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Particulate Matter: Capture and Quantification in Natural and Anthropogenic Sources

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Abstract

Air pollution has a category of pollutants called particulate matter (PM) emitted into the environment as one of the six principal pollutants. High concentrations of PM, of any category, can be found in natural and anthropogenic phenomenon known as dust storms. Such concentrations in this phenomenon can reach 6000 μg/m^3, and at the same time large amounts of dust that accumulate in these events, reduce visibility at one kilometer, and also the path followed by this dust can reach distances exceeding thousands of kilometers. Recent epidemiological studies have shown a relationship between particulate matter and the environment in their health effects. For full extent implies the presence of PM in our daily lives, the objective of this review article is to present the information necessary to determine techniques that focus on monitoring air quality during dust storms and other events with similar characteristics, based on experiments conducted by researchers around the world in agriculture, industrial and unpaved zones.

Keywords: Dust storm; Particulate matter; Air pollution techniques

Introduction

Throughout history, humans have struggled to improved quality of life, focusing primarily on making it more simple, practical, and productive at the same time; taking this into account, a high development in anthropogenic activities, and as a result it bring consequences in the impact in air quality parameter found in environmental pollution. Air, made with different compounds of chemical and physical characteristics, is in constant contact with us in our daily life. This daily relationship with breathable air and what it contains, there is the possibility of damage to human health and this damage does not discriminate age, gender, economics, and education level. High concentrations of PM in any category can be found in dust storms. Such concentrations can reach 6000 μg/m^3, large amounts of dust that accumulate in these events, reduce visibility at one kilometer, and also the path followed by the dust involves distances that can exceed thousands of kilometers. With such a need and importance of evaluating air quality in these specific events, there are environmental agencies focusing in daily, weekly, monthly, and annual monitoring; having among the most important rules-based standards in relation to the EPA (Environmental Protection Agency). Because there are different socio-economic conditions, it must implement a correct application of monitoring based on the different techniques, with the focus on the parameter and site conditions assessment. Giving to the above, it is necessary to have available information on the PM quantification techniques to determine which tool is evaluating air quality in the best way, related to this selection cost, time, particle size, and efficiency to use. Therefore, the objective of this review article is to present the necessary information to determine the techniques that focus on monitoring air quality during dust storms and other events with similar characteristics that based on experiments conducted by researchers around the world.

Air pollution

It is known as air pollution to the frequent presence of substances produced by human activities, or natural processes, which have a proper concentration for a sufficient period of time and under such conditions to affect the comfort, health, or welfare of the living things presented in that scenario. Because there is the possibility that a large portion of the gaseous pollutants are transformed by heterogeneous processes in particles, the particles present in the atmosphere leads to its importance in air pollution [1]. The National Standards for Ambient Air Quality (NAAQS) for its acronym in English, found that there are six main air pollutants, which include carbon monoxide, lead, nitrogen dioxide, ozone, sulfur dioxide and PM [2]. For the last, the progress of its investigation regarding his evaluation and characterization, have been increasing the impact on health and the impact on air quality caused by this contaminant.

Particulate matter (PM)

The PM presents different characteristics that influence their classification and their dissemination in the environment in which it is located; it can be defined as a complex combination of particles with extremely small liquid droplet size and can be composed of acid, organic chemical, metal, and dust particles [2]. Sources causing these particles may be natural or anthropogenic, which are known as primary particles. The result of anthropogenic sources may be from combustion processes, mechanical or industrial, vehicular emissions and cigarette smoke. Regarding natural sources it includes volcanoes, forest fires, dust storms, sea salt aerosolized [3,4]. Different sources of particulate matter result in their classification according to their aerodynamic diameter size. In this classification there are the total suspended particles (TSP) that have a diameter from 45 to 100 μ are presented; there are particles known as coarse (PM_{10}) which are respirable or inhalable, weighting less than 10 μ diameter; there are fine ($PM_{2.5}$) with a diameter less than 2.5 μ, and there are particles known as ultrafine (PM_1), with a less than 1 μ diameter [5-8].

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PM and health effects

Recent epidemiological studies have shown a relationship between the effects of the particulate matter in the environment and in the human health. The relationship is found in cardiovascular diseases and in the respiratory rate [9,10]. As shown in Table 1, the fine particulate matter is known as having a health effect from short to long term cardiovascular, respiratory diseases, and mortality (EPA, 2009) [11,12].

