Original Article

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Global prevalence of natural disaster-induced acute respiratory infections: A systematic review and meta-analysis of 290,380 participants

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Abstract

Acute respiratory infections (ARI) can be caused by the occurrence of natural disasters such as earthquakes, volcanic eruptions, landslides, tsunamis, floods, and droughts. The aim of this study was to determine the global prevalence of acute respiratory infections during post-natural disasters across countries. A systematic review and meta-analysis were conducted in accordance with the PRISMA guidelines. Studies reporting acute respiratory infections prevalence in natural disaster-impacted areas were identified and screened from PubMed, Scopus, Crosreff, Scilit, and medRxiv as of March 16th, 2024. The meta-analysis was conducted using the Freeman-Tukey double arcsine transformation with a random-effects model. A total of 15 out of 2,052 studies, covering 290,380 subjects, were included in the meta-analysis. The pooled estimate of acute respiratory infection prevalence following natural disasters across multiple countries was 43.0% (95% confidence interval (CI): 31–55%; p-Het<0.01; I^2=99.97%). No statistical significance was observed between subgroups, including population density (p=0.281), country income (p=0.583), and types of disasters (p=0.468), suggesting the indiscriminate nature of disaster-induced acute respiratory infections. The highest prevalence was observed in studies from 2015–2019, with a prevalence of 52% (95%CI: 32.7–72.2%; p-Het<0.001; I^2=99.97%). In conclusion, the global prevalence of disaster-induced ARI is considered high, reaching 43%, highlighting the need for countermeasures to address these diseases during disasters.

Keywords: Natural disaster, tsunami, earthquake, acute respiratory infection, post-disaster infection

Introduction

Natural disasters, such as earthquakes, volcanic eruptions, landslides, tsunamis, floods, and droughts, are major events with catastrophic effects on health, society, and the economy. Over the past two decades, natural disasters have killed millions and affected billions, causing significant damage [1]. From 2011–2015, the top five countries with the highest disaster-related mortality rates were Liberia (224.5 per million), Sierra Leone (123.8 per million), Dominica (82.8 per million), Nepal (72.3 per million), and Guinea (40.3 per million) [1]. In this light, developing countries are more severely impacted due to limited resources and infrastructure [2].

Natural disasters may lead to infectious disease outbreaks when they cause substantial population displacement and exacerbate synergic risk factors for disease transmission. Natural

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disasters can significantly impact respiratory health, particularly in children. These events often lead to increased air pollution, which is associated with a higher risk of acute respiratory infections (ARIs) [3]. ARIs remain a predominant cause of acute illnesses globally, exerting a significant impact on public health systems and communities worldwide [4,5]. Primary causative organisms associated with ARIs in children include *Streptococcus pneumoniae, Haemophilus influenza*, respiratory syncytial virus (RSV), and parainfluenza virus [6,7]. Among older adults, pneumonia resulting from influenza continues to be a leading contributor to mortality [6,8]. ARIs are a significant health concern among displaced populations, exacerbated by limited access to healthcare and antimicrobial treatments. Risk factors for these populations include overcrowding, indoor cooking with open flames, and poor nutrition [7,9]. Crowding, which is common among populations displaced by natural disasters, can facilitate the spread of communicable diseases [10].

After the 2011 earthquake and tsunami in Japan, two influenza outbreaks occurred, with a total of 25 diagnosed patients and an attack rate of 1.8% [11]. At Tatekoshi Elementary School, 20 individuals were diagnosed with influenza, resulting in a 10.0% attack rate [11]. Similar trends of increased ARIs were observed after natural disasters such as Hurricane Mitch, the Aceh tsunami, and the Pakistan earthquake [7,9]. During Hurricane Katrina, ARIs prevalence surged notably, reaching 12% within four days and escalating to 20% over four weeks [12]. ARI outbreaks documented post-disaster had attack rates of 10% and 15% at shelters [11-15]. A cross-sectional study conducted in the Netherlands reported an 88% prevalence of ARIs during flooding events [16]. Despite the evidence of increased ARI prevalence during post-natural disasters, none of the previous literature has estimated the global prevalence. Understanding the global prevalence of disaster-induced ARI is essential, as it can serve as a parameter to determine the level of health system resilience against disasters. Moreover, the prevalence could be used as the basis to conduct preventive measures against certain diseases, particularly communicable respiratory diseases. The aim of this study was to estimate the global prevalence of disaster-induced ARI through a systematic review and meta-analysis.

