBAN

Figure 1: Location of sampling sites in MZM.

N and S atmospheric inputs in a given place [6]. Throughfall deposition is defined as the hydrologic flux of ions to floor contained within a solution [7]. Throughfall sampling devices were installed in each atmospheric monitoring station of SIMA by using passive collectors assembled and operated according to Simkin et al. [8]. Passive collectors based on ionic exchange resin (IER) were used, consisting of a funnel connected to a column which contains a IER bed. The main advantage of this kind of devices is that can be used during long periods and at a low cost. NO_3^- and SO_4^{2-} ions can be exchanged by IER and trapped by functional groups with electric charges opposed [9]. IER columns consist of a funnel covered with a mesh (to avoid the fall of solid material as leaves and insects) connected to a PVC tube; inside the tube, 30 g of IER are poured. The resin used by the collectors is a mixed resin of polystyrene for anions and cations. The PVC tube is sealed with glass fiber in the bottom (as a platform of support for the resin bed) and in the top (as a filter). This tube is collocated inside of an exterior PVC tube which serves as a shadow tube to protect the resin from solar radiation and to avoid changes in its physical and chemical properties. The bottom edge of the column opens or closes by using a standard valve of PVC to let or avoid the drainage.

3.2 Chemical analysis and IER extraction procedure

An extraction system specially designed for this propose was constructed with a PVC tube of 5 mm ID and 15 cm length which is connected to the resin tubes. The extraction is carried out adding 100 ml of KCI 2N, and letting rest during 20 minutes, after that, the valve is open. Once, the samples extracts are obtained, are refrigerated and stored until their analysis. Nitrate ions were determined by a colorimetric technique [5] and sulfate ions were determined by a turbidimetric technique [6]. Finally, from nitrate and sulfate concentrations, and considering the sampling area and time period of sampling, atmospheric deposition fluxes for N and S (kg Ha^{-1} yr^{-1}) were estimated.

3.3 Meteorological parameters and wind analysis

During the two sampling periods, meteorological parameters were measured in the atmospheric monitoring stations of SIMA. In addition, an analysis of the influence of winds on ionic concentrations was carried out calculating wind roses by using WRPLOT software at local scale, and calculating the back trajectories of air masses by using the Lagrangian hybrid model HYSPLIT from US NOAA at regional scale.

3.4 Statistical analysis

It was carried out a descriptive, relational and comparative statistical analysis by applying different statistical tools by using XLSTAT 2016 software.

4 RESULTS AND DISCUSSION

4.1 Nitrate deposition fluxes

4.1.1 Before COVID-19 pandemic

The mean deposition flux for nitrate during the rainy season 2018 was 6.54 kg Ha^{-1} yr^{-1} with a maximum value of 7.39 kg Ha^{-1} yr^{-1} corresponding to site 8, San Pedro, located at SW from MZM; and a minimum flux of 5.62 kg Ha^{-1} yr^{-1}, for site 10, Juárez, located at SE from MZM. In the other hand, the mean deposition flux for NO_3^- for the dry season 2017 was 3.30 kg Ha^{-1} yr^{-1}, with a maximum value of 4.38 kg Ha^{-1} yr^{-1} in site 8, San Pedro, located at SW from MZM, and a minimum flux of 0.40 kg Ha^{-1} yr^{-1}, corresponding to site 9, La Pastora, located at SE from MZM. According to Fig. 2, where analysis by season is presented, it can be observed that the mean deposition flux of nitrate was higher for the rainy season 2018. In addition, the maximum value was found during this season. Nitrate levels during the period before COVID-19 pandemic were higher during the rainy season, suggesting that chemical reactions in aqueous phase played an important role in the removal process of pollutants during this season. By applying a Friedman test, it was found that there were significant differences between nitrate deposition fluxes between seasons. In the analysis by sampling point, a mean nitrate deposition flux of 4.37 kg Ha^{-1} yr^{-1} was found, with a maximum value of 7.39 kg Ha^{-1} yr^{-1} during the rainy season 2018 in site 8, San Pedro, located at SE from ZMZ; and a minimum flux of 0.41 kg Ha^{-1} yr^{-1}, observed during dry season 2017 in site 9, La Pastora, located at SE from MZM.

