



UK Health
Security
Agency

Health equity impacts of climate change

A rapid mapping review

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Main messages

The purpose of this rapid mapping review was to identify and categorise primary studies that reported on the health impacts of climate change and the solutions and responses to address climate change in population groups experiencing social vulnerabilities in the UK.

The review includes 24 studies (search date: 19 February 2024) which were mapped onto an interactive evidence gap map (available at [Evidence gap map: health equity impacts of climate change](#)) by population group and climate change exposure pathway.

Of the 24 studies, one was a prospective cohort study (quality criteria checklist (QCC) rating medium quality), 12 were time series (QCC rating: 4 high, 6 medium and 2 low quality), 4 case-crossover (QCC rating: 2 high and 2 medium quality), 3 retrospective (QCC rating: one medium and 2 low quality), one cross-sectional (QCC rating: low quality), one before-after study (QCC rating: low quality), and 2 modelling studies (no quality rating assigned).

Eighteen of the 24 studies identified investigated the health equity impacts of climate change related hazards (increase in ambient temperature, extreme cold, extreme heat, and heavy rainfall and flooding). No studies were identified for drought or other extreme weather events.

Only one of the 24 studies identified investigated the health equity impacts of climate change related health risks, which reported on wildfire-related air pollution. No studies were identified for changes to vector ecology, changes to food supply and safety, changes to water supply and safety, or environmental degradation.

Five of the 24 studies identified reported on the health equity impacts of solutions and responses to address climate change (4 on climate change mitigation and one on climate change adaptation policy and interventions). No evidence was identified for community resilience, or disaster risk reduction, response and recovery.

In terms of population groups, most studies (20 out of 24) reported on people experiencing the greatest deprivation. However, 18 of these used an area level measure of deprivation (rather than an individual level measure). Therefore, it is unclear whether the findings of these studies can be generalised to individuals within these areas.

Limited evidence was identified for other population groups experiencing social vulnerabilities: 2 studies each on ethnic minority groups and people experiencing homelessness, and one study for people with drug and or alcohol dependence. No studies were identified for people from protected characteristics groups related to gender reassignment or sexual orientation and to religion or belief, people in contact with the criminal justice system, vulnerable migrants, Gypsy, Roma and Traveller communities, sex workers and victims of modern slavery.

Further research is needed to address the evidence gaps identified in this mapping review, both in terms of population groups experiencing social vulnerabilities and associated settings, and climate change related exposure pathways.

Background

Climate change is one of the biggest threats to health security worldwide. Our changing climate is projected to cause a substantial increase in the frequency and intensity of extreme weather events, such as heatwaves, flooding, and drought, and to alter environmental conditions in a way that will increase other environmental threats to health. Health impacts from climate change can be direct (for example, exposure to extreme heat) or indirect (for example, adverse mental health impacts because of displacement or disruption due to flooding). These impacts are significant and wide-ranging in nature. The Health Effects of Climate Change (HECC) in the UK report highlights that the health effects from climate change will not be distributed equally across the UK population geographically, or across generations, and the worst effects on health will be in disadvantaged and vulnerable populations (1).

Differential outcomes can result from population differences in vulnerability to the health impacts of climate change, depending on their degree of exposure, susceptibility and adaptive capacity; as well as from differences in the extent to which climate change solutions support or worsen particular populations' health needs. Differential health impacts can also be caused by the impact of climate change and climate change solutions on the wider determinants of health, such as housing and livelihoods. Taken together, these differential health impacts between population groups can lead to new and widening health inequities, as highlighted in the HECC UK report (1).

NHS England's Core20PLUS framework (2), adopted by the UK Health Security Agency (UKHSA) (3), identifies populations considered as being at potentially higher risk of health inequities, including the most deprived 20% of the national population and groups such as those with protected characteristics and inclusion health groups.

We conducted an initial scoping exercise between February and March 2023 to identify available reviews on the health effects of climate change in Core20PLUS populations in the UK context (see [Annexe A](#)). Our findings showed that existing reviews (4 to 27) tended to focus on a small number of Core20PLUS populations, particularly older adults, children, pregnant women, and people with long-term conditions including mental health conditions. There was limited review-level evidence for other Core20PLUS population groups, such as the most socio-economically deprived, ethnic minority groups and people from inclusion health groups. It was, however, unclear whether this uneven distribution of review-level evidence reflects underlying gaps in primary research, or at the review level.

In light of this, we conducted a mapping review of primary studies focusing on the Core20PLUS population groups for which review-level evidence was limited; that is, people experiencing the greatest deprivation, ethnic minority groups, inclusion health groups, and protected characteristics groups related to gender reassignment, to sexual orientation, and to religion or belief. In this report, we will refer to these groups for whom vulnerabilities are likely to be related to social exclusion and socio-economic circumstances as 'population groups experiencing social vulnerabilities'.

By mapping the evidence by population groups and climate change related exposure pathways, the objective of this work was to identify where evidence on health impacts already exists for these groups and where the evidence gaps are, in order to guide areas for future action, engagement and research.

Purpose

The purpose of this rapid mapping review was to identify and categorise primary studies reporting on the health impacts of climate change on UK population groups experiencing social vulnerabilities (people experiencing the greatest deprivation, ethnic minority groups, inclusion health groups, and protected characteristics groups related to gender reassignment, to sexual orientation, and to religion or belief). Related settings such as prisons, asylum seeker accommodation settings or temporary housing accommodation were also considered.

For this review, climate change related exposures were grouped into climate change related hazards (such as extreme heat or flooding), climate change related health risks (such as vector-borne diseases or changes to air quality), and climate change related solutions (such as mitigation or adaptation interventions).

The review question, as defined in the protocol, was: “What is the available evidence on the health impacts of both climate change and the solutions taken to address climate change in population groups experiencing social vulnerabilities in the UK?”.

Methods

Review process

A rapid mapping review was conducted (see full details on the methodology in [Annexe B](#) and search strategy in [Annexe C](#)), following streamlined systematic methodologies to accelerate the review process ([28](#)). The protocol was published on the Open Science Framework (OSF) before the review process started ([29](#)). The review question and protocol were informed by a scoping exercise as part of best practice (see [Annexe A](#)).

A literature search was undertaken by an information scientist using sources including Medline, Embase, Web of Science, the Finding Accessible Inequalities Research (FAIR) database and the King's Fund Library to identify primary studies published (or available as preprint) between 1 January 2010 and 17 July 2023 (search conducted on 18 July 2023). The database searches were updated on 19 February 2024.

The initial database search results were screened using EPPI-Reviewer web version ([30](#)), whereas the results from the search update were screened using Rayyan ([31](#)). Title and abstract screening was completed in duplicate by 2 reviewers for 10% of the studies; the remaining 90% were screened by one reviewer. Full text screening was conducted by one reviewer and checked by a second.

An extensive grey literature search was conducted on 22 August 2023 (11 resources searched, see full list in [Annexe B](#)). Title and abstract screening of records identified was completed by one reviewer using Rayyan and Microsoft Excel (depending on the export format available). Full text screening was done by one reviewer and checked by a second using EPPI-Reviewer web version.

Citation analysis (forwards, backwards and co-citation) was conducted on 17 October 2023 using the papers included from the initial database search results as seed papers. Title and abstract screening of identified records was completed by one reviewer using EPPI-Reviewer web version. Full text screening was done by one reviewer and checked by a second using EPPI-Reviewer web version.

Data extraction was conducted by one reviewer and checked by a second. A pre-specified data extraction template and coding system was used to consistently classify the population groups and climate change exposure pathway for each study (see [Annexe B](#) for the full list of codes used).

Critical appraisal of epidemiological studies was performed in duplicate by 2 reviewers, using the quality criteria checklist (QCC) tool ([32](#), [33](#)). Studies were given a quality rating of high, medium or low (see [Annexe D](#)), which reflects the methodological quality of a study (how well a study was conducted to minimise potential risk of bias), but does not take into account the risk of bias inherent to different study designs ([34](#)). Therefore, each study was classified into one of 4 study classes based on the hierarchy of evidence ([32](#)):

- class A – randomised controlled trials, cluster randomised trials and randomised crossover trials (class A studies were not eligible for inclusion in this review)
- class B – prospective cohort studies and retrospective cohort studies
- class C – non-randomised controlled trials, non-randomised crossover trials, case-control studies, case-crossover studies, time series studies, diagnostic, validity or reliability studies
- class D – non-controlled trials, case studies, case series, other descriptive studies, cross-sectional studies, retrospective studies, trend studies, before-after studies

The critical appraisal took into account the study class (or level of evidence) as well as the QCC rating. The study class provided information on the potential for bias based on study design (with studies in class A having lowest potential for bias and studies in class D the highest). The QCC rating provided information about the potential for bias within each study class.

No validated tools were used to critically assess the modelling studies. However, the main methodological limitations were identified by the reviewers and reported in the [supplementary tables](#) and narrative summary.

Visual synthesis was performed by generating an interactive evidence gap map in EPPI-Mapper ([35](#)), using the coding extracted to represent the evidence identified on health equity impacts of climate change by population groups and by climate change exposure pathways. A third dimension was added to represent the health outcomes assessed by each study. Microsoft Excel was used to produce additional visualisations.

Full details on the methodology are provided in [Annexe B](#). A protocol was produced a priori and was published on the OSF ([29](#)). Minor modifications made to the protocol are described in [Annexe B](#).

Eligibility criteria

A scoping exercise was conducted at review-level as part of best practice before developing the protocol (see [Annexe A](#)). This showed that the evidence available from the UK in the reviews identified (systematic reviews with or without meta-analysis, scoping reviews, and review protocols) was limited to a few population groups. These were mainly focused on older adults, children, pregnant women and people with long-term health conditions. However, the evidence available (at review-level) on other Core20PLUS population groups experiencing social vulnerabilities, such as ethnic minority groups, people from protected characteristics groups relating to sexual orientation or gender reassignment, and inclusion health groups was very limited. However, it was unclear whether this was due to a gap in review-level evidence or a lack of primary studies.

In this context, the population groups included in this mapping review were those for which limited evidence was identified during the scoping exercise:

- people experiencing the greatest deprivation (the most deprived 20% as defined by the Index of Multiple Deprivation (IMD), other deprivation measures were also considered)
- people from protected characteristics groups related to ethnicity (referred to as 'ethnic minority groups' in this report)
- people from protected characteristics groups related to gender reassignment
- people from protected characteristics groups related to sexual orientation
- people from protected characteristics groups related to religion or belief
- people from inclusion health groups, including
 - people experiencing homelessness
 - people with drug and or alcohol dependence
 - people in contact with the criminal justice system
 - vulnerable migrants
 - Gypsy, Roma and Traveller communities
 - sex workers
 - victims of modern slavery
 - other groups with experience of social exclusion

Studies conducted in the general population but which reported on one of the populations of interest in secondary analysis (for example by stratifying the study population by the characteristic of interest and reporting subgroup analysis) were included.

Settings related to these population groups such as prisons, asylum seeker accommodation settings, rehabilitation centres or temporary housing accommodation were also considered

Studies reporting on other Core20PLUS groups, including population groups with other protected characteristics (age, disability, pregnancy and maternity, and sex), populations with pre-existing health conditions, and place-based vulnerability were excluded.

In terms of climate change exposure pathways, studies were considered for inclusion if they reported on:

- climate change related hazards (increase in ambient temperature, extreme heat, extreme cold, heavy rainfall and flooding, drought and other extreme weather events)
- climate change related health risks (changes to vector ecology, changes to food supply and safety, changes to water supply and safety, changes to air quality and environmental degradation)
- climate change related solutions (mitigation or adaptation interventions and policy, community resilience, and disaster risk reduction)

To be considered for inclusion, studies reporting on climate change related health risks and solutions needed to have an explicit link to climate change. For example, studies reporting on air pollution levels were excluded if they lacked a clear link, framing or discussion connecting changes in air quality to climate change (climate change related health risks) or to a policy implemented to mitigate climate change. For instance, studies reporting on the health impacts of low emission zones were not included as the aim of these policies is to improve health

outcomes, not to mitigate climate change. This more selective eligibility criterion was based on the understanding that not all changes to air quality or infectious disease prevalence, for example, can be directly attributed to climate change. Conversely, studies on climate change related hazards were not required to establish an explicit link, since exposures such as extreme heat and flooding can be more directly attributed to climate change.

In terms of outcomes, studies were considered for inclusion if they reported on observed health outcomes, including mortality (all causes and cause-specific) and morbidity (such as respiratory and cardiovascular diseases and mental health conditions). Healthcare usage, such as Accident and Emergency (A&E) visits or 999 calls, was also considered for inclusion, as well as projected health measures, such as health impact scores or life-years gained.

Studies reporting on the proximal determinants of health (exposure to air pollution, unsafe working conditions, poor nutrition, exposure to infectious diseases and vectors, exposure to poor quality water, poor sanitation, and access to healthcare) were also considered for inclusion.

The inclusion and exclusion criteria are provided in [Annexe B \(Table B.1\)](#).

Results

Search results

The initial database search (conducted on 18 July 2023) returned 21,559 records. After removal of duplicates by [Deduplick \(36\)](#) and EPPI-Reviewer, 15,325 records were screened on title and abstract. Of these, 244 full-text articles were assessed for eligibility and 19 were included in this review.

Citation searching identified a further 862 unique records (after deduplication). These 862 records were screened on title and abstract. Of these, 56 full text articles were assessed for eligibility and 3 were included in this review.

The grey literature searches returned 1,555 records. After deduplication, 1,512 records were screened on title and abstract, of which 54 full text articles were sought for retrieval and 52 assessed for eligibility (2 articles could not be retrieved). No additional unique studies meeting the inclusion criteria were identified.

The database search update (conducted on 19 February 2024) returned 2,910 records. After removal of duplicates, 2,315 records were screened on title and abstract. Of these, 76 full-text articles were assessed for eligibility, and one was included in the review.

No additional unique studies were identified by searching reference lists of relevant reviews and included studies.

In total, 24 studies were included in this review (one article reported on 2 studies). Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) diagrams are provided in [Annexe B](#).

Details of the included studies can be found in Table S.1 in the [supplementary material](#) (if this link does not work, please visit [UKHSA evidence reviews](#)). Results of the critical appraisal of the observational studies are reported in [Annexe D](#).

The list of the 405 reports excluded on full text can be found in Table S.2 in the [supplementary material](#). Studies were excluded for the following reasons:

- 137 reported on the wrong population
- 75 had no explicit link to climate change
- 73 did not meet the inclusion criteria for outcome
- 40 reported on non-UK countries
- 33 used the wrong study design
- 24 did not meet the inclusion criteria for exposure
- 16 were duplicate references
- 6 were the wrong publication type
- one was not published in English

Evidence identified

Out of the 24 studies identified:

- one was a prospective cohort (study design class B; QCC rating: medium quality) ([37](#))
- 12 were time series (study design class C; QCC rating: 4 high quality ([38 to 41](#)), 6 medium quality ([42 to 47](#)) and 2 low quality ([48, 49](#)))
- 4 were case-crossover (study design class C; QCC rating: 2 high quality ([50, 51](#)) and 2 medium quality ([52, 53](#)))
- 3 were retrospective studies (study design class D; QCC rating: one medium quality ([54](#)) and 2 low quality ([55, 56](#)))
- one was a cross-sectional study (study design class D; QCC rating: low quality) ([57](#))
- one was a before-after study (study design class D; QCC rating: low quality) ([55](#))
- 2 were modelling studies (no study design class and no quality rating assigned; main limitations reported in the text and [supplementary tables](#)) ([58, 59](#))

Of these 24 studies, 18 investigated health impacts of climate change related hazards, of which 10 studies reported on increase in ambient temperature ([38 to 40, 43, 44, 46, 50, 52 to 54](#)), 5 on extreme cold ([39, 42, 46, 47, 51](#)), 4 on extreme heat ([41, 42, 46, 47](#)), and 4 on heavy rainfall and flooding ([45, 48, 57, 59](#)). Three studies assessed 2 temperature-related exposures and one study assessed 3 temperature-related exposures. These studies have been counted more than once. No studies were identified for drought or other extreme weather events.

One of the 24 studies reported on changes to air quality ([37](#)). No studies were identified for the other climate change related health risks, including changes to vector ecology, changes to food supply and safety, changes to water supply and safety, or environmental degradation.

Five of the 24 studies assessed the health impacts of climate change solutions (one paper ([55](#)) reported on 2 studies). Four these studies reported on mitigation policy: 3 studies reported on UK Net Zero policy ([55, 56](#)), of which 2 also reported on the Clean Growth Strategy ([55](#)), and one study reported on the Climate Change Act ([58](#)). The other study reported on climate change adaptation policy and interventions ([49](#)). No studies were identified for community resilience, or disaster risk reduction, response and recovery.

In terms of population groups, 20 of the 24 studies identified reported on people experiencing the greatest deprivation ([38, 39, 41 to 43, 45 to 53, 55 to 59](#)), 2 on ethnic minority groups ([37, 59](#)), 2 on people experiencing homelessness ([44, 54](#)), and one on people with drug and or alcohol dependence ([40](#)). One study reported on 2 population groups of interest for this review and has been counted more than once.

No studies meeting the inclusion criteria were identified for the following population groups:

- people from protected characteristics groups related to gender reassignment
- people from protected characteristics groups related to sexual orientation

- people from protected characteristics groups related to religion or belief
- people in contact with the criminal justice system
- vulnerable migrants
- Gypsy, Roma and Traveller communities
- sex workers
- victims of modern slavery
- other groups with experience of social exclusion

No studies were identified that reported on settings relevant to the population groups of interest.

The included studies reported on a range of health outcomes, including:

- 10 studies that assessed morbidity (cardiovascular diseases, respiratory diseases, mental health, and other conditions) ([39](#), [43 to 46](#), [53](#), [55 to 57](#))
- 10 studies that assessed all-cause or cause-specific mortality (including cardiovascular and respiratory causes) ([37](#), [40 to 42](#), [47 to 52](#))
- 2 studies that assessed healthcare usage (A&E department attendance) ([38](#), [54](#))
- 2 studies that assessed proximal determinants of health (access to healthcare ([59](#)) and exposure to air pollution ([58](#)))

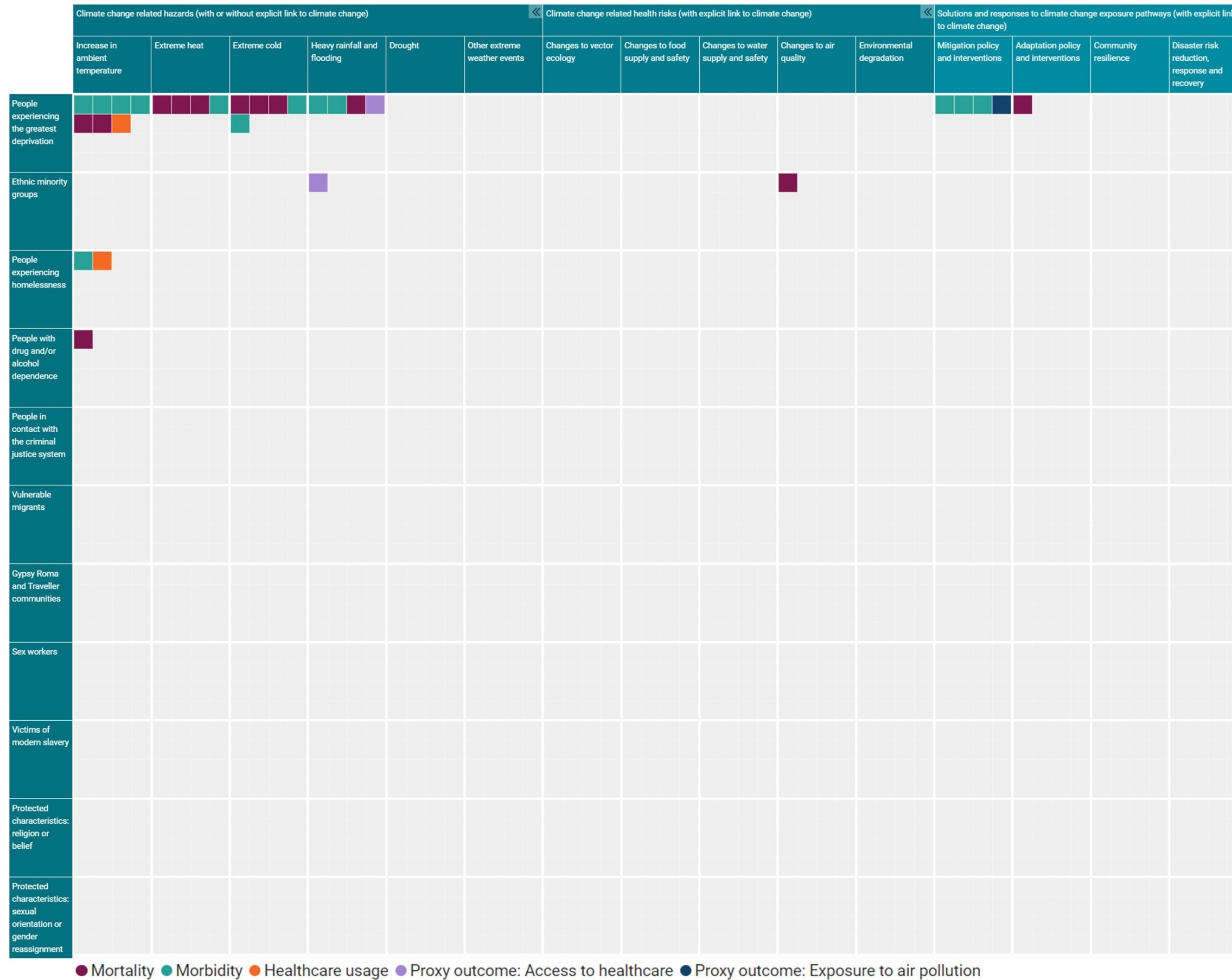
The included studies were conducted across the UK, including:

- 9 studies in England ([39](#), [40](#), [43](#), [45](#), [46](#), [51](#), [53](#), [57](#), [59](#))
- 8 studies in individual cities or regions ([38](#), [44](#), [49](#), [50](#), [54 to 56](#))
- 4 studies in England and Wales ([41](#), [42](#), [48](#), [52](#))
- 2 studies in Great Britain (England, Wales and Scotland) ([37](#), [58](#))
- one study in Scotland ([47](#))

Seventeen of the 24 studies identified aimed to investigate health impacts of climate change with a focus on health equity ([Figure E.1](#)) ([39 to 42](#), [44](#), [46](#), [47](#), [49 to 55](#), [57 to 59](#)). The remaining 7 studies aimed to investigate the association between climate change and health outcomes in the general population and did not focus on health equity. However, they were considered as meeting the inclusion criteria of this review as they reported on the populations of interest in secondary analysis ([37](#), [38](#), [43](#), [45](#), [48](#), [56](#)).

The 24 studies identified were mapped onto an interactive evidence gap map generated via EPPI-Mapper ([35](#)). In the map, available at [Evidence gap map: health equity impacts of climate change](#), the studies are visually displayed by climate change exposure pathway and population group (see screenshot of the map in [Figure 1](#)). The colour of each tile indicates the type of health outcome that each study assessed ('Mortality', 'Morbidity', 'Healthcare usage', 'Proxy outcomes: access to healthcare' and 'Proxy outcomes: exposure to air pollution'). The number of tiles corresponds to the number of studies identified. Studies reporting on more than one climate change exposure pathway (4 studies), or more than one population group (one study) are counted more than once.

Figure 1. Screenshot of evidence gap map representing the number of studies identified for each climate change exposure pathway and each population group



Evidence on climate change related hazards

Eighteen of the 24 studies identified reported on the health impacts of climate change related hazards for populations experiencing social vulnerabilities in the UK (see [Table 1](#)) ([38 to 48](#), [50 to 54](#), [57](#), [59](#)). Of these, 15 studies assessed the health impacts of climate change related hazards for people experiencing the greatest deprivation, one of which also reported findings for ethnic minority groups ([59](#)), 2 studies for people experiencing homelessness ([44](#), [54](#)), and one for people with drug and or alcohol dependence ([40](#)).

No studies reporting on the health impacts of climate change related hazards in the UK were identified for any of the other population groups of interest in this mapping review.

People experiencing the greatest deprivation

Of the 15 studies identified for people experiencing the greatest deprivation, 7 reported on increase in ambient temperature ([38](#), [39](#), [43](#), [46](#), [50](#), [52](#), [53](#)), 5 on extreme cold ([39](#), [42](#), [46](#), [47](#), [51](#)), and 4 on extreme heat ([41](#), [42](#), [46](#), [47](#)) (4 studies reported on more than one climate change related hazard). The remaining 4 studies reported on heavy rainfall and flooding ([45](#), [48](#), [57](#), [59](#)).

Increase in ambient temperature

Of the 7 studies reporting on increase in ambient temperature and health outcomes for people experiencing the greatest deprivation, 4 were time series ([38](#), [39](#), [43](#), [46](#)) and 3 were case-crossover ([50](#), [52](#), [53](#)).

Five of the 7 studies aimed to investigate the health equity impacts of increase in ambient temperature, including for people experiencing the greatest deprivation ([39](#), [46](#), [50](#), [52](#), [53](#)). The other 2 studies aimed to assess the association between increase in ambient temperature and health outcomes in the general population (primary objective not on health equity) but reported on people experiencing the greatest deprivation in secondary analysis ([38](#), [43](#)).

Increase in ambient temperature – studies with a focus on health equity

Murage and others ([50](#)) (study design class C; QCC rating: high quality) used a case-crossover design to investigate the association between increase in ambient temperature (daily mean temperature at postcode level) and risk of all-cause mortality in Greater London during the months May to September of 2007 to 2016. Lower-layer super output area (LSOA) level data for indicators of deprivation (including income and employment) was used to estimate the relationship between increased ambient temperature and mortality risk in the most and least deprived quartiles.

Bennett and others ([52](#)) (study design class C; QCC rating: medium quality) used a case-crossover design to investigate the association between increase in ambient temperature (daily

mean temperature at postcode level) and mortality from cardiorespiratory diseases for all 376 local authority districts in England and Wales during the months May to September of 2001 to 2010. The study assessed whether this association varied by quintiles of the Carstairs score, an area-level indicator of deprivation, which was assigned based on postcode of residence recorded on death certificates.

Konstantinoudis and others (53) (study design class C; QCC rating: medium quality) used a case-crossover design to investigate the association between increase in ambient temperature and risk of hospital admission for chronic obstructive pulmonary disease (COPD) in England during the months June to August of 2007 to 2018. The study reported the percentage change in heat-related risk of hospitalisation for COPD for each IMD quintile (relative to the most deprived quintile).

Lambourg and others (39) (study design class C; QCC rating: high quality) used time series analysis to investigate the association between increase in ambient temperature (monthly mean temperature at LSOA level) and rates of prescribing for antibiotics, bronchodilators, and antidepressants in England during the period 1 January 2011 to 31 December 2018. The study reported the relative change in prescribing rates with increasing temperature for the most and least deprived IMD quintiles.

Rizmie and others (46) (study design class C; QCC rating: medium quality) used time-series analysis to investigate the association between increase in ambient temperature (daily outdoor temperature measurements at hospital level) and risk of emergency hospital admissions for several diseases (including circulatory and respiratory diseases) in England between 1 April 2001 and 31 March 2012. The study reported the relative change in risk of hospital admission associated with increasing temperature for those living in the most and least deprived IMD quintiles (based on individual's postcodes recorded in hospital records).

Increase in ambient temperature – studies reporting on health equity in secondary analysis

Corcuera Hotz and others (38) (study design class C; QCC rating: high quality) used time-series analysis to investigate the association between increase in ambient temperature and A&E department visits in Greater London during 2007 to 2010. The exposure was daily mean temperature, averaged across the whole of Greater London. The study reported on people experiencing the greatest deprivation by stratifying the analysis into quintiles of the IMD.

Gong and others (43) (study design class C; QCC rating: medium quality) used time series analysis to investigate the association between increase in ambient temperature (daily mean temperature at the regional level) and risk of emergency hospital admissions for dementia in England between 1998 to 2009. The study reported on people experiencing the greatest deprivation by stratifying the analysis into IMD quintiles.

Summary findings – health impacts of increase in ambient temperature for people experiencing the greatest deprivation

Seven studies were identified that reported on the health impacts of increase in ambient temperature for people experiencing the greatest deprivation, of which 2 assessed mortality

(one all-causes and one cardiorespiratory causes), 4 assessed morbidity (cardiovascular diseases, respiratory diseases, mental health, dementia, and other morbidity), and one assessed healthcare usage (A&E attendances).

The studies identified were of time series and case crossover design (study design class C) and were generally well conducted (QCC ratings: 3 high quality and 4 medium quality). The main limitation of this body of evidence was that the analyses for deprivation were conducted using an area-based measure of deprivation, rather than measuring deprivation at the individual level. As area-based measures may not be an accurate representation of deprivation at the individual level ([60](#), [61](#)), the findings of these studies may not be generalisable to individuals within those areas. The exposure (ambient temperature) was also assessed at the area level in all studies. However, we did not judge this as resulting in an increased risk of bias because temperature tends to be consistent within regions of the UK (the largest geographical area in the included studies). Similar judgements were made for the studies reporting on extreme cold and extreme heat described below.

Table 1. Summary table of studies identified on climate change related hazards

Reference	Study methods	Population group	Climate change related hazard	Outcomes	Quality criteria checklist rating
Bennett and others (52)	Case-crossover (study design class C) <ul style="list-style-type: none"> Total n=921,288 deaths Sample size for population of interest not reported England and Wales May to September, 2001 to 2010	People experiencing the greatest deprivation: <ul style="list-style-type: none"> most deprived quintile of Carstairs Index (area-level) 	<ul style="list-style-type: none"> Increase in ambient temperature Population-level exposure assessment: daily temperature at postcode level	Mortality: <ul style="list-style-type: none"> cardiorespiratory causes 	Medium quality
Brown and others (54)	Retrospective study (study design class D) <ul style="list-style-type: none"> n=2,930 A&E attendances Sheffield 1 January 2003 to 31 December 2008	People experiencing homelessness: <ul style="list-style-type: none"> identified from A&E attendances with address recorded as no fixed abode (individual-level) 	<ul style="list-style-type: none"> Increase in ambient temperature Population-level exposure assessment: daily temperature averaged for whole city	Healthcare usage: <ul style="list-style-type: none"> A&E visits 	Medium quality
Corcuera Hotz and others (38)	Time series (study design class C) <ul style="list-style-type: none"> Total n=13.4 million A&E attendances Sample size for population of interest not reported Greater London 2007 to 2010	People experiencing the greatest deprivation: <ul style="list-style-type: none"> most deprived quintile of IMD (area-level) 	<ul style="list-style-type: none"> Increase in ambient temperature Population-level exposure assessment: daily temperature averaged for whole city	Healthcare usage: <ul style="list-style-type: none"> A&E visits all causes cause-specific (respiratory, cardiovascular, cerebrovascular, fractures and psychiatric) 	High quality
Gasparrini and others (42)	Time series (study design class C) <ul style="list-style-type: none"> Total n=10,716,879 deaths Sample size for population of interest not reported England and Wales 1 January 2000 to 31 December 2019	People experiencing the greatest deprivation: <ul style="list-style-type: none"> most deprived quintile of IMD (area-level) 	<ul style="list-style-type: none"> Extreme cold Extreme heat Population-level exposure assessment: daily temperature at LSOA level	Mortality: <ul style="list-style-type: none"> all causes 	Medium quality
Gong and others (43)	Time series (study design class C) <ul style="list-style-type: none"> Total sample size not reported Sample size for population of interest not reported England 1998 to 2009	People experiencing the greatest deprivation: <ul style="list-style-type: none"> most deprived quintile of IMD (area-level) 	<ul style="list-style-type: none"> Increase in ambient temperature Population-level exposure assessment: daily temperature at regional level	Morbidity: <ul style="list-style-type: none"> emergency hospital admissions for dementia 	Medium quality
Hajat and others (44)	Time series (study design class C) <ul style="list-style-type: none"> n=168,918 admissions Greater London 2011 to 2019	People experiencing homelessness: <ul style="list-style-type: none"> identified from admissions with address recorded as no fixed abode or a diagnosis 	<ul style="list-style-type: none"> Increase in ambient temperature 	Morbidity: <ul style="list-style-type: none"> all-cause emergency hospital admissions 	Medium quality

Reference	Study methods	Population group	Climate change related hazard	Outcomes	Quality criteria checklist rating
		of homelessness (individual-level)	Population-level exposure assessment: daily temperature averaged for whole city		
Konstantinoudis and others (53)	Case-crossover (study design class C) <ul style="list-style-type: none"> Total n=320,411 admissions Sample size for population of interest not reported England June to August, 2007 to 2018	People experiencing the greatest deprivation: <ul style="list-style-type: none"> most deprived quintile of IMD (area-level) 	<ul style="list-style-type: none"> Increase in ambient temperature Population-level exposure assessment: daily temperature at postcode level	Morbidity: <ul style="list-style-type: none"> hospital admissions for COPD 	Medium quality
Lambourg and others (39)	Time series (study design class C) <ul style="list-style-type: none"> All general practices in England (number not reported) Number of prescriptions in most deprived quintile: <ul style="list-style-type: none"> antibiotics n=142,053 antidepressants n=141,948 bronchodilators n=140,374 England 1 January 2011 to 31 December 2018	People experiencing the greatest deprivation: <ul style="list-style-type: none"> most deprived quintile of IMD (area-level) 	<ul style="list-style-type: none"> Extreme cold Increase in ambient temperature Population-level exposure assessment: monthly temperature at LSOA level	Morbidity: <ul style="list-style-type: none"> prescriptions for: <ul style="list-style-type: none"> antibiotics (other morbidity) antidepressants (mental health) bronchodilators (respiratory disease) 	High quality
Lamond and others (57)	Cross-sectional (study design class D) <ul style="list-style-type: none"> Total n=280 households Sample size for population of interest not reported 15 areas in England, mainly in Yorkshire and South West regions At least 5 years after 2007 floods	People experiencing the greatest deprivation: <ul style="list-style-type: none"> low household income (individual-level) 	<ul style="list-style-type: none"> Heavy rainfall and flooding Household-level exposure assessment: household flooding assessed using insurance claims records	Morbidity: <ul style="list-style-type: none"> mental health (self-reported) 	Low quality
Milojevic and others (48)	Time series (study design class C) <ul style="list-style-type: none"> Total n=771 deaths in year before flood events and n=693 in year after flood events Sample size for population of interest not reported England and Wales 1994 to 2005	People experiencing the greatest deprivation: <ul style="list-style-type: none"> most deprived quintile of IMD (area-level) 	<ul style="list-style-type: none"> Heavy rainfall and flooding Population-level exposure assessment: postcode flooding assessed using administrative data on 319 flood events	Mortality: <ul style="list-style-type: none"> all causes 	Low quality
Milojevic and others (45)	Time series (study design class C) <ul style="list-style-type: none"> Total n=930 general practices 	People experiencing the greatest deprivation:	<ul style="list-style-type: none"> Heavy rainfall and flooding 	Morbidity:	Medium quality

Reference	Study methods	Population group	Climate change related hazard	Outcomes	Quality criteria checklist rating
	<ul style="list-style-type: none"> n=186 general practices in population of interest <p>Areas of England affected by 5 major flood events June 2011 to November 2014</p>	<ul style="list-style-type: none"> most deprived quintile of IMD (area-level) 	Population-level exposure assessment: within 10km of flood boundaries	<ul style="list-style-type: none"> mental health (prescriptions for antidepressants) 	
Murage and others (50)	<p>Case-crossover (study design class C)</p> <ul style="list-style-type: none"> Total n=185,397 deaths Sample size for population of interest not reported <p>Greater London May to September, 2007 to 2016</p>	<p>People experiencing the greatest deprivation:</p> <ul style="list-style-type: none"> most deprived quartile for income (area-level) most deprived quartile for employment (area-level) 	<ul style="list-style-type: none"> Increase in ambient temperature <p>Population-level exposure assessment: daily temperature at postcode level</p>	<p>Mortality:</p> <ul style="list-style-type: none"> all causes 	High quality
Page and others (40)	<p>Time series (study design class C)</p> <ul style="list-style-type: none"> n=8,000 deaths (calculated from figures reported in paper) <p>England 1 January 1998 to 31 December 2007</p>	<p>People with drug and or alcohol dependence:</p> <ul style="list-style-type: none"> patients with alcohol misuse or other substance misuse recorded in primary care records who died during study period (individual-level) 	<ul style="list-style-type: none"> Increase in ambient temperature <p>Population-level exposure assessment: daily temperature at regional level</p>	<p>Mortality</p> <ul style="list-style-type: none"> all causes 	High quality
Rizmie and others (46)	<p>Time series (study design class C)</p> <ul style="list-style-type: none"> Total n=29,371,084 admissions Sample size for population of interest not reported <p>England 1 April 2001 to 31 March 2012</p>	<p>People experiencing the greatest deprivation:</p> <ul style="list-style-type: none"> most deprived quintile of IMD (area-level) 	<ul style="list-style-type: none"> Extreme cold Extreme heat Increase in ambient temperature <p>Population-level exposure assessment: daily outdoor temperature at hospital level (unclear how assigned)</p>	<p>Morbidity – emergency hospital admissions for:</p> <ul style="list-style-type: none"> infectious diseases metabolic diseases neoplastic diseases respiratory diseases circulatory diseases injuries 	Medium quality
Tammes and others (51)	<p>Case-crossover (study design class C)</p> <ul style="list-style-type: none"> Total n=34,752 deaths, of which n=5,649 (16.3%) in population of interest Winter-related deaths n=7,710, of which n=1,260 (16.3%) in population of interest <p>England 1 April 2012 to 31 March 2014</p>	<p>People experiencing the greatest deprivation:</p> <ul style="list-style-type: none"> most deprived quintile of IMD (area-level) 	<ul style="list-style-type: none"> Extreme cold <p>Population-level exposure assessment: daily temperature at 10 English Strategic Health Authorities level</p>	<p>Mortality:</p> <ul style="list-style-type: none"> all causes winter-related causes (diseases of the circulatory system, respiratory system and nervous system, and mental and behavioural disorders) 	High quality

Reference	Study methods	Population group	Climate change related hazard	Outcomes	Quality criteria checklist rating
Wan and others (47)	Time series (study design class C) <ul style="list-style-type: none"> Total n=2,683,885 deaths, of which n=569,094 in population of interest Scotland 1974 to 2018	People experiencing the greatest deprivation: <ul style="list-style-type: none"> most deprived quintile of (modified) Carstairs Index (area-level) 	<ul style="list-style-type: none"> Extreme cold Extreme heat Population-level exposure assessment: daily temperature at area level (resolution unclear)	Mortality: <ul style="list-style-type: none"> all causes 	Medium quality
Yu and others (59)	Modelling study (no study design class) England	People experiencing the greatest deprivation: <ul style="list-style-type: none"> household deprivation (individual-level) Ethnic minority groups: <ul style="list-style-type: none"> Asian, Black, Mixed, and Other ethnic groups (individual-level) 	<ul style="list-style-type: none"> Heavy rainfall and flooding Population-level exposure assessment: modelled based on flood risk maps	Proxy outcome – access to healthcare: <ul style="list-style-type: none"> ambulance response times 	Not assessed
Zafeiratou and others (41)	Time series (study design class C) <ul style="list-style-type: none"> Total n=247,836 deaths Sample size for population of interest not reported England and Wales May to September, 2000 to 2018	People experiencing the greatest deprivation: <ul style="list-style-type: none"> fifth percentile of employment rate (area-level) fifth percentile of gross domestic product (GDP) per inhabitant (area-level) 	<ul style="list-style-type: none"> Extreme heat Population-level exposure assessment: daily temperature at LSOA level	Mortality: <ul style="list-style-type: none"> respiratory causes 	High quality

Extreme cold

Of the 5 studies identified on the health impacts of extreme cold for people experiencing the greatest deprivation, 4 were time series ([39](#), [42](#), [46](#), [47](#)) and one was a case-crossover study ([51](#)). All 5 studies aimed to assess impacts on health equity.

Extreme cold – studies with a focus on health equity

Tammes and others ([51](#)) (study design class C; QCC rating: high quality) used a case-crossover design to investigate the association between extreme cold and mortality (all-causes and winter-related causes, including circulatory and respiratory diseases) in England during 1 April 2012 to 31 March 2014. The study estimated the risk of mortality with decreasing temperature (mean daily temperature recorded for 10 English strategic health authorities (SHAs); note that SHAs have been abolished since this study was published). The study estimated relative cold-related mortality risk for people living in the most deprived IMD quintile compared with the least deprived IMD quintile, after adjusting for a range of individual-level covariates (including sex, age and pre-existing health conditions).

Gasparrini and others ([42](#)) (study design class C; QCC rating: medium quality) used time series analysis to investigate the association between extreme cold and all-cause mortality in England and Wales during 1 January 2000 to 31 December 2019. Extreme cold was defined as days where the temperature was at the first percentile of the distribution of daily temperature for each LSOA. The study reported the rate of excess cold-related mortality for people living in the most deprived LSOAs based on quintiles of the IMD.

Wan and others ([47](#)) (study design class C; QCC rating: medium quality) used time series analysis to investigate the association between extreme cold and all-cause mortality in Scotland during October to April of each year between 1974 and 2018. Extreme cold days were defined as days where the temperature was at the first percentile (-1.7°C) of the distribution of daily mean recorded temperatures, pooled across 3 regions and 4 major cities in Scotland. The study examined whether the relative risk of mortality on extreme cold days varied by area deprivation based on quintiles of a modified version of the Carstairs Index (the proportion of unemployed males was replaced with proportion of unemployed people).

The studies by Lambourg and others ([39](#)) (study design class C; QCC rating: high quality) and Rizmie and others ([46](#)) (study design class C; QCC rating: medium quality) also reported on the health impacts of extreme cold. Extreme cold in these studies was defined as temperatures between 1.5°C to 7.3°C and -5°C or less, respectively. These studies have been described in detail in the previous section on [Increase in ambient temperature](#).

Summary findings – health impacts of extreme cold for people experiencing the greatest deprivation

Five studies were identified that reported on the health impacts of extreme cold for people experiencing the greatest deprivation, of which 3 assessed mortality (all-causes and

cardiorespiratory causes) and 2 assessed morbidity (circulatory and respiratory diseases, mental health, and other morbidity).

The studies identified were of time series and case crossover design (study design class C) and were generally well conducted (2 rated as high quality and 3 rated as medium quality). However, the main limitation of the evidence is that analyses for deprivation were conducted using an area-based measure of deprivation (rather than individual level). Although the exposure (extreme cold) was also assessed at the area-level, this was not considered to increase the risk of bias in these studies.

Extreme heat

All 4 studies identified on the health impacts of extreme heat for people experiencing the greatest deprivation used time-series designs and aimed to investigate impacts on health equity ([41](#), [42](#), [46](#), [47](#)).

Extreme heat – studies with a focus on health equity

Zafeiratou and others ([41](#)) (study design class C; QCC rating: high quality) used time series analysis to investigate the association between extreme heat and mortality from respiratory causes in England and Wales during the months of May to September of 1994 to 2018. Extreme heat was defined for each LSOA as temperatures at the 95th percentile of the recorded daily mean temperature distribution. The study examined whether the risk of heat-related mortality varied by 2 indicators of deprivation: the proportion of working-age people in employment and GDP per inhabitant, both measured at area level (LSOA).

The studies by Gasparini and others ([42](#)) (study design class C; QCC rating: medium quality), Rizmie and others ([46](#)) (study design class C; QCC rating: medium quality) and Wan and others ([47](#)) (study design class C; QCC rating: medium quality) also investigated the health impacts of extreme heat for people experiencing the greatest deprivation. These studies have been described in detail in previous sections. Two studies defined extreme heat as days where the temperature was at the 99th percentile of the recorded daily temperature distribution ([42](#), [47](#)). Rizmie and others defined extreme heat as days where temperatures were at least 30°C ([46](#)).

Summary findings – health impacts of extreme heat for people experiencing the greatest deprivation

Four studies were identified that reported on the health impacts of extreme heat for people experiencing the greatest deprivation, 3 of which assessed mortality and one assessed morbidity.

All 4 studies were time series (study design class C) and were generally well conducted (one rated as high quality and 3 rated as medium quality). The main limitation of the evidence was that analyses of deprivation were conducted using an area-based measure of deprivation (rather than at the individual level). Although the exposure (extreme heat) was also assessed at the area level, this was not considered to increase the risk of bias in these studies.

Heavy rainfall and flooding

Of the 4 studies identified on the health impacts of heavy rainfall and flooding for people experiencing the greatest deprivation, 2 were time series (45, 48), one was a cross-sectional study (57), and one was a modelling study (59). One of these studies investigated the health equity impacts of heavy rainfall and flooding, including for people experiencing the greatest deprivation. The other 3 studies reported on people experiencing the greatest deprivation in secondary analysis.

Heavy rainfall and flooding – studies with a focus on health equity

The modelling study by Yu and others (59) used flood risk maps for England to model changes in access to healthcare (ambulance service response times) for flood event scenarios of varying levels of severity. The study used 2011 Census data to obtain estimates of the number of deprived households (based on data on employment, health and disability, education, and housing). The authors predicted the percentage of households experiencing deprivation that could be accessed by ambulances within 7 minutes and 15 minutes under different flood event scenarios. This study was generally well conducted, and the findings deemed to be valid, but the lack of sensitivity analyses for some of the assumptions made in the model means it is unclear whether the results are generalisable to different flood scenarios.

Heavy rainfall and flooding – studies reporting on health equity in secondary analysis

Milojevic and others (45) (study design class C; QCC rating: medium quality) used time series analysis to investigate the association between flooding and rates of prescribing for antidepressants between June 2011 and November 2014. Data on antidepressant prescribing was obtained from 930 GP practices in England that were within 10km of 5 major flood events. The study compared the change in rates of antidepressant prescriptions in the year before each flood event to the following year, stratified by IMD quintile based on each GP practice location.

Milojevic and others (48) (study design class C; QCC rating: low quality) used time series analysis to investigate the association between flooding and all-cause mortality in the year following 319 floods occurring in England and Wales between 1994 to 2005. The study calculated the change in all-cause mortality in the year following each flood relative to the preceding year, compared with the change observed in non-flooded areas within 5km of the flood boundaries. Flooding was assessed based on postcode of residence retrieved from death certificates, which may have meant that some people who were displaced by floods were incorrectly recorded as living in non-flooded areas. The analysis was stratified into IMD quintiles to assess whether the association varied by area-level deprivation.

Lamond and others (57) (study design class D; QCC rating: low quality) conducted a cross-sectional study (survey) to investigate predictors of mental health outcomes among 280 households that had been flooded during the 2007 floods in England (15 areas sampled, most in Yorkshire and South West regions). The survey assessed long-term mental health outcomes at least 5 years after the flooding took place. The study reported the likelihood of self-reported

mental health deterioration associated with flooding for low-income households, relative to high-income households (at least £55,000).

Summary findings – health impacts of heavy rainfall and flooding for people experiencing the greatest deprivation

Four studies reporting on the health impacts of heavy rainfall and flooding for people experiencing the greatest deprivation were identified, of which 3 were observational studies and one was a modelling study. Two studies reported on mental health outcomes, one on all-cause mortality and one on healthcare access (ambulance service response times).

Of these 4 studies, one modelling study focused on the health equity impact of heavy rainfall and flooding, including for people experiencing the greatest deprivation. The 3 other studies (2 study design class C, one rated as medium quality and one as low quality, and one study design class D rated as low quality) addressed health equity only through secondary analysis. The main limitation of the evidence was that, in 2 of the 3 observational studies, deprivation and flooding were assessed at the area level (with no assessment of whether households had been flooded). In addition, the outcome was self-reported in one study.

Summary of evidence – people experiencing the greatest deprivation

Fifteen studies (9 time series, 4 case-crossover, one cross-sectional and one modelling) were identified on people experiencing the greatest deprivation, of which 7 reported on ambient temperature, 5 on extreme cold, 4 on extreme heat, and 4 on heavy rainfall and flooding (4 studies reported on more than one temperature-related exposure). No studies were identified for drought or other extreme weather events.

In terms of outcomes, most studies focused on mortality (7 out of 15) or morbidity (6 studies), especially cardiovascular diseases and respiratory diseases, with the remainder reporting on healthcare usage (one study) or access to healthcare (one study).

In terms of study quality, the studies assessing the health impacts of increase in ambient temperature, extreme cold, and extreme heat were generally of higher quality than those on heavy rainfall and flooding: none of the studies on temperature were rated as low quality, compared with 2 out of 3 observational studies on flooding. This was mainly because these studies assessed exposure to flooding at area-level rather than assessing whether each household had actually experienced flooding. Conversely, while all studies reporting on temperature also measured the exposure at the area level, this was not considered to be a limitation (or to increase risk of bias) as temperature does not vary substantially across regions. Other reasons that studies of heavy rainfall and flooding were rated as lower quality included that outcomes were self-reported in one study (which is more prone to bias than objectively measured outcomes), and 2 studies may not have been representative of the target population due to the potential risk of selection bias.

Finally, 13 out of the 15 studies identified reported on people experiencing the greatest deprivation using an area-based measure of deprivation (such as IMD, Carstairs index or

employment rate at area level), rather than measuring deprivation at the individual level (see [Figure E.2](#)). Therefore, the findings of these studies may not be generalisable to individuals because associations observed at the population level may not apply to individuals within those populations (ecological bias).

Ethnic minority groups

One modelling study was identified that reported on the predicted health impacts of heavy rainfall and flooding for ethnic minority groups ([59](#)). No studies were identified that reported on health impacts of other climate change related hazards for ethnic minority groups.

Heavy rainfall and flooding

The modelling study by Yu and others ([59](#)) (described in the previous section) also predicted the impact of flood events on ambulance response times for ethnic minority groups based on population estimates of the following ethnic groups: Asian, Black, Mixed, White, and Other ethnic groups. The same methodological limitations apply to this study for this population group as described for people experiencing the greatest deprivation (see [supplementary tables](#)).

Summary of evidence – ethnic minority groups

Only one study reporting on the health impacts of climate change related hazards for ethnic minority groups was identified. This was a modelling study that reported on the predicted impact of flooding on access to healthcare (considered as a proximal determinant of health for this mapping review) for a range of population groups experiencing social vulnerabilities, including ethnic minority groups. No observational studies that used real-world data to examine health impacts of actual flood events were identified for this population group. In addition, no studies reporting on other climate change related hazards were identified, highlighting an evidence gap for this population group.

People experiencing homelessness

Two studies (one time series ([44](#)) and one retrospective study ([54](#))) were identified that reported on the health impacts of climate change related hazards for people experiencing homelessness, both of which reported on increase in ambient temperature. No studies were identified that reported on the health impacts of other climate change related hazards for people experiencing homelessness.

Increase in ambient temperature

Hajat and others ([44](#)) (study design class C; QCC rating: medium quality) used time series analysis to investigate the association between increase in ambient temperature and risk of

emergency hospital admission (all-causes) among people experiencing homelessness. The study included hospital admissions occurring in Greater London during 2011 to 2019. Daily maximum temperature data was averaged across the whole of Greater London. The study population was sampled using hospital admissions with either no fixed abode recorded as the patient's address (148,177 admissions) or homelessness recorded as the primary or secondary diagnosis (20,804 admissions).

Brown and others (54) (study design class D; QCC rating: medium quality) conducted a retrospective study, which investigated whether increase in ambient temperature was associated with the likelihood of attending A&E among people experiencing homelessness. The study included data from a single A&E department in Sheffield (England) during the period 1 January 2003 to 31 December 2008. Daily minimum and maximum temperature data was obtained from a single weather station in Sheffield. The authors estimated the association between daily maximum temperature and number of A&E department visits where the patients' address was recorded as no fixed abode (2,930 attendances).

Summary of evidence – people experiencing homelessness

Only 2 studies (one time series and one retrospective) were identified for people experiencing homelessness, both of which reported on increase in ambient temperature. One of these studies reported on morbidity (all-cause hospital admissions) and the other study reported on healthcare usage (A&E attendances). These 2 studies were generally well conducted (both rated as medium quality). No studies were identified for other climate change related hazards for this population group.

People with drug and or alcohol dependence

One study was identified that reported on the association between increase in ambient temperature and all-cause mortality for people with drug and or alcohol dependence (40). No studies were identified that reported on the health impacts of other climate change related hazards for this population group.

Increase in ambient temperature

Page and others (40) (study design class C; QCC rating: high quality) used time series analysis to investigate the association between increase in ambient temperature and risk of all-cause mortality for people with "alcohol misuse" or "other substance misuse". The study sample comprised approximately 8,000 people who had been diagnosed with alcohol or other substance misuse in national primary care records for England and died between 1 January 1998 to 31 December 2007. The study estimated the change in mortality risk associated with a 1°C increase in temperature above 18°C, based on daily mean regional temperature linked to individual's region of residence obtained from mortality records.

Summary of evidence – people with drug and or alcohol dependence

Only one study was identified for people with drug and or alcohol dependence, which reported on increase in ambient temperature and risk of all-cause mortality. This study, a time series analysis, was deemed to be of high quality. No studies were identified for other climate change related hazards for this population group.

Evidence on climate change related health risks

One study was identified that reported on the health equity impacts of climate change related health risks for populations experiencing social vulnerabilities in the UK (see [Table 2](#)) ([37](#)). This prospective cohort study, which reported on wildfire-related air pollution, did not have a focus on healthy equity but reported on several population groups, including ethnic minority groups.

No studies were identified for any of the other population groups of interest, or other climate change related health risks.

Ethnic minority groups

Changes to air quality

Changes to air quality – studies reporting on health equity in secondary analysis

Gao and others ([37](#)) (study design class B; QCC rating: medium quality) conducted a prospective cohort study to investigate the association between exposure to wildfire-related PM_{2.5} (particulate matter less than 2.5 micrometres in diameter) and mortality. The cohort included 492,394 participants enrolled in the UK Biobank Cohort between 2004 to 2010 and living in England, Wales and Scotland (mean follow-up time = 11.2 years). The exposure was wildfire-related PM_{2.5} within 10km of each participant's home address. Exposure levels were estimated using modelling techniques to assess PM_{2.5} levels from wildfires occurring globally over a 3-year period. Subgroup analysis was conducted in participants of non-white ethnicity (n=57,244), adjusting for a range of covariates obtained from self-reported questