

Air Quality Regarding to TSP in Six Cities of Sonora, Mexico, a Criticism to the NOM-025-SSA1-1993 and a Proposed Criterion for Its Non-Compliance

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Abstract

In the present study, the air quality is assessed for the year 2010 regarding to the Total Suspended Particles (TSP) for six cities of Sonora, Mexico, representing the first regional study in Sonora in air quality. The assessment used performance indicators and indicators of compliance with the regulations. It is established that in all the cities the maximum limit value of daily concentration of 210 $\mu\text{g}/\text{m}^3$ is exceeded, being the percentage of days above the rule of 30%, 78%, 76%, 6%, 3% and 62% for Agua Prieta, Nogales, Puerto Peñasco, Hermosillo, Guaymas and Obregón respectively, classifying these days with poor air quality. According to the annualized index used, the air quality was not satisfactory for the period of study in the six cities. Nogales and Puerto Peñasco presented the most adverse conditions of air quality with annual average values of TSP of 363 and 345 $\mu\text{g}/\text{m}^3$ and maximum daily of 1047 and 1239 $\mu\text{g}/\text{m}^3$ (498% and 590% above the norm) respectively. The requirements of coverage that establishes the Mexican Official Standard NOM-025-SSA1-1993 (SSA, 2005) are questioned for its compliance, proposing in this paper a criterion of non-compliance by prioritizing the protection of health and the precautionary principle. It is recommended to implement air quality management programs (PROAIRE) in these cities.

Keywords

Particles, TSP, Air Quality, NOM-025-SSA1-1993, Sonora Mexico

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1. Introduction

The suspended particles are a complex multiphase system that are transported by air and whose aerodynamic diameter goes from 0.01 to 100 μm [1]. High concentrations cause or exacerbate cardiovascular and pulmonary diseases reducing lung function, generating asthma attacks, chronic bronchitis, causing arrhythmias and heart attacks, and they may affect the central nervous and reproductive systems and even cause cancer by promoting premature death [2]. The damage to health by high concentrations of particles has been demonstrated by the increase of the mortality and morbidity particularly for Total Suspended Particulates (TSP) increasing to a 6% risk of dying in each 100 $\mu\text{g}/\text{m}^3$ increase in this parameter [3]. Ramirez-Leal [4] stated that the TSP are constituted by a large variety of elements, including toxic as lead and chromium identified in the particles in the air of Hermosillo, a city which has been classified with non-satisfactory air quality by TSP in 2002 [5]. The inhabitants of Agua Prieta and Nogales have expressed their discomfort by the visible pollution by powders, condition that must be evaluated to represent areas with industrial maquila activity type with potential border atmospheric emissions. The town of Puerto Peñasco has been characterized by presenting adverse events to the air quality derived from dust devils and dust storms. In the cities of Guaymas and Obregón dissatisfaction in its residents is also identified because of the dubious quality of the air. The first is because of the visible atmospheric emissions of power plants, and the second is by the dust devils that carry terrigenous material from agricultural fields in the region, as well as by the smoke produced by the burning of sheaf.

According to the environmental authority in Mexico [6], studies are required to contribute with information, assessment and diagnostics to support in the decision-making in the local level in terms of reducing health risks by ambient air pollution. In the present investigation, the air quality is assessed with respect to TSP for the cities of Agua Prieta, Nogales, Puerto Peñasco, Hermosillo, Guaymas and Obregón, in the State of Sonora, Mexico, during 2010 through different methodologies.

It is discussed in addition, the irrelevance of the criteria for coverage that the Mexican Official Standard NOM-025-SSA1-1993 [3] provides for its observance, affecting with the protection of the health of the population by discriminating relevant information to that effect, presenting in this paper a proposed criterion of non-compliance by prioritizing the precautionary principle.

2. Materials and Methods

2.1. Area of Study

In **Table 1**, the demographic and geographic information of the study sites is presented [7] and in **Figure 1**, its location is shown. For the year 2010, the municipalities of Hermosillo, Cajeme (Obregón) and Nogales were the most populous in the State (in that order); Guaymas is ranked in sixth place, Agua Prieta in the ninth and Puerto Peñasco on the eleventh of the 72 municipalities of the State of Sonora, Mexico. The kind of weather, the annual average temperature and annual precipitation corresponding to the cities where the sampling stations are located are presented in **Table 2** [7], still in general localities with dry and warm weather.

