Review article

Climate change impacts on the health of South Asian children and women subpopulations - A scoping review

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ABSTRACT

Background and objectives: Climate change impacts are felt unequally worldwide; populations that experience geographical vulnerability, those living in small island states and densely populated coastal areas, and children and women are affected disproportionately. This scoping review aims to synthesize evidence from relevant studies centred on South Asia, identify research gaps specifically focused on children and women's health, and contribute to knowledge about South Asia's existing mitigation and adaptation strategies.
Methods: A research librarian executed the search on six databases using controlled vocabulary (e.g., MeSH, Emtree, etc.) and keywords representing the concepts "vulnerable populations" and "climate change" and "health impacts" and "South Asia." Databases were searched from January 2010 to May 2020. Papers were screened independently by two researchers.
Results: Forty-two studies were included, of which 23 were based in India, 14 in Bangladesh, and five in other South Asian countries. Nineteen studies focused on meteorological factors as the primary exposure. In contrast, thirteen focused on extreme weather events, nine on air pollution, and one on salinity in coastal areas. Thirty-four studies focused on the health impacts on children related to extreme weather events, meteorological factors, and air pollution, while only eight studies looked at health impacts on women. Undernutrition, ARI (acute respiratory infection), diarrheal diseases, low birth weight, and premature mortality were the major health impacts attributed to extreme weather events, meteorological factors, and air pollution exposure in children and women in the region.
Conclusion: Extreme weather events, meteorological factors and air pollution have affected the health of children and women in South Asia. However, the gap in the literature across the South Asian countries concerning relationships between exposure to extreme weather events, meteorological factors, air pollution and health effects, including mental health problems in children and women, are opportunities for future work.

1. Introduction

Climate change is a critical issue worldwide [1]. There has been an average increase of 0.85 °C in the Earth's surface temperature since the 1950s [2]. Globally, the number of cold days and nights has decreased, and the number of warm days and nights has increased [3]. In large parts of Europe, Asia, and Australia, the frequency of heatwaves has also

increased [3]. Changes in extreme weather events, such as floods, drought, cyclones and wildfires, have impacted human health across countries [4].

According to 2019 World Bank data, South Asia - Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka - is home to approximately 1.84 billion people (one-fourth of the world's population) and the most densely populated and most populous

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geographical region globally [5]. About 65% of South Asia's population lives in rural areas and accounts for 29% of those living in extreme poverty globally [6]. The region has experienced warming over the 20th century and into the 2000s [7]. Specifically, Afghanistan experienced the greatest temperature change (0.27 °C) between 1990 and 2010, while the Maldives has experienced the smallest temperature change (0.07 °C) for the same time period [8]. Other countries in the region have experienced temperature change between 0.09 °C and 0.17 °C from 1990 to 2010 [8]. Consequently, the region is highly vulnerable to catastrophic events such as floods, landslides, drought, wildfires, and cyclones and thus faces severe consequences [9, 10]. The Bay of Bengal region, including the coast of Bangladesh and India's eastern coast, has observed a 20% increase in cyclonic events due to increasing sea surface temperature and sea-level rise between 1961 to 1990 [11]. The total number of natural disasters in the region increased from 133 in 1990–94 to 166 in 2000–04 [12]. In the decade 2005–2016, a total of 481 events (hydrological, climatological, and meteorological) were reported in the region, claiming around 135,000 lives [13]. The region consistently registers the most significant number of lives and assets lost when disasters occur (e.g., floods, landslides, wildfires) [13] due to its large population and limited capacity to recover [9].

Food security, water resources protection and public health are strongly related to climate [14]. The increasing temperature, changing precipitation patterns, and higher frequency of extreme events already affect food security [15]. Climate change impacts health in different ways, including leading to death and illness from increasing frequency and intensity of extreme weather events, such as heatwaves, storms and floods, food systems disruption, increases in food, water, and vector-borne diseases, and mental health issues. Between 2030 and 2050, climate change-related effects are expected to result in 250,000 additional deaths per year globally from malnutrition, malaria, diarrhea, and heat stress [16].

Another environmental issue linked to climate change is air pollution. Air pollution is a significant public health problem in low-and middle-income countries, particularly in South Asia. According to the 2016 Environment Performance Index, 17 of the 30 cities in the world with the poorest air quality were located in South Asia [17]. In addition, the 2015 Global Burden of Disease (GBD) estimated a population-weighted mean annual ambient particulate matter ≤ 2.5 μm ($PM_{2.5}$) exposure of 73 μg/m^3 in the region [18]. Approximately 91% of the population in the region was living in areas routinely exceeding World Health Organization (WHO) recommended air quality standard (Interim Target-1) of $PM_{2.5}$ annual mean concentration - 35 μg/m^3 [15]. In 2016, World Health Organization (WHO) estimated that ambient air pollution caused around 4.2 million premature deaths worldwide, of which 91% occurred in low-and middle-income countries, primarily in South-East Asia [19]. India, Bangladesh, and Pakistan experience higher burdens due to the number of people in these countries, relatively higher exposure levels, and proportion of people affected by chronic diseases [17]. For example, in Pakistan, 135,000 deaths per year are attributed to ambient air pollution, making it the leading underlying contributor to illness and death in the country [20]. Poor air quality in Pakistan has reduced life expectancy by approximately five years [20]. Similarly, the annual number of premature deaths attributed to outdoor air pollution in Nepal had been estimated to be 24,000 in 2020 [21].

Everyone is susceptible to climate change and air pollution-related health impacts [22]. However, some population subgroups are at greater risk [23] due to their socioeconomic status, culture, caste/ethnicity, race, gender, age, physical, physiological, and psychosocial status [10]. Population subgroups such as pregnant women, older adults, children, those with co-existing chronic morbidities, and people with lower socioeconomic status are particularly at risk of climate change and air pollution-related health impacts [24]. Effects can be compounded or magnified in higher-risk groups.

Evidence has shown that women also disproportionately bear the greater climate change impacts than men due to cultural norms and the distribution of roles, resources, and decision-making power, particularly in low-and middle-income countries [25]. Women and girls often eat last and eat the least in certain parts of the world [26]. Extreme weather events affect crop yields and the average essential nutrients supply, such as folate, calcium, thiamine, and pyridoxine, which are critical during pregnancy [26]. Climate change also heavily affects children as their physical, physiologic, and cognitive systems are still developing [22, 27]. The critical health effects include increased respiratory and cardiovascular disease, injuries and premature deaths related to extreme weather events, variations in the prevalence and geographical distribution of food- and water-borne illnesses and other infectious diseases, and threats to mental health [28]. The World Health Organization (WHO) estimated that 88% of the global burden of climate change-related diseases occurs in children younger than five years of age [29].

This scoping review aims to synthesize evidence from recent studies on associations of climatic and meteorological factors and air pollution with the health effects in children and women in South Asia, identify research gaps specifically focused on children and women, and contribute to knowledge about the region's existing mitigation and adaptation strategies.

2. Methods

We conducted a scoping review following the Briggs Institute Reviewer's Manual guidelines [30], which include the following steps: identifying the research questions, finding relevant studies, selecting studies, charting the data, collating, summarizing, and reporting the results.

2.1. Search strategy

A health research librarian (S.C.) executed a search on the following health databases: PROSPERO, OVID Medline, OVID EMBASE, OVID Global Health, Cochrane Library (CDSR and Central), EBSCO CINAHL, Proquest Dissertations and Theses Global and SCOPUS using controlled vocabulary (e.g., MeSH, Emtree, etc.) and keywords representing the concepts "vulnerable populations" or "women" or "children" and "climate change" and "air pollution" and "health impacts" and "South Asia." The publication date limits from January 2010 to May 2020 aimed to capture recent data on the topic.

2.2. Screening criteria

We included only peer-reviewed articles (primary research and review articles) focusing on South Asia and those involving human cases of communicable and non-communicable diseases, deaths and hospital admission as outcomes of interest. Only studies that referred to climatic factors or climate and weather-related extreme events such as floods, wildfires, cyclones, drought, and air pollution as the principal exposure were included. The review consists of studies that reported results related to children younger than five years old and women. We included all open access papers and those obtainable through our university library databases. All available ways were explored to obtain the missing full-text articles. Studies focusing on animals, vectors, or vaccines were excluded during the screening. We also excluded editorials, opinion and commentary articles.

2.3. Data management

A total of 2283 identified papers were exported to COVIDENCE review management software [31], and 531 duplicates were removed (Figure 1). Search details are available in Appendix 1. The study protocol has been registered on Open Science Framework (OSF) [32]. Two reviewers (I.T. and M.T.) independently screened the titles and abstracts, following the abovementioned inclusion and exclusion criteria. Abstract and title screening excluded 1406 studies. Full text (346) screening was conducted by the same two reviewers, which yielded 42 relevant studies
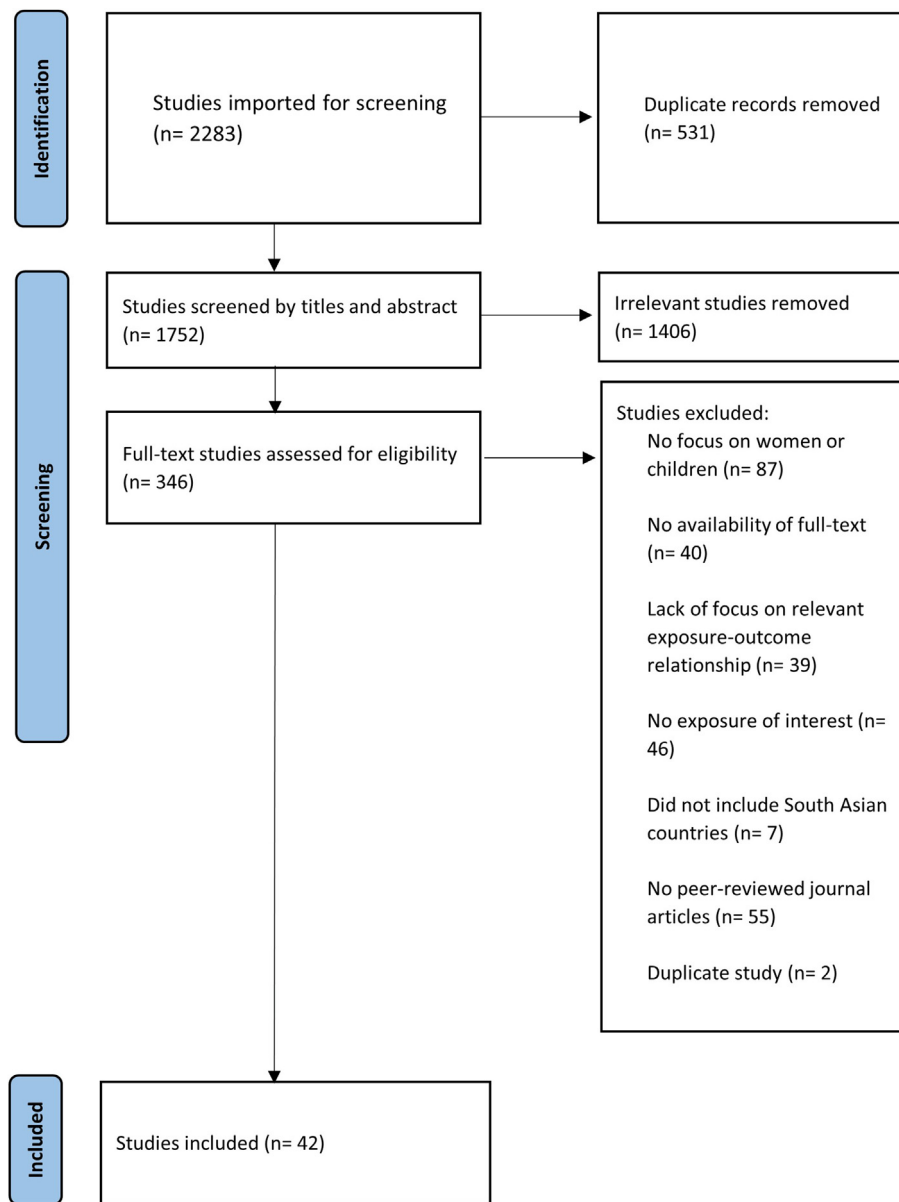
Figure 1. PRISMA flow diagram of the study selection process

for data charting (Table 1). Both reviewers discussed and reached a consensus to resolve the conflicts that occurred during both steps of the screening process.

2.4. Data charting

For each included study, one reviewer (I.T.) recorded information about study place, time and study population, objectives, study methodologies, exposures, outcomes, statistical methods, and results in an Excel spreadsheet.

3. Results

The summary of the studies by geographic location is shown in Figure 2. A description of the included studies is listed in Table 1, followed by a narrative synthesis of the data.

The majority of the studies were conducted in India (n = 23), followed by Bangladesh (n = 14), Nepal (n = 4), and Pakistan (n = 1). We did not identify relevant studies from Afghanistan, Bhutan, Maldives, or Sri Lanka. The unavailable articles did not focus on these countries. Most of the 42 studies (n = 18) focused on meteorological factors

(temperature, rainfall, and humidity) and children. Nineteen studies focused on meteorological factors as the primary exposure. In contrast, 13 focused on extreme events (floods, drought, heatwaves, and cyclones), nine focused on air pollution, and the remaining study (one) focused on salinity in coastal areas. A significant proportion of studies [34] focused on health impacts on children related to extreme weather events, meteorological factors, and air pollution. In comparison, only eight studies looked at health impacts on women.

We organized our scoping review results based on exposure (extreme weather events, meteorological factors, and air pollution) grouped by health effects. We discuss six grouped health outcomes: undernutrition, diarrheal diseases, respiratory infections, adverse birth outcomes, mortality, and others.

3.1. Extreme weather events

The adverse health impacts of extreme weather events (floods, drought, and cyclones) were examined in 13 different studies [15, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44]. Six studies explored the impact of extreme weather events on child undernutrition [15, 33, 35, 38, 40, 42],

Table 1. Summary table of the included studies.

Authors	Location, setting, and period	Population (n, sex, age categories)	Study type	Health impact category	Socioeconomic factors and effect modifiers	Key findings
Extreme events						
Arlappa 2011 [33]	India; rural; 2003	3657 participants; Children (less than five years)	Cross-sectional study	Nutrition deficiency	Female literacy, community backwardness	The prevalence of Vitamin A deficiency was significantly higher among pre-school children of chronic drought-affected areas than non-drought areas.
Beier 2015 [34]	Bangladesh; rural; 2013	977 households; Male: 47.6% and female: 52.4%; Age category: 14–25 (12.7%), 26–35 (32.2%), 36–45 (22.0%), 46–55 (16.6%), and 56+ (16.5%)	Cross-sectional study	General physical health	Age, education level, employment	Women were at higher risk of severe diseases associated with extreme weather and climate events compared to men.
Goudet 2011 [35]	Bangladesh; rural; 1998-99	143 participants; Infants and young children less than three years	Cross-sectional study	Undernutrition	Household expenditure, mother's education	Flooding showed a significant increase in stunting and underweight percentage among children less than three years of age.
Khan 2016 [36]	Bangladesh; 2009–2010	Climate refugee (C.R.) mother: 267 and Non-CR mother: 552	Cross-sectional study	Neurodevelopment	NA	Pregnant mothers who were exposed to natural disasters Sidr cyclones were more likely to have children with neurodevelopmental impairments.
Paul 2012 [15]	Bangladesh; rural; 2008	307 women participants (15–49 years); 158 children participants: (6–59 months)	Cross-sectional study	Undernutrition	Education level, primary occupation, annual income	Cyclone Sidr did not have a discernible negative impact on the nutritional status of reproductive-age women (15–49 years) and children (6–59 months).
Tran 2013 [37]	India; urban; 2012	1650 participants; Children less than five years	Cross-sectional study	Heat-related symptoms	Occupation and work location	Younger children less than five years of age were not at higher risk of heat-related symptoms than all other ages.
Rodriguez-LIanes 2016 [38]	India; rural; 2009	900 participants; Children (6–59 months)	Cross-sectional study	Undernutrition	Maternal education, land ownership, religion, annual income	Flooding was most significantly associated with wasting indicators. Statistically significant associations with underweight were reported.
Milojevic 2012 [39]	Bangladesh; rural; 2001-07	For ARI: 48794 participants; For diarrhea: 8378 participants; Children (less than five years)	Time series study	Respiratory infections and waterborne disease	Income level	The study found little evidence of elevated risk of diarrhea in a flooded area compared to a non-flooded site. There was no significant difference in the risk of acute respiratory infections in flooded and non-flooded areas.
Shaw 2020 [40]	India; 2015-16	259627 participants; Children (less than five years)	Spatial study	Undernutrition	Mother's education, economic status, media exposure	The study found a positive association between drought and child stunting.
Datar 2013 [41]	India; rural; National Family Health Survey: 1992–93; 1998–99; 2005-06	80000 participants; Children (less than five years)	Ecological study	Childhood morbidity, physical growth	Gender/sex, income, education	Disaster in the past month significantly increased the likelihood of diarrhea, fever, and ARI. Disaster in the past year was significantly associated with underweight and stunting. Significant interactions between disasters and gender and disasters and education were observed for undernutrition.
Kumar 2016 [42]	India; rural; DLHS-2: 2002–04; Monthly rainfall data: 1970–2005	149386 participants; Children (less than five years)	Ecological study	Undernutrition, Infant mortality	Seasonality	Drought exposure in the year before birth or in the year of birth for those born in the second half of the year (June–December) had a positive and statistically significant effect on underweight. Infant mortality was significantly higher for children born in the second half of the year in which the drought occurred.

Table 1 (*continued*)

Authors	Location, setting, and period	Population (n, sex, age categories)	Study type	Health impact category	Socioeconomic factors and effect modifiers	Key findings
Abdullah 2019 [43]	Bangladesh; rural; 2015	Focus group discussion (FGD): 9–11 participants for each FGD; Age category:18–50 years; In-depth interview: 8 Age category: 25–60 years	Qualitative study	Perception of maternal death; practices and challenges of the community people for emergency maternal care with complications	Marginalized community	Maternal deaths mainly occurred during the rainy season in flood-affected areas. Negligence of maternal healthcare, lack of appropriate healthcare services, communication and transportation problems, unavailability of qualified health workers were important reasons to cause maternal deaths.
Joshi 2011 [44]	India; rural; 2009	807 participants; Children (5–59 months)	Cluster survey	Waterborne disease	Annual income, caste, religion, landholding	There was no significant difference in the prevalence of diarrhea between flood-exposed and flood-unexposed regions.
Meteorological factors						
Kakkad 2014 [45]	India; urban; 2009-12	2025 participants; Infants (less than one year)	Cohort study	Neonatal hospital admission	Seasonality	An increase in temperature was associated with an increase in heat-related admissions of neonates.
Mertens 2019 [46]	India; rural; 2008-09	1284 participants; Male: 50.2%, female: 49.5%; Children less than five years	Cohort study	Waterborne disease	Effect modification by longer-term (60 days) rainfall trends	Diarrhea prevalence was associated with higher quartiles of average temperature during the first, second, and third weeks before the 7-day diarrhea recall period. The heavy rainfall events (vs. no heavy rainfall events) after a 60-day dry period were associated with higher diarrhea risk in the following 1–3 weeks.
Mullany 2010 [47]	Nepal; rural; 2002-06	23240 participants; Newborns	Cohort study	Neonatal hypothermia	Seasonality	A decrease in ambient temperature is associated with the increased risk of moderate/severe hypothermia. There is a strong association between season and hypothermia, with incidence rates peaking in the coldest months of the year.
Rashid 2017 [48]	Bangladesh; rural; 2001-04	Pregnant women: 4436; Infants: 3298	Cohort study	Fetal growth and birth size	Education level	Infants born in colder months were shorter (birth length) than those born in hot, dry and monsoon months. The increased temperature during the last month of pregnancy was significantly related to increased birth length after adjustment. The increased temperature at mid-gestation was significantly associated with increased birth weight.
Babalola 2018 [49]	Bangladesh; rural; 1982–2008	49426 participants; children (less than five years); Female and male mortality (<153 days); Neonate mortality (<30 days); Mortality between 30 and 153 days	Time series study	Mortality	N.A.	There was a protective effect of temperature on child mortality. There is no evidence that child survival is adversely affected by monthly temperature extremes in Bangladesh.
Bhandari 2020 [50]	Nepal; urban; 2003-13	219774 participants; Children (less than five years)	Time series study	Waterborne disease	N.A.	An increase in maximum temperature and rainfall was strongly associated with diarrheal disease among children less than five years of age.
Bush 2014 [51]	India; urban; 2004-07	14723 participants; Children (less than five years)	Time series study	Hospital admission for gastrointestinal-related illness	Age, seasonality	Hospital admissions related to gastrointestinal illness of under-five children were positively and significantly associated with extreme precipitation.
Imai 2014 [52]	Bangladesh; urban; 2005-08	Influenza A: 333, Influenza B: 246;	Time series study	Tropical influenza incidence	N.A.	There was a difference in the associations between influenza

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Table 1 (continued)

Authors	Location, setting, and period	Population (n, sex, age categories)	Study type	Health impact category	Socioeconomic factors and effect modifiers	Key findings
		Children (less than five years)				and weather variability by influenza subtypes. Weather factors were significantly associated with influenza A as compared to influenza B.
Ingole 2012 [53]	India; rural; 2003-10	Total mortality: 1662, Mortality (0–4 years): 46, Mortality (5–19 years): 62 Mortality (20–59 years): 627 Mortality (60 + years): 927 mortality (men): 954, mortality (female): 708	Time series study	Mortality	Age and gender/sex	The study indicated that a strong association with temperature and rainfall exists for all-cause mortality in all age groups, including children (0–4 years). Women are more susceptible to mortality effects following rainfall events compared to men.
Singh 2019 [54]	India; urban; 2009-16	Total all-cause mortality: 64712 Mortality (0–4 years): 4132 Mortality (5–44 years): 10130 Mortality (45–64 years): 17709 Mortality (65 + years): 32741	Time series study	Mortality	Age, gender/sex, seasonality	The daily mean temperature was strongly associated with child mortality. All-cause mortality varied with the season for both men and women. In summer, daily mean temperature increase was significantly associated with increased all-cause mortality for both sexes. In winter, daily mean temperature increase was significantly associated with decreased all-cause mortality for both sexes.
Bharti 2019 [55]	India; rural; Undernutrition data:2015-16 Census data: 2011	Children (less than five years)	Spatial study	Undernutrition	Wealth, literacy	Districts with extreme temperature levels (>40 °C) positively associated with childhood stunting. However, the rainfall levels in districts did not show a strong association with childhood stunting.
Alam 2012 [56]	Bangladesh; rural; 1983–2009	4850 participants; Infants (less than one year) Children (1–4 years); Other age categories: (5–19 years); (20–59 years); (60 + years)	Ecological study	Mortality	Age and gender/sex	The temperature and mortality association was insignificant for infants and children (1–4 years) but was significantly higher for age groups 5–19 years and 20–59 years. Low temperature (below 75th percentile) was associated with increased mortality risk among females but not males. Temperature above the 75th percentile was not associated with mortality risk of any sex and age group. Average rainfall below 14 mm showed a significant reduction in female mortality, while average rainfall over 14 mm showed significantly increased mortality risk for both males and females. Average rainfall below 14 mm showed an insignificant reduction of infant mortality but increased mortality of children 1–4 years (insignificant).
WU 2014 [57]	Bangladesh; rural; Health outcome data: 2000-06 Temperature data: 1982–2011 Rainfall data: 1998–2008	16551 diarrhea cases Children (less than five years)	Ecological study	Waterborne disease	Economic status	Higher temperatures and heavy rainfall were significantly associated with the risk of diarrhea. The average temperature and rainfall showed a weak negative association with childhood diarrhea.
Banerjee 2020 [58]	India; urban; District Level Household Survey (DLHS)-2: 2002–04; DLHS-3: 2007/08 Temperature and rainfall data: 1900–2010	DLHS-2: 507622 (married women); DLHS-3: 643,944 (married women)	Ecological study	Infant mortality	Residence (rural vs urban)	Exposure to high temperatures during pregnancy significantly increases infant death risk.

Table 1 (*continued*)

Authors	Location, setting, and period	Population (n, sex, age categories)	Study type	Health impact category	Socioeconomic factors and effect modifiers	Key findings
Mannan 2011 [59]	Bangladesh; urban; 2004-05	12836 participants; Children (0–1 month)	Ecological study	Newborn illness	Seasonality	Higher temperature and heat humidity index values were significantly associated with the incidence of very severe disease in newborns.
Tiwari 2016 [60]	Nepal; Demographic Health Survey (DHS) 2005; 2011; 2016;	Wasting: 13682; Male children: 6880; Female children: 6802 Stunting: 13683; Male children: 6884; Female children: 6799; Children (less than five years)	Ecological study	Undernutrition	Seasonality, sex/gender	An increase above normal monsoon rainfall was strongly associated with an increase in the prevalence of wasting. In contrast, an increase above normal monsoon rainfall was strongly related to reduced wasting. The impact of past monsoon shocks on wasting was similar in both males and females. The study showed that rainfall shocks experienced early in life contribute to faltering child growth.
Shively 2015 [61]	Nepal; Health outcome data: DHS 2006, 2007	7572 participants; Children (less than five years)	Ecological study	Undernutrition	Seasonality	There was a positive association between height-for-age z-score (HAZ), weight-for-height z-score (WHZ), and rainfall.
Murray 2011 [62]	Bangladesh; urban; 2004-05	718 participants; Children (less than five years)	Case-crossover study	Respiratory infections	Household crowding	Rainfall was significantly associated with an increased risk of acute respiratory infections in children less than five years of age.
Ajjampur 2010 [63]	India; urban; 2005-08	2579 participants; Children (less than five years)	Non-randomized experimental study	Waterborne disease	Seasonality, age	The temperature was associated with a higher rate of cryptosporidium positivity during hotter and drier weather in Delhi.
Air pollution						
Maji 2017 [64]	India; urban; 2008-10	Children (0–4 years)	Time-series study	All-cause mortality	Age and gender/sex	The risk of particulate matter pollution attributed mortality was slightly greater in females than males. The mortality attributed to particulate matter pollution in young children (0–4 years) showed a positive but insignificant association.
Akhmat 2014 [65]	Pakistan; 1975–2012	Children (less than one year)	Time-series study	Low birth weight	N.A.	The study showed that air pollution and greenhouse emissions significantly affect low birth weight.
Chakrabarti 2019 [66]	India; rural; Health outcome data: District Level Health Survey-4, 2012-13	252539 participants; Children (less than five years)	Ecological study	Respiratory infections	Residence, sex/gender	Children (less than five years of age) living in an urban area where crop burning is practiced were at higher risk of acute respiratory infections (ARI) than those living in rural areas. The risk of ARI attributed to the burning of agricultural crop residue was significantly higher among women than men.
Goyal 2017 [67]	Bangladesh; urban-rural; 2004-14	23187: stunting and underweight; 23188: wasting; 11870: small birth size; Children (less than five years)	Ecological study	Undernutrition	Wealth and education	Exposure to high levels of PM2.5 in utero was significantly associated with an increased relative risk of stunting, wasting, underweight, and small birth size. Female children were at significantly higher risk of stunting and being underweight than male children.
Sinha 2014 [68]	India; 1971–2010	Children (less than one year)	Ecological study	Mortality	Industrialization growth	Bidirectional causal associations were found between changes in infant mortality rate and growth in CO_2 emission.

Table 1 (*continued*)

Authors	Location, setting, and period	Population (n, sex, age categories)	Study type	Health impact category	Socioeconomic factors and effect modifiers	Key findings
Kurata 2020 [69]	Bangladesh; national Air pollution data: 1998–2016 Child health data: 2011 and 2016	Children (less than five years)	Ecological study	Undernutrition and respiratory infections	Mother's education, father's education, gender/sex, media access, economic status	The prenatal exposure to PM$_{2.5}$ was correlated with stunting only in boys after adjusting for monthly seasonal variation. Postnatal exposure to PM$_{2.5}$ was strongly correlated with stunting in both boys and girls, and its correlation with respiratory illness was statistically insignificant.
Maji 2018 [70]	India, Bangladesh, Pakistan; urban; 2016	Children (less than five years)	Air pollution	Premature mortality	Age	PM$_{2.5}$ pollution in India, Bangladesh, and Pakistan megacities contributes to significant premature mortality in children under five years of age due to acute lower respiratory infections.
Ghosh 2015 [71]	India; urban; 2005-06	4665 participants; Children (less than five years)	Non-randomized experimental study	Respiratory ailments	Residence (slum vs non-slum)	Exposure to higher levels of PM$_{10}$ and PM$_{2.5}$ is a significant contributor to childhood respiratory ailments. Thus, children in the slum are at greater risk of adverse health effects from pollution than children living outside the slum.
Goswami 2014 [72]	India; urban; Health outcome data: 2011 annual report on registration of births and deaths for acute respiratory disease (ARD) death and ARD case was taken from http://www.india.stat.com Air pollution data: 2000-05 Meteorological data: 2000-05	Children (less than five years)	Correlation study	Respiratory diseases (Acute Respiratory Diseases: ARD)	N.A.	Respiratory suspended particulate matter (RSPM) and nitrogen dioxide (NO$_2$) showed a clear correlation with the observed morbidity rate (ARD). There was no significant correlation between ARD morbidity rate and suspended particulate matter (SPM) and sulphur dioxide (SO$_2$). The number of cold days (temperature ≤ 20 °C) showed a significant correlation with the actual number of ARD deaths in Delhi.
Drinking water salinity						
Scheelbeek 2020 [73]	Bangladesh; rural; 2009-10	701 participants; Pregnant women	Case-control study	Elevated blood pressure	N.A.	Drinking water with high saline concentrations was associated with higher blood pressure in normotensive pregnant women in Bangladesh's coastal areas.

and one of which also included women of reproductive age, i.e., 15–49 years [35]. Two studies investigated extreme weather events' impact on diarrheal diseases [39, 44] and one each on respiratory infections [39] and mortality [42]. Nine of 13 studies reported a positive association between extreme weather events and different health outcomes [33, 34, 35, 36, 38, 40, 42, 43].

3.1.1. Extreme events and undernutrition

All three studies that had drought as the primary exposure found a positive association with adverse nutrition-related outcomes in children [33, 40, 42]. The adverse impact of severe drought on Vitamin A status was identified in pre-school children, particularly those with illiterate and older-aged mothers [33]. Spatial clusters of districts with a higher prevalence of stunting were seen in drought-prone areas. However, the district-level burden of children underweight and wasting was not significantly predicted by drought [40]. Another study that examined the effect of in-utero drought exposure on children's health outcomes under five years in rural India found that drought exposure in the year before birth or the year of birth was associated with underweight [42].

Two studies examined the relationship between flooding and child undernutrition [35, 74]. Goudet et al. [35] found a significant positive association between flooding and child undernutrition (stunting and

underweight) a year after the flood. Rodriguez-Llanes et al. [74] observed a positive relationship between flooding and wasting, a minor association with underweight, but not stunting. However, exposure to cyclone Sidr did not have a noticeable negative impact on children and women's nutritional status [15].

3.1.2. Extreme weather events and other health impacts

The prevalence of diarrhea was not found to be associated with flooding events. Milojevic et al. [39] did not observe strong evidence of an elevated risk of diarrhea in flooded areas compared to non-flooded areas in children younger than five years. Joshi et al. [44] observed similar findings in their study. Milojevic et al. [39] did not find a significant difference in the risk of acute respiratory infections (ARI) in flooded and non-flooded areas. Kumar et al. [42] observed that infant mortality was increased for children born in the second half of a year in which drought occurs in India.

3.2. Meteorological factors (temperature, rainfall, and humidity)

The adverse impacts of meteorological factors were investigated in 19 studies [45, 46, 47, 48, 49, 51, 52, 55, 57, 58, 59, 60, 75, 76, 77, 78, 79, 80, 81]. Most studies focused on the impacts of meteorological factors on
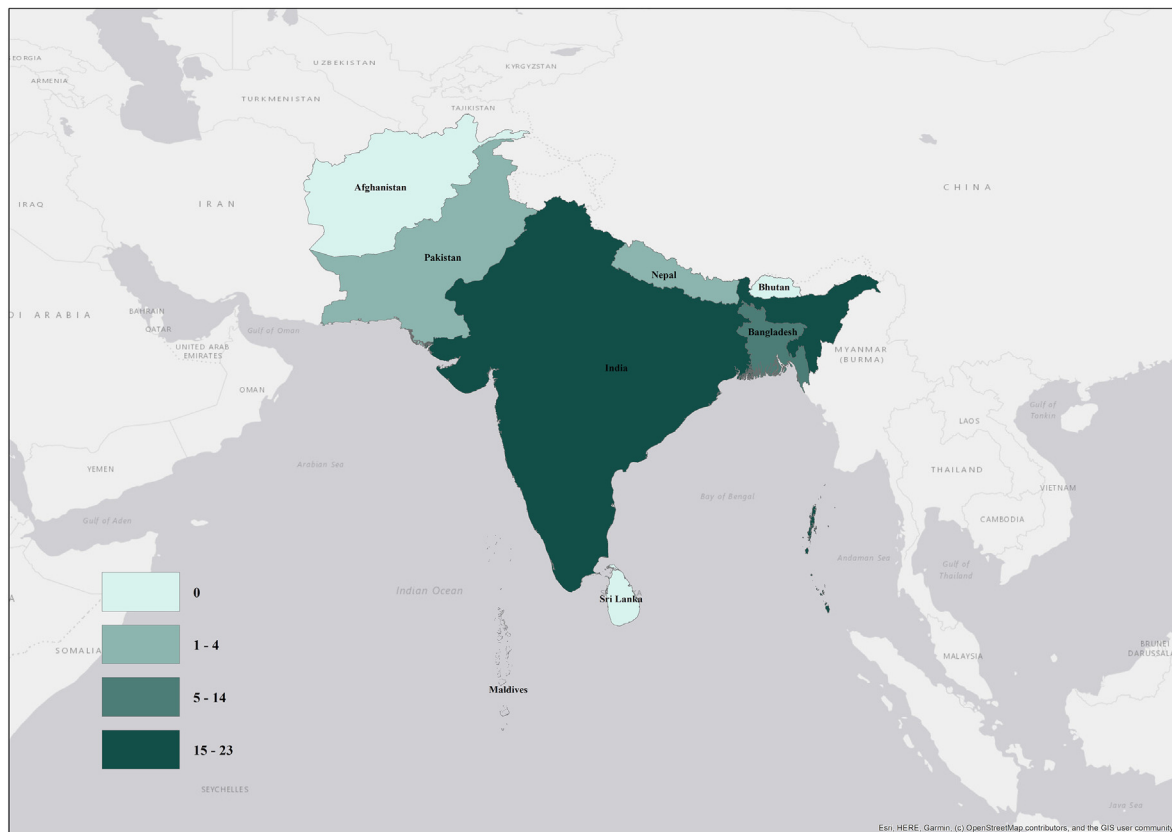
Figure 2. Map of South Asia showing distribution and frequency of included studies.

mortality (n = 5) and diarrheal diseases (n = 4). Few studies focused on examining the relationship of meteorological factors with undernutrition (n = 3), other health effects (n = 3), respiratory infections (n = 2), and adverse birth outcomes (n = 1). Almost 95% of the studies (18 of the 19 studies) reported a positive association between meteorological factors and different health outcomes [45, 46, 47, 48, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63].

3.2.1. Meteorological factors and undernutrition

Three studies observed a positive association between extreme temperature and rainfall with childhood undernutrition [55, 60, 61]. Two studies in Nepal used Demographic and Health Survey (DHS) data linked with meteorological data to investigate the association between rainfall and child undernutrition [60, 61]. One study found a positive association between childhood undernutrition (stunting and wasting) and rainfall [61]. The other study observed an increase above current monsoon rainfall levels was strongly associated with reduced wasting [60]. A spatial study in rural India observed that extreme temperatures (>40 °C) were positively associated with childhood stunting in districts [55].

3.2.2. Meteorological factors and diarrheal diseases

All five studies found positive associations between meteorological factors and the risk of diarrheal diseases [46, 50, 51, 57, 63]. In a study in rural India, the prevalence of diarrhea was associated with higher quartiles of average temperature (≥30.5 °C) during the first, second, and third weeks before a seven-day diarrhea recall period [46]. Ajjampur et al. [63] similarly observed a higher rate of cryptosporidium positivity during hotter and drier weather in Delhi. They also observed that heavy rainfall events (vs. no heavy rainfall events) after a 60-day dry period were associated with higher diarrhea risk in the following 1–3 weeks. Bhandari et al. [50] estimated an 8.1% (RR.: 1.081; 95% CI: 1.02–1.14)

increase in the risk of diarrhea cases in children less than five years of age per 1 °C increase in maximum temperature above the monthly average recorded within that month. They also estimated a 0.9% (RR.: 1.009; 95% CI: 1.004–1.015) increase in the risk of diarrhea cases per 10 mm increase in rainfall above the monthly cumulative values recorded within that month. Overall, the study estimated that 7.5% (95% CI: 2.2%–12.5%) of the current burden of diarrhea among children less than five years in Kathmandu (urban setting) was attributable to meteorological factors [50]. Likewise, Bush et al. [51] observed a positive association between extreme precipitation and hospital admission due to gastrointestinal illness among children less than five years of age. Wu et al. [57] also observed an association between higher temperature (OR: 1.018; 95% CI: 1.011–1.025) and heavy rainfall (OR: 1.013; 95% CI: 1.019–1.044) with diarrhea risk.

3.2.3. Meteorological factors and respiratory infections

Temperature and precipitation were found to have a positive association and/or correlation with the risk of respiratory infections. Murray et al. [62] found that rainfall was associated with the increased risk of ARI in children under five years of age. Goswami and Baruah [72] observed that the number of cold days (temperature ≤20 °C) per month significantly correlated with acute respiratory disease (ARD) morbidity in Delhi. However, ARD morbidity was found even in the absence of cold days, likely indicating the role of other drivers of ARD, such as air pollution.

3.2.4. Meteorological factors and birth outcomes

Rashid et al. [48] found a significant impact of temperature during pregnancy on the birth length and weight. The temperature increase in the last month of pregnancy was associated with the increased birth length. However, the effect varied by the mother's nutritional status.

They also found a significant positive association between the increased temperature at mid-gestation and increased birth weight.

3.2.5. Meteorological factors and mortality

Three studies observed a significant association between meteorological factors and mortality [53, 54, 56]. For example, Alam et al. [56] observed that weekly mean temperatures below the 25th percentile and between the 25th and 75th percentiles were associated with increased mortality risk after adjusting for seasonal patterns and time trends, particularly in females of all ages. Female mortality increased by 4.3% and 3.8% with every 1 °C decrease in temperature below the 25th percentile and between the 25th and 75th percentile, respectively. Average rainfall below 14 mm over lag 0–4 weeks significantly reduced female mortality, while average rainfall over 14 mm was associated with significantly increased mortality risk in both males and females [56]. Singh et al. [54] found that all-cause mortality varied with the season for both males and females. During the summer season, the daily mean temperature was positively correlated with all-cause mortality for both sexes. During the winter season, the daily mean temperature was negatively correlated with all-cause mortality for both sexes [54]. Similarly, Ingole et al. [53] observed that mortality was associated with daily ambient temperatures and rainfall for all age groups, including those 0–4 years, after adjusting for seasonality and long-term time trends. Singh et al. [54] also observed the highest relative risk of mortality from heat stress in children in the age group 0–4 years (RR 1.39, 95%CI 1.16–1.69).

3.2.6. Meteorological factors and other health impacts

One study examined the association between meteorological factors and heat-related hospital admission. The researchers found a 43% increase in neonatal intensive care unit admission for heat-related illnesses (e.g., dehydration, increased respiratory rate, convulsion) [45]. Community-based surveillance in urban Bangladesh also showed that higher temperature and heat humidity index were significantly associated with very severe diseases in newborns [59]. Mullany et al. [47] showed that moderate/severe hypothermia risk increased by 41.3% (95% CI: 40.0%–42.7%) for every 5 °C decrease in average ambient temperature. Furthermore, relative to the highest quintile, the risk was 4.03 (95% CI: 3.77–4.30) times higher among infants exposed to the lowest average ambient temperature quintile (3.8 °C–11.7 °C) [47].

3.3. Air pollution

The adverse health impacts of air pollution were examined in nine studies [64, 65, 66, 67, 68, 69, 70, 71, 72]. Most studies (n = 4) focused on respiratory health impacts [66, 69, 71, 72]. Three studies examined impacts on mortality [64, 68, 70], two on nutrition [67, 69] and one on the adverse birth outcomes [65].

3.3.1. Air pollution and undernutrition

Two studies found that exposure to particulate matter pollution was positively associated with undernutrition in children [67, 69]. Masamitsu et al. [69] found gender differences in the association of fine particulate matter ($PM_{2.5}$) exposure with childhood undernutrition. Prenatal exposure to $PM_{2.5}$ showed a strong association with stunting only in boys, while postnatal exposure to $PM_{2.5}$ was strongly associated with stunting in both boys and girls [69]. Goyal and Canning [67] found a significant positive association between $PM_{2.5}$ exposure in utero and child stunting. They also observed that a female child had a significantly higher risk of stunting and being underweight.

3.3.2. Air pollution effect on respiratory infections

Two of the four studies that focused on air pollution observed a significant positive relationship between exposure to air pollution and ARI risk [66, 71]. Chakrabarti et al. [66] found that living in a district with intense agricultural crop residue burning (ACRB) - ≥ 100 fires per day - was a leading risk factor for ARI in children (aRR: 2.99; 95% CI:

2.77–3.23). Ghosh and Mukherji [71] found that exposure to a higher level of PM_{10} and $PM_{2.5}$ significantly contributes to childhood respiratory ailments. Maji et al. [70] found that long-term exposure to $PM_{2.5}$ is positively associated with increased ARI incidence in children younger than five years. The risk of ARI associated with ACRB was greater in females (aRR: 3.08; 95% CI: 2.75–3.45) than in males (aRR: 2.93; 95% CI: 2.64–3.25) [66].

3.3.3. Air pollution and other health impacts

Akhmat et al. [65] found an inverse relationship between maternal air pollution exposure and birth weight. A one percent increase in carbon dioxide emissions was associated with a 0.412 percentage point decrease in babies' birth weights.

A positive association between air pollution exposure and mortality was reported in the selected studies [64, 68, 70]. For example, Maji et al. [70] found that long-term exposure to $PM_{2.5}$ was associated with increased mortality risk due to cerebrovascular disease (e.g., stroke), ischemic heart disease (IHD), chronic obstructive pulmonary disease (COPD) and lung cancer among adults (≥25 years). Another study found that pollutants exhibit age and sex-selective effects. A significant effect of particulate matter (PM_{10}) on increased mortality was observed among females (female: RR 1.002 (95% CI 1.001 to 1.004); male: RR 1.001 (95% CI 0.99 to 1.002)). Age group-based analysis revealed that particulate matter affected the age group ≥65 years (RR 1.002; 95% CI 1.000 to 1.004) vs the age group below five years (RR 1.000, 95% CI 0.997 to 1.003)) [64].

4. Discussion

Overall, a limited number of studies focused on extreme weather events, meteorological factors, and air pollution-related health impacts, particularly on women in South Asia. Findings indicate the urgent need for study in other South Asian countries beyond India and Bangladesh. Findings showed that undernutrition, diarrheal disease, low birth weight, premature mortality, and temperature-related illnesses (e.g., hypothermia) are critical adverse health impacts attributed to extreme weather events, meteorological factors, and air pollution in children and women in the region. The identification of only one qualitative study in the review reflects the lack of other methodologies in this type of research, thus restricting a complete understanding of the complex relationship between climate change, air pollution and children and women's health.

4.1. Evidence of climate-and air pollution-related health impacts in children and women

This scoping review found evidence of health impacts in children and women attributed to extreme weather events, meteorological factors, and air pollution-related exposure. Undernutrition, diarrheal disease, low birth weight, and premature mortality were critical health risks among children associated with exposure to extreme weather events, meteorological factors and air pollution. Undernutrition in children was positively associated with air pollution exposure. Children were also at greater risk of ARI and premature mortality attributed to meteorological and air pollution exposure. However, few studies linked women's adverse birth outcomes and ARI to air pollution exposure.

The risk of specific types of undernutrition (stunting, underweight, or wasting) varied with exposure from one extreme event to another. For example, exposure to drought was positively associated with chronic undernutrition (e.g., stunting and underweight) [33], while exposure to flooding was positively associated with acute undernutrition, i.e., wasting [74]. The education level and age of mothers were critical sociodemographic factors affecting the association between exposure to extreme events and the risk of undernutrition in children. Arlappa et al. [33] observed a stronger association for older mothers and those with lower level of education or no education. This finding aligns with that of other regions as well. Dimitrova [82] also found that drought-exposed

children in Ethiopia born to less educated mothers were at higher risk of undernutrition in Ethiopia than those who were born to more educated mothers.

This review also found evidence of a significant association between exposure to air pollution and the risk of childhood undernutrition [67, 69]. A gender difference was evident in the risk of stunting and underweight children, particularly for air pollution exposure, where female children had higher risks than male children [69]. The evidence for the relationship between air pollution exposure and child undernutrition (stunting) is scarce; however, some studies in other regions have supported the positive association between exposure to air pollution and the risk of undernutrition in children [83, 84]. One potential pathway through which air pollution might impair the growth of children is through repeated episodes of respiratory illness, which are linked with increased child stunting risk [85].

No significant associations between flood exposure and the risk of diarrheal diseases were reported in the studies in this review. It may be that previous exposure to flooding in the region might have reduced the vulnerability of the population. In contrast, diarrhea prevalence was significantly associated with meteorological factors. Similar results have been reported from other regions [86, 87]. Studies have linked higher temperatures with increased diarrheal disease risk in children. This could be due to the rapid multiplication and survival of pathogens causing diarrhea over a longer period, which mainly occurs in the warmer season. Temporal changes in human behaviour, such as higher water consumption, using unimproved drinking water sources, and compromised hygiene practice due to water scarcity are also potential pathways of exposure [88, 89, 90]. Extreme rainfalls are expected to cause a rise in waterborne diseases due to deterioration in water quality [2, 88].

The association between ARI and air pollution exposure varied with the place of residence, i.e., urban vs rural and slum vs outside slum. Odo et al. [91] analyzed demographic and health survey data from 35 low-and middle-income countries. They found a significant association between long-term $PM_{2.5}$ exposure and ARI in children younger than five years. They observed evidence of effect modification by sex, age, and place of residence, suggesting that children, particularly boys, living in rural areas experienced greater ARI effects at the same level of $PM_{2.5}$ exposure compared to girls and those living in urban areas [91].

There is inconsistent evidence of an association between air pollution and adverse pregnancy outcomes (stillbirth, preterm birth, low birth weight, and macrosomia). Still, several studies have suggested adverse pregnancy outcomes attributed to exposure to air pollution [92, 93, 94]. One plausible explanation is that maternal exposure to particulate matter may represent a critical risk factor for intrauterine inflammation, which could then impact the placenta's growth, development, and function [95]. Studies have identified that the effect of air pollutants on adverse pregnancy outcomes varies with specific types of air pollutants. For example, a systematic review showed a consistent association between sulfur dioxide (SO_2) and low birth weight and preterm birth [92]. PM_{10} was also consistently associated with congenital anomalies, particularly cardiovascular defects [92]. In another study, a significant inverse relationship was detected between air pollution exposure, particularly carbon dioxide emissions, and birth weight [65]. The effect of air pollution was also found to vary depending upon maternal comorbidities. For example, the effect of $PM_{2.5}$ and nitrogen dioxide (NO_2) on preterm birth was found to be higher among diabetic mothers, while the effect of ozone on preterm birth was higher among mothers with asthma [94].

Positive associations between air pollution and meteorological factors with mortality was detected in several studies. We found that more women are impacted by air pollution exposure and disaster-related events to a greater extent than men [42, 64]. Other studies globally have also found women are more impacted by climate disasters [96, 97, 98]. Neumayer and Plumer observed that the socioeconomic status of women is a critical factor that plays a greater role in women being more impacted by climate disasters than men [96].

4.2. Research gap: children and women's health risk and geographical coverage

Overall, studies focusing on extreme weather events, meteorological factors and air pollution-related health impacts on women were scarce. Several studies included women or children only as a subpopulation of the main analysis. As such, the evidence of the social, political, and economic determinants of climate change and air pollution impacts on children and women's physical and mental health were limited. In particular, studies that assess mental health in women exposed to extreme weather events (e.g., floods) are lacking in the region. South Asia is one of the most flood-prone regions globally. Floods in the region are often triggered by heavy monsoon precipitation, which can cause considerable damage to lives, crops, assets, and infrastructure [99]. Floods increase the physical injury risk for women and who are more likely to be evicted from their dwellings. In addition, women can face difficulties fetching adequate water for drinking and cooking, securing safe shelter, and maintaining personal hygiene and sanitation. Furthermore, women can be exposed to domestic violence and may be subject to physical and sexual harassment [100].

Some areas (India, Bangladesh, Sri Lanka, and Maldives) of South Asia are more vulnerable to the effects of climate change and air pollution than others (Nepal, Bhutan, Afghanistan, and Pakistan). For example, coastal area populations in the region face the combined threat of rising sea levels and extreme weather events impacting populations, particularly those who are poor and live in remote areas [9]. However, there were a lack of studies in remote coastal areas. Most of the literature in this scoping review focused only on urban settings in India and Bangladesh. Studies from other South Asian countries and those living in the remote coastal areas were limited, which is a critical knowledge gap.

4.3. Strengths and limitations

The extensive terminology of our search is one of the strengths of the review, but it is possible that we missed studies that additional terms might have retrieved. We also did not consider the pertinent potential papers in the references of the retained papers. The world discourse on climate change has increased significantly in recent years. Our review focuses on post-2010 literature to capture that current discourse; however, it is possible that there is evidence in earlier studies that might have informed our review. Two reviewers independently screened the studies to ensure consistency; however, only one reviewer did the data extraction, and no quality assessment of the evidence included in this review was conducted. We used library databases to retrieve most papers that were not open access, though some papers were not available.

5. Conclusion

The selected literature studied in this scoping review indicates that extreme weather events, meteorological factors and air pollution have affected the health of children and women living in South Asia. The evidence of the relationship between exposures and health impacts on children and women was consistent, except for extreme weather events where evidences was inconsistent across wasting, underweight, and stunting. Most studies have considered children and women only in subgroup analyses, rather than the main population of interest. Therefore, the limited knowledge concerning the relationship between exposure to extreme weather events, meteorological factors and air pollution and the risk of adverse health impacts, particularly in women, are critical knowledge gaps. The lack of literature concerning mental health impacts on both children and women is an area for future research. There is a disparity in the distribution of studies within and across the countries, as most studies focused on urban settings in India and Bangladesh. This highlights the need for more studies within and across all South Asian countries that will provide a comprehensive picture of the effects of climate change and air pollution on children and women.

Declarations

Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

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No data was used for the research described in the article.

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Additional information

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