There is an association in the increase and the high concentration of particulate matter, and the increase in daily mortality and hospital admissions. When we expose to a PM concentration of 200 μg/m^3, there is a moderate health effect resulting in a decrease in respiratory capacity. Similarly, there is a moderate effect in the exposure to concentrations of 250 μg/m^3, which suggests an increase in respiratory illness in the elderly and children. Also, when we expose to concentrations of 400 μg/m^3, it has a dramatic effect, since it affects the entire population. Above all, when humans are exposed to high concentrations of 500 μg/m^3, there is a serious health effects not only causing diseases, but also affecting the mortality of the elderly [13,14].

According to EPA, the total suspended particulate matter particles in the environment need to be 100 μg/m^3 annually and over a period of 24 h of 300 μg/m^3. In the other hand, the concentration of PM_{10} allowed by the EPA is 50 μg/m^{3}per day, and annually is 150 μg/m^3. By the OMS, of PM_{10} concentration annually is 20 μg/m^3 and daily 50 μg/m^3. In addition, for $PM_{2.5}$ environment allowed by the OMS is a concentration of 10 μg/m^{3}annually, and daily of 25 μg/m^3 [13-15]. Unfortunately, these concentrations are increasing so they are affecting more and more the human health.

According to the EPA, its recommended that when we expose to particulate matter with a moderate, severe, or extremely severe concentrations, action should be taken, so do not aspire extensively, and avoid being outdoors for a long period of time [2].

Dust storms

High concentrations of PM, in any of its categories, can be found in dust storms. Such concentrations of this phenomenon can reach up to 6000 μg/m^3, large amounts of dust that accumulate in these events, reducing visibility to a mile, and in the same time, the path followed by the dust present involves distances that exceed thousands of kilometers. This phenomenon is caused by violent winds that affect both, humans and the environment. Similarly, these dust storms can be caused by anthropogenic modification of the soil surface and the variability in climate change like global warming. At an environmental level, dust storms affect air temperature through the absorption or scattering of solar radiation, cloud formation, and the levels of both, sulfur and carbon dioxide, in the atmosphere. At a human level, as mentioned above, cause cardiovascular, respiratory diseases, and even certain kind of cancer. The change of the surface is a result from human activities, such as vehicular traffic, removing natural vegetation, soil, and agricultural plantations. With the identification of the important parts where dust storms occur, human intervention can reduce anthropogenic effects and thus control the harmful effects on both, the environment and human beings [16].

Methodology

The scientific articles used in this review were investigated in three main databases: Academic Search Complete from EBSCO, American Chemical Society, and Environmental Health Perspective. Figure 1 shows the research process to get the articles needed in this article review.

Techniques used in event of high concentrations of particulate matter

As we have seen, the impact that the PM may have on human health and everyday life, it is very important to carry out repeated measurements to determine the concentrations present in the material during a specific time interval, primarily based on quality standards air presented by EPA. There are different units of measurement for the mass concentration of PM in suspension: milligrams per cubic meter (mg/m^3), microgram per cubic meter (μg/m^3) and nanogram per cubic meter (ng/m^3); these units are representatives of some of the results of monitored carried out around the world.

To perform monitoring of air pollutants, such as particulate matter, there are methods that can differ by the objective of the study and the monitoring locations. According to the form of operation, there are discontinuous or continuous methods and automated methods. The first ones are manual methods where the sampling on site it's followed by the laboratory analysis; and the second, involve the use of automatic equipment in one location, where it performs sampling and analysis. In relation to the method used, exist physic-chemical where

PM inhalation	Sources	Deposition %	Organ affected directly	How affected	Organ affected indirectly
***PM_{10}*, coarse particles**	Include crushing or grinding operations, and dust stirred up by vehicles traveling on roads.	60% in upper respiratory tract; 20% bronchial tube	Lungs	Inflammation, oxidative stress, accelerated progression and exacerbation of COPD, increased respiratory symptoms, effected pulmonary reflexes reduced lung function	Heart, blood, systemic inflammation oxidative stress
***$PM_{2.5}$*, fine particles**	Include all types of combustion, including motor vehicles, power plants, residential wood burning, forest fires, agricultural burning, and some industrial processes.	4% in upper respiratory tract; 7% bronchial tube; 10% fine pulmonary airways; 50% pulmonary alveolus	Heart	Altered cardiac autonomic function, increased dysrhythmic susceptibility, altered cardiac repolarization, increased myocardial ischemia	Vasculature
			Blood	Altered rheology, increased coagulability, translocated particles, peripheral thrombosis, reduced oxygen saturation	Brain, systemic inflammation oxidative stress
			Systemic inflammation oxidative stress	Increased CRP, proinflammatory mediators, leukocyte and platelet activation	Heart, blood, vasculature
			Vasculature	Atherosclerosis, accelerated progression of and destabilization of plaques, endothelial dysfunction, vasoconstriction and Hypertension	Heart, brain
			Brain	Increased cerebrovascular ischemia	Vasculature, blood

Table 1: Consequences, deposition and sources of PM_{10} and $PM_{2.5}$ inhalation (EPA, 2009).

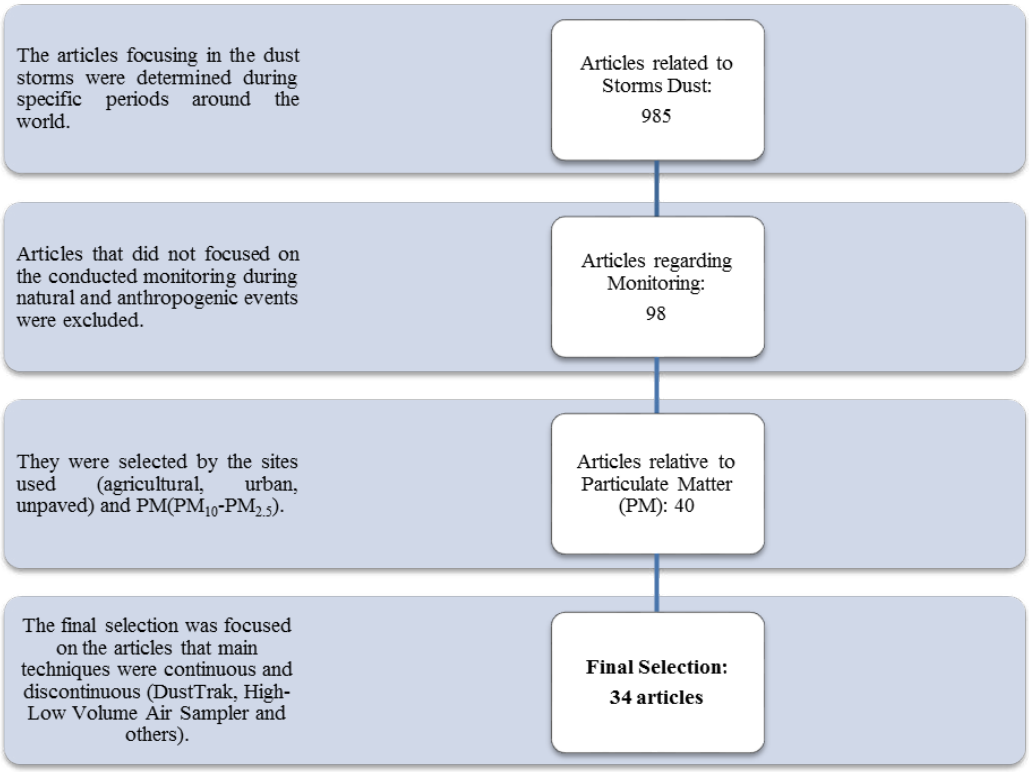

Figure 1: Research process followed in this review.

the contaminant is determined in relation to the product of a chemical reaction by a specific analytical technique; and physical, in which only the physical property is measured, or the variation, without having changes in the composition of the air sample. With respect to spatial volume on which the measurement is averaged, there are specific and zonal methods. The struts have the use of sensors to determine the concentration of the contaminant with a detector, and the sample is continuously; by the other hand, the zonal methods measure the average concentration by the loss of a light beam absorption by molecular contaminants, but this is not efficient for the evaluation of PM.

