International Journal of Sustainable Development and Planning
Vol. 19, No. 4, April, 2024, pp. 1307-1318
Journal homepage: http://iieta.org/journals/ijsdp

$PM_{2.5}$ and PM_{10} Airborne Concentrations Resulting from Fireworks During Festivities: A Systematic Review

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https://doi.org/10.18280/ijsdp.190409

Received: 22 January 2024
Revised: 25 March 2024
Accepted: 7 April 2024
Available online: 28 April 2024

Keywords:
air quality, standard, particulate matter, pyrotechnics, VOSviewer

ABSTRACT

The burning of fireworks damages air quality by causing elevated concentrations of particulate matter ($PM_{2.5}$ and PM_{10}) in short periods of time. In this context, the research aimed to compare airborne concentrations of $PM_{2.5}$ and PM_{10} from fireworks with the National Ambient Air Quality Standards (NAAQS) and the World Health Organization (WHO) guideline. The applied methodology involved the use of the PRISMA 2020 statement. The literature review was conducted on digital databases such as Scopus, ScienceDirect, Taylor & Francis, Wiley, and Ebsco. Annual growth in scientific production was calculated using a digital tool (Calcuvio), and data analysis was performed using Microsoft Office Excel and VOSviewer. The annual growth in production (1999 to 2022) was 18.74%. The highest scientific production per year was concentrated in 2019 and 2020, with China being the leading country. The festivities where sound pressure levels were predominantly measured were during the Spring Festival and Diwali. The most frequently mentioned keywords were "fireworks" and "$PM_{2.5}$". In conclusion, the percentage of studies that exceeded the NAAQS for $PM_{2.5}$ and PM_{10} was 2% and 15%, respectively, while for the WHO guideline, it was only 1% for PM_{10}.

1. INTRODUCTION

The world is facing significant challenges related to the deterioration of air quality, primarily due to high concentrations of emissions from anthropogenic sources such as urbanization, industrialization, and vehicular traffic, this is compounded by a lack of environmental awareness [1, 2]. Fireworks displays are a global phenomenon, deeply rooted in familial and social settings [3], and are a habitual practice worldwide during folk, religious, sporting, political events, and holidays. Notable festivities associated with extensive fireworks usage include New Year's Eve, Diwali Festival (India), and Spring Festival (China) [4, 5]. The burning of fireworks is a significant anthropogenic source of air pollution [6-8] causing significant harm to air quality in a short period [9, 10], Studies have found that the released gaseous components with higher concentrations in the air include sulfur dioxide, ozone, nitrogen oxides [11-13] and certain metals such as Ba, Mg, Cu, K, Al, Pb, and S [14-16]. Furthermore, concentrations of $PM_{2.5}$ and PM_{10} are generally higher during festivities than on regular days [17].

The burning of fireworks brings about a decrease in visibility, direct injuries, and health effects [18]. Particulate matter represents one of the hazards affecting the climate, ecosystems [19] and health worldwide. It is classified into particulate matter with aerodynamic diameters PM_1 (particles with an aerodynamic diameter less than one micron), $PM_{2.5}$ (particles with an aerodynamic diameter equal to 2.5 microns), and PM_{10} (particles with an aerodynamic diameter less than 10 microns), these particles consist of a mixture of mineral dust, elemental carbon, organic carbon, nitrate, ammonia, sulfate, and heavy metals [20], annually contributing to approximately 8.9 million premature deaths [21, 22]. In 2010, India, China, and the United States experienced 575,000, 1.3 million, and 52,000 premature deaths, respectively [23], the damage caused depends on the morphology, chemical composition, and size of the particles [24]. The methods of exposure to $PM_{2.5}$ include inhalation, dermal absorption, and hand-to-mouth ingestion [25]. Ultrafine (PM_1) and fine particles ($PM_{2.5}$) are the most harmful, as they reach the lungs and penetrate cell membranes

[26] depositing in brain tissue [27]. The International Agency for Research on Cancer (IARC) classified particles as carcinogenic to humans [28]. $PM_{2.5}$ is stored in reproductive organs, affecting fertility and altering hormonal levels [29], additionally, it leads to cardiovascular and respiratory diseases, dysfunction in the nervous system, and malignant tumors [30, 31]. Air pollution from fireworks, where emissions are sporadic but significant compared to other sources that occur in lower concentrations, but for a prolonged period.