In Fig. 3, the analysis by sampling point can be observed, the higher mean flux and the maximum flux of nitrate were found in site 8, followed by site 1, that corresponds to San Pedro located at SW, and Escobedo, located at NE from MZM. In addition, the minimum fluxes were observed in sites 9 and 10, corresponding to La Pastora and Juárez, both sites located at SE from MZM. Therefore, it suggests that the main emission sources of nitrogen oxides were vehicular sources, since the higher fluxes were found in sites grouped as urban sites. From the Friedman test, it was concluded that there were significant differences between sampling sites. From Fig. 4, it can be observed that nitrate deposition fluxes were higher in sites with a land use type urban (sites 1, 4, 6, 8, 9 and 10) that corresponds to Escobedo, San Nicolás, Obispado, San Pedro, La Pastora and Juárez, located at N, NE, in the center, SW, and SE from MZM, respectively. However, sites grouped as rural and industrial showed also high levels of nitrate. Since, a greater variability was observed, a possible explanation can be the variability in the strength of the sources, since the main source of nitrate precursors is the high vehicular traffic. It was supported by a Friedman test applied to grouped sites, concluding that there were not significant differences in nitrate deposition fluxes by land use, suggesting that the main sources were local sources, in this case vehicular sources in urban areas.

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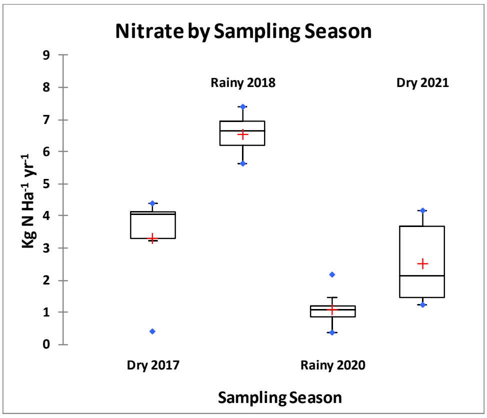


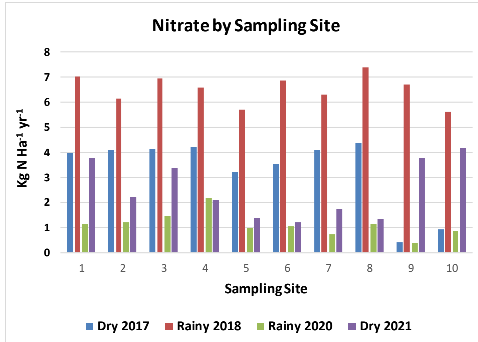


Figure 2: N atmospheric deposition fluxes by season before COVID-19 (dry 2017 and rainy 2018) and during COVID-19 (rainy 2020 and dry 2021).

Figure 3: N atmospheric deposition fluxes by sampling site before COVID-19 (dry 2017 and rainy 2018) and during COVID-19 (rainy 2020 and dry 2021).

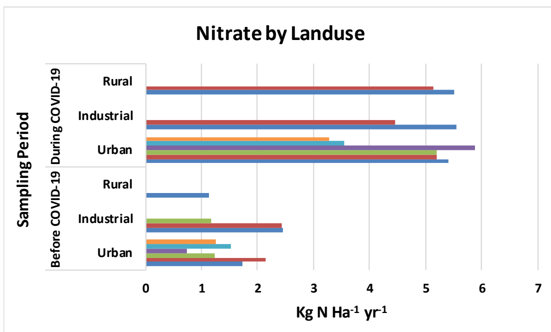


Figure 4: N atmospheric deposition fluxes by land use before COVID-19 and during COVID-19.