The technical parameters presented for the design, or construction, of an analytical method is based on the selectivity, specificity, sensitivity, accuracy, precision, ease of calibration, calibration gas availability, and volume of gas required for analysis, and the response time of the instrument or equipment. Regarding the operational parameters, it has to have the availability of the sensors, spatial resolution, maintenance, percentage of time interval out of operation, additional equipment required, and skilled labor for operation and maintenance work. A synthesis is presented in relation to the research that has been published in recent years, focusing on monitoring the particulate matter (TSP, PM_{10}, and PM2.5) primarily present in dust storms. In Sonora, Mexico, during the years 2001-2002, Cruz et al. [17-19] determined the concentrations of TSP using PTFE filters and by the gravimetric method. Obtaining the following results: 260 μg/m^3 in 24 h average and 75 μg/m^3 for the annual arithmetic measurement. Similarly, in Ahvaz City, Iran, Rezaei et al. [20,21] by using glass fiber filters and high volume sampler type Anderson, found PM_{10} concentrations with a rank of 2000 to 10.00 g/m^3. In California, USA, studies were conducted in urbanized deserts with focus on $PM_{2.5}$ and PM_{10} during 2009-2013 using filters coupled to FRM samplers, determining through 24 h monitoring values greater than 35 mg m^{-3} for $PM_{2.5}$ and 150 mg m^{-3} with relation to MP_{10}. Continuing with the use of filters, in Washington, USA, used for agriculture locations, Claiborn et al. [22,23] identified concentrations of PM_{10} of 300 μg/m^3 for the average value of 24 h in the period 1993-1995, this based on the use of membrane filters PTFE Teflon and quartz filters Whatman, and programmable samplers. Likewise, Kalaiarasan et al. during the years 2005-2008, monsoon winds, through PTFE filters and QMA, low-volume samplers MiniVol by the gravimetric method for $PM_{2.5}$; resulting in an annual average of 15 μg/m^3 for 24 h value of 35 μg/m^3 [24,25]. Also, in a study conducted in central Salamanca, Guanajuato, Mexico, by Murillo et al. [26] during November 2006 to 2007, they obtained an annual average values for $PM_{2.5}$ of 45 μg/m^3, this thanks to the use of samplers low volume and Teflon membrane filters and quartz [27]. Also, Pei-Shih et al. [28] in Taiwan, Republic of China, during dust storms from January to May 2006, they determined an average concentration of de PM_{10} 81.55 μg/m^3 and $PM_{2.5}$ with an average of 46.42 μg/m^3 by high volume samplers (TE-6070 MFC) and PTFE filters.

Furthermore, in relation to high volume samplers with cellulose filters and quartz glass fiber, has also been applied using a particle counter named CPC-LASER, the method used by Chauhan et al. [29] in their study for industrial and attached to the existing residence dust storms in the period 1990-1993 and 1994-2007, achieving the rank values for 8 h TSP periods for the residential area of 294-393 μg/m^3 sectors and to the industrial area with a range of 325 to 383 g/m^3; for periods of 24 h for one residential area 331-394 μg/m^3 for industrial area and 350-440 μg/m^3 [30]. For the use of this sensor during events with the presence of particulate matter, there have been used different types of detectors. In Ciudad Juarez, Mexico, Hernandez et al. [31] during the dust storms in 2012, they determined sectors without paving average values for $PM_{2.5}$ of 2.3 mg/m^3 by DustTrak (instrument 8535). In New Mexico, USA, and Chihuahua, Mexico, Flores et al. [32] evaluated the concentrations of $PM_{2.5}$ and TSP, which were present at sites that did not have some kind of paving and were dispersed by using a Ford F-150, 2011, weighing 2300 kg for the site of NM and Chevy Silverado, 2001, weighing 2100 kg for the Mexican side; these evaluations were conducted with the equipment DustTrak model 8535 to measure the $PM_{2.5}$, and rotorods with glass-adhesive tape to determine the TSP. In this study, the measurements for $PM_{2.5}$ were in range of 1.11 to 37.1 mg/m^3, and for TSP the range was from 0.529 to 3.054 mg/m^3 [33].

Regarding to the use of rotorods, Hernandez et al. [31] in dust storms presented in 2012, made use of this method based on the measurement of TSP, determining in unpaved sites concentrations of approximately 1.29 mg/m^3. Also, using the same technique DustTrak plus a collector of TSP (AB DF-75 L-Li), Csavina et al. [34] during dust storms from March to May 2011 in Arizona, USA, and Ciudad Juarez, Mexico; they evaluated the TSP concentrations reaching 0.35 mg/m^3 $PM_{2.5}$ worth .01 mg/m^3 for PM_{10} and a value of 0.05 mg/m^3, these values for the site of Arizona and Ciudad Juarez values of PM_{10} reaching 350 μm/m^3. Continuing with this type of detector, Shukla et al. [35] found that for activities of soil tillage in 2008, a study conducted in New Mexico, USA, they reported values for $PM_{2.5}$ of 1272 mg/m^3 [36]. Also for determining $PM_{2.5}$, there is the use of MET-1, where Flores et al. gave an application on unpaved agricultural areas, presented in New Mexico, USA, and Ciudad Juarez, Mexico; this experimental development was during the year of 2007, obtaining values for Juarez with a range from 0.07 to 0.11 mg/m^3 and the site found in New Mexico, a range from 0.08 to 0.13 mg/m^3.

