Disaster Medicine and Public Health Preparedness

www.cambridge.org/dmp

Global Health Impacts of Wildfire Disasters From 2000 to 2023: A Comprehensive Analysis of Mortality and Injuries

Zakaria A. Mani[1], Amir Khorram-Manesh[2,3,4] and Krzysztof Goniewicz[5]

[1]Nursing College, Jazan University, Jazan, Saudi Arabia; [2]Department of Surgery, Institute of Clinical Sciences, Sahlgrenska Academy, University of Gothenburg, Goteborg, Sweden; [3]Center for Disaster Medicine, University of Gothenburg, Gothenburg, Sweden; [4]Gothenburg Emergency Medicine Research Group (GEMREG), Sahlgrenska University Hospital, Goteborg, Sweden and [5]Department of Security, Polish Air Force University, Deblin, Poland

Original Research

Cite this article: Mani ZA, Khorram-Manesh A and Goniewicz K (2024). Global Health Impacts of Wildfire Disasters From 2000 to 2023: A Comprehensive Analysis of Mortality and Injuries. *Disaster Medicine and Public Health Preparedness*, **18**, e230, 1–11
https://doi.org/10.1017/dmp.2024.150

Received: 08 April 2024
Revised: 18 June 2024
Accepted: 25 June 2024

Keywords:
wildfires; public health; mortality; morbidity; forest fires; disaster preparedness; climate change; urban expansion; global impact; health burden

Corresponding author:
Zakaria A. Mani and Krzysztof Goniewicz;
Emails: k.goniewicz@law.mil.pl;
Email: Zakaria.mani@jazanu.edu.sa

Abstract

Background: Wildfires have escalated into a global threat with profound impacts on health, society, and the environment. The increasing frequency and intensity of these disasters, influenced by climate change and urban expansion, necessitate a comprehensive understanding of their direct health consequences.

Methods: This study conducted a retrospective analysis of global wildfire disasters from January 2000 to December 2023, utilizing data from the Emergency Events Database (EM-DAT). The analysis focused on the direct health outcomes—mortalities and injuries—excluding indirect effects such as smoke inhalation. Data were meticulously cleaned, categorized, and analyzed using quantitative methods, with statistical tests employed to validate the findings.

Results: The study identified 309 significant wildfire disasters, with forest fires accounting for 80% of these events. These incidents resulted in 1890 fatalities and 14 360 injuries, with the highest tolls observed in Southern Europe, Northern America, and the Australia-New Zealand region. A notable rise in wildfire incidents was observed over the study period, underscoring the critical intersections between climate change, urban expansion, and wildfire risks. The analysis highlighted significant geographical and temporal patterns, emphasizing the regions and factors contributing to heightened wildfire vulnerability.

Conclusions: The findings underscore the urgent need for robust disaster preparedness and effective mitigation strategies. Integrating advanced early warning systems and Traditional Ecological Knowledge into wildfire management practices is essential. The study calls for proactive public health measures and interdisciplinary approaches to address the multifaceted challenges posed by wildfires. Continuous research and policy formulation are crucial to protect vulnerable communities and mitigate the increasing threat of wildfires globally.

Wildfires are escalating as a global peril, fundamentally altering societies, ecosystems, and economies with unprecedented impacts. This escalation, closely intertwined with the multifaceted implications of climate change, signals a significant transformation of our environmental landscape. The frequency and intensity of wildfires serve as a stark reminder of this ongoing change, prompting an urgent examination of their direct consequences on human health.

Wildfires, encompassing bushfires, forest fires, and vegetation fires represent spontaneous and unplanned events that can devastate vast natural areas within remarkably short periods. To et al. (2021) vividly describe these occurrences as rapidly expanding, uncontrollable infernos, driven by winds and capable of extensive destruction.[1] The pace at which these fires spread poses a significant challenge, often surpassing the ability of humans to outpace the flames, thereby elevating the direct risk to life and physical well-being.

Global climate change contributes to more frequent meteorological anomalies and extreme events, affecting the timing and severity of wildfires.[2] Instances like the devastating wildfires in Australia during 2019-2020 and the repeated fires in California in recent years exemplify this trend. Research by Abatzoglou and Williams highlights a concerning increase in wildfire frequency and magnitude in the western United States, attributed to rising global temperatures.[3] This changing climate scenario sets a backdrop for our investigation into the direct health impacts of such disasters.

Heatwaves, often coinciding with dry conditions, exacerbate the likelihood and severity of wildfires. The relationship between heatwaves and wildfires is particularly critical, as extreme heat not only dries out vegetation, creating ideal conditions for fires to start and spread, but also strains human health systems already burdened by the direct impacts of fires. This interplay between heatwaves and wildfires intensifies the challenges faced by affected regions, compounding the health risks and complicating disaster response efforts.

Focusing on regions like California, particularly vulnerable to wildfire threats, this study acknowledges the immediate dangers of mortality and injury, recognizing the broader public health concerns that arise from such events.[4] Displacement and the exacerbation of health conditions, including asthma and mental health disorders, underscore the complex health dimensions associated with wildfires.[5]

However, our analysis specifically aims to understand the direct health outcomes—mortalities and injuries—arising from wildfire events. Although similar to other natural disasters in terms of immediate human impact, wildfires uniquely contribute to the aggravation of respiratory conditions, primarily through smoke exposure.[7] The economic burden of combating wildfires further complicates the challenge, with costs surpassing $1.7 billion annually on US federal lands alone.[6] Despite the wealth of research on wildfires, a holistic examination of their global reach, significance, and direct health implications, particularly over the last two decades, is lacking.

Our study seeks to fill this gap, exploring the frequency, geographical spread, and direct health outcomes of wildfire disasters from 2000 to 2023. By focusing on these aspects, we aim to provide insights into national and international responses to wildfire challenges and the implications of climate-driven changes on wildfire patterns.

Materials and Methods

Study Design and Framework

This study embarked on a comprehensive retrospective analysis focusing on global wildfire disasters from January 2000 to December 2023. The primary aim was to examine the direct health outcomes—mortalities and injuries—resulting from these events, explicitly excluding indirect effects such as those related to smoke inhalation and air quality. This approach ensures a focused examination of the immediate health impacts of wildfires.

We utilized a robust quantitative analysis framework to derive meaningful insights from the data. This involved selecting reputable data sources, meticulous data cleaning, and organizing the data for comprehensive analysis. The goal was to elucidate global trends in wildfire disasters, focusing on direct health impacts and associated patterns over the past two decades. This methodology aimed at dissecting past and current trends and intended to generate insights for future research and policy formulation in disaster management and public health arenas.

Data Collection

Source

We selected the Emergency Events Database (EM-DAT) as our primary data source. Operated by the Centre for Research on the Epidemiology of Disasters (CRED), EM-DAT is a comprehensive global repository, archiving data on natural and anthropogenic disasters. Esteemed for its reliability and extensive coverage, EM-DAT's utility in disaster impact analysis has been corroborated through its application in numerous research endeavors.

EM-DAT aggregates data from several sources, including United Nations agencies, nongovernmental organizations, reinsurance companies, research institutes, and press agencies. This eclectic compilation enhances the database's accuracy and representativeness. Such diversity in data provenance equips EM-DAT to offer a detailed and nuanced perspective on the impacts of disasters, rendering it particularly suitable for examining the direct health effects stemming from wildfire disasters.

It is imperative to clarify within our methodological framework that our investigation focuses on the direct impacts of wildfire activity. Although natural hazards, such as lightning, can cause wildfires, they are increasingly recognized as anthropogenic disasters due to human activities like arson, land-use changes, and climate change. This dual nature of wildfires highlights the complex interplay of ecological, climatic, and social factors in their occurrence and impacts. Recognizing this complexity is crucial for understanding wildfire dynamics and their direct consequences on human health.

Inclusion criteria

Our study required targeted and precise data extraction to focus specifically on incidents directly attributable to wildfires. This scope included a variety of wildfire categorizations such as forest fires, bushfires, and grass fires, among others, ensuring a comprehensive approach to capturing the diverse nature of wildfire disasters. We analyzed data from January 2000 to December 2023, with a global geographical scope that encompassed all countries and regions reported within the EM-DAT database.

To adhere to the robust inclusion criteria set by EM-DAT for disaster events, only incidents fulfilling at least one of the following conditions were selected for our analysis: 1) resulting in 10 or more fatalities; 2) affecting 100 or more people; 3) leading to a declaration of a state of emergency; or 4) prompting a call for international assistance. These criteria were instrumental in ensuring that our study focused on significant wildfire disasters that had substantial human and economic impacts. Our focus remains strictly on the immediate consequences of wildfires—including injuries, fatalities, and displacement—whereas indirect effects from smoke and air quality concerns are not considered within our analysis scope.

Data Preparation

Following the data extraction phase, we undertook a rigorous cleaning process to guarantee the dataset's consistency and accuracy. Entries with missing or ambiguous details were carefully reviewed and either corrected using supplementary sources or removed to uphold the dataset's integrity. Subsequently, the cleaned dataset was systematically organized by geographical regions and classified according to the intensity of the wildfire incidents.

Data Analysis

Analytical approach

Our investigation employed a quantitative research methodology foundational to our analytical framework. This choice was driven by the methodology's grounding in the positivist research paradigm, which prioritizes empirical evidence and objective analysis. This alignment is crucial for our goal of quantifiably and impartially measuring the data to systematically evaluate the direct impacts of wildfires on health outcomes.

To convert raw data from the EM-DAT database into actionable insights, we followed several key steps to ensure the integrity of our data analysis. First, we imported the raw data into statistical software, including R and Microsoft Excel. The data cleaning process involved identifying and correcting errors, removing duplicates, and addressing missing values. For missing data, we used methods such as mean imputation and regression imputation, depending on the nature and extent of the missing values.

https://doi.org/10.1017/dmp.2024.150 Published online by Cambridge University Press

Next, we aggregated data based on specific variables such as wildfire type, geographic region, and year. This involved summarizing the data to obtain totals and averages for key metrics like the number of wildfires, fatalities, and injuries. Following this, we selected appropriate statistical tests to analyze the data. For instance, chi-square tests were used to examine the distribution of wildfires across different categories, whereas t-tests or ANOVA were employed to compare means between groups. Additionally, we utilized regression analysis to explore the relationship between wildfire occurrences and health outcomes.

To ensure the robustness and reliability of our findings, we validated our results through techniques such as cross-validation and bootstrapping. This included splitting the data into training and test sets to verify the consistency of the patterns identified. Finally, we utilized data visualization tools to create charts and graphs that illustrate the patterns and trends in the data. These visual aids were crucial for interpreting the results and effectively communicating our findings.

Descriptive analysis

The initial phase of our analysis utilized Microsoft Excel for a comprehensive descriptive analysis, aiming to uncover patterns, trends, and broad insights from the wildfire data. This foundational step was pivotal for establishing the basis for more intricate analyses that followed.

We commenced by examining the frequency of wildfire occurrences, categorizing and analyzing the data across various regions and years to identify significant temporal or geographical patterns. This exploration included assessing the distribution of wildfire events and impacts to determine if their distribution followed a normal pattern or exhibited skewness, indicative of disproportionate impacts in certain areas or periods.

We categorized the data by the type of wildfire (e.g., forest fires, bushfires, grass fires), geographical regions, and the intensity of events. This categorization revealed nuanced patterns and variances in wildfire impacts across diverse settings. A crucial component of our descriptive analysis was the evaluation of direct health impacts resulting from wildfires, specifically focusing on reported injuries and fatalities. We quantified these incidents and examined their distribution across different wildfire events and regions. This analysis was instrumental in identifying health outcome trends, such as specific regions or wildfire types associated with higher health impacts.

By adhering to this structured framework, our goal was to elucidate the global trends in wildfire disasters, focusing on their direct health impacts and associated patterns over the past two decades. This methodology was not solely aimed at dissecting past and current trends but also conceived to generate insights instrumental for future research endeavors and the formulation of policies in disaster management and public health arenas

Results

Global Overview of Wildfire Disasters (2000-2023)

Over the past two decades, the global landscape has witnessed a significant transformation in the frequency and impact of wildfire disasters. This period, extending from 2000 to 2023, has been marked by a notable escalation in wildfire activity, reflecting broader environmental and climatic shifts. Within this context, our study has cataloged and analyzed the extent and repercussions of wildfires across various countries and regions, providing a comprehensive snapshot of a growing global challenge. During this period, a total of 309 wildfire disasters were meticulously recorded, each contributing to a complex tapestry of ecological disturbance and human hardship.

Trends Over Time

The turn of the millennium in 2000 witnessed a marked spike in wildfire activity, culminating in 30 significant incidents. This peak was closely succeeded by another surge in 2002, with 22 recorded wildfires, delineating a period of heightened wildfire prevalence. The distribution of these incidents over the years, as visually captured in Figure 1, elucidates the fluctuating nature of wildfire disasters, offering insights into temporal patterns and potential predictive indicators.

Table 1 details the annual distribution of wildfire incidents across various countries, spanning from 2000 to 2023. This dataset allows for an examination of the temporal trends in wildfire occurrence, providing insights into the annual fluctuations of these disasters. A chronological analysis reveals variability in the frequency of wildfires

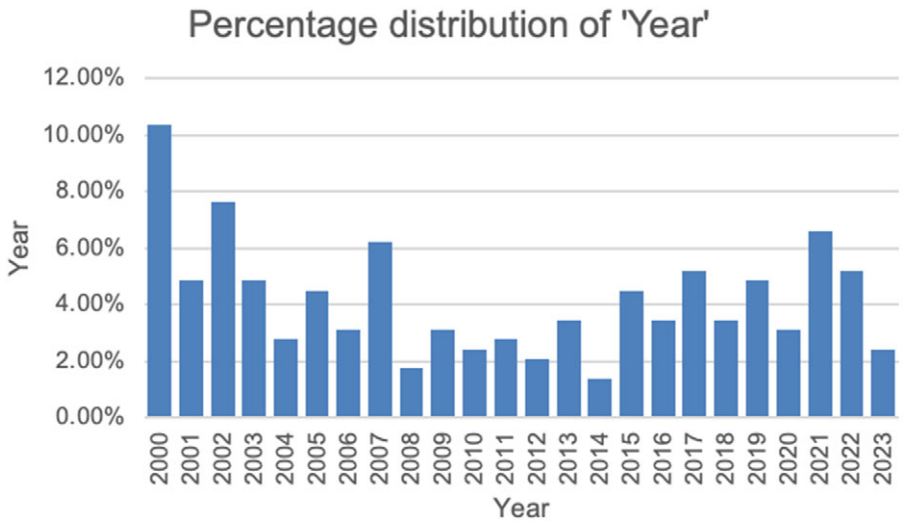

Figure 1 Global distribution of wildfire disasters (2000-2023).

https://doi.org/10.1017/dmp.2024.150 Published online by Cambridge University Press

Table 1. Annual wildfire disaster occurrences from 2000 to 2023

Years	The number of wildfire disasters
2000	This year saw the highest activity, with 30 wildfire disasters, marking it as notably active across multiple countries. The Russian Federation recorded the most incidents this year, with 5 occurrences.
2001–2002	These years witnessed a consistent number of disasters, with 14 and 22 occurrences, respectively. Notably, the United States experienced a surge in 2002 with 8 incidents.
2003–2006	Each year in this interval saw incidents numbering in the teens, peaking in 2005 with 13 occurrences. Although multiple countries were impacted, the United States consistently reported several incidents each year.
2007	There was a significant rise to 18 occurrences this year, with European countries like Greece and Bulgaria notably affected.
2008–2011	A slight decrease was observed in these years, with occurrences ranging from 5 to 8 annually. The United States and Australia were frequently impacted.
2012–2014	Occurrences varied, with 6, 10, and 4 incidents respectively, and the United States remained a frequent hotspot.
2015–2017	An upward trend in occurrences was evident, especially in 2015 with 13 and in 2017 with 15 incidents. Australia, Canada, and the United States were commonly affected.
2018–2019	These years recorded 10 and 14 incidents, respectively. In 2019, Australia and the United States were particularly noteworthy for experiencing multiple wildfires.
2020	Marked by 9 occurrences, this year included devastating wildfires in regions such as Bolivia and the western United States.
2021	This year reflected one of the highest numbers of incidents in the table, with 19 occurrences. The United States saw 6 events, and several Mediterranean countries also faced significant fires.
2022	A total of 15 occurrences were noted, with the United States again seeing a higher number with 4, and Chile experiencing 2 incidents.
2023	To date, there have been a total of 7 occurrences, with several countries experiencing one incident each.

year on year, indicative of underlying patterns or influences affecting their occurrence.

Breakdown by Disaster Subtype

The 309 wildfire occurrences were further distinguished based on their subtypes: forest fires and land fires, the latter encompassing brush, bush, and pasture fires. Forest fires significantly dominated the scene, accounting for a substantial 75.08% of the occurrences, equating to 232 incidents. This overwhelming presence of forest fires emphasizes their critical role in the overall number of wildfire disasters. This distribution is visually depicted in Figure 2, highlighting the predominant occurrence of forest fires compared to other subtypes.

Wildfire Distribution: A Global Overview

Table 2 presents a comprehensive analysis of wildfire incidents globally, categorized by subtype—forest fire, unknown, and land fire—and the cumulative count for each country. This categorization elucidates the incidence of wildfires across different terrains and conditions, facilitating a nuanced understanding of their distribution worldwide. Notably, the United States leads with the highest total number of incidents, predominantly forest fires, underscoring the significant risk and impact of these disasters within its territories. Following are Australia and the Russian Federation, with notable incidences categorized mainly as land fires and forest fires, respectively. This ranking highlights the varied nature of wildfire disasters across different geographical and environmental contexts.

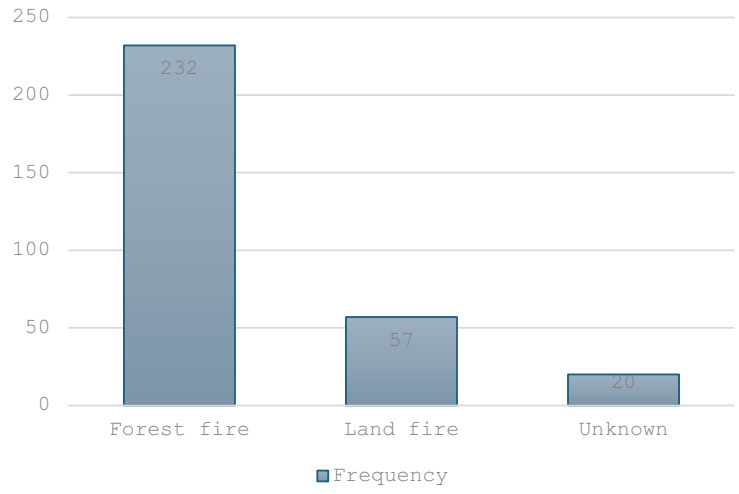

Figure 2 Global distribution of wildfire disasters by subtype (2000-2023).

https://doi.org/10.1017/dmp.2024.150 Published online by Cambridge University Press

Table 2. Wildfire incidents and subtypes by country

Country	Forest fire	Unknown	Land fire (brush, bush, pasture)	Grand total
United States of America	60	18	13	91
Australia	5	2	18	25
Russian Federation	17		3	20
Canada	10	2		12
Chile	5	3	4	12
Spain	10	1		11
Portugal	9	1		10
Greece	9	1		10
South Africa	1	1	5	7
Indonesia	5	1		6
Korea	4	2		6
Bulgaria	3	2		5
Bolivia	5			5
Croatia	5			5
Algeria	2	2		4
France	3	1		4
Turkey	4			4
China	3		1	4
Argentina	3	1		4
Israel	1	1	1	3
Congo			3	3
Colombia	2	1		3
North Macedonia	3			3
Italy	2	1		3
Ukraine	2			2
Lebanon	1	1		2
Cyprus	2			2
Honduras	1	1		2
Tunisia	2			2
India	2			2
Paraguay	2			2
Central African Republic	1	1		2
Mexico	1		1	2
Eswatini	1			1
Pakistan	1			1
Slovakia	1			1
Latvia	1			1
Kazakhstan		1		1
Benin		1		1
Serbia	1			1
Ecuador	1			1
Dominican Republic	1			1
Malaysia	1			1
Panama		1		1
South Sudan		1		1

(*Continued*)

https://doi.org/10.1017/dmp.2024.150 Published online by Cambridge University Press

Table 2. (*Continued*)

Country	Forest fire	Unknown	Land fire (brush, bush, pasture)	Grand total
Peru	1			1
Canary Island	1			1
Ethiopia	1			1
Syrian Arab Republic		1		1
Sierra Leone		1		1
Iran			1	1
Brazil	1			1
Viet Nam	1			1
Nicaragua	1			1
Sweden	1			1
Montenegro	1			1
Thailand	1			1
Mozambique		1		1
Guatemala	1			1
Nepal	1			1
Guinea			1	1
New Zealand	1			1
Albania	1			1
Japan	1			1
Grand Total	**192**	**51**	**46**	**309**

Regional Analysis of Wildfire-Related Mortality and Injuries: Impact on Global Death and Injury Rates

From 2000 to 2023, wildfires had a significant impact on global health, resulting in 1890 fatalities and 14 360 reported injuries. Parsing these figures by region provides a vivid picture of the areas most significantly impacted.

Southern Europe bore the highest toll, with 403 deaths and 2288 injuries. Northern America followed closely with 319 deaths and 960 injuries. Australia and New Zealand reported 243 deaths and 864 injuries. In Northern Africa, there were 226 deaths, whereas Eastern Europe saw 171 deaths and 2375 injuries. South America had 144 deaths and a significant number of injuries, totaling 6178. Table 3 shows the number of wildfire fatalities and injuries per region, from highest to lowest.

Analysis of Fatalities and Injuries from Wildfire Disasters

The devastating toll of wildfire disasters on global communities is further illuminated when examining the aggregate data on fatalities and injuries, as comprehensively detailed in Table 4. This period of scrutiny, from 2000 to 2023, reveals the severe human cost of wildfires, marking a significant concern for global health and safety. Wildfires during this span have led to a harrowing total of 1890 deaths alongside 14 360 injuries, highlighting the destructive potential of these natural disasters and underscoring the critical need for enhanced preventive measures and disaster response strategies.

A breakdown by disaster subtype within Table 4 offers insightful revelations into the nature of these incidents. Forest fires, with 6223 injuries and 1054 fatalities, emerge as the most lethal, underscoring their vast reach and the intense danger they pose to affected communities. Land fires, including brush, bush, and pasture fires, also represent a significant threat, with 4472 injuries and 487 deaths recorded. The category labeled as "(unspecified)"—accounting for

Table 3. Regional death toll from wildfires (2000-2023)

Region	Total deaths	Total injuries
Southern Europe	403	2288
Northern America	319	960
Australia and New Zealand	243	864
Northern Africa	226	291
Eastern Europe	171	2375
South America	144	6178
Southern Africa	105	525
Eastern Asia	75	53
Western Asia	63	375
Eastern Africa	49	28
Southern Asia	39	4
Southeast Asia	19	400
Central Asia	14	0
Middle Africa	12	0
Western Europe	7	16
Western Africa	1	0
Grand Total	**1890**	**14 360**

https://doi.org/10.1017/dmp.2024.150 Published online by Cambridge University Press

Table 4. Summary of injuries and fatalities by wildfire subtype

Disasterd subtype	Sum of injured	Sum of deaths
Forest fire	6223	1054
Land fire (brush, bush, pasture)	4472	487
(Unspecified)	3665	349
Grand total	14 360	1890

instances with unspecified fire types—still reflects substantial impact, with 3665 injuries and 349 fatalities. This categorization underscores the breadth of wildfire-related challenges, pointing to varied environments and conditions under which these disasters occur.

The stark figures presented in Table 4 serve as a compelling call to action. They highlight the urgent need for a concerted effort in combating wildfires, leveraging both technology and traditional knowledge to foster resilience and enhance the capacity of communities to withstand and recover from these increasingly frequent and severe natural calamities. Advanced technologies, such as early warning systems, satellite monitoring, and GIS mapping, play a crucial role in improving the detection, monitoring, and management of wildfires. These technologies enable more accurate predictions of wildfire behavior and facilitate timely responses, potentially reducing the human and environmental toll.

In parallel, traditional knowledge, particularly indigenous fire management practices, has been shown to be effective in wildfire management. Indigenous communities have historically used controlled burns to manage landscapes and reduce fuel loads, preventing larger uncontrolled wildfires. These practices are based on a deep understanding of local ecosystems and have proven their efficacy over centuries.

Combining modern technological advancements with traditional ecological knowledge creates a more holistic and adaptive approach to wildfire management. This integrated strategy not only addresses the immediate threat posed by wildfires but also contributes to long-term ecosystem health and community resilience

Discussion

The comprehensive exploration into the impacts of wildfires on global health from 2000 to 2023 paints a multifaceted picture of the interplay between natural phenomena and human health outcomes. A consistent pattern emerges from our findings, with certain regions experiencing disproportionately higher rates of wildfires and their associated health impacts.

Central to our findings is the undeniable influence of climate change on the frequency and severity of wildfire incidents globally. Climate change, characterized by rising global temperatures, altered precipitation patterns, and increased frequency of extreme weather events is anticipated to significantly heighten wildfire risks.[8] These environmental shifts not only create conditions more susceptible to the ignition and spread of wildfires but also challenge traditional management and mitigation strategies. The interplay between changing climate conditions and wildfires forms a vicious cycle, where wildfires contribute to carbon emissions, further exacerbating global warming.[9] This complex relationship underscores the critical need for integrating climate change adaptation strategies into wildfire risk management and disaster preparedness plans, to effectively address the expected increase in wildfire occurrences and their impacts on human and ecological systems.