4.1.2 During COVID-19 pandemic

The mean value obtained during rainy season 2020 was 1.10 kg Ha^{-1} yr^{-1}, with a maximum values of 2.17 kg Ha^{-1} yr^{-1} corresponding to site 4 (Juárez), located at SE from MZM; and a minimum of 0.36 kg Ha^{-1} yr^{-1}, corresponding to site 9 (La Pastora), both with a land use type urban (Fig. 2). The mean value obtained during the dry season 2021 was 2.51 kg Ha^{-1} yr^{-1} with a maximum value of 4.17 kg Ha^{-1} yr^{-1} corresponding to site 10 (Escobedo), located at N from MZM; and a minimum value of 1.23 kg Ha^{-1} yr^{-1} in the site 6 (García) (Fig. 2). From Fig. 2, it can be observed that the mean N deposition flux was higher during the dry season in comparison with that observed during the rainy season. Even the minimum deposition flux during dry season was above of maximum deposition flux observed during the rainy season, suggesting that, a dilution phenomenon (as a result of the washing of the atmospheric column during the rainy season) played an important role in the nitrate deposition patterns in MZM.

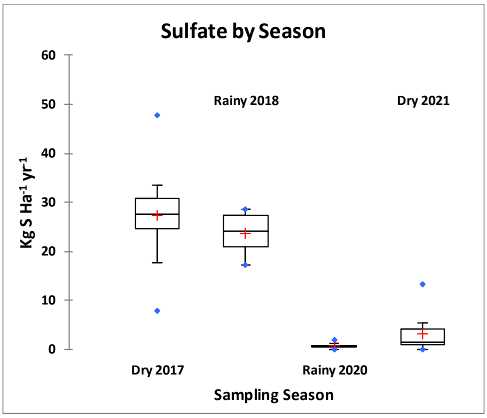
From Friedman tests, it was found that, there were significant differences in nitrate levels between seasons, therefore, the occurrence of precipitation played an important role in the nitrate deposition patterns in MZM. Analyzing the differences between sites, the higher mean value was registered for site 10 (Escobedo) with a value of 2.50 kg Ha^{-1} yr^{-1} located at N from MZM; whereas the minimal value was found for site 6 (García) with a value of 1.13 kg Ha^{-1} yr^{-1} (Fig. 3). From Fig. 3, it can be observed that the minimal concentration was obtained for site 9 (La Pastora), whereas the maximum concentration was found in site 10 (Escobedo). From the Friedman test, it was found that there were not significant differences in nitrate deposition fluxes between sites; it suggests that nitrate levels were uniformly distributed along ZMZ, with origin in local sources. It can explain the differences in the seasonal pattern in comparison with the sampling period occurring before COVID-19 pandemic. Finally, from Fig. 4, it can be observed that nitrate deposition fluxes were higher in sites with a land use type industrial, followed by sites with a land use type urban. From Friedman tests, it was found that there were not significant differences in nitrate levels by land use, suggesting that nitrate levels were uniformly distributed along MZM with sources in common, in this case, vehicular sources.

4.2 Sulfate deposition fluxes

4.2.1 Before COVID-19 pandemic

The mean deposition flux of sulfate obtained during the rainy season 2018 was 23.65 kg Ha^{-1} yr^{-1}, with a maximum value of 28.63 kg Ha^{-1} yr–[1] in site 1, Escobedo, located at N from MZM; and a minimum value of 17.31 kg Ha^{-1} yr^{-1}, corresponding to site 8, San Pedro, located at SW from MZM. In the other hand, the mean deposition flux for sulfate for dry season 2017 was 27.30 kg Ha^{-1} yr^{-1} with a maximum value of 47.69 kg Ha^{-1} yr^{-1} in site 6, Obispado, located at the center of MZM, and a minimum value of 7.86 kg Ha^{-1} yr^{-1}, in site 9, La Pastora, located at SE from MZM. From Fig. 5, it can be observed that the mean sulfate deposition flux was higher during the dry season, and showing in some cases values too high. From Friedman test it was found that, there were significant differences between seasons suggesting that, besides local sources, sulfate could have its origin in regional sources located at SE from MZM. In Fig. 6, the analysis by sampling point is presented, it was found a mean sulfate deposition flux of 25.03 kg Ha^{-1} yr^{-1}, with a maximum value of 47.69 kg Ha^{-1} yr^{-1}, during the dry season in site 6, Obispado; and a minimum value of 7.86 kg Ha^{-1} yr^{-1}, during the dry season in site 9, La Pastora, located at SE from MZM. From Fig. 6, it can be observed that the mean deposition flux of sulfate was higher in site 6, followed by sites 4 and 5, Obispado, San Nicolás and Apodaca, respectively. Since the higher sulfate deposition fluxes were found in the center and at N of MZM, it can be established that vehicular sources contributed in a significant way on the emission process of primary pollutants precursors of sulfate. From a Friedman test, it was found that there were not significant differences in sulfate deposition fluxes by sampling site, suggesting that sulfate levels were uniformly distributed along MZM.