The 1970 Clean Air Act mandates the U.S. Environmental Protection Agency (EPA) to establish National Ambient Air Quality Standards (NAAQS) to protect crops, forests, and human health [32]. One of the pollutants considered is $PM_{2.5}$ and PM_{10}, with 24-hour average values of 35 µg/m^3 and 100 µg/m^3, respectively, not to be exceeded [33], on the other hand, the World Health Organization (WHO) has set more stringent guidelines with values of 15 µg/m^3 and 45 µg/m^3, respectively [34]. Currently, only these particle sizes are regulated by the mentioned agencies. This study will review the concentrations of $PM_{2.5}$ and PM_{10} emitted into the atmosphere and determine if they exceed the NAAQS and then analyze and discuss the causes of the problem.

Based on the information provided, the research aimed to compare $PM_{2.5}$ and PM_{10} concentrations in the air resulting from fireworks during festivals with the National Ambient Air Quality Standards (NAAQS) and the World Health Organization (WHO) guidelines. Consequently, the following research questions (RQ) were established:

RQ1: What percentage of studies exceed the NAAQS and WHO guidelines?

RQ2: What is the distribution of studies by year and country?

RQ3: How has the scientific production of particulate matter generated by fireworks evolved annually?

RQ4: During which festivals were $PM_{2.5}$ and PM_{10} concentrations measured?

2. MATERIAL AND METHODS

The systematic review used the PRISMA 2020 statement [35] was employed to facilitate a more effective synthesis, preparation, and presentation of the study [36].

2.1 Eligibility criteria

In the inclusion criteria, the search considered (1) scientific research articles, (2) globally, (3) in all languages, (4) without year restrictions, up to March 2023. On the other hand, the exclusion criteria ruled out (1) duplicate articles, (2) closed-access articles, (3) articles based on title and abstract (unrelated to fulfilling the study's objective) and (4) conference paper, review, conference review, book chapter, book, letter, note and short communication.

2.2 Information sources and search strategy

The information search was conducted from November 15, 2022, to March 30, 2023, across five digital databases: Scopus, ScienceDirect, Taylor & Francis, Wiley, and Ebsco (including Academic Search Ultimate, Biological & Agricultural Index Plus, Environment Complete, and GreenFile) (Table 1), were chosen because the authors had a membership to access all the information, on the other hand, they are databases of great impact in the scientific field. Regarding the search strategy, conference papers, reviews, conference reviews, book chapters, books, letters, notes, and short communications were filtered out, furthermore, the following search equations were employed:

Table 1. Search process

Digital Databases	Search Equations
Scopus ScienceDirect Taylor & Francis Wiley Ebsco (Academic Search Ultimate, Biological & Agricultural Index Plus, Environment Complete, GreenFile and Veterinary Source)	TITLE-ABS-KEY (fireworks AND air) TITLE-ABS-KEY (pyrotechnics AND air) TITLE-ABS-KEY (pyrotechnics AND particulate AND matter) TITLE-ABS-KEY (pyrotechnics AND PM)

2.3 Selection and data extraction

Article selection was carried out independently by pairs of two authors, each reviewing a digital database to gather information (authors, title, DOI or link, country where the research was conducted and festival where $PM_{2.5}$ and PM_{10} concentrations were measured). Discrepancies were resolved through discussion with the lead author (MRI) at the end of the selection process. The systematization of the article selection strategy was conducted using a digital tool that facilitates the development of the PRISMA 2020 flowchart [37] where the studies were chosen according to the eligibility criteria proposed, and the tool used for the screening was Microsoft Office Excel version 2016 because it was economically and operationally accessible. Initially, 14 617 articles were identified and after applying exclusion criteria, 107 articles remained for the review (Figure 1).

