environments

Review

Environmental Impact of Fireworks

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Abstract

Fireworks have been used in China for more than a millennium, though they are an increasing part of celebration globally. Consumption of fireworks is on the rise despite increased regulation of their use. This review examines the key themes that are apparent in contemporary research: contamination of air, water and soil, in addition to waste debris, noise and light pollution, along with contemporary approaches to mitigate environmental impact. Research is, as expected, more frequent from countries with high fireworks use, so some rather small countries such as the Netherlands, Malta and Iceland are notably active. Concentrations of emitted gases (especially SO_2) and fine particles are frequently studied, along with associated toxic metals and semimetals (especially Cu, Zn, Cd, As, Ba and Sr). There are many projections of effects of fireworks, but relatively few epidemiological studies of health outcomes or the impact of contamination on local ecosystems. Fireworks waste and debris is an environmental problem; it is expensive to clear and aesthetically unpleasing. Excessive noise (up to 137 dB) created by fireworks affects pets and wildlife, as well as posing a risk to pyrotechnicians. Fireworks produce bursts of light that can be distracting to motorists and disturb wildlife, while smoke particles cause lowered visibility. Green fireworks and festivals of light with lasers or drone technology present routes to lower impact. Contemporary society is sympathetic towards restricting fireworks, but recognition of their cultural importance remains.

Keywords: air pollution; occupational exposure; metal contamination; health; noise; animal behaviour; light pollution; green fireworks

1. Introduction

Gunpowder was developed in China during the late Tang dynasty (9th century) and enabled more sophisticated fireworks to be used in festivals [1]. The adoption of fireworks has been evident in India and Europe from the medieval period [2]. Royal displays were important events, as seen with *The Music for the Royal Fireworks* composed by George Frideric Handel for the fireworks in London's Green Park on 27 April 1749. Fortunes were to be made from increasingly innovative displays such as those of the British businesswoman Sarah Hengler (c.1765–1845) [3], a far cry from early Nian festivals, which focused on the noise from firecrackers to aim at scaring away evil spirits [4,5]. As evidence of environmental impact, the Song Dynasty (960–1279) administrator Meng Yuanlao described the pall of smoke that arose from civic displays in his book *The Eastern Capital: A Dream of Splendor* (1147) [6].

The aim of this review is to explore the way fireworks affect our environment by examining some of the key research themes that are apparent in the academic literature.

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Much of the review literature in this area is rather specific, so this work tries to cover the breadth of potential environmental issues. Although the detrimental effects of fireworks displays are well recognised, their cultural importance makes regulation a delicate issue. The review will also draw attention to some knowledge gaps that need to be addressed to inform sound policy. It addresses contamination of air, water and soil, in addition to waste debris, noise and light pollution, along with health and environmental outcomes and contemporary approaches to mitigate environmental impacts, as summarised in Figure 1.

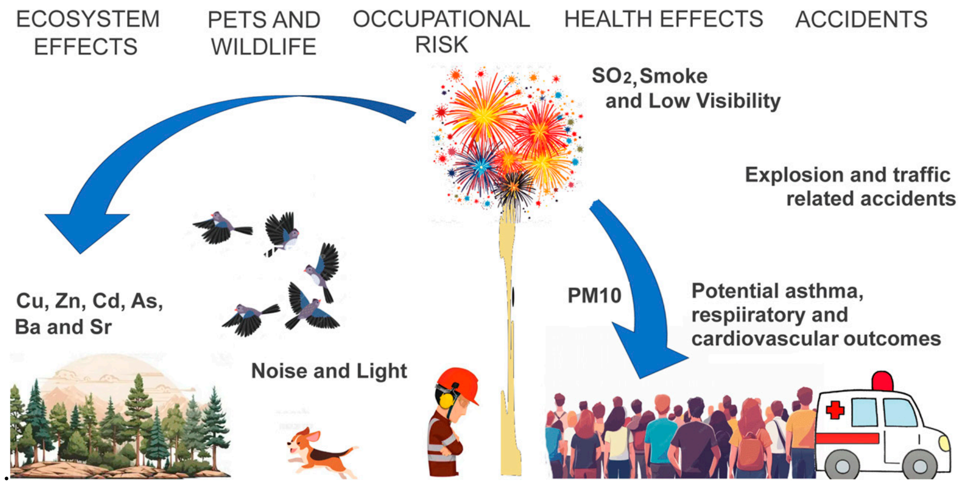

Figure 1. Schematic diagram of some potential environmental effects from fireworks.

2. Materials and Methods

Given the large amount of work done on environmental issues arising from the use of fireworks, it is difficult to be comprehensive in the treatment of the available academic literature. In the past, some reviews have overcome this by limiting the scope to emissions at the Spring Festival in China [7], which is particularly restrictive, as the period can also be described as Chinese New Year or the Lantern Festival (especially at the end of the celebratory period). Other reviews have similarly chosen to limit their breadth using the search term "Diwali" [8], which focusses on India and the Indian diaspora. Additionally, the literature captured through the use of keywords depends on a careful choice of words. The output of such analyses has often been reported as quantitative measures of the material published or through tools such as VOS viewer [9], which examines connections and draws links within the data [8].