2.2. Sampling and Analysis of Results Methodology

The information generated by the State Information and Infrastructure on Air Quality Network (REIICA) for the cities of Agua Prieta, Nogales, Puerto Peñasco, Guaymas and Obregón, and by the Program of Evaluation and Improvement of the Air Quality (PEMCA) for the city of Hermosillo of the year 2010 was used. The sampling method corresponded to the established in the Mexican Official Standard NOM-035-SEMARNAT-1993 [8] coinciding with the sampling method of high volume of the Environmental Protection Agency from USA [9]. A sampling frequency was established every 6 days with non-simultaneous sampling in the six cities monitored.

To determine the air quality, the following was used: 1) the methodology of the protocol data management of air quality for performance indicators and indicators related to standards of quality of the air [10]; 2) the annualized air quality index proposed by Cruz-Campas [11] which involves the algorithm of the Uniform Air Quality Index [12] applied by the Pollutant Standard Index (PSI) in the US and by the Metropolitan Air Quality Index (IMECA) in Mexico, but using as a variable of calculation the annual average of TSP just of the days that the value of maximum concentration established in the rule was exceeded. And it is proposed to this, new breaking points ranges for TSP; and 3) the days with good, fair and bad air quality according to SEMARNAT criteria [13] were defined.

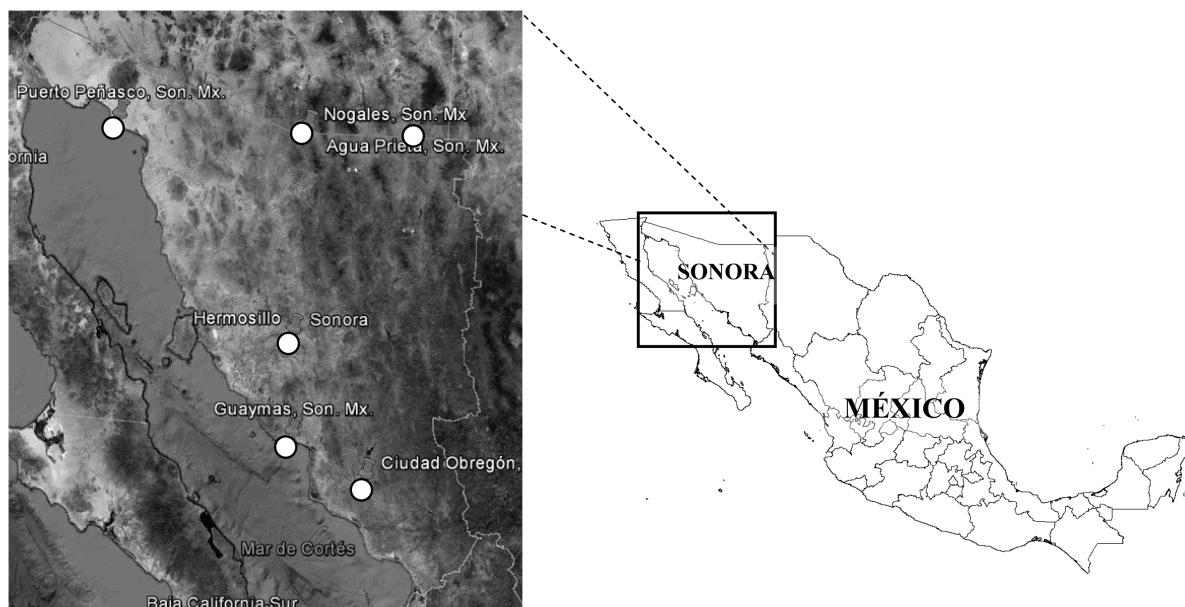


Figure 1. Location of the six cities in the State of Sonora, Mexico where the sampling of TSP was done in 2010.

Table 1. Demographic and geographical information of the sampling sites of TSP in Sonora, Mexico in 2010.