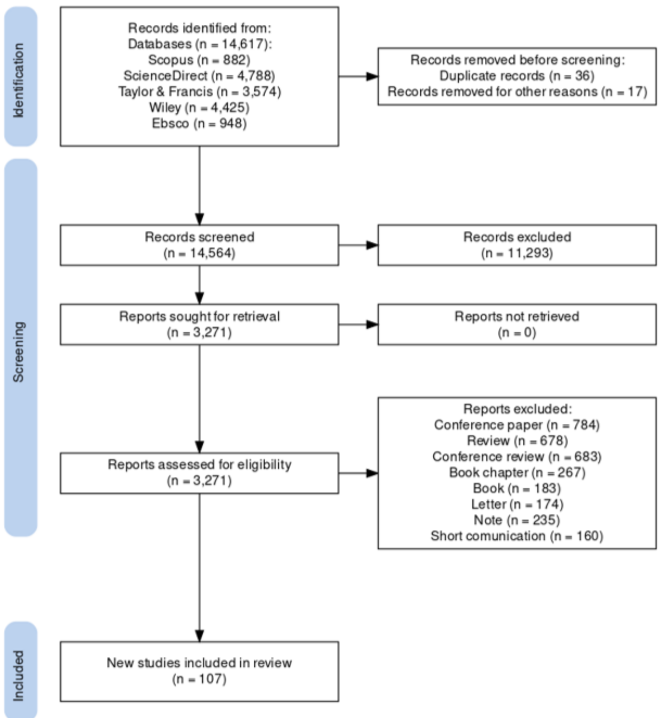

Figure 1. Item selection flowchart

2.4 Compound Annual Growth Rate (CAGR)

The CAGR signifies the annual growth of a variable over a specific period exceeding one year [38], in this context, it was employed to determine the annual growth of scientific production from 1999 to 2022 using a digital tool [39]. This tool was chosen for its accessibility, speed, and user-friendly interface [40].

2.5 Data analysis

The data were downloaded in CSV format and processed in Microsoft Office Excel version 2016 to determine the distribution of research by year and country. The analysis was conducted using VOSviewer version 1.6.19 [41], a tool widely employed by the scientific community to visualize and comprehend bibliometric networks in diverse colors, aiding in understanding and discovering collaboration (co-authorship) among authors (based on the number of documents or citations), institutions, countries, journals, and co-occurrence relationships of keywords [42, 43]. Therefore, it was used for the analysis of collaboration between countries based on the number of documents and co-occurrences of keywords.

3. RESULTS

Table 2 shows the 107 studies reviewed and compared with the NAAQS and the WHO guideline.

Table 2. Comparison of $PM_{2.5}$ and PM_{10} concentrations with NAAQS and WHO guideline