Another type of sensor used for determining TSP, PM_{10} and $PM_{2.5}$ is called Aqua-MODIS sensor, method and equipment used by Samoli et al. [37] during 2001-2006 in dust storms presented in Athens, Greece; an average annual value for TSP of 66.8 μg/m^3 during dust storms, and 52.0 μg/m^3 in the other day to $PM_{2.5}$ 16.7 μg/m^3, and 23.0 μg/m^3 for PM_{10}, and finally 42.2 and 27.6 μg/m^3, respectively. Similarly another technique used is called TEOMs, for direct reading of PM_{10}; Krasnov et al. [38] use the equipment for evaluating PM_{10} presented during dust storms in the years 2001 to 2012, Beer-Sheva, Israel. The results showed higher concentrations than 2000 mg m^{-3} and an increase in daily PM_{10} of 122 μg/m^3. Continuing with the TEOM (Model 1400), Wang et al. [39] during the dust storms of 2008, determined globally PM_{10} values with range of 14 to 410 μg/m^3. The use of monitors type VIR (visible and infrared) and images TIR, are efficient for the evaluation of concentrations of particulate matter, such is the use and equipment performance that Shao et al. [23], during dust storms in Asia during the years 1998-2003, as a result it reach values of a range 12-1400 μg/m^3 for $PM_{2.5}$ to TSP. Serbula et al. [40], during the years 2006-2008, in industrial areas presented in Bor, Serbia; conducted a study based on the evaluation of $PM_{2.5}$ and PM_{10} by the OSIRIS team, identifying monthly average concentrations for $PM_{2.5}$ of 24.1 μg/m^3 and for PM_{10} of 37.1 μg/m^3.

During two important dust periods was compared differences of PM_{10} in Guangzhou, China in 2009 [41, 42]. In this study, at 15 m high from the ground during 1 day were measured particles PM_{10} and $PM_{2.5}$ by using aerosol filters made of Teflon and glass fiber to analyze chemical components. The results showed that the average PM_{10} concentration during storm outbreak was 0.231 mg/m^3, which was two times of that on non-dust days (0.103 mg/m^3). The contents of water-soluble cation and anion of the particles during dust and non-dust episode was a descending order of NH_4^+>Ca^{2+}>Na^+>K^+>Mg^{2+}, while that of anions was SO_4^{2-}>NO_3^->Cl^->F^->CH_3COO^-. Comparing with those of non-dust episode, the contents of all water-soluble cation and anion ions of airborne particles in dust episode increased especially water-soluble cationic K^+, Ca^{2+}, anionic NO_3^-, and Cl^- content. Regarding heavy metals, the concentrations of Na, Ti, Zn, Cu, and Cr all increase in dust episodes. To analyze the trajectory sources of PM_{10} during dust hours in more detail, NOAA's trajectory model was used to track the routes of air mass that affected the weather process in Guangzhou.

Regarding investigations in relation to bushfires and dust storms, Johnston et al. [43] conducted a monitoring PM_{10} concentrations present in those events in the city of Sydney, Australia. The conditions of this city have the highest concentration of smoke from forest fires eucalyptus in the west of the city, while dust is transported from the interior of the continent. As a result of the assessments made in the period of the year 1994-2007 were presented in 6 days with extreme observations of dust storms, with the average value of 96.8 μg/m^3 and maximum values of 199.2 μg/m^3. These values exceeded the recommended health limit value in this city, taking the recommended value of 47.3 μg/m^3. The technique used is known as TEOM (Tapered Element Oscillating microbalances) technique whereby the gravimetric method used for its development.