City	Population (2010)	Height above sea level (m)	Geographic location of sampling sites
Agua Prieta	79,138	1220	31°18'41.76"N 109°32'07.33"W
Nogales	220,292	1238	31°19'28.58"N 110°57'18.44"W
Puerto Peñasco	57,342	10	31°20'30.29"N 113°30'58.46"W
Hermosillo	784,382	227	29°02'38.50"N 110°57'27.80"W
Guaymas	149,299	20	27°54'51.53"N 110°54'11.91"W
Obregón	409,310	61	27°29'01.92"N 109°56'51.93"W

Table 2. Type of climate, annual average temperature and annual precipitation of the six cities where TSP sampling stations are located.

City	Climate	Annual average temperature (°C)	Annual precipitation (mm)
Agua Prieta	Semi-Arid BSokw (C''),	17	335
Nogales	Semi-Arid BS1Kw (x') (e')	17.8	461
Puerto Peñasco	Arid (Desert) BWhw (x') (e')	20.1	91
Hermosillo	Arid (Desert) BW (h')	24	320
Guaymas	Arid (Desert) BW (h')	19	200
Obregón	Steppe BS h	24	410

3. Results and Discussions

3.1. Performance Indicators of TSP in Six Cities of Sonora Mexico in 2010

3.1.1. Daily Average

Figure 2 presents the behavior of the concentration of TSP for the six cities throughout the year 2010; the charted