NAAQS 24 Hour Average		WHO 24 Hour Average		Reference
$PM_{2.5}$ 35 μg/m^3	PM_{10} 150 μg/m^3	$PM_{2.5}$ 15 μg/m^3	PM_{10} 45 μg/m^3	
18.5*	NR	18.5**	NR	[44]
173**	141*	173**	141**	[45]
NR	174.5**	NR	174.5**	[46]
122.7**	338.4**	122.7**	338.4**	[47]
NR	45.8*	NR	45.8**	[13]
NR	49.8*	NR	49.8**	[48]
NR	753.3**	NR	753.3**	[49]
352**	NR	352**	NR	[50]
NR	38.9*	NR	38.9*	[6]
1199.74**	2237.25**	1199.74**	2237.25**	[51]
NR	507.2**	NR	507.2**	[52]
NR	275.83**	NR	275.83**	[53]
1000**	NR	1000**	NR	[54]
250**	429**	250**	429**	[55]
1102.43**	1610.22**	1102.43**	1610.22**	[56]
NR	800**	NR	800**	[57]
588**	723**	588**	723**	[58]
NR	118*	NR	118**	[59]
387**	NR	387**	NR	[14]
112.61**	NR	112.61**	NR	[60]
2180**	2700**	2180**	2700**	[61]
183**	NR	183**	NR	[15]
1514.8**	NR	1514.8**	NR	[62]
395.4**	555.5**	395.4**	555.5**	[63]
NR	711**	NR	711**	[12]
NR	430**	NR	430**	[64]
597**	624**	597**	624**	[65]
NR	246.1**	NR	246.1**	[66]
601.33**	545**	601.33**	545**	[67]
440**	580**	440**	580**	[68]
NR	55*	NR	55**	[69]
141.89**	146.1*	141.89**	146.1**	[70]
333**	419.3**	333**	419.3**	[71]
380**	NR	380**	NR	[72]
17*	NR	17**	NR	[73]
116.85**	184.71**	116.85**	184.71**	[74]
65**	138*	65**	138**	[75]
428**	714**	428**	714**	[76]
116.14**	NR	116.14**	NR	[77]
146.9**	NR	146.9**	NR	[78]
1620**	2070**	1620**	2070**	[79]
130.7**	200**	130.7**	200**	[80]
128.33**	NR	128.33**	NR	[81]
366**	NR	366**	NR	[82]
450**	620**	450**	620**	[83]
966.67**	1966.67**	966.67**	1966.67**	[84]
428**	714**	428**	714**	[85]
248.9**	NR	248.9**	NR	[86]
330**	170**	330**	170**	[87]
321.4**	567**	321.4**	567**	[88]
639.3**	NR	639.3**	NR	[89]
578**	NR	578**	NR	[90]
400**	NR	400**	NR	[91]
132**	232**	132**	232**	[92]
330**	550**	330**	550**	[93]
140**	NR	140**	NR	[94]
537.5**	640**	537.5**	640**	[95]
NR	500.5**	NR	500.5**	[96]
130**	NR	130**	NR	[97]
358**	NR	358**	NR	[98]
NR	195**	NR	195**	[99]
157**	NR	157**	NR	[100]
305**	178**	305**	178**	[101]
92.4**	NR	92.4**	NR	[5]
61.6**	NR	61.6**	NR	[102]
70**	60*	70**	60**	[103]
537.65**	NR	537.65**	NR	[104]
59.2**	70.3*	59.2**	70.3**	[105]
97.1**	134.21*	97.1**	134.21**	[106]
3014**	4042**	3014**	4042**	[107]
110**	121*	110**	121	[108]
NR	598**	NR	598**	[9]
70**	89.5*	70**	89.5**	[109]
1218.75**	NR	1218.75**	NR	[110]
493.75**	NR	493.75**	NR	[111]
393.54**	NR	393.54**	NR	[112]
144**	75*	144**	75*	[113]
125.79**	201.53**	125.79**	201.53**	[114]
504**	NR	504**	NR	[115]
146.82**	NR	146.82**	NR	[116]
108.59**	974.75**	108.59**	974.75**	[117]
1376.55**	1804.48**	1376.55**	1804.48**	[118]
240.25**	NR	240.25**	NR	[10]
219**	NR	219**	NR	[119]
98.75**	NR	98.75**	NR	[120]
NR	311**	NR	311*	[121]
46.05**	NR	46.05**	NR	[122]
383.9**	NR	383.9**	NR	[123]
NR	262.17**	NR	262.17**	[124]
36.25**	NR	36.25**	NR	[125]
261.25**	381.25**	261.25**	381.25**	[126]
92.89**	77.25*	92.89**	77.25**	[127]
219**	NR	219**	NR	[128]
53**	NR	53**	NR	[129]
120**	NR	120**	NR	[130]
119**	383**	119**	383**	[4]
92.5**	NR	92.5**	NR	[131]
201**	NR	201**	NR	[3]
118.33**	169.17**	118.33**	169.17**	[132]
197.5**	NR	197.5**	NR	[133]
165.7**	186.9**	165.7**	186.9**	[134]
154.4**	223.5**	154.4**	223.5**	[135]
84.37**	153.1**	84.37**	153.1**	[136]
114**	266.5**	114**	266.5**	[137]
102.17**	NR	102.17**	NR	[138]
73**	NR	73**	NR	[139]
95.25**	133.77*	95.25**	133.77**	[140]

The study found that the highest scientific output occurred in 2019 and 2020 (Figure 2a) with 14 and 12 publications, respectively. Conversely, the lowest scientific production was observed in 2003 and 2009, each with only one publication. Regarding the growth indicated by the Compound Annual Growth Rate (CAGR), global scientific production evolved by 18.74%.

Among the countries with the highest scientific production, China and India stand out with 48 and 34 publications, respectively (Figure 2b).