Several factors contributed to the heightened vulnerability to wildfires during the early 2000s. Declining forest health due to insect infestations, diseases, and the intrusion of invasive species were significant contributors. For instance, the mountain pine beetle infestation in North American forests and diseases like sudden oak death have weakened trees, increasing the accumulation of dead and dry biomass that serves as fuel for wildfires. Additionally, the intrusion of invasive species such as cheatgrass in the western United States has altered fire regimes by providing continuous fine fuels that facilitate the spread of fires. Furthermore, the encroachment of human communities into forested areas, known as the wildland-urban interface (WUI), has increased the likelihood of human activities igniting fires.

One of the most salient findings was the pronounced frequency of wildfires in the United States, accounting for over a quarter of all incidents. This finding underscores the persistent vulnerability of certain regions to wildfire incidents and highlights the critical need for enhanced, region-specific wildfire management strategies. Although it is well documented that areas like California are particularly susceptible to wildfires due to their unique climatic and vegetative conditions, our study provides empirical data that reinforces the need for continuous adaptation and improvement of existing wildfire management practices. Additionally, the data from our study can be used to identify emerging trends and shifts in wildfire patterns, which are crucial for updating predictive models and improving resource allocation.[1] Furthermore, human interventions and urban encroachments into wild areas, as outlined in our results, have also been identified as exacerbating factors by Geo and colleagues.[10] However, although the United States dominated in terms of frequency, the toll of wildfires on human health, in terms of fatalities and injuries, was more dispersed across regions.[11]

Beyond the health ramifications, wildfires leave a significant economic dent.[12] Destruction of infrastructure, loss of agricultural yield, decreased property values, and long-term costs associated with recovery can cripple local economies.[13] Tourism, a primary revenue source for many forested regions, can be deterred for years after a significant blaze.[14] Understanding the full economic scale of these fires is essential for allocating appropriate funding for prevention, mitigation, and recovery.

Apart from the direct financial impacts, the paramount human toll of these fires is evident across various regions globally.[15] In particular, South America's significant share of injuries due to wildfires stands out as a stark reminder of the intertwined nature of economic activities, deforestation, and human health.[16] Given the extensive Amazon rainforest and other densely vegetated areas in South America, our findings resonate with reports of rampant deforestation leading to subsequent wildfires.[17]

Robinne noted that man-made deforestation activities, often for agriculture or infrastructure development, leave cleared areas prone to wildfires, especially during dry seasons.[18]

Our analysis indicated that forest fires were the dominant subtype of wildfires, comprising 80% of all incidents. This prevalence can be attributed to the dense and continuous fuel available in forest ecosystems, supporting the findings of Bowman et al.[19] Forest fires, being more intense, have often been associated with greater health impacts compared to brush or land fires. Inhalation of smoke from forest fires, particularly, has been linked to respiratory issues, cardiovascular events, and other acute health impacts.[20]

The aftermath of wildfires is not just physical but also societal.[21] Many affected individuals face displacement, often leading to community fragmentation.[22] Mental health issues rise post-wildfire, with survivors grappling with trauma, loss, and the stress of

https://doi.org/10.1017/dmp.2024.150 Published online by Cambridge University Press

rebuilding.[23] The breakdown of social structures, the loss of community spaces, and the nostalgia for what was once "home" can have lingering effects on the psychosocial well-being of individuals.[24]

Southern Europe, Northern America, Australia, and New Zealand stood out in terms of fatalities due to wildfires.[25-28] Forests with dense vegetation and increased human activities, often without appropriate preventive measures, could be potential drivers. A study conducted by Moreira et al. highlighted how regions in Southern Europe, particularly the Mediterranean, faced risks due to the confluence of climatic factors and anthropogenic pressures.[29]

What is intriguing and slightly counterintuitive is the lower frequency of wildfires in African nations despite large parts of the continent having conditions conducive to such disasters. This could be attributed to underreporting or efficient local mitigation strategies, an area that warrants further exploration. To complement this analysis, data from open databases such as Copernicus and NASA, which have extensive records on African fires, could provide additional insights into the frequency and management of wildfires across the continent.[30]

The age of technology has provided us with tools to better predict, monitor, and combat wildfires. Advancements in early warning systems allow communities to prepare or evacuate in advance, potentially saving lives.[31] Modern firefighting technologies, combined with satellite monitoring, enable faster response times and efficient allocation of resources.[32] Harnessing these technological aids is imperative as we continue to grapple with increasing wildfire frequencies.

The holistic management of wildfires necessitates an interdisciplinary approach. It is paramount to recognize that the complexities of wildfire dynamics are not just ecological but interwoven with sociopolitical, technological, and cultural factors.[33] As we strive to formulate effective wildfire prevention and mitigation strategies, it is crucial to integrate insights from fields as varied as ecology, urban planning, social sciences, technology, and even anthropology. For instance, understanding traditional indigenous fire management practices can provide invaluable insights into sustainable land management. Indigenous communities across various regions have, for centuries, used controlled burns to maintain landscapes, demonstrating an intricate understanding of local ecosystems.[34] These traditional methods can be juxtaposed with modern technological solutions, creating a balanced strategy that values both time-tested wisdom and innovative advancements. Furthermore, collaboration across disciplines can help in designing more inclusive policies that consider the socioeconomic realities of vulnerable communities, ensuring that interventions are both efficient and equitable.