This study largely followed the PRISMA approach [https://shribe.eu/prisma-literature-review/, accessed on 16 May 2026]. We firstly undertook a literature search. Although the present study used keyword searches, they did not dominate the choice of material. Occasionally, artificial intelligence was used to explore key ideas within a theme, often adopting Scopus AI, which draws upon abstracts and references within the Scopus database [10]. Secondly, material was selected for use in the review; in particular, it was grouped into themes that emerged as most strongly reflecting current concerns about the impacts of fireworks on the environment. Even within particular themes, the literature was often very rich, so where a multitude of sources were available, recent examples were chosen. Next, key observations and findings were drawn from the selected studies. Not all the claims made within these seemed equally reliable, especially those concerning health effects, so the strength of claims is addressed at the appropriate points in the text.

3. Results

3.1. Festival Dates and Geography

The use of fireworks is now widespread, even in places that have not traditionally used them, such as celebrations in Iceland [11] or Iran [12]. The New Year begins with fireworks almost universally now, so it is difficult to provide a sense of the global extent of the displays, but a list of the best displays suggests that they can be found on all continents [13]. There are numerous studies of air pollution during New Year celebrations that give an indication of the geographical range of studies: Kansal, Germany [14], Honolulu, Hawaii [15], Queretaro, Mexico [16], Metro Manila, Philippines, [17], Ljubljana, Slovenia [18], Rio de Janeiro, Brazil [19], Brno, Czech Republic and Graz, Austria [20].

The Spring Festival (Table 1) or Chinese New Year (21 January to 20 February) has also been widely studied [21–23], together with Diwali in India (mid-October to mid-November) [24–26]. Some other annual festivals celebrated with fireworks include: (i) Guy Fawkes or Bonfire Night in the UK, Australia and New Zealand [27], (ii) Independence Day in the US on 4 July [28], (iii) the Last Wednesday Eve Festival in Tehran, when Iran celebrates the coming new year that begins at the March equinox [12] and (iv) Loy Krathong Thai, an event celebrated on the full moon of the 12th month in the traditional calendar [29].

Table 1. Principal fireworks festivities around the world.

Festival	Dates	Geographical Range
New Year	1 January	Almost universal
Spring Festival [1]	21 January–20 February	Typically, China and Southeast Asia
Last Wednesday Eve	<20 March	Iran
Independence Day	4 July	United States
Diwali	Mid-Oct–mid-Nov	India and its diaspora
Loy Krathong	~November	Thailand
Guy Fawkes [2]	5 November	UK, Australia and New Zealand
Christmas	25 December	Mexico, Peru, El Salvador and Colombia

[1] Chinese New Year. [2] Bonfire Night.

3.2. Trends in Fireworks Production and Use

Fireworks production has become highly regulated, with strict laws regarding the production and storage of fireworks. Nevertheless, accidents occur, such as the May 2000 explosion of poorly stored fireworks at Enschede, in the Netherlands, which killed 23 people [30]. Continued concerns lead to increasingly stringent legislation at national levels that additionally relates to the sale and use of fireworks, which puts pressure on the manufacture of fireworks and their sale [31,32]. China is the main producer of fireworks, exporting 0.365 Mt in 2023 [33], with most of this going to the United States, where there is continued growth in consumption (Figure 2) [34]. There was a notable increase in consumption during the period of COVID-19 in the US (2020–2021), as exhibited by a sharp increase in use by individual consumers [35]. There was also an increase in fireworks emissions in some parts of China during the Spring Festival of 2020, where social media revealed an increase in the number of comments about Nian traditions. This might be associated with a belief that the pandemic could be seen as an evil spirit to be driven away by firecrackers [32].

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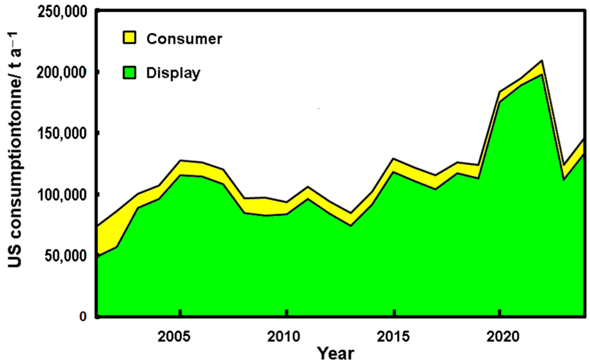

Figure 2. Consumption (tonnes per annum) of fireworks in the United States.