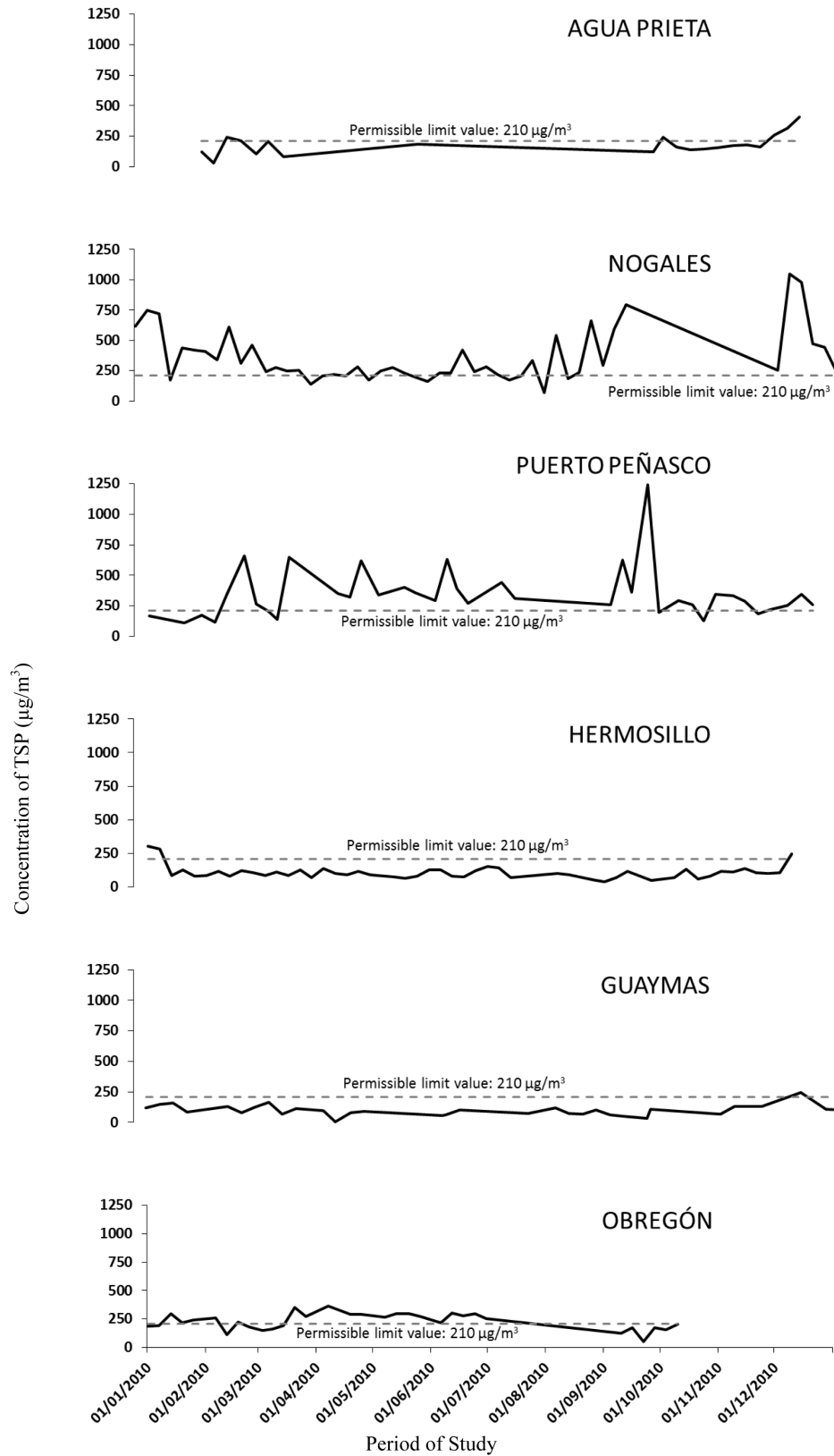


Figure 2. Distribution and comparison of TSP concentrations with the maximum permissible value ($210 \mu\text{g}/\text{m}^3$) in six cities in Sonora, Mexico, in 2010.

values correspond to sampling of 24 h. The cities of Nogales and Puerto Peñasco present an amplitude of the order of $1000 \mu\text{g}/\text{m}^3$ between minimum and maximum concentration; while in the other four cities that amplitude is between 200 and $400 \mu\text{g}/\text{m}^3$, such a difference in amplitude of concentrations may be related to the regional weather conditions in particular temperature and/or wind speed. **Figure 2** shows with dotted line the maximum permissible value of TSP ($210 \mu\text{g}/\text{m}^3$) showing that in all the cities is exceeded at any time of the year, but in Nogales and Puerto Peñasco is where it occurs more frequently. Only antecedent of measurements of TSP for the city of Hermosillo was identified [5] and its established that the daily maximum concentration detected in the year 2010 of $305 \mu\text{g}/\text{m}^3$ is located between the maximum detected in 2002 ($243 - 610 \mu\text{g}/\text{m}^3$). The annual average determined for the year 2010 was $108 \mu\text{g}/\text{m}^3$, and in 2002, the annual average was between 110 and $244 \mu\text{g}/\text{m}^3$ in three analyzed sites. According to this comparison, the levels of concentration of TSP in the city of Hermosillo would have remained similar between 2002 and 2010.

3.1.2. Monthly Average

This indicator shows the change in the concentrations of a contaminant in the year, presenting the typical values for each month using the average of the daily logs, and it allows associating the concentration of pollutants with the intensity of the anthropogenic activities or weather patterns. In **Table 3**, the monthly average values of concentration of TSP ($\mu\text{g}/\text{m}^3$) for each city are presented. The cities of Nogales and Puerto Peñasco highlight with the monthly average values higher, being the highest of $694 \mu\text{g}/\text{m}^3$ in September for Nogales, followed by Puerto Peñasco with $536 \mu\text{g}/\text{m}^3$ also in September; Agua Prieta with $364 \mu\text{g}/\text{m}^3$ in December, Obregón with $315 \mu\text{g}/\text{m}^3$ in April, Hermosillo with $246 \mu\text{g}/\text{m}^3$ in December, and finally Guaymas with $153 \mu\text{g}/\text{m}^3$ in December. This indicator of behavior points out the months in which the possible conditions of anthropogenic activity or weather patterns have an impact on the air quality, and can serve to alert on the months with conditions that pose a danger to health by TSP. This information should be considered to protect the most susceptible population such groups as infants, pregnant women, older adults and people with cardiovascular or respiratory diseases.

3.1.3. Maximum, Minimum and Annual Average

In **Figure 3**, the maximum, average and minimum concentrations of TSP for the six cities during the period of study are presented. The maximum obtained in those cities ranging from 245 to $1239 \mu\text{g}/\text{m}^3$ exceeds the ruled value for 24 h of $210 \mu\text{g}/\text{m}^3$. The cities of Nogales and Puerto Peñasco presented the highest concentrations exceeding on 498 and 590 per cent respectively the norm.

The city of Nogales presents an ambient temperature from moderate to cold, which combined with the mostly dry climate of the region, favors the presence of dust in the atmosphere. On the other hand, the town of Puerto

Table 3. Monthly average values of TSP ($\mu\text{g}/\text{m}^3$) in six cities of Sonora, Mexico, in 2010.

Month	Agua Prieta	Nogales	Puerto Peñasco	Hermosillo	Guaymas	Obregón
January	-	520	139	201	128	228
February	152	418	321	97	106	195
March	132	295	315	102	117	226
April	-	211	429	104	67	315
May	183	214	366	79	-	282
June	-	282	395	107	72	265
July	-	200	377	122	72	-
August	-	383	-	73	90	-
September	181	694	536	75	63	132
October	150	-	255	92	68	179
November	192	252	256	114	131	-
December	364	637	286	246	153	-

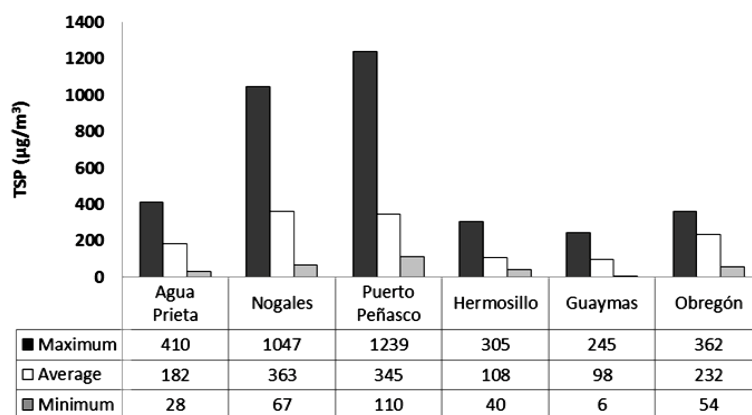


Figure 3. Maximum, average and minimum values of TSP ($\mu\text{g}/\text{m}^3$) in six cities of Sonora, Mexico, in 2010.

Peñasco is located in a desert area characterized by events of dust devils and dust storms, situations that significantly affect the air quality.

The annual averages obtained in the six cities fluctuated from 98 to 363 $\mu\text{g}/\text{m}^3$. Currently the standard NOM-025-SSA1-1993 [3] does not set a maximum annual allowable limit. In the previous norm of TSP (NOM-024-SSA1-1993 in force until 2005) it is established a maximum allowable value of 75 $\mu\text{g}/\text{m}^3$ of TSP annual average, which would have been exceeded in the six cities.

In previous studies of TSP [5] reported for Hermosillo, Sonora (June 2001 to May 2002), the maximum values are from 243 to 610 $\mu\text{g}/\text{m}^3$, and annual average of 110 to 244 $\mu\text{g}/\text{m}^3$ for three sites in the city. Although none of these three sites corresponds to the site analyzed in the 2010 (Station COBACH Sur), the levels of concentration can be considered similar in both periods. With respect to the rest of the cities, publications of previous studies on TSP are not currently available.

3.2. Indicators Related to Air Quality Standards

In general, the air quality standards are set based on the results obtained in toxicological and epidemiological studies that relate the exposure to a contaminant and the effects on health. In Table 4, the concentrations limits and the maximum permissible frequency for suspended particles in ambient air according to the Mexican regulations are presented.

3.2.1. 98th Percentile

The maximum frequency that is allowed to exceed the limit value is 2% of the daily concentrations in a year (percentile 98), which was established in the Mexican Official Standard NOM-025-SSA1-1993 [3] for TSP. In order to be able to check its enforcement, it will be required to meet with a minimum coverage of sampling 75% of valid samples per quarter and three quarters fulfilling the requirement to assess the year. In the sites where the monitoring did not perform daily, the number of samplings timetabled for that period shall be based on. Table 5 shows the evaluation of the criterion of completeness or data coverage for each of the cities of the present study.

Based on the results obtained, it is not possible to assess compliance with the rule cited above for TSP in the cities of Agua Prieta, Puerto Peñasco, Guaymas and Obregón, due to failure to obtain the 75% of samples in three quarters.

The cities of Nogales and Hermosillo complied with this criterion by which it is possible to assess their compliance with the standard. The data that were considered for the calculation of the percentile 98 correspond to Nogales to the samplings in the first three quarters of the year and to Hermosillo for all quarters. In Table 6, the corresponding concentration at the 98th percentile of both cities is presented.