Methods

Study design

A systematic review and meta-analysis were conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The research questions were formulated as follows: (a) What is the incidence and distribution of ARIs following natural disasters on a global scale? (b) What are the key factors influencing ARIs post natural disasters prevalence and impact?

Search strategy

A systematic search of the literature was conducted across five scientific databases: PubMed, Scopus, medRxiv, Scilit, and Crossref. The search included records from the inception of each respective database through March 16, 2024. Boolean operators and MeSH terms were used when applicable. The main keywords, 'natural disaster' and 'acute respiratory infection,' were later developed into a full search strategy, which is presented in **Table 1**.

Study eligibility criteria

The eligibility criteria were pre-designed, based on the PECOS framework (Population, Exposure, Control, Outcome, and Study designs), before the literature screening to ensure an unbiased review. The population (P) was individuals affected by natural disasters; exposure (E) was the natural disaster; control (C), if applicable, was individuals who did not acquire an ARI; outcome (O) was individuals who acquired ARI after the disaster; and study designs (S) were cohort or cross-sectional studies. Studies predetermining the ARI and non-ARI cases before the study (such as case-control studies) were excluded. Natural disasters are defined as events that occur naturally and cause massive destruction or require evacuation, including earthquakes, floods, tsunamis, typhoons, storms, wildfires, and tropical cyclones. Studies with full text that were not accessible or written in non-English languages were excluded. In cases where prevalence rates were reported without the exact number of cases and sample sizes, the corresponding authors were contacted. Studies were excluded if no response was received. Exclusion was also applied to editorials, commentaries, conference abstracts, and case reports or case series.

Table 1. Keyword combinations used in different databases

Database	Combination of keywords
PubMed	(Natural disasters OR Earthquake OR Tornado OR Storm OR Flood OR Volcanic Eruption OR Forest Fire OR Tsunami OR Landslide OR Drought OR Strong Winds OR Snowstorm OR Cyclone OR Blizzard OR Typhoon OR Hurricane AND Acute Respiratory Infection OR Influenza OR Flu OR Grippe OR Common Cold OR Coryza OR Pneumonia OR Pneumonitis OR Pneumonias OR Lung Inflammation OR Bronchitis OR Sinusitis OR Sinusitides OR Sinus Infection OR Pharyngitis OR Pharyngitides OR Croup OR Respiratory Syncytial Virus OR RSV Infection OR Epiglottitis OR Epiglottitides OR Laryngotracheitis OR Cough OR Rhinitis OR Rhinitides OR Nasal Cattarh OR Tonsillitis OR COVID-19 OR SARS COV 2 Infection OR Sore Throat)
Scopus	(Natural disaster* OR Earthquake OR Tornado OR Storm OR Flood OR Volcanic Eruption* OR Forest Fire OR Tsunami OR Landslide OR Drought OR Strong Winds OR Snowstorm OR Cyclone OR Blizzard OR Typhoon OR Hurricane AND Acute Respiratory Infection OR Influenza OR Flu OR Grippe OR Common Cold OR Coryza OR Pneumonia OR Pneumonitis OR Pneumonias OR Lung Inflammation OR Bronchitis OR Sinusitis OR Sinusitides OR Sinus Infection OR Pharyngitis OR Pharyngitides OR Croup OR Respiratory Syncytial Virus OR RSV Infection OR Epiglottiti* OR Laryngotracheitis OR Cough OR Rhiniti* OR Nasal Cattarh OR Tonsillitis OR COVID-19 OR SARS-COV-2 Infection OR Sore Throat AND NOT cytokine storm OR thyroid storm)
Scilit	Natural Disaster AND Acute Respiratory Infection
Crossref	(Natural disasters OR Earthquake OR Tornado OR Storm OR Flood OR Volcanic Eruption OR Forest Fire OR Tsunami OR Landslide OR Drought OR Strong Winds OR Snowstorm OR Cyclone OR Blizzard OR Typhoon OR Hurricane AND Acute Respiratory Infection OR Influenza OR Flu OR Grippe OR Common Cold OR Coryza OR Pneumonia OR Pneumonitis OR Pneumonias OR Lung Inflammation OR Bronchitis OR Sinusitis OR Sinusitides OR Sinus Infection OR Pharyngitis OR Pharyngitides OR Croup OR Respiratory Syncytial Virus OR RSV Infection OR Epiglottitis OR Epiglottitides OR Laryngotracheitis OR Cough OR Rhinitis OR Rhinitides OR Nasal Cattarh OR Tonsillitis OR COVID-19 OR SARS COV 2 Infection OR Sore Throat)
medRxiv	Natural Disaster AND Acute Respiratory Infection