3.3. Trends in Research

As mentioned earlier, the analysis here is not intended to be comprehensive or quantitative, yet it is important to establish a few quantitative parameters. Although the study did not focus on keywords, they were used to represent the proportional interest. Using the search (TITLE-ABS-KEY (fireworks pollution) AND PUBYEAR > 2000 AND PUBYEAR < 2026) in Scopus suggests that from the year 2000 to the beginning of May, 582 items were available. About one third arise from Chinese affiliations, with 20% from India and 10% from the United States. These are all countries with large populations using considerable quantities of fireworks. Some sense of the global spread of research interest in fireworks pollution is given in Figure 3. Nevertheless, we found very small countries such as Malta, with a population of just half a million in 2021 (compared with China 1.4 billion), to be affiliated with five articles. China's long history of use of fireworks explains its publication dominance, but the tiny island of Malta has equally strong traditions of celebrating events with fireworks, so it is comparatively well represented in terms of research. The absence of research in Africa is evident from Figure 3, despite very good New Year displays in South Africa [13].

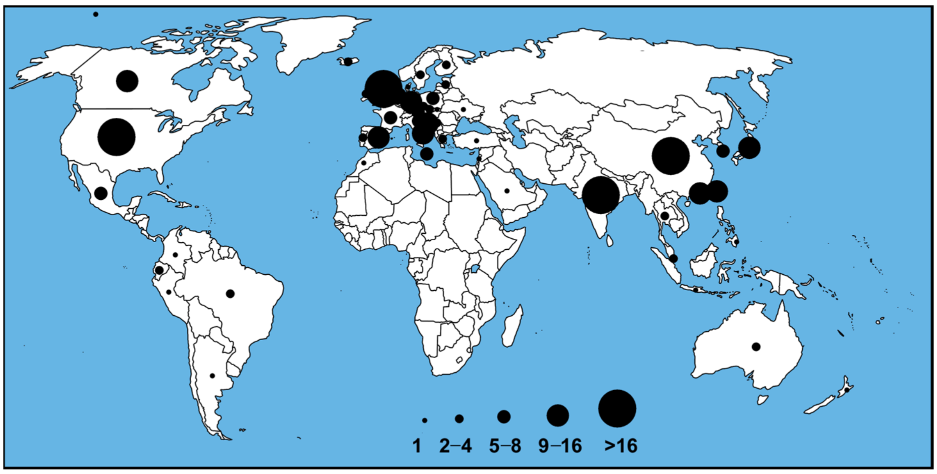

Figure 3. Number of country affiliations in fireworks publications from the Scopus database 2001–2026. Note: size of dot gives a sense of number of affiliations as shown in the legend.

3.4. Regulation and Illegality

Regulating the use of fireworks is often by means of limiting the size of available items, specifying the duration or place of purchase, having age requirements for purchase or requiring permits [36]. Control of the use of fireworks, as distinct from their manufacture, can change rather frequently and switch between liberal and restrictive approaches [37]. The pyrotechnic industry has argued that restrictive laws increase injuries, because illegal products are more dangerous. However, in the US, states that allow consumer fireworks have seven times more injuries and 50 times more fires from fireworks than those with restrictive regulations [37].

Although bans on the use of fireworks can be effective, this may take a concerted effort by authorities. In Beijing, increasing restrictions meant that they slowly came to be accepted by the public, leading to a fall in illegal sales [32]. Caulkins and Reimer [37] have compared the regulation of fireworks and cannabis. Their use is different in that "fireworks are not addictive and create substantial positive externalities", yet fireworks-related harm to health is physical and acute, leading to four times the level of emergency department visits compared with cannabis. However, public concern creates a kind of "moral panic", which may drive rather punitive and divisive policies relating to cannabis use. In the case of fireworks, restrictions may be more broadly accepted in society, but contravening the regulations tends be viewed as a mere peccadillo. An increased willingness to indulge in anti-social behaviour is apparent in carnival-like situations, such that revellers may feel permitted to take a "moral holiday" [38], while some excesses in fireworks use may derive from local rivalries [39]. This might explain the continued use of illegal fireworks, which remain a problem even in the face of evidence of the potential for injury [15]. While in China, bans and restrictions have lowered the environmental impact, in other places, cultural traditions and the persistence of illegal fireworks sales continue to represent a problem [22]. Nevertheless, policymakers have a difficult problem in balancing environmental governance with a respect for cultural heritage [22].

3.5. Fireworks Particulate Emissions

The smoke from fireworks has been apparent since ancient times [6], so it is hardly surprising that the increasing particulate load has been well documented. Lin [40] reviewed much published work and tabulated the difference between the concentrations during the fireworks period and the background. He notes that 19 of 20 $PM_{2.5}$-related studies have reported average $PM_{2.5}$ levels that exceeded the 24 h U.S. National Ambient Air Quality Standard of 35 μg m^{-3} (and 15 μg m^{-3} from the World Health Organization), while 19 of 25 PM_{10}-related studies reported levels that exceeded the 24 h standard of 150 μg m^{-3} (and 45 μg m^{-3} from the World Health Organization). In recent work on the Lantern Festival in Changchun, $PM_{2.5}$ and PM_{10} concentrations increased by 144% and 64% compared to background levels [41]. Determining the amount of the particulate material that arises from fireworks, as distinct from other sources, benefits from positive matrix factorization models [23]. There is additionally a potential for increases in indoor air pollution during the Spring Festival in China [7]. Several recent reviews [8,22,42] of air pollutants from fireworks also suggest that particulate levels are elevated up to five times compared to their background levels during celebrations in China [22,42]. In India, data is also available at regional levels from north [25,43] to south [44] and across the entire nation, which shows increases as a whole.

The rise in particulate concentration can be very rapid [45]; in Tianjin, $PM_{2.5}$ and PM_{10} concentrations rose by 178 μg m^{-3} and 305 μg m^{-3}, respectively, within a single hour [46]. Many other countries, from tiny Iceland [11] and Malta [47] to the United States [28] and Brazil [19], also reveal substantially elevated particulate concentrations after celebrations with fireworks.

Vertical and circumnavigation flights were conducted using an uncrewed aerial vehicle in Changchun, Northeast China. These showed that PM_{10} concentration attained peak values of 243 μg m^{-3}, reflecting double that of background values, with an accumulation within the boundary layer [41]. This accumulation may explain the observation that where fireworks are used over a wide area, the boundary layer thickness might be a more significant factor in controlling concentration than wind speed [32].

Widespread use of fireworks means pollutants can persist for days and be transported long distances, as found in India [43]. While the immediate impact is localised, long-range transport of pollutants has been documented, such as the movement of fireworks-related particulate material from China to the Korean Peninsula [48]. Broad regional increases in the satellite aerosol index are found across the Indo-Gangetic Plain, which is elevated in the week after Diwali [43]. Lin [40] points to evidence that particulate matter remains suspended in the air for a week or even up to a month after festival displays. Thus, particle concentrations may be elevated for prolonged periods [49], although the reasons are not entirely clear. It is true that fine particles can remain suspended for a long time, but air masses typically move with the wind. Maintaining high particulate concentrations for long periods can occur if the air remains stagnant or if there is long-range transport from other places or large amounts of resuspension from the ground. Persistence could be important, as it would elevate human exposure to fireworks particles.

The size of fireworks aerosols is allocated to the $PM_{2.5}$ and PM_{10} range. However, fireworks emissions yield a wide range of aerosol particle sizes, with notable contributions from both ultrafine and accumulation mode particles. Particles smaller than 100 nm (Aitken mode) are generally less prominent during fireworks events due to coagulation and condensation processes [50,51]. Some studies report significant contributions of particles in the 10–100 nm range during fireworks events [52,53]. Particle size distributions often show peaks between 80 and 175 nm [52,54]. These particles dominate the number and mass concentrations during fireworks events, contributing significantly to air pollution [40,50,53]. Coarse particles may exhibit peaks around 0.93 µm and 5.5 µm, indicating growth of accumulation particles [55].

The optical properties of the atmosphere are affected as fireworks increase the aerosol optical depth (AOD) because of high particle concentrations. During events such as Lunar New Year and Diwali celebrations, AOD values can rise dramatically, with fine-mode particles dominating [56]. Fireworks aerosols tend to have high Single Scattering Albedo (SSA), indicating the dominance of scattering over absorption. For example, SSA values during fireworks events are higher than those observed during dust storms or biomass burning [57,58]. Fireworks particles, particularly those containing water-soluble ions such as potassium chloride (and probably perchlorates), exhibit increased hygroscopicity, which affects their ability to scatter light and act as cloud condensation nuclei [17].

3.6. Pollutant Gases

Fireworks emit a notable amount of sulphur dioxide, which is hardly surprising given that they contain ~10% sulphur as part of the black powder [59,60]. Several studies [45,61] have noticed that sulphur dioxide (SO_2) concentrations (up to 100 µg m^{-3}) aligned with the peaks in particulate matter, but even these extremes do not exceed the 24 h World Health Organization guideline of 45 µg m^{-3}. During Diwali in Jodhpur, SO_2 concentrations were observed to be 2.5–5.6 times higher on the festival day compared to pre-festival levels [62]. However, in Seoul and Busan, firework festivals caused only light increases in SO_2 levels compared to the dramatic spikes in particulate matter ($PM_{2.5}$ and PM_{10}). Peak SO_2 concentrations reached 4.9 ppb in Seoul and 5.7 ppb in Busan, which were relatively modest compared to other pollutants [63].