Effective policymaking can play a pivotal role in curbing wildfire frequency and impact.[35] Some regions have successfully implemented land management practices and building codes to reduce wildfire risk.[36] In contrast, a lack of enforcement or policies that do not account for local ecological and societal nuances can exacerbate vulnerabilities. Evaluating and revising policies based on their on-ground effectiveness is essential for a resilient future. However, the health impact of wildfires, expressed as direct deaths and injuries, is relatively low compared to the daily amount of burn accidents in homes and domestic fires. The 2016 Global Health Estimate of the World Health Organization (WHO) reported that 152 601 deaths occurred globally related to fire, heat, and hot substances, with almost 75% of them occurring in low-income (LIC) and lower-middle-income countries (LMIC). Most countries have all-risk firefighters, not dedicated forest services, whose attention is naturally focused on the types of incidents that cause the most fire injuries and deaths—home fires. Consequently, they may be reluctant to focus on landscape treatments and activities to make future fires more manageable. With climate change inducing longer fire seasons and drier conditions in several regions of the earth, the whole society must engage in creating more fire-resilient landscapes.[37]

One of the foundational pillars of wildfire prevention is community education and awareness. Empowering communities with knowledge about fire-safe practices, evacuation protocols, and land management can significantly mitigate risks. A well-informed community can act as the first line of defense, identifying potential hazards and responding promptly.[38] Most fatalities occur in the Wildland-Urban Interface (WUI), where human developments are adjacent to wildlands.[39] Early evacuation is crucial in reducing the number of victims, though it may not affect socioeconomic losses and could even worsen them. With rising global temperatures, prolonged droughts, and shifts in precipitation patterns, many regions worldwide are becoming tinderboxes, waiting for the slightest spark. Effective mitigation strategies, including controlled burns, forest management, and stringent regulations on activities in vulnerable areas, must be employed and shared globally.[40-41]

Our findings and the accompanying literature underscore the pressing need for unified global strategies to address the escalating threat of wildfires. Although wildfires may seem local in occurrence, they bear global repercussions, a truth magnified in our interconnected world. A single spark in one region can affect air quality continents away, with smoke traveling thousands of miles and contributing to global health crises. The same fire can hasten the pace of climate change, further compounding the very conditions that led to the fire's outbreak.

International cooperation stands as a cornerstone in addressing the multifaceted challenges posed by wildfires. Various global organizations, including the United Nations, the WHO, and the World Bank, among others, have emphasized the importance of cross-border collaboration in dealing with the rising threat of wildfires.[42-44] Such collaborations can foster knowledge exchange on best practices, resource sharing during emergencies, and the harmonization of policies that respect regional nuances while ensuring global coherence. Countries with extensive experience in handling wildfires can offer expertise and training to regions grappling with newer challenges, thereby building a cohesive global response. Regional alliances, bilateral agreements, and international conventions can further streamline efforts, ensuring that nations are not just reactive but proactively preparing for and preventing large-scale wildfire disasters.[45-48]

The actions and decisions of one nation—be it in forestry management, urban planning, or climate action—can set precedents and ripple out, influencing policies and practices worldwide. This is a clear testament to the boundless reach of local actions in our globalized era. Thus, although lessons must undoubtedly be drawn from regions that have adeptly managed and mitigated wildfires, it is equally crucial for nations to consolidate their efforts, recognizing that the battle against wildfires is a shared one.

In this age of climate change, where boundaries blur and global health remains precariously balanced, the urgency for collective action has never been more palpable. In addressing wildfires, we do not just combat flames, we fight for a sustainable, safe, and shared future for all.

As the data illustrate, the fight against wildfires requires a concerted effort, leveraging both technology and traditional

https://doi.org/10.1017/dmp.2024.150 Published online by Cambridge University Press

knowledge to foster resilience and enhance the capacity of communities to withstand and recover from these increasingly frequent and severe natural calamities. Advanced technologies, such as early warning systems, satellite monitoring, and GIS mapping, play a crucial role in improving the detection, monitoring, and management of wildfires.[49] These technologies enable more accurate predictions of wildfire behavior and facilitate timely responses, potentially reducing the human and environmental toll.[50-51] Our analysis quantifying the direct health impacts of wildfires provides a critical foundation for identifying effective strategies to manage catastrophic fires. The significant number of injuries and fatalities underscores the urgency of integrating advanced early warning systems and traditional ecological knowledge (TEK) into wildfire management practices.[52] Early warning systems, by providing timely alerts and facilitating rapid responses, can significantly reduce the health impacts of wildfires, as evidenced by the lower injury and fatality rates in regions with such systems in place. Similarly, TEK, with its emphasis on controlled burns and landscape management, offers sustainable methods for reducing fuel loads and mitigating wildfire risks. By examining our data in conjunction with these strategies, it becomes clear that a combination of modern technology and traditional practices can offer a robust approach to reducing the catastrophic consequences of wildfires.

In addition to traditional methods, there are other promising approaches to surveillance of deaths and injuries from wildfires. Syndromic surveillance of emergency room events can provide real-time data on health impacts related to wildfires.[53] This method involves monitoring health data that precede diagnosis and signal a potential outbreak or health event, such as increases in respiratory issues during wildfire events. Furthermore, enhanced collaboration between health jurisdictions and national and international organizations, such as the CDC and the WHO, can improve data collection and sharing.[54] These partnerships can facilitate the development of standardized protocols for reporting and analyzing wildfire-related health data, ensuring a more comprehensive and coordinated response to wildfire disasters.

Limitations

This study, although comprehensive in many respects, is subject to several limitations that must be acknowledged. A primary concern is our reliance on the EM-DAT database, a collaboration between CRED and WHO. Despite its widespread recognition and rigorous approach, the database's reliance on a variety of sources ranging from UN agencies to press archives could lead to inconsistencies or discrepancies in the data. This heavy reliance on newspaper and other media reports for information could result in an undercount of the true numbers of wildfire incidents and their impacts, as significant events may go unreported or be underreported, particularly in regions with limited media coverage.

This limitation is especially pertinent in the context of underreporting in low-income countries. Severe wildfires in regions like Central Africa and Southeast Asia are often underrepresented in global databases due to limited media coverage or reporting capabilities, despite evidence of their severity from satellite observations. This leads to a geographical imbalance in our data, where certain regions such as the United States are overrepresented while others are underreported.

Another limitation is the temporal scope of our study, spanning from 2000 to 2023. While this provides a substantial period for analysis, it excludes potentially significant events and trends before 2000. Furthermore, the data, although rich in quantitative information like the number of wildfires and immediate health impacts, lacks detail on aspects such as the severity, duration, and spatial extent of each fire. These details are crucial for a complete understanding of the broader implications of wildfires.

Our focus primarily on direct health impacts also constitutes a limitation, as we did not explore the indirect health consequences of wildfires. The aftermath of wildfires often includes a rise in respiratory issues, mental health challenges, and other long-term health problems. Additionally, the study did not cover the broader economic and environmental repercussions of wildfires, such as infrastructural damage, loss of livelihoods, and long-term environmental degradation.

Lastly, the methodological choices and statistical techniques employed, although rigorous, were not exhaustive. Our approach was predominantly retrospective and quantitative, which, while providing objective insights, could have been enriched by integrating qualitative methods for a more localized context. Furthermore, the use of descriptive statistics leaves room for the application of more advanced statistical or predictive modeling in future research endeavors in this domain.

Conclusions

This study examined the global health impacts of wildfires from 2000 to 2023 using data from the EM-DAT database, revealing that forest fires were the dominant subtype, accounting for 80% of incidents and causing the most significant losses. We documented 1890 deaths and 14 360 injuries, underscoring the severe threat wildfires pose to both the environment and human health.

Our analysis highlighted the geographical variations in wildfire impacts, with regions like the United States, Australia, and Southern Europe experiencing substantial effects. The increased frequency of wildfires, particularly between 2000 and 2002, is linked to adverse climate conditions, increased human activity, and compromised forest health. This pattern stresses the need for comprehensive wildfire risk management strategies, including ecological management, urban planning, and public awareness.

Integrating advanced early warning systems and TEK into wildfire management practices emerged as crucial. Combining these strategies with controlled burns and strategic thinning can significantly reduce wildfire risks.

Future research should include per capita analyses for a more standardized comparison of wildfire impacts across different regions. As climate change progresses, the need for proactive, data-informed measures to mitigate wildfire threats becomes increasingly urgent.

In summary, this study emphasizes the critical importance of continued research and the implementation of effective wildfire management strategies to protect communities and ecosystems.

Data availability statement. The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Acknowledgments. The authors extend their appreciation to the Deputyship for Research & Innovation, Ministry of Education in Saudi Arabia for funding this research work through project number ISP2398.

Author contribution. ZAM provided the main framework, identified and organized primary materials, and collaborated in writing the manuscript. KG identified appropriate references and collaborated on the writing and editing of

https://doi.org/10.1017/dmp.2024.150 Published online by Cambridge University Press

the manuscript. AKM collaborated on the writing and editing of the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding statement. This research received no external funding.

Competing interests. The authors declare no conflicts of interest.

References

1. **To P**, **Eboreime E**, **Agyapong VI.** The impact of wildfires on mental health: a scoping review. *Behav Sci.* 2021;**11**(9):126.
2. **Seneviratne SI**, **Nicholls N**, **Easterling D**, et al. Changes in Climate Extremes and their Impacts on the Natural Physical Environment. In: Field CB, Barros V, Stocker TF, Dahe Q, eds. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press; 2012:109–230.
3. **Williams P**, **Abatzoglou JT**. The impact of anthropogenic climate change on wildfire across western US forests. *Proc Natl Acad Sci U S A*. 2016;**113** (42):11770–11775.
4. **Martinuzzi S**, **Stewart SI**, **Helmers DP**, et al. The 2010 wildland-urban interface of the conterminous United States-geospatial data. *United States Research Map NRS-8*. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station; 2015, 124.
5. **Palinkas LA**. *Global Climate Change, Population Displacement, and Public Health*. Springer; 2020.
6. **Liao Y and Kousky C.** The fiscal impacts of wildfires on California municipalities. *J Assoc Environ Resour Econ.* 2022;**9**(3):455–493.
7. **Borchers Arriagada N**, **Bowman DM**, **Palmer AJ**, et al. Climate change, wildfires, heatwaves and health impacts in Australia. In: *Extreme Weather Events and Human Health: International Case Studies.* 2020:99–116.
8. **Mani ZA**, **Goniewicz K.** Adapting disaster preparedness strategies to changing climate patterns in Saudi Arabia: a rapid review. *Sustainability.* 2023;**15**(19):14279.
9. **Skinner R**, **Luther M**, **Hertelendy AJ**, et al. A literature review on the impact of wildfires on emergency departments: enhancing disaster preparedness. *Prehosp Disaster Med.* 2022**37**(5):657–664. https://doi.org/10.1017/S1049023X22001054
10. **Gao C**, **Feng Y**, **Tong X**, et al. Modeling urban encroachment on ecological land using cellular automata and cross-entropy optimization rules. *Sci Total Environ.* 2020;**744**:140996.
11. **Cowan OS**, **Anderson PM**. Litter decomposition variation across a degradation gradient and two seasons in a critically endangered vegetation type within the Fynbos biome, South Africa. *S Afr J Bot.* 2019;**121**:200–209.
12. **Kim E**, **Kwon YJ**. Analyzing indirect economic impacts of wildfire damages on regional economies. *Risk Anal.* 2023;**43**: 2631–2643. https://doi.org/10.1111/risa.14106.
13. **Maria SF**. Climate change, natural disasters and the spillover effects on unpaid care. In: *Feminist Political Ecology and the Economics of Care: In Search of Economic Alternatives*. Routledge; 2018:70.
14. **Bauman MJ**, **Yuan J**, **Williams HA**. Developing a measure for assessing tourists' empathy towards natural disasters in the context of wine tourism and the 2017 California wildfires. *Curr Issues in Tourism.* 2020;**23**(19):2476–2491.
15. **Incropera FP**. *Climate Change: A Wicked Problem: Complexity and Uncertainty at the Intersection of Science, Economics, Politics, and Human Behavior*. Cambridge University Press; 2016.
16. **Mistry J**, **Schmidt IB**, **Eloy L**, et al. New perspectives in fire management in South American savannas: the importance of intercultural governance. *Ambio.* 2019;**48**:172–179.
17. **Pontes-Lopes A**, **Silva CV**, **Barlow J**, et al. Drought-driven wildfire impacts on structure and dynamics in a wet Central Amazonian forest. *Proc Roy Soc B.* 2021;**288**(1951):20210094.
18. **Robinne FN**. *Impacts of disasters on forests, in particular forest fires*. UNFFS Background paper. New York, NY: United Nations Forum on Forests Secretariat. 2021.
19. **Bowman DM**, **Murphy BP**, **Neyland DL**, et al. Abrupt fire regime change may cause landscape-wide loss of mature obligate seeder forests. *Glob Change Biol.* 2014;**20**(3):1008–1015.
20. **Robinne FN**, **Burns J**, **Kant P**, et al. *Global fire challenges in a warming world*. Vienna, Austria: IUFRO; 2018.
21. **Tedim F**, **McCaffrey S**, **Leone V**, et al. Supporting a shift in wildfire management from fighting fires to thriving with fires: the need for translational wildfire science. *For Policy Econ.* 2021;**131**:102565.
22. **Moritz MA**, **Batllori E**, **Bradstock RA**, et al. Learning to coexist with wildfire. *Nature.* 2014;**515**(7525):58–66.
23. **Tedim F**, **Leone V**, **Amraoui M**, et al. Defining extreme wildfire events: difficulties, challenges, and impacts. *Fire.* 2018;**1**(1):9.
24. **Castellnou M**, **Prat-Guitart N**, **Arilla E**, et al. Empowering strategic decision-making for wildfire management: avoiding the fear trap and creating a resilient landscape. *Fire Ecol.* 2019;**15**:1–7.
25. **Mani ZA**, **Khorram-Manesh A**, **Goniewicz K**. Global health emergencies of extreme drought events: Historical impacts and future preparedness. *Atmosphere* 2024; **15**: 1137. https://doi.org/10.3390/atmos15091137.
26. **Kitzberger T**, **Perry GL**, **Paritsis J**, et al. Fire–vegetation feedbacks and alternative states: common mechanisms of temperate forest vulnerability to fire in southern South America and New Zealand. *New Zeal J Bot.* 2016; **54**(2):247–272.
27. **Hagmann RK**, **Hessburg PF**, **Prichard SJ**, et al. Evidence for widespread changes in the structure, composition, and fire regimes of western North American forests. *Ecol Appl.* 2021;**31**(8):e02431.
28. **Duane A**, **Castellnou M**, **Brotons L.** Towards a comprehensive look at global drivers of novel extreme wildfire events. *Clim Change.* 2021;**165** (3-4):43.
29. **Moreira F**, **Ascoli D**, **Safford H**, et al. Wildfire management in Mediterranean-type regions: paradigm change needed. *Environ Res Lett.* 2020;**15**(1):011001.
30. **Roteta E**, **Bastarrika A**, **Padilla M**, et al. Development of a Sentinel-2 burned area algorithm: generation of a small fire database for sub-Saharan Africa. *Remote Sens Environ.* 2019;**222**:1–7.
31. **Goniewicz K**, **Burkle FM**. Disaster early warning systems: the potential role and limitations of emerging text and data messaging mitigation capabilities. *Disaster Med Public Health Prep.* 2019;**13**(4):709–712.
32. **Sun L**, **Wan L**, **Wang X.** Learning-based resource allocation strategy for industrial IoT in UAV-enabled MEC systems. *IEEE Trans Industr Inform.* 2020;**17**(7):5031–5040.
33. **Alexandra J.** Designer ecosystems for the Anthropocene—deliberately creating novel ecosystems in cultural landscapes. *Sustainability.* 2022;**14** (7):3952.
34. **Bardsley DK**, **Prowse TA**, **Siegfriedt C.** Seeking knowledge of traditional Indigenous burning practices to inform regional bushfire management. *Local Environ.* 2019;**24**(8):727–745.
35. **Pandey P**, **Huidobro G**, **Lopes LF**, et al. A global outlook on increasing wildfire risk: current policy situation and future pathways. *Trees For People.* 2023;**14**:100431. https://doi.org/10.1016/j.tfp.2023.100431.
36. **Cowie AL**, **Berndes G**, **Bentsen NS**, et al. Applying a science-based systems perspective to dispel misconceptions about climate effects of forest bioenergy. *GCB Bioenergy.* 2021;**13**(8):1210–1231.
37. **Gibson C**, **Bessey PQ**, **Gallagher JJ**. The global burn registry: a work in progress. *J Burn Care Res.* 2020;**41**(5):929–934.
38. **Khorram-Manesh A.** Flexible surge capacity–public health, public education, and disaster management. *Health Promot Perspect.* 2020;**10**(3):175.
39. **Hayhoe K.** *Saving Us: A Climate Scientist's Case for Hope and Healing in a Divided World*. Simon and Schuster; 2021.
40. **Goniewicz K**, **Khorram-Manesh A**, **Burkle FM**. Beyond boundaries: addressing climate change, violence, and public health. *Prehosp Disaster Med.* 2023;**38**(5):551–554.
41. **Hessburg PF**, **Prichard SJ**, **Hagmann RK**, et al. Wildfire and climate change adaptation of western North American forests: a case for intentional management. *Ecol Appl.* 2021;**31**(8):e02432.
42. **Dasandi N**, **Graham H**, **Lampard P**, et al. Intergovernmental engagement on health impacts of climate change. *Bull World Health Organ.* 2021; **99**(2):102.
43. **Roos EJ**. Call for leadership: climate change and the future health of girls. *J Pediatr Adolesc Gynecol.* 2022;**35**(2):107–108.
44. **Gallagher C**, **Fenton H.** From Amazon floods and Australian wildfires to human spills and explosions: what disasters mean to wildlife. In:

Wildlife Population Health. Springer International Publishing; 2022: 129–143.

45. **Khorram-Manesh A**, **Goniewicz K**, **Burkle Jr FM.** Unleashing the global potential of public health: a framework for future pandemic response. *J Infect Public Health*. 2024;**17**(1):82–95. https://doi.org/10.1016/j.jiph.2023.10.038.
46. **Goniewicz K**, **Khorram-Manesh A**, **Burkle FM**, et al. The European Union's post-pandemic strategies for public health, economic recovery, and social resilience. *Glob Transit.* 2023;**5**:201–209.
47. **Gautam U**, **Tewari DB**. Regulatory framework for regional cooperation on disaster risk reduction (DRR) in India and globe. In: *Making India Disaster Resilient: Challenges and Future Perspectives*. Springer International Publishing; 2024:297–311.
48. **Wojakowska M**, **Gromek P**, **Sobolewski G.** The North Atlantic Treaty Organisation and disaster risk reduction in shaping national security. In: *Shaping National Security*. Routledge; 2024:65–89.
49. **Kumsa A**, **Feyisso F.** Applications of geospatial science and technology in disaster risk management. *J Robot Auto Res.* 2022;**3**(3):270–281.
50. **Vásquez F**, **Cravero A**, **Castro M**, et al. Decision support system development of wildland fire: a systematic mapping. *Forests.* 2021;**12**:943.
51. **Morgan GW**, **Tolhurst KG**, **Poynter MW**, et al. Prescribed burning in southeastern Australia: history and future directions. *Aust Forestry*. 2020;**83**(1):4–28.
52. **Newman R.** Human dimensions: traditional ecological knowledge—Finding a home in the ecological society of America. *Bull Ecol Soc Am.* 2021; **102**(3):e01892.
53. **Boroujeni SP**, **Razi A**, **Khoshdel S**, et al. A comprehensive survey of research towards ai-enabled unmanned aerial systems in pre-, active-, and post-wildfire management. *Inf Fusion.* 2024:102369.
54. **Goniewicz K**, **Khorram-Manesh A**, **Burkle F.** Navigating climate challenges: strategic directions for a sustainable future. *Health Probl Civiliz.* 2024. doi:10.5114/hpc.2024.140255

https://doi.org/10.1017/dmp.2024.150 Published online by Cambridge University Press