Screening and selection

The screening and selection were divided into two stages. The first stage included identification, duplicate removal, and title and abstract screening. The duplicate removal was performed using Zotero Desktop (Digital Scholarship, Virginia, USA). The second stage involved full-text retrieval and full-text screening, in which the eligibility criteria were applied. The two stages were performed by the same two independent investigators (MBD and MHG), where disagreements were resolved by revisiting the article or consultation with the third investigator (FK) if a consensus was not reached.

Data extraction and synthesis

Study characteristics, including population (female to male ratio), age, post-disaster time, country income, type of disaster, and type of ARI, were extracted from articles that were pre-selected. Continuous data are presented as mean values accompanied by their standard deviations (SD). Median data were transformed into mean values with their corresponding SD utilizing (available at https://www.math.hkbu.edu.hk/~tongt/papers/median2mean.html).

Risk of bias assessment

The assessment of survey or cross-sectional studies was performed using the standardized quality assessment checklist for survey studies in psychology (Q-SSP), consisting of 20 checklist items [17]. Studies were marked as having high quality if they passed a minimum score of 70%. The score was determined by the percentage of 'Yes' responses. The use of this tool is in accordance with a previous study [18]. Meanwhile, the quality of the cohort studies was assessed using the Newcastle-Ottawa Scale (NOS), as recommended by a previous study [19]. Risk of bias

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assessment was performed by one investigator (MBD), with the results independently verified through an agreement with the second investigator (FK). The third reviewer (MHG) was involved in a consultation in case of disagreements.

Statistical analysis

Meta-analysis was conducted using Jamovi version 2.4.14 (https://www.jamovi.org/) and Comprehensive Meta-Analysis (CMA) version 3 software (Biostat, Englewood, USA). The pooled data was considered heterogeneous if $I^2>50\%$ or $p<0.1$. The restricted maximum-likelihood model and Freeman-Tukey double arcsine transformation (FTT) with a random-effects model were used to obtain the total proportion. The prevalence was estimated by multiplying the total proportion by 100%. Publication bias was measured based on Egger's test and Begg's funnel plot. Stratification analysis was carried out on the following covariates: population density, country income, type of disaster, and year. Population density was obtained from the Worldometer website (https://www.worldometers.info/), and the country's income was obtained from data provided by the World Bank [20]. Statistical significance between covariates was estimated using Z-statistics, with $p<0.05$ was used as the significance threshold.

Results

Searching results

The systematic search identified 2,052 published papers, with 670 duplicates removed. Following a review of titles and abstracts, 1,254 articles were excluded due to their lack of relevance to the research question. Subsequently, 128 studies underwent full-text screening, resulting in the elimination of 46 studies that did not meet the eligibility criteria. Consequently, 15 studies [15,16,21-33] were included in the systematic review and meta-analysis. The process of screening and selection of articles is outlined in the PRISMA flow chart (**Figure 1**). The included studies [15,16,21-33] covered a total of 290,380 individuals impacted by natural disasters, among whom there were 109,393 reported cases of ARI.