The concentration of carbon monoxide (CO) can be relatively low and has been used as the CO-ratio method to determine the fraction of pollutants that arise from fireworks [23,45]. During the Deepawali festival in Agra, CO concentrations increase by a factor of 1.7 compared to typical winter days [64], while in Delhi, CO mixing ratios also showed an increase during Diwali celebrations, although the impact was less pronounced compared to particulate matter [65]. Emissions from fireworks include nitrogen oxides, and where these are emitted in large quantities, they can lead to ozone formation or depletion through photochemical or titration reactions [24,66]. However, it is sometimes unclear whether this arises from enhanced motor vehicle emissions associated with the events. For example, nitrogen dioxide levels increased as more individuals attended football games [67]. In the period around the fireworks celebrations at Yanshui, Taiwan, high concentrations of gaseous pollutants were attributed to motor vehicles [68]. At some festivals, the nitrogen oxides partly derived from cooking emissions [69].

Emissions of ammonia have been observed during fireworks events [59], and more generally, gases such as ethylamine have been identified as part of fireworks emissions, highlighting the presence of atmospheric amines [70]. Hydrogen chloride can be released in the combustion of chlorine-containing compounds in fireworks, so it contributes to acidic particles [60,71]. Secondary pollutants (e.g., sulphates) are formed through oxidation and heterogeneous reactions, especially if oxidants such as ozone are at high concentration. There have been claims of ozone production by fireworks, perhaps from the cardboard materials they contain, which leads to 3–8 ppb increases in concentrations in Chinese megacities [72], although the relevance of this remains uncertain.

3.7. Health Exposures

It has long been clear that particulate loads and the concentrations of gases emitted from fireworks exceed guideline values from the World Health Organization and national objectives [73]. There is much evidence that emissions from fireworks are harmful, as they include particulate matter, sulphur dioxide and nitrogen oxides, so they could potentially exacerbate asthma, bronchitis, chronic obstructive pulmonary diseases and cardiovascular problems, including heart attacks and strokes, especially in vulnerable individuals such as those with underlying heart conditions [74]. Nevertheless, as fireworks exposures are likely quite short, more apparent symptoms might include coughing, wheezing, and shortness of breath, especially among asthmatics [75,76].

Observations of health status are not typically part of campaigns that study fireworks episodes, which means many studies offer only limited support for claims of an impact on health. Rather, the association of fireworks air pollution with health is derived through comparison with our more general understanding of the relationship between air pollution and health [77]. Lin [40] wrote that few studies directly address the health effects of air pollution related to fireworks, while others [71,78] note there were few reports on the effects of these exposures, a major gap when attempting to assess health outcomes. The oxidative potential of particulate matter is often seen as a possible driver of acute health effects [79]. Fireworks-related emissions contribute $\sim$32% to the oxidative potential during the Diwali period [80], with modest 1.5-fold increases on Diwali night [81]. There are other drivers of negative health outcomes in times of celebration, as people might spend more time indoors in domestic environments affected by enhanced levels of cooking [82]. For example, the Spring Festival in China sees higher blood pressure in rural households as families re-unite [83].

Where more direct evidence of short-term health outcomes is available, it often comes from very limited numbers of exposed individuals. During New Year celebrations in Honolulu, when respirable particulate concentration exceeded 3800 $\mu g\ m^{-3}$, two male subjects with history of chronic respiratory disease experienced an average decrease of 26% in maximal mid-expiratory flow, much greater than what was found in normal subjects [84]. Harai et al. [85] reported acute eosinophilic pneumonia in a habitual cigarette smoker who had shown no respiratory distress. Following inhalation of fireworks smoke for three nights, the patient complained of cough, fever and dyspnoea. There is some evidence from Iceland that particulate loads from fireworks lead to increased use of medication among asthmatics [11,86]. In India, there are indications of increased hospital admissions [87] during Diwali, and almost half those questioned complained of cough, while 38% complained of runny nose and eye irritation and 27% of breathlessness [88]. However, Greven et al. [89] found that any changes in daily mortality in the Netherlands after fireworks displays are difficult to detect.

There may also be some potential long-term health issues from exposure to the pollutants released by fireworks, which could derive from exposure to carcinogens, heavy metals [42] or polycyclic aromatic hydrocarbons (PAHs). The cancer risk from chromium exposure during Diwali increased 2.6-fold [25]. Pyrene and benzo(b)fluoranthene were the main contributors to PAH toxic equivalent values of aerosol components during the pre- and post-spring festival period [21]. Pongpiachan et al. [29] determined the mean incremental lifetime cancer risk for adults during displays and found that they were at acceptable levels.

The pollution-derived risks often seem modest when compared to the risk from airborne fragments and shrapnel produced by the fireworks explosions. Eye injuries, which include corneal abrasions and lacerations, are frequent and may lead to permanent loss of vision in severe cases [90]. Injuries to upper extremities are also common [91], such as burns and lacerations due to mishandling fireworks or from accidents during displays, especially among children [92].

While the exposure to environmental risk from fireworks is infrequent and of relatively short duration for typical spectators, this is not the case for pyrotechnicians, who handle and use fireworks much more regularly. Many public displays use aerial fireworks, so the route to such occupational exposures may be different to that of more distant spectators. Studies within the industry typically focus on issues related to production, although there are a few studies of environmental exposure to noise [93]. However, pyrotechnicians are regularly exposed to very loud noise (>100 dB), so hearing loss should be minimised through the use of earplugs or earmuffs [93].