In the other hand, in Fig. 7, it can be observed that the mean deposition fluxes were higher in sites with a land use type industrial (sites 3 and 5), that corresponds to San Bernabé and Apodaca, located at NW and NE from MZM; followed by sites with and urban land use (sites 1, 4, 6, 8, 9 and 10) that corresponds to Escobedo, San Nicolás, Obispado, San Pedro, La Pastora, and Juárez, located at N, NE, in the center, SW and SE from MZM. Applying a Friedman test, it was found that there were not significant differences in sulfate deposition fluxes by land use.



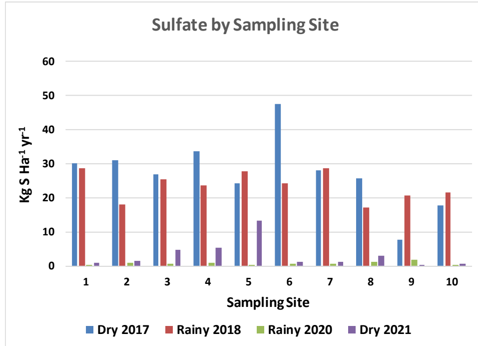


Figure 5: S atmospheric deposition fluxes by season before COVID-19 (dry 2017 and rainy 2018) and during COVID-19 (rainy 2020 and dry 2021).

Figure 6: S atmospheric deposition fluxes by sampling site before COVID-19 (dry 2017 and rainy 2018) and during COVID-19 (rainy 2020 and dry 2021).

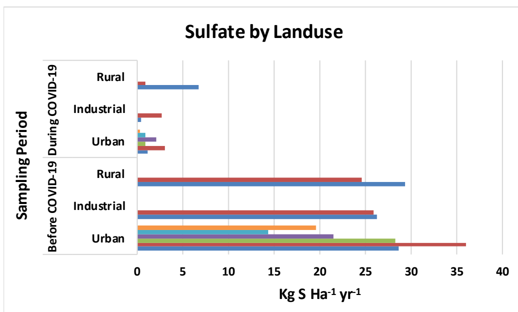


Figure 7: S atmospheric deposition fluxes by land use before COVID-19 and during COVID-19.

4.2.2 During COVID-19 pandemic

The mean value obtained for the rainy season 2020 was of 0.71 kg Ha^{-1} yr^{-1}, with a maximum value of 1.83 kg Ha^{-1} yr^{-1} corresponding to site 9 (La Pastora) located at E from MZM; and a minimum value of 0.045 kg Ha^{-1} yr^{-1}, corresponding to site 1 (Apodaca), with a land use type urban and industrial, respectively (Fig. 5). The mean value obtained for the dry season 2021 was of 3.18 kg Ha^{-1} yr^{-1} with a maximum value of 13.18 kg Ha^{-1} yr^{-1} corresponding to site 5 (Santa Catarina), located at SW from MZM; and a minimum value of 0.0021 kg Ha^{-1} yr^{-1}, corresponding to site 9 (La Pastora), with a land use type industrial and urban, respectively. From Fig. 5, analyzing the differences by season, it can be observed that the mean deposition flux for sulfate was considerably higher during the dry season in comparison with the rainy season, suggesting that during the rainy season, a dilution phenomenon as a result of the washing of the atmospheric column could contribute to obtain concentrations significantly lower in comparison with those obtained during the dry season. By applying a Friedman tests, it was concluded that, there were significant differences between seasons in S atmospheric deposition fluxes.

Analyzing the differences between sites, the highest mean value was registered for site 5 (Santa Catarina) with a value of 6.8336 kg Ha^{-1} yr^{-1} located at SW from MZM; whereas the minimum mean value was registered in site 10 (Escobedo) with a value of 0.39 kg Ha^{-1} yr^{-1}, with a land use type industrial and urban, respectively (Fig. 6). In addition, it can be observed that the minimum concentration was obtained for site 9 (La Pastora), whereas the maximum concentration was found for site 5 (Santa Catarina). From Friedman test, it was found that there were not significant differences in sulfate levels between sites, therefore, it can be concluded that sulfate levels were uniformly distributed along MZM; it suggests that only local sources were important during this period of pandemic, and regional sources did not contribute in a significant way on S deposition patterns considering that restrictions on mobility and industrial activities were applied not only in Mexico but also USA.

According to Fig. 7, it can be observed that mean sulfate deposition fluxes were higher with an industrial land use, however, the values obtained with an urban land use were also high, suggesting that anthropogenic local sources played an important role in S deposition. From Friedman test, it was found that there were not significant differences in sulfate levels by land use, suggesting that S deposition is uniformly distributed along MZM; this is in accordance with those found when differences between sampling sites were analyzed.

4.3 Meteorological analysis

Meteorological analysis at regional scale was carried out by estimating 24 h back air-masses trajectories at 500, 1000 and 1500 m altitude, by using HYSPLIT model from NOAA (National Oceanic and Atmospheric Administration, USA), by choosing one of the sampling sites located at NE from MZM, in this case, the site 1 Apodaca. In addition, meteorological parameters measured by stations from SINAICA (National System of Air Quality Information) were processed and analyzed to obtain wind roses for each sampling period to identify the prevailing wind direction. From meteorological analysis at regional and local scale, the prevailing wind direction before COVID-19 pandemic and during COVID-19 pandemic was E–SE, suggesting that the seasonal patterns found are related not only to the occurrence or not of precipitation (dilution phenomena) but also to the influence of regional sources, specially before COVID-19 pandemic, when regional sources contributed in a significant way on S deposition patterns in MZM. In the other hand, the spatial patterns found indicate that N and S levels were uniformly distributed along MZM; it means that local sources were important, however, since prevailing wind direction was the same during both sampling periods, differences found between sampling sites can be attributed to the strength of emission from the local sources in each specific case, since there were sites with a higher vehicular traffic in comparison with other sites; and the strength of emission was higher before the COVID-19 pandemic since regional contribution was higher than during the pandemic.

4.4 Reference values

4.4.1 Reference values

It has been proposed a critical load value of 5 kg N Ha^{-1} yr^{-1} for alpine ecosystems, which are more sensitive that ecosystems in low lands [7]. In the case of S, it has been proposed a critical load value of 3 kg S Ha^{-1} yr^{-1} for sensitive areas in Europe; whereas for natural forests, it has been proposed a range between 2 and 5 kg S Ha^{-1} yr^{-1} [8]. Regarding to Mexico, reference values are not available to compare the current N and S deposition fluxes in MZM.

4.4.1.1 Before COVID-19 pandemic

Considering the sampling period corresponding to 2 years before pandemic (2017–2018), the mean deposition fluxes for N and S were 4.88 and 25.03 kg $Ha^{-1}yr^{-1}$, respectively. N deposition fluxes did not exceed the reference value reported for alpine ecosystems, however, these values are already in the upper limit of this range. In addition, N deposition fluxes found in MZM were almost two times than those reported by Escoffie et al. [4] in Carmen Island (2.15 kg N $Ha^{-1}yr^{-1}$) in Campeche; by Sánchez [14] in Orizaba Valley (1.44 kg N $Ha^{-1}yr^{-1}$) in Veracruz; and almost 4 times than those reported by García [15] in Atasta-Xicalango (1.15 kg N $Ha^{-1}yr^{-1}$) in Campeche.