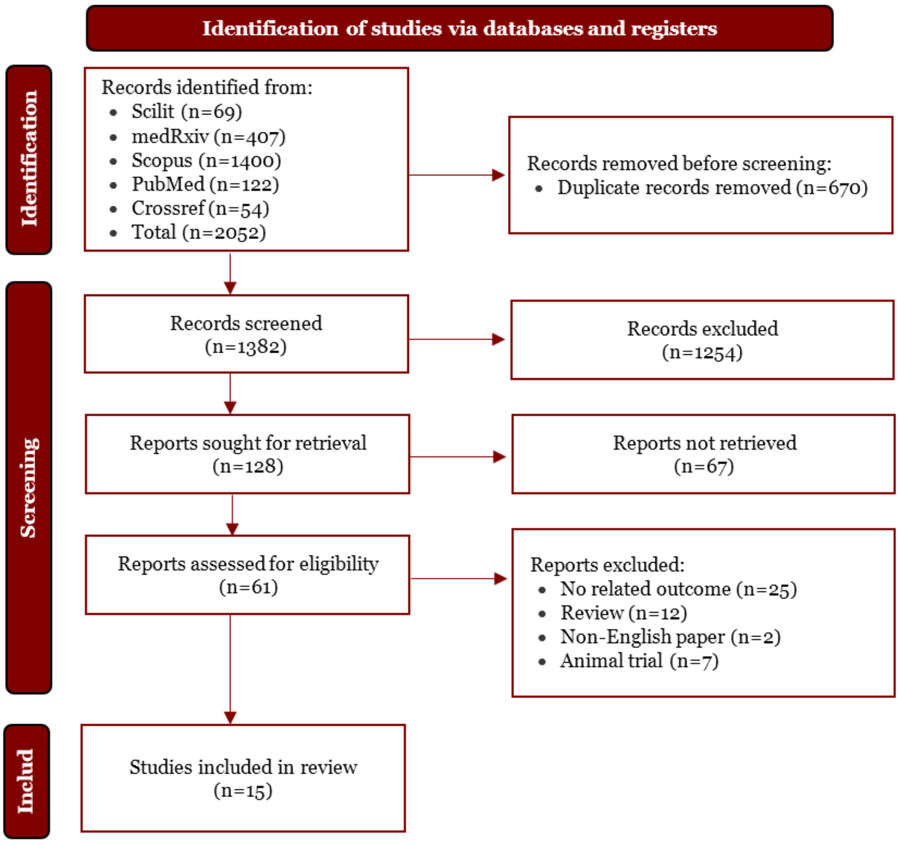

Figure 1. PRISMA diagram for the screening and selection process of published studies.

Characteristics and the quality of the included studies

Characteristics of the included studies, along with their quality, are presented in **Table 2**. A total of 15 studies were included, with a total sample size of 290,380 people affected by natural disasters. The studies originated from Japan (n=7), the Netherlands (n=2), the Philippines (n=1), India (n=1), the United States (n=2), Bangladesh (n=1), and Nepal (n=1). Detailed assessment results based on Q-SSP tools and NOS are presented in **Table 2**.

Prevalence of disaster-induced ARI

The global prevalence of disaster-induced ARI was estimated through a pooled proportion analysis comprising 15 studies with 26 scenarios. The results of this pooled proportion are presented as a forest plot in **Figure 2**.

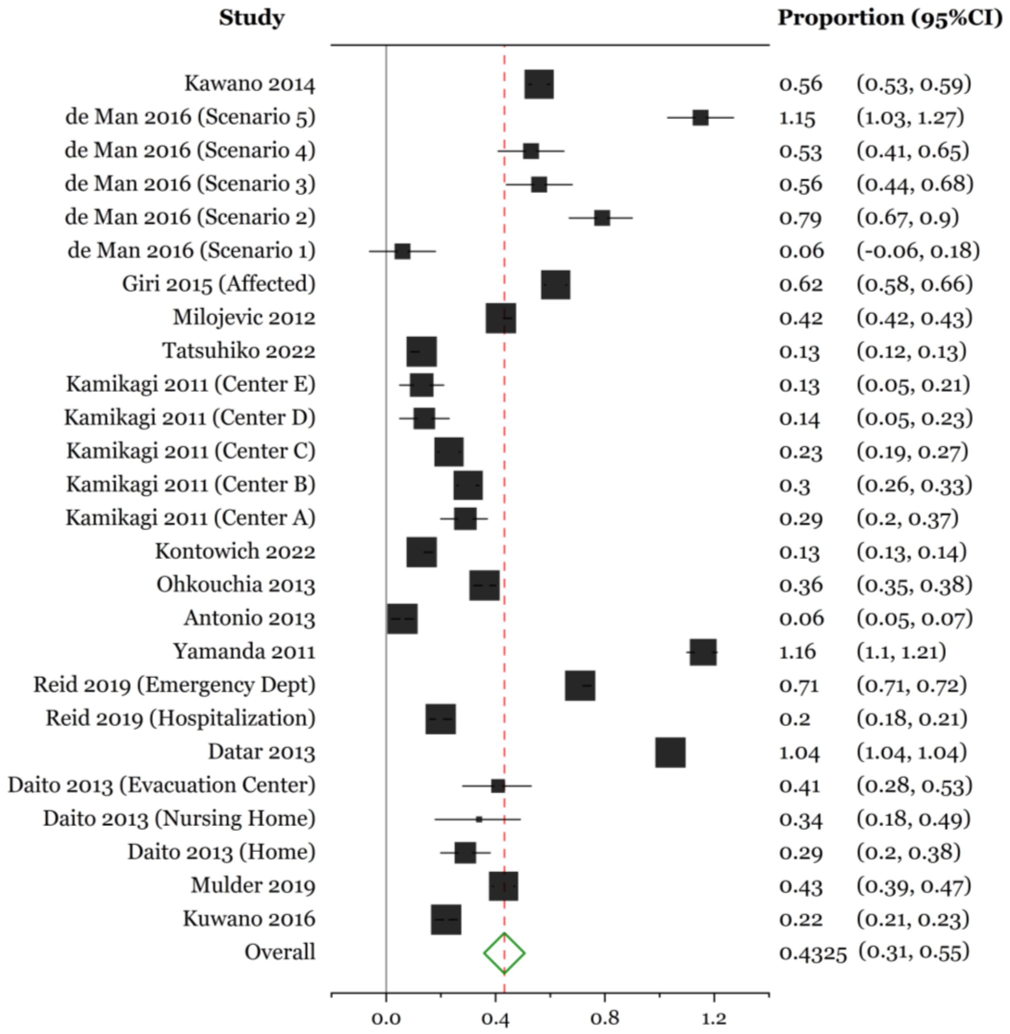

Figure 2. Forest plot for acute respiratory infections (ARI) prevalence during disasters. p-total<0.01; ARI prevalence 43.0% (95%CI: 31–55%); p-heterogeneity <0.01; I^2=99.97%.

The pooled proportion for disaster-induced ARI was found to be 0.43 (95%CI: 0.31–0.55%), hence the prevalence was 43% (95%CI: 31–55%). High heterogeneity was observed in this pooled analysis with I^2=99.97% and p<0.001. Based on a meta-regression with sample size as the covariate, it was revealed that the proportion was affected by the sample size (**Figure 3**). A higher sample size was found to be more likely yielding higher prevalence with R^2=0.54 and p<0.001 (**Figure 3**).

Publication bias

Publication bias was observed through an inverted funnel plot, which is presented in **Figure 4**. The analyses revealed the asymmetrical shape of the funnel plot, with p=0.006 in the rank correlation test, suggesting the presence of publication bias.

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Table 2. Characteristics and quality of the included studies

Author, year	Country	Study design	Sample size, n	Post-disaster time (weeks)	Population density (km²)	Country income	Type of disasters	Type of ARI	Quality of SSP
Kawano *et al.* 2016 [23]	Japan	Retrospective study	7,439	3	338	High	Earthquake and tsunami	ARI	33%
Mulder *et al.* 2019 [16]	Netherlands	Cross-sectional survey	699	2	42	High	Flood	ARI	75%
Daito H *et al.* 2013 [25]	Japan	Observational study	217	16	338	High	Earthquake and tsunami	Pneumonia	61%
Datar *et al.* 2013 [34]	India	Retrospective descriptive	109,032	2	481	Lower-middle	Earthquake, flood, storm, wildfire	ARI	55%
Reid *et al.* 2019 [30]	USA	Retrospective study	13,814	20	16	High	Wildfire	ARI	30%
Yamanda *et al.* 2011 [21]	Japan	Cross-sectional study	1,769	8	338	High	Earthquake	Pneumonia	55%
Salazar *et al.* 2013 [32]	Philippines	Descriptive analysis	4,645	21	394	Lower-middle	Earthquake, typhoon, flood	Cough, colds with or without fever	44%
Ohkouchia *et al.* 2013 [24]	Japan	Cross-sectional study	2778	4	338	High	Earthquake	Community acquired pneumonia, influenza	44%
Kontowich *et al.* 2022 [27]	USA	Descriptive study	62,277	48	37	High	Flood	Influenza	55%
Kamikagi *et al.* 2011 [35]	Japan	Descriptive study	1,810	4	338	High	Earthquake	Influenza	67%
Kubo *et al.* 2022 [36]	Japan	Descriptive study	17,098	16	338	High	Tropical cyclone	ARI	55%
Milojevic *et al.* 2012 [31]	Bangladesh	Cohort studies	66,777	240	1329	High	Flood	ARI	Good (NOS: 9)
Giri *et al.* 2015 [20]	Nepal	Descriptive study	586	16	216	Lower-middle	Earthquake	ARI	77%
de Man *et al.* 2016 [22]	Netherlands	Cross-sectional survey	272	4	42	High	Flood	Influenza	55%
Kawano *et al.* 2014 [15]	Japan	A retrospective study	1167	4	338	High	Earthquake	ARI	55%