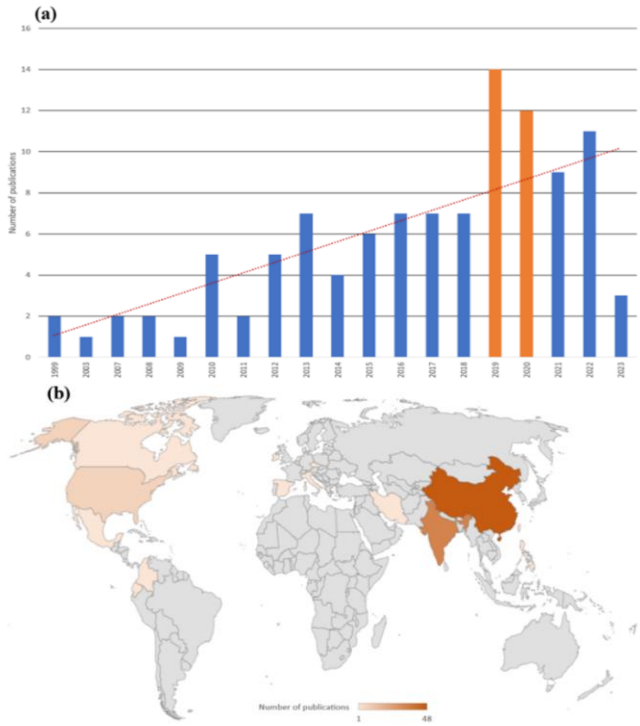

Figure 2. Evolution of scientific production (a) per year (b) per country

The Festival of Spring and Diwali recorded the highest number of studies evaluating $PM_{2.5}$ and PM_{10} concentrations, with 38 and 31 studies, respectively (Figure 3).

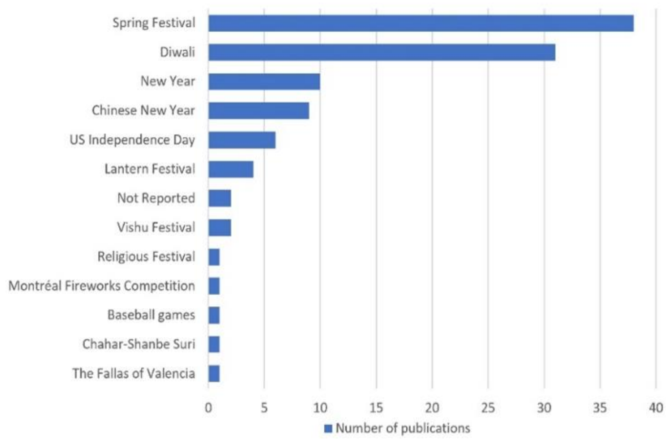

Figure 3. Research carried out for festivities

The countries with the highest scientific production in particulate matter concentrations from fireworks are China, India, and the United States, aligning with the analysis. Furthermore, the collaboration network between countries indicates that China exhibits greater collaboration with the United States (Figure 4).

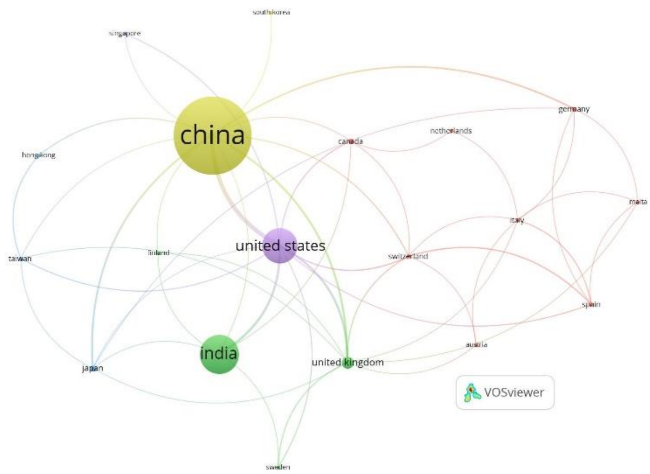

Figure 4. Country co-authorship network

The keywords most frequently mentioned in the studies reviewed are "fireworks" and "$PM_{2.5}$" (Figure 5).