In the other hand, S deposition fluxes found 2 years before COVID-19 pandemic exceeded almost eight times the reference value proposed as critical load for sensitive areas, and almost five times the upper limit of the exceedance range established for natural forests in Europe. S deposition fluxes were almost six times than those found by Escoffie et al. [4] in Carmen Island (4.7 kg S Ha^{-1} yr^{-1}); and three times higher than those reported by García [15] in Atasta-Xicalango (8.57 kg S Ha^{-1} yr^{-1}); both sites in Campeche.

4.4.1.2 During the COVID-19 pandemic

Considering the sampling period corresponding to 1.5 years during pandemic (2020–2021), the mean deposition fluxes for N and S for MZM were 1.81 kg N Ha^{-1} yr^{-1} and 1.95 kg S Ha^{-1} yr^{-1}, respectively. In the case of N, this value is below of the reference value reported for alpine ecosystems; whereas in the case of S, the mean value is already close to the threshold value for sensitive areas and forests in Europe. However, besides the mean value, it is necessary to consider that in the case of S, maximum values occurring in site 5 (Santa Catarina) with 13.18 kg S Ha^{-1} yr^{-1} and in site 4 (Juárez) with 5.37 kg S Ha^{-1} yr^{-1} during the dry season 2021 exceeded almost 4 and 2 times the reference values proposed.

N levels found in MZM were in some cases lower and in other cases comparable to those reported by Escoffie et al. [4] in Carmen Island, in Campeche (2.15 N kg Ha^{-1} yr^{-1}); by Sánchez [14] in Orizaba Valley, in Veracruz (1.44 N kg Ha^{-1} yr^{-1}); and by García [15] in Atasta-Xicalango, in Campeche (1.15 kg Ha^{-1} yr^{-1}). In the other hand, in the case of S, mean S deposition fluxes in MZM during the COVID-19 pandemic were lower than those reported by Escoffie et al. [4] in Carmen Island (4.7 S kg Ha^{-1} yr^{-1}) and by García [15] in Atasta-Xicalango (8.57 S kg Ha^{-1} yr^{-1}); both sites in Campeche. However, it is necessary to consider that extreme values of S deposition occurred in sites 5 and 4 with 13.18 and 5.37 kg Ha^{-1} yr^{-1}, respectively; and these values were higher than those found in Carmen island, and Atasta. In addition, values reported by Sánchez [14] in Orizaba Valley (55.16 S kg Ha^{-1} yr^{-1}) in Veracruz were significantly higher than values reported by this study.

5 CONCLUSIONS

Comparing results found in both sampling periods (before and during COVID-19 pandemic) in MZM, before COVID-19 pandemic, N levels (4.88 kg N Ha^{-1} yr^{-1}) were 2.7 times higher than those found during COVID-19 pandemic (1.81 kg N Ha^{-1} yr^{-1}), it means that N deposition fluxes were 63%–67% lower during the pandemic, suggesting that due to a decrease in economical and industrial activities, and the restrictions of population mobility, nitrate levels were reduced significantly. Comparing S deposition fluxes obtained two years before COVID-19 pandemic (25.03 kg S Ha^{-1} yr^{-1}) with those values obtained during the pandemic (1.95 kg S Ha^{-1} yr^{-1}) in MZM, S deposition were 12.83 times higher than those

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found during the pandemic, it means that S deposition fluxes were 90% lower during the COVID-19 pandemic, suggesting that the restrictions in economical, industrial and vehicular activities had a positive effect not only on air quality but also S deposition patterns. The response of S was more sensitive to the lockdown than N, it can be explained from the regional origin of sulfate since the restrictions during the global pandemic not only were applied in Mexico but also in USA and Central America resulting in a marked decrease in the regional contribution. However, besides the lockdown due to COVID-19 pandemic, the observed changes in temporal deposition patterns for N and S also can be attributed to meteorological conditions associated to each sampling season, particularly to precipitation patterns well marked that occur in semi-arid zones of Mexico as Monterrey. Mean atmospheric deposition fluxes for N and S for the two studied periods were compared with critical load values established for sensitive ecosystems in Europe; exceedances to critical load values before pandemic were significant higher than those found during pandemic period, suggesting that the lockdown improved the air quality in MZM.

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