It is important to note that the Mexican Official Standard NOM-025-SSA1-1993 [3], does not provide basis for its requirement of 75% of completeness or coverage per quarter to be valid, and also for the criterion of at least three quarters valid in order to be able to diagnose that a site complies with the standard. It is assumed that these requirements guarantee that there is enough information to be able to establish compliance with the rule.

Table 4. Mexican regulations for suspended particles in ambient air.

Pollutant	Permissible value or limit			Mexican official norm
	Acute exposure		Chronic exposure	
	Concentration ($\mu\text{g}/\text{m}^3$) 24-hour average	Maximum allowed frequency	Concentration ($\mu\text{g}/\text{m}^3$) annual arithmetic mean	
TSP	210	2% per year measurements	-	NOM-025-SSA1-1993 [3]
PM10	120	2% per year measurements	50	
PM2.5	65	2% per year measurements	15	

Table 5. Evaluation of the requirement of completeness or coverage for TSP sampling conducted in six cities of Sonora, Mexico in 2010.

Quarter	Expected samples	75% of the expected	Valid samples per city and meeting the completeness or coverage criterion											
			Agua Prieta		Nogales		Puerto Peñasco		Hermosillo		Guaymas		Obregón	
			Samples	Meets	Samples	Meets	Samples	Meets	Samples	Meets	Samples	Meets	Samples	Meets
Jan-Mar	15	11	7	No	15	Yes	10	No	14	Yes	10	No	14	Yes
Apr-Jun	16	12	1	No	16	Yes	10	No	14	Yes	7	No	14	Yes
Jul-Sep	15	11	2	No	12	Yes	7	No	11	Yes	9	No	3	No
Oct-Dec	14	10	10	Yes	6	No	11	Yes	11	Yes	6	No	2	No

Table 6. Determination of the 98th percentile for concentrations of TSP in the cities of Nogales and Hermosillo, Sonora, Mexico in 2010 and determination of compliance with the norm NOM-025-SSA1-1993 [3].

City	Concentration corresponding to the 98th percentile ($\mu\text{g}/\text{m}^3$)	Maximum permissible value ($\mu\text{g}/\text{m}^3$)	Compliance with standard
Nogales	794	210	No
Hermosillo	305	210	No

However, these criteria would be irrelevant for determining non-compliance with the standard by the fact that the maximum permissible value is exceeded, and then the purpose of the rule to protect the health of the population more susceptible would be without effect identifying controversy in its application. Moreover, that situation should detonate the consequential actions for the protection of human health and control of environmental pollution that the authorities should implement.

Because the sampling of TSP corresponds to manual type with a frequency of every 6 days, would be sufficient that for two days of being exceeded the maximum allowable value for a coverage of 100% (60 valid samples per year) or overstepping one day for a coverage of 75% (45 valid samples per year) to be exceed 2% which is the maximum allowable frequency of days above the maximum permissible value of $210 \mu\text{g}/\text{m}^3$ during the year, to be in noncompliance with the norm.

Under this perspective, it would be sufficient to note as a criterion of non-compliance the number of days that the value of maximum permissible concentration would be exceeded discarding the coverage requirement. Based on the foregoing and under the precautionary principle that any standard of environmental protection and health must consider [14]-[16] it is irrelevant the requirement of coverage requested by the standard NOM-025-SSA1-1993 [3].

Therefore, under the philosophy of the standard to protect the health of the susceptible population, criteria should be established considering non-compliance parameters making relevant the normative instrument.

Considering the analysis of the two preceding paragraphs, in **Table 7** a criterion of non-compliance of the standard for TSP is proposed without the requirement of completeness or coverage now established in it.

This proposal preserves the criteria of the rule with respect to the regulated concentration ($210 \mu\text{g}/\text{m}^3$) and frequency allowed (percentile 98) and enables to check the noncompliance of the rule with respect of TSP for many sites in Mexico in which the concentrations of TSP could be high but do not have enough measurements to apply the norm currently. As an example of implementation of the proposal, in **Table 8** the analyses for the cities in study in this work are presented.