3.8. Fireworks Metals and Trace Substances

Metals and semi-metals are typical components of fireworks, which create colours, produce glitter and cause bright flashes. These components disperse and are ultimately deposited into the local environment, so they accumulate in the soil, often exceeding natural background levels [94].

Copper is frequently elevated during fireworks events, contributing to air pollution and potentially enhancing ecological risks [94–96]. Along with zinc [97], it leads to an increase in soil concentrations, so it poses an ecological risk in urban areas [94]. Lead is well known for its toxicity and concentrations often spike during fireworks displays, posing potential risks to human health and ecosystems [96,97]. Cadmium poses a high ecological risk and is often released during fireworks displays [97]. Arsenic creates both ecological and health risks [46,94,98]. Carcinogenic risks can arise from elevated concentrations of chromium following fireworks events [46,94,95]. Concentrations of both barium and strontium rise sharply during displays, which makes them a useful tracer of fireworks use [18,46,96].

Doubtless there are concerns over the deposition of these trace metals and semi-metals in the environment. This is understandable, as a large display might use 20 tonnes of fireworks. The pyrotechnic elements amount to about ~50%, with the rest being casing and small amounts of clay plugs, etc. The pyrotechnic elements contain ~5% barium and strontium, 2% copper and 1% antimony, which would respectively deposit 0.5 g m^{-2}, 0.5 g m^{-2}, 0.1 g m^{-2} and 0.05 g m^{-2} over a square kilometre. These deposits can be compared with the copper deposited near a metal smelter, which ranges from 0.11 to 1.30 g m^{-2} a^{-1} [99,100], so it is certainly high. Suggested drinking water guidelines for barium (1.3 mg L^{-1}) [101], strontium (0.7 mg L^{-1}) [102], copper (2 mg L^{-1}) [103] and antimony (0.02 g mg L^{-1}) [104] would suggest that fireworks might lead to local concentrations exceeding desirable ones, suggesting further research on water-borne pollutants post-display would be of value.

Additionally, there are a range of water-soluble ions (potassium, sulphate, perchlorate) [42,97]. Perchlorates are especially notable [105] and can leach into soil and water sources during and after fireworks displays. They are highly soluble in water, leading to widespread contamination of ground and surface water, especially in areas with frequent fireworks use. Sulphides and sulphates from displays add to air pollution and can acidify rainwater that might ultimately leach essential nutrients from soil.

The aquatic toxicity of firework-derived metals, notably lead, chromium and copper, can be a particular problem, as they readily accumulate in aquatic organisms, leading to bioaccumulation and biomagnification in the food chain. This affects aquatic life by impairing metabolism, reproduction, and growth [105]. The metals from fireworks also accumulate in soil, potentially affecting vegetation and agricultural productivity [106,107].

3.9. Waste and Debris

Fireworks displays can leave behind a surprisingly complex mix of debris, and the impacts go well beyond simple litter. The problems tend to fall to environmental and safety management, with local authorities dealing with an environment contaminated with large quantities of paper and cardboard waste (casings, wadding) that accumulates on the ground and in waterways [107,108]. Debris can block storm drains and gutters, leading to water buildup and damage. Although the waste is often assumed to be biodegradable, many components are treated or coated and persist longer than expected. Additionally, the waste is associated with chemical residues from fireworks, with relatively high concentrations of strontium, barium and copper that can ultimately adhere to debris, so it remains in the soil and water. The trace elements can affect plants and aquatic life and potentially enter food chains. Microplastics and synthetic fragments from modern fireworks (plastic plugs, tapes, stabilisers) also contribute to long-term pollution [109].

There are fire hazards related to hot debris falling onto roofs, gutters, or flammable vegetation [110]. This creates a risk of secondary fires after the display has ended. Debris containing unburnt or partially burnt materials can smoulder and reignite the waste itself or dry vegetation.

Contaminated areas may be unsafe, as sharp fragments (wires, sticks, casings) create trip and injury hazards. Residual chemicals on debris can cause skin irritation or mild toxicity if handled, especially by children. There are also risks to wildlife. Animals may ingest debris, mistaking it for food, leading to internal injury or poisoning. Residues can contaminate habitats, especially in parks, rivers, and coastal zones. Accumulated waste can clog drainage systems, contributing to localised flooding [111].

Littered public spaces reduce the perceived aesthetic value of parks and streets, sometimes dominated by a “red snow” from firecracker casings. Poor cleanup can affect tourism and community satisfaction after events, so effective post-display management typically includes rapid cleanup, the use of biodegradable materials, exclusion zones over sensitive environments, and monitoring for unexploded ordnance. Clean-up costs for municipalities can be substantial, particularly after large public events. In Nanjing, more than 2000 tonnes of debris were collected following the Chinese New Year celebrations of 2013.

Such considerations led to the stricter control of fireworks in the city over the following years [45].

3.10. Noise

Many fireworks are designed to create noise, and this is firmly part of Nian culture [4,5]. It is also a part of the inter-village rivalry during celebrations in Malta [39]. Reategui-Inga et al. [73] have systematically reviewed noise from fireworks. These generate impulsive noise that can exceed occupational noise limits, posing risks of hearing loss. For example, measurements during New Year's Eve in Kraków showed noise levels exceeding safe thresholds by 1.8 dB at 25 m and 6.2 dB at 15 m [112]. Noise pollution from fireworks is linked to stress, high blood pressure, coronary heart disease and stroke, as well as emotional and digestive disorders [113]. Communities located in urban and residential areas near fireworks displays often experience significant annoyance due to the transient and high-intensity nature of the noise [112,114]. There are occupational health risks also [115], so it is necessary to recognise that pyrotechnicians face a challenging working environment in terms of health and safety [116] due to exposure to noise in particular [93]. Peak sound levels from explosions during events could reach 137 dB(C), far exceeding Directive 2013/29/EU, which sets a maximum level of 120 dB(A), revealing an occupational risk of hearing loss [115].

Fireworks cause distress in domestic animals and disrupt wildlife [117], especially during migratory or reproductive periods. Fireworks cause significant physiological stress in birds. For example, greylag geese exhibit elevated heart rates and body temperatures during and after fireworks events, indicative of a stress response and increased energy expenditure [118].

Fireworks noise can cause long-term population effects on wildlife [106]. The noise disturbs birds, which may fly away over considerable distances [119] with long-lasting effects on their populations [120]. Fireworks thus trigger strong flight responses in birds at night when they would typically be roosting [121,122]. Studies using radar and direct observation have shown that birds fly at higher altitudes and in greater numbers during fireworks events [119,120,123]. Sudden nocturnal disturbances from fireworks can cause erratic flight patterns and frequent changes in direction, particularly in corvids [121], leading to injury and death through collision [124].

The ecological consequences can be reduced abundance and richness in natural habitats, particularly during events with fireworks near conservation areas [122,125]. Noise from fireworks during the breeding season has been associated with reduced juvenile productivity in house sparrows, likely due to stress and disruption of reproductive behaviour [126]. This can ultimately reduce avian populations and the ecological value of important habitats [122].

Pets are affected by fireworks noise, with dogs and cats commonly exhibiting fear-related behaviour, such as hiding, shivering, cowering, panting, and vocalisations during fireworks [127–129]. Fireworks noise triggers stress responses in dogs, evidenced by increased cortisol levels during displays. The levels are lower on quiet nights, indicating a direct link between fireworks and physiological distress [129,130]. Dogs tend to show more active fear responses such as running or barking, while cats are more likely to hide or cower. Fear responses can worsen over time, especially if owners comfort their pets during these events, potentially reinforcing the fear [127]. Fireworks can also lead to physical injuries to pets, as they are likely to collide with objects or become hurt while breaking through fences. As many as six percent of the animals in surveys were reported to have sustained injuries after being frightened by fireworks [127,128].

3.11. Visibility and Light

High particle loads, dominated by soot and soluble and hygroscopic aerosol products, reduce visibility during fireworks displays [131], especially under stagnant weather conditions. Sulphates, potassium and chloride, in that order, and to some extent magnesium are in a particle size range that effectively scatters visible light. This can enhance night-time skyglow [132]. Although fireworks themselves create only short-term light disturbances, scattering by particles can be a more persistent change in light at night. Such light pollution can disturb wildlife and pets [106], although it may be difficult to separate from noise effects.

Flashes of light, reduced visibility and loud noise were a distraction to more than half the drivers surveyed by *MoneySuperMarket* in the UK, and a third actively avoided driving when there were fireworks displays nearby. These statistics highlight the potential dangers of fireworks displays for road safety, especially during busy evening journeys [133]. According to UK government road safety data, 292 road accidents were recorded on 5 November 2024 in the UK, with 1320 accidents in total across the week of Bonfire Night celebrations. At times, fireworks smoke may be so dense that it reduces visibility on roads. In November of 2011, a multi-vehicle crash killed five people and injured 51 others on the M5 motorway adjacent to a fireworks display. Dense fog along with fireworks smoke may have contributed to the accident [134].

3.12. Reducing Fireworks Impacts

Concern over the environmental consequence of fireworks has led to a range of approaches to mitigate the problem. Green fireworks have been proposed as a more acceptable alternative to traditional formulations [135]. These fireworks replace toxic chemicals (e.g., barium) with safer alternatives such as potassium nitrate and incorporate zeolite and boric acid hydrogel as additives to suppress dust, absorb gaseous emissions and sequester metals [136,137].