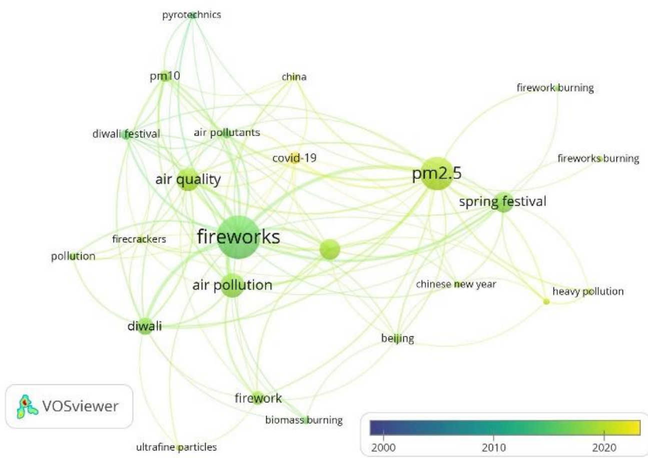

Figure 5. Keyword co-occurrence network

4. DISCUSSIONS

Of the total number of studies reviewed, in $PM_{2.5}$ 2% exceeded the NAAQS, while in PM_{10} 10% exceeded the WHO guideline. The evolution of scientific production from 1999 to March 2023 has been increasing and the major scientific production was concentrated in 2019 and 2020, mainly because the coronavirus, at that time [141, 142], led to a reduction in vehicular traffic, construction activities, restrictions in industrial factories, and the prohibition of fireworks [143, 144]. Various countries around the world suffered economic losses due to the quarantine; however, there were improvements in air quality [145-148], these events prompted further research to examine how fireworks influence air quality.

The scientific evolution has seen an increase of 18.74%, indicating the significant interest in the subject to determine the effects caused by the prohibition of fireworks during the festivities throughout the duration of the coronavirus pandemic.

China and India are the countries with the highest scientific production in this field. This is attributed to the fact that fireworks originated in China [149], and it is currently the largest consumer of these materials. Additionally, the tradition of burning fireworks dates back approximately 1000 years [150, 151]. On the other hand, there are laws prohibiting the use of fireworks, but the population has shown resistance as it goes against their cultural and traditional value [152], Moreover, the production and sale of these materials constitute a significant source of income (both through export and production) in the industry [112]. On the other hand, the World Health Organization (WHO) and the World Bank have indicated that India is the eighth most polluted country in terms of particulate matter [153], furthermore, it is the second most populous country in the world [154] and is one of the largest producers of fireworks, boasting a well-established industry within the country [155, 156].

The festival with the highest scientific production is the Spring Festival, which has a 4000-year history and is among the four traditional festivals in China [140]. In the capital, Beijing, approximately 10 million tourists gather for this festival [91] and the significant and critical deterioration of air quality during this short period is attributed to the burning of fireworks [103, 157]. On the other hand, the festival that ranked second in scientific production is Diwali, celebrated annually between October and November [118, 158], it is one of the most significant festivals in India [159, 160] with a history dating back around 2500 years. Approximately in 1400 AD, fireworks started becoming a new way to celebrate Diwali [161]. During the days of celebration, major cities are affected by reduced visibility and air pollution [162].

The most frequently found keywords are related to the large number of research studies obtained in the review; on the other hand, the clusters indicate that studies on the subject began to emerge in 2012, coinciding with what was determined in the analysis of scientific production by year.

5. CONCLUSIONS

Research efforts surged starting in 2019, and the trend indicates that it will continue to grow in the coming years. The Spring Festival, celebrated in China, and Diwali in India, both lead in research on festivals and countries regarding particulate matter in the air. The majority of $PM_{2.5}$ and PM_{10} concentrations surpass the NAAQS and the WHO guidelines, on the other hand, the cultural traditions of a specific nation work against governments, as they hinder control over the burning of fireworks, despite the restrictions in place in countries with high particulate matter concentrations, such as China and India. It is crucial to implement strategies for enforcing fireworks restrictions. This way, regulations can be effectively enforced, or alternative options can be explored to replace fireworks. Such measures, in the long run, will contribute to improving the air quality in many countries.

Finally, apart from the environmental policies that can be implemented, our environmental habits will help to preserve the environment in all its forms, which is why we must work on environmental education in schools.

ACKNOWLEDGMENTS

The researchers would like to thank the Universidad Nacional Intercultural de la Selva Central Juan Santos Atahualpa for facilitating the process of conducting this research.

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