In turn, exist in colder weather also the spreading factor of PM, regarding such situations, Thorsteinsson et al. [44] evaluated in the city of Reykjavik, Iceland, PM_{10} concentrations present during the period 2007-2008. They assessed such particulate material by using satellite image, air parcel trajectory analyzes and meteorological data, this for the identification of dust sources and modeling of its strength. Two permanent stations, known as GRE and FHG, appointed by EMS Thermo Andersen FH 62 IR instruments and instrument Eberline Instrument Gmbh, were used in turn. Also for satellite photo was given to him using the MODIS. For the modeling of the air path and identifying the sources of dust HYSPLIT model was used. The limit for health regarding the daily concentration of PM_{10} in Iceland is 50 μg/m^3, and was surpassed in 2009 on 20 occasions in 2008 on 19 occasions in 2007 on 17 occasions and in 2006 with 29 times.

In Beijing, China, an assessment of $PM_{2.5}$ and TSP were made during sandstorms in 2001, by Dillner et al. (2006) [45]. The technique used was based on filter holders, cyclone separator, Air Industrial Hygiene Laboratory (AIHL) and two parallel 10-stage micro-orifice uniform deposit impactors (MOUDI, MSP Corp. model 110). The results obtained were in the range of 246 μg/m^3 (urban pollution day) to 930 μg/m^3 (dust storm day) for TSP; $PM_{2.5}$ mass averages 106 μg/m^3 during the sampling period in 2001.

Qian et al. [10] in the period from October 2009 to October 2010, conducted an experiment concerning the magnetic properties present in the particulate material known as TSP, this made in Putuo, Qingpu and Minhang districts of Shanghai city. Through a patented and designed technique by the authors, named SIPO, which is an YLK-1 type percussive sampler and used glass fiber filters. Results for sandstorms affected the 10-day average concentrations of TSP, PM_{10} and $PM_{2.5}$ at the site Putuo, Shanghai, were 239.69, 124.66 and 79.16 μg/m^3, Which are 1.97, 1.70 and 1.71 times, respectively, of the average annual local concentrations. Similarly, the concentrations at the site Minhang, were 188.73, 124.69 and 93.38 μg/m^3, which are 1.86, 1.84, 2.09 times higher, respectively, than the mean annual local concentrations. Concentrations at the Qingpu site were 226.22, 154.05 and 41.39 μg/m^3, which are 1.88, 1.77, 0.70 times higher, respectively, than the mean annual concentrations. In summary, concentrations

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of TSP, PM_{10} and $PM_{2.5}$ during the dust storm period are 1 to 2 times higher at each site than the mean annual concentrations.

In turn, there are models for the evaluation of different contaminants in water, air and soil; such models serve us as auxiliary tools for the determination of particulate matter and other pollutants from the air. Source of pollutants has been determined with process flow diagram and energy systems in industrial companies reported by Valipour et al. [30]. The environmental flow diagram designated was used to explaining impacts of solutions to reduce environmental pollutants and energy optimization for industrial process. Examples of such models were performed by Valipour et al. [33], where through an Environmental Flow Diagram (EFD) being performed based on the Energy Reference System (RES) and the Process Flow Diagram (PFD) for each unit to be evaluated. In this project was determined between pollutants evaluated with the model an excess concentration of CO present with a standard value of 130 ppm and presented to 709 ppm. These researchers in turn made such modeling diagrams relating to the need to evaluate overall pollution sources such acceptor. Also same researchers in 2012 implemented the diagram in industrial units, taking this diagram the source of production, transmission and conversion processes as well as the recipients of the environmental sources of these pollutants. These models serve us as tools for gaining a higher quality compared to the levels of pollution and area solution for the environmental crisis.

With all the information above, we can see that for the choice of a method with objective study of particulate matter and high concentrations for specific events, there are great technical variety based in relation to particle size, sampling time, costs, and sites evaluating; so it is very important that the design of research protocol to determine the focus of study, either health or monitoring, and time itself, that to make proper results management and exposing them to a high impact the good of the society in which they work.

Conclusion

As we can see, the human beings are in constant contact with air and contaminant PM in their daily lives, the constant possibility of getting some kind of damage to their health directly, such as cardio-respiratory diseases, or indirectly lifestyle presented, as is the lack of visibility when driving in the sectors where higher concentrations or damage to infrastructure around it are presented. Therefore, it is utmost importance to develop and implement ongoing monitoring with a focus on events that occur as high as those found in dust storms concentrations, so we should not stop consulting the commonly techniques used and to approach finding new applications to the results reported for the same, as the techniques are more available to society in relation to cost and effectiveness of the same, as are the development of predictive models for them.

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