3.2.2. Number of Days above the Limit

This indicator is obtained as the count of days above the maximum permissible value and indicates the impact that pollution has by a specific contaminant in a given region, and is equivalent to the “percentage of days above the limit”. The calculation should consider the criteria of completeness of at least 75% of the data. The number of days the maximum permissible value is exceeded for two cities that meet the criteria of completeness is presented in **Table 9**.

Under the approach carried out in the previous paragraph (irrelevant requirement of coverage) and considering that the standard NOM-025-SSA1-1993 [3] establishes that “for the purposes of protection of the health of the most susceptible population the values of maximum concentration are established”, then the importance of this indicator is to know the times that the health of the population was endangered in order for the authorities to react through relevant strategies, regardless of the coverage achieved by strengthening the importance of this indicator.

In **Table 10** the number of days and the percentage of days in which the limit value in the rule is exceeded are

Table 7. Proposed criteria of non-compliance to the standard NOM-025-SSA1-1993 [3], with respect to Total Suspended Particles (TSP).

Number of samples (average 24 h) of TSP on one site annually	Proposed non-compliance criterion to the standard: days above the limit value for acute exposure concentration ($210 \mu\text{g}/\text{m}^3$) per year
50 or less	1
51 or more	2

Table 8. Proposal for assessment of non-compliance with the air quality standard for TSP in six cities of Sonora, Mexico, in 2010.

City	Number of samples of TSP (24 h)		Number of days above the concentration limit value ($210 \mu\text{g}/\text{m}^3$)	Does the site meet the proposed air quality criteria?
	50 or less	51 or more		
Agua Prieta	x		6	No
Nogales	x		38	No
Puerto Peñasco	x		29	No
Hermosillo	x		3	No
Guaymas	x		1	No
Obregón	x		21	No

Table 9. Number of days above the maximum permissible limit of TSP in two cities of Sonora, Mexico during the year 2010. It includes only quarters with sampling coverage equal to or greater than 75%.

City	Total days with valid samples	Days above the maximum permissible limit ($210 \mu\text{g}/\text{m}^3$)	Percentage of days over the maximum permissible limit
Nogales	43	32	74.4
Hermosillo	50	3	6.0

presented, without considering the criterion of completeness set by the standard. Note that in three of six cities over 60% of the sampled days the permissible value is exceeded.

3.3. Air Quality Index

3.3.1. Annualized Index

For this indicator the annualized index of air quality [11] was used, proposing new breaking points for ranges of air quality from 2005, that calculation was based on the percentage increase that existed in the previous table of IMECA [17] between each breaking point starting from the previous maximum permissible of $260 \mu\text{g}/\text{m}^3$ (Table 11).

The average values obtained only with the days in which the limit value regulated was exceeded for each city, as well as the calculation of the annualized index of air quality based on the proposal of breaking points and the resulting air condition or quality are presented in Table 12.

Table 10. Number of days above the maximum permissible limit of TSP in six cities of Sonora, Mexico, in 2010 without considering the coverage requirement.

City	Total days with valid samples	Days above the maximum permissible limit ($210 \mu\text{g}/\text{m}^3$)	Percentage of days over the maximum permissible limit
Agua Prieta	20	6	30.0
Nogales	49	38	77.6
Puerto Peñasco	38	29	72.5
Hermosillo	50	3	6.0
Guaymas	32	1	3.1
Obregón	34	21	61.8

Table 11. Proposal of breaking points ranges for the calculation of the annualized index of air quality with respect to TSP.

Index ranges	Air quality	Breaking points for TSP ($\mu\text{g}/\text{m}^3$; 24 h)	
		Before 2005*	After 2005**
Below 50	Good	-	-
50 to 100	Satisfactory	260	210
101 to 200	No Satisfactory	546	441
201 to 300	Bad	627	506
301 to 500	Very bad	864	698

*INE-SEMARNAP (1997), **Proposal for this study.

Table 12. Annualized index for TSP in six cities of Sonora, Mexico in 2010, considering the average of the days in that the regulated limit value was exceeded and the proposal of breaking points for air quality.