Green fireworks can reduce particulate matter ($PM_{2.5}$) emissions by 30–50% compared to traditional fireworks [136–138]. Reductions in particulate matter emissions have been reported to be as high as 70–73%, while for sulphur dioxide and the nitrogen oxides, the reductions are 50–85% and 25–30%, respectively [136]. Despite these reductions, the overall air quality deterioration during large-scale fireworks events remains important, especially when the volume of fireworks used is high. Doubling the use of green fireworks can still result in pollution levels comparable to traditional fireworks [138]. Again, while the heavy metals and nanoparticles associated with fireworks, such as aluminium, barium and strontium, are reduced, they can still contribute as pollutants [18].

Non-pyrotechnic alternatives, such as drone and laser-based light shows, offer a more sustainable and environmentally friendly option for celebrations. The best known of these may be the Symphony of Lights, a nightly light and sound show across Victoria Harbour in Hong Kong that uses synchronised lasers, searchlights and building illumination rather than fireworks [139].

4. Discussion

Much of the research on the environmental impact of fireworks is aimed at supporting improved protection of the environment and health, which would lead to sound and well-justified fireworks policies. The work deals with concerns over reducing air pollution and lowering health effects [140] or strengthening policy implementation [23,141]. Studies frequently take the view that pollutant concentrations are too high, so the use of fireworks should be reduced, with authors noting that the concentrations exceed guideline values. Some authors point out that a small number of exceedances is allowed within some national legislation [142], and a study concluded that the fireworks display celebrating National Day in Hong Kong was not a significant source of ambient air pollution [143]. Far less attention is given to the short exposure times and the lack of well-structured epidemiological studies that examine health outcomes after festivities. The dangers of acute injury are set on a firmer basis with epidemiological evidence that is suitably convincing.

Contamination of the environment with metals and compounds such as perchlorate is also well-established, although there seem to be few long-term studies of contaminated environments. The issue of noise impact on animals is well researched and convincing. Multipoint monitoring of sound pressure levels produced by fireworks is important [73], and sound is one of the many worrying occupational exposures for pyrotechnicians. There is evidence that carefully developed policies to restrict fireworks use can become acceptable to the public, along with an acceptance of newer forms of display. Hong Kong's nightly Symphony of Lights which illuminates buildings is a fine and much appreciated example [139]. Nevertheless, some authors worry about the cultural loss [22], and even those of us who are critical of the use of fireworks can be carried away by the noise, brilliance and colour.

The evidence to support health impacts from air pollutants at fireworks is very limited, yet there are many risks from fireworks displays. However, public health experts would see these as a lesser concern than a range of other potential burdens imposed by large festive gatherings. They rank such risks [144], placing those associated with alcohol or drugs [134], traffic accidents, infectious diseases [145] and illnesses arising from food prepared in temporary facilities [146] highest. Risk of crowd-related injuries is more moderate, though occasionally very serious, along with aggressive behaviour that can sometimes be an issue [147]. Air and noise pollution, along with fireworks injuries, are seen to represent lower burdens by comparison. Despite the risks incurred by festivals, they are encouraged, as they have great cultural value and create a sense of cohesion and shared enjoyment within communities.

5. Conclusions and Future Perspectives

This review has outlined key themes found within contemporary studies of the environmental impacts of fireworks. Celebrations using fireworks typically occur on key dates, and despite restrictions, their use is still increasing in many countries. Bans can be effective, but there is often a reluctance by authorities to interfere with cultural activities. In summary, much attention is given to air pollution from fireworks, especially because of enhanced particulate loads. These are paralleled by sharp peaks in sulphur dioxide and more modest amounts of carbon monoxide. Nitrogen oxides can be associated with motor vehicles and other activities that occur at festivals. However, there are few epidemiological studies of the impact of these pollutants on human health. Research has revealed a range of additional environmental issues. Barium, strontium, copper and antimony are emitted in large quantities, but there is little understanding of their impact when dispersed into the neighbouring environment. Waste and debris from fireworks displays, in addition to potential environmental impacts, can impose costly clean-up operations on local authorities. The noise from displays disturbs animals, so it has considerable ecological impact, along with disturbance from flashes of light. Additionally, low visibility may cause increased traffic accidents.

There are important gaps in our knowledge. Perhaps the most striking is the need to have more epidemiological studies of the impact of displays on short-term health outcomes. This would also provide better understanding of the routes to occupational exposures and longer-term effects on pyrotechnicians. The persistence of fireworks pollutants over many days remains a puzzle, so the potential for resuspension or advection from other

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areas deserves investigation. It is likely that more care is required to distinguish fireworks pollutants from those arising from other sources, e.g., vehicles and cooking. This is possible using fireworks tracer compounds or computational methods such as positive matrix factorization. Ozone production from fireworks is curious, though poorly understood. Although the pollution problems may be largely solved by displays of laser light or drone technology, it seems our cultural attachment to old-fashioned fireworks remains strong.

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