ARI: acute respiratory infections; NOS: Newcastle ottawa scale; SSP: survey studies in psychology

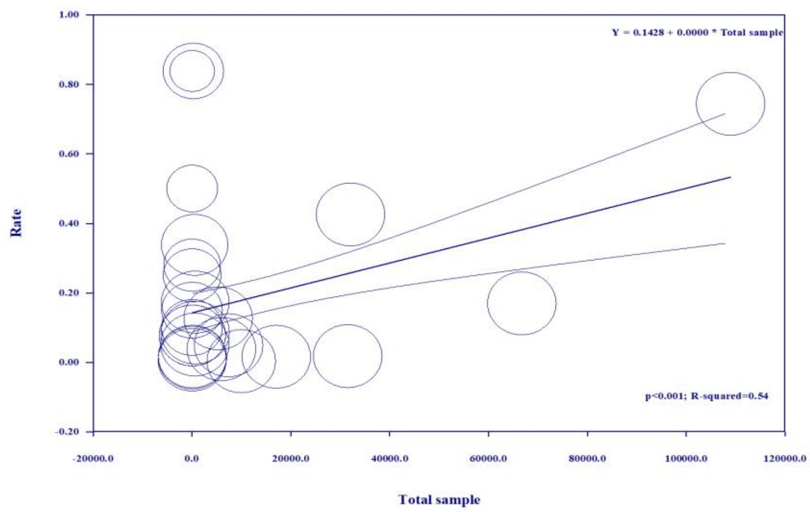

Figure 3. Bubble plot for the meta-regression of the disaster-induced ARI prevalence as affected by the total sample size. p<0.001; R^2=0.54.

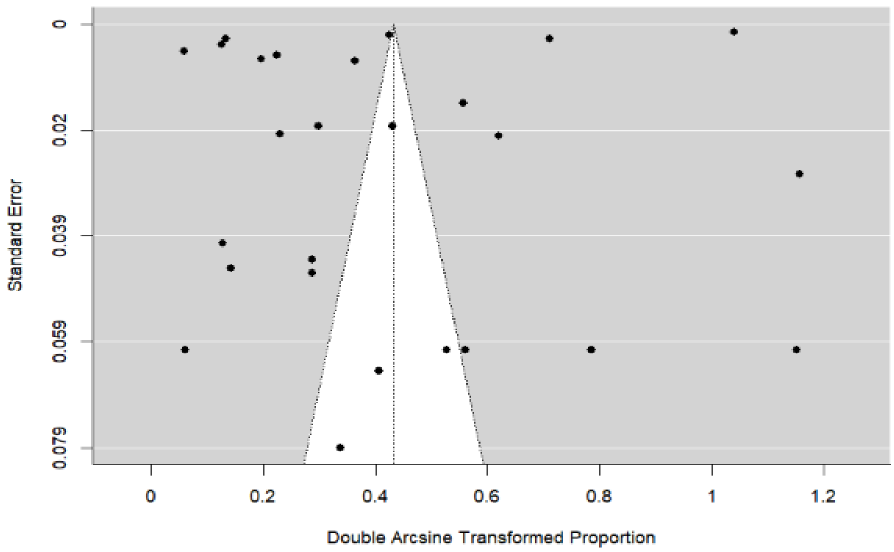

Figure 4. Funnel plot for the acute respiratory infections prevalence during disasters. Rank correlation test p=0.006.

Sensitivity test

The sensitivity of pooled estimates was observed through leave-one-out analysis, with the forest plot presented in **Figure 5**. The prevalence ranged from 40.2% (95%CI: 29–51.5%) obtained when Yamanda *et al.* 2011 [21] was removed to 44.7% (95%CI: 32.3–57.1%) when Salazar *et al.* 2013 [32] was removed. Overall, no significant changes were observed throughout the analysis, indicating the stability and reliability of the pooled estimates.

Stratification analysis

We further stratified the pooled estimate of prevalence based on several variables, with the results presented in **Table 3**. The results suggested that all covariates, such as population density (p=0.281), country income (p=0.583), and type of disaster (p=0.468) did not show statistically significant differences in prevalence. The prevalence of disaster-induced ARI in 2015–2019 was the highest (52%), but it was not statistically different from previous years (41%, p=0.275).

Table 3. Stratification analysis based on the characteristics of participants

Variable	Study, n (%)	Sample, n	Prevalence (95%CI) (%)	Sub-groups *p*-value	I^2 (%)	*p*-Het
Population density						
≥338 km²	16	219096	38 (22.7–53.2)	0.281	99.97	<0.001
<338 km²	10	71284	52 (31.2–72.0)		99.95	<0.001
Country income						
High	23	170762	41 (29.0–53.5)	0.583	99.95	<0.001
Lower-middle	3	119618	57 (1.5–113.1)		99.99	<0.001
Types of disasters						
Water-related	8	1618	51 (26.7–74.7)	0.468	99.97	<0.001
Non-water related	12	64321	40 (22.7–57.7)		99.93	<0.001
Year						
2010–2014	14	194559	41 (12.6–13.5)	Ref.	99.97	<0.001
2015–2019	10	47168	52 (32.7–72.2)	0.275	99.9	<0.001
2020–2024	2	48653	13 (12.6–13.5)	0.388	65.05	0.091

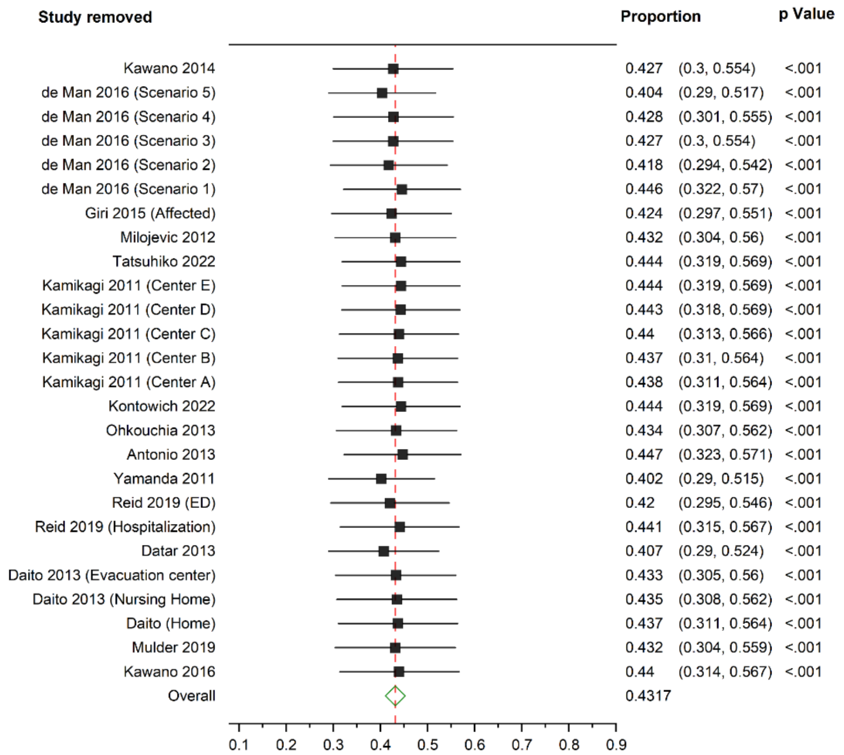

Figure 5. Forest plot for leave-one-out analysis to observe the sensitivity of overall ARI prevalence.

Discussion

The current study's findings suggest that during natural disasters, the prevalence of ARIs could soar as high as 43%, based on data from 15 studies encompassing 109,393 ARI cases across various countries. Notably, this meta-analysis marks the first attempt to quantify ARI prevalence due to natural disasters across multiple nations. The cumulative prevalence of ARIs in both developed and developing countries typically ranges from 20% to 30%, indicating that disaster environments are more conducive to ARI outbreaks [37]. The study also found no significant difference in prevalence between high and lower-middle-income countries. However, lower-middle-income populations are generally more vulnerable to higher prevalence rates of diseases caused by natural disasters. This vulnerability is primarily due to limited resources for disaster preparedness, inadequate infrastructure, and restricted access to healthcare. Consequently, these communities are more likely to experience higher rates of illness and mortality following natural disasters, which further exacerbates the cycle of poverty and hinders economic recovery.

Individual studies included in the present review revealed that ARI incidence notably decreased when individuals avoided direct contact with floodwaters [23]. Conversely, subjects affected by disasters exhibited a higher ARI prevalence compared to those unaffected. However, it's essential to highlight that even the non-affected community in one study displayed an ARI prevalence of 50%, surpassing the pooled estimate obtained in the present study [21].

The heightened susceptibility to respiratory infections post-natural disasters is attributed to the myriad environmental shifts in the aftermath [38]. The repercussions of natural disasters consistently disrupt societal structures and daily life [39]. As per the findings of the studies incorporated in this analysis, earthquakes and floods stand out as the predominant catalysts for ARIs. The rapid spread of ARIs during such crises can primarily be traced back to overcrowded shelters. Mitigating this issue involves tackling issues such as overcrowding, insufficient heating, and shortages of crucial supplies within these shelters [9].

Respiratory problems emerge as a prominent cause of mortality during diverse natural disasters, such as forest fires and volcanic eruptions, primarily due to the release of harmful airborne particles. Volcanic eruptions, in particular, present a substantial risk to lung health due to exposure to toxic gases and ash particles emitted from volcanic vents, thereby increasing the likelihood of respiratory issues. Inhalation-related consequences include the development of airway fibrinous casts and damage to the alveoli, exacerbating respiratory morbidity [40].

Respiratory infections can persist for days, weeks, or even months following a disaster due to widespread population displacement and increased risk factors for disease transmission. Even in disasters primarily causing health issues through direct means, such as earthquakes, respiratory infections significantly contribute to mortality rates. In the aftermath of the Marmara earthquake, trauma victims, particularly those suffering from crush syndrome, encountered the most severe complications, notably hospital-acquired infections like wounds and pulmonary infections, which correlated with heightened mortality rates. Identifying the causes of ARI and pneumonia proves challenging in such circumstances due to the difficulty in obtaining adequate specimens for microbiological diagnosis[2]. Common respiratory pathogens observed in post-disaster settings include viral strains such as influenza, respiratory syncytial virus (RSV), and adenoviruses, bacterial agents like *Streptococcus pneumoniae*, pertussis, and tuberculosis, as well as diseases transmitted through respiratory routes, such as measles and varicella [41].

The strength of our study includes our systematic approach to gathering data from peer-reviewed reports indexed in various databases. We also employed Q-SSP and NOS to appropriately appraise the quality of the included studies. FTT used in the present study is a sophisticated statistical analysis in performing pooled estimation of rates or prevalence, which could overcome the variety in the research setting of each study. However, there are some limitations. Firstly, we did not identify reports from informal sources such as reports from government agencies or non-government organizations and unpublished reports from renowned researchers in the field. Secondly, the interpretation of our data is limited by the high heterogeneity, which suggests a moderate level of evidence in this present study. Moreover, the real prevalence of ARI is likely to be higher than estimated in the present study, as suggested by the results of the meta-regression. To overcome these challenges, calculations of ARI during disasters should be carried out by researchers around the globe. It is clear that more research to determine the ARI prevalence on a large scale is required to obtain a precise estimation.

Conclusion

The prevalence of ARI during disasters is collectively 43%, which is relatively higher compared to normal conditions. We recommend the deployment of healthcare facilities and medicines to mitigate the increase in ARI incidences. Protective personal equipment should be worn by the medical personnel to prevent the nosocomial transmission of airborne diseases.

Ethics approval

This study is a systematic review and meta-analysis that uses publicly available data from previously published studies. It does not involve new data collection from human participants or animals, so no additional ethical approval is required.

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None to declare.

Competing interests

All the authors declare that there are no conflicts of interest.

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Underlying data

Derived data supporting the findings of this study are available from the corresponding author on request.

Declaration of artificial intelligence use

This study used artificial intelligence (AI) tools and methodologies in the following capacity for manuscript writing support: AI-based language models, such as ChatGPT was employed to language refinement (improving grammar, sentence structure, and readability of the manuscript). We confirm that all AI-assisted processes were critically reviewed by the authors to ensure the integrity and reliability of the results. The final decisions and interpretations presented in this article were solely made by the authors.

How to cite

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