City	Average concentration of the days when the regulated limit value was exceeded ($\mu\text{g}/\text{m}^3$)	Index calculation algorithm	Results for the air quality index	Condition of the air quality
Agua Prieta	281		131	
Nogales	418		190	
Puerto Peñasco	404	$I = ((200 - 100)/(441 - 210)) \times (\text{Average} - 210) + 100$	184	No satisfactory
Hermosillo	278		129	
Guaymas	245		115	
Obregón	276		129	

Although the index-rating are based on an arbitrary scale used to inform the population about the pollution of the atmosphere. It is pertinent to note that it is intended to inform of the danger to the health by such pollution and in the case of exceeding a satisfactory quality, or what is the same to exceed the norm, then this condition of the atmosphere is considered dangerous [18]. It is important to note that in Mexico the Government of the Federal District [19] published a new classification for the IMECA index in the NADF-009-AIRE-2006 standard, establishing the air quality as: good from 0 to 50, regular 51 to 100, bad from 101 to 150, very poor from 151 to 200 and extremely bad when the value is greater than 200 points. However, this classification was not considered the parameters of TSP and Lead (Pb) as air pollutant criteria even though both are currently regulated in Mexico.

3.3.2. Days with Good, Fair and Poor Air Quality

From the search of an understandable indicator for air quality, there is a classification of the days with good, fair, and bad air quality [13] defining as: good when the day concentration is located between zero and half of the respective maximum permissible, regular when the data is between the half and the limit, and bad when the journal data exceeds the norm. **Figure 4** shows the percentage according to the type of air quality for the six cities of Sonora, Mexico during the year 2010.

4. Conclusions

According to the criteria for assessing the air quality with respect to TSP established in Mexican Official Standard NOM-025-SSA1-1993, and based on the results obtained for the year 2010 in six cities of Sonora, Mexico, it is established that for the sampling sites in Hermosillo and Nogales the concentration and the maximum permissible frequencies were exceeded not complying with the standard.

The cities of Agua Prieta, Puerto Peñasco, Guaymas and Obregón exceeded the maximum permissible value and maximum frequency set in the standard at any time of the year, but due to the fact that the coverage criterion sampling was not reached, it was not possible to apply the standard. This work presents a proposal for the determination of non-compliance using a criterion of days above the normed value omitting coverage requirements or completeness of data, contributing to the protection of the health of the susceptible population and in response to the precautionary principle that any environmental or health protection standard must be considered. Under this proposal, the six cities in study would be in non-compliance in the year of study.

According to the annualized index, it is established that the air quality was not satisfactory for the six cities during the period of study. About the distribution of days with good, fair, and poor air quality, the six cities presented days with poor air quality and it is significant that three of them reported more than 60% of sampled days with this situation.

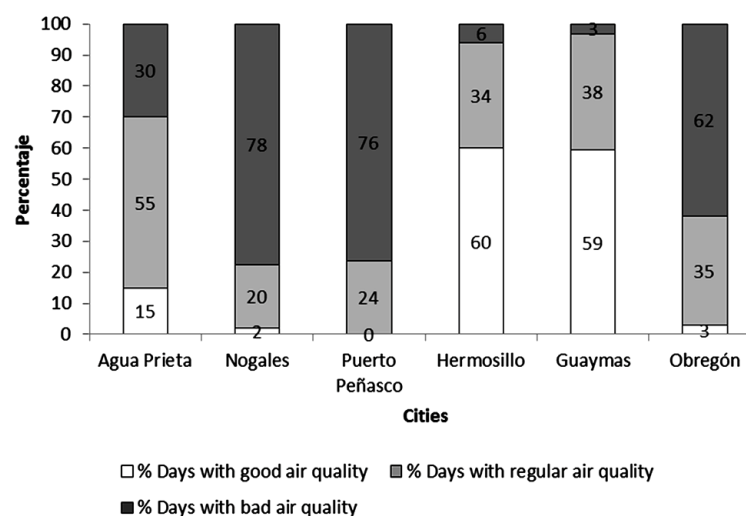


Figure 4. Percentage of days with good, fair and poor air quality with respect to TSP in six cities of Sonora, Mexico in 2010.

It is recommended that the evaluated cities have a program of air quality management (PROAIRE) that allows meeting under appropriate strategies and through actions and defined responsibilities for the different instances and sectors, the events of danger to the health of the population because of the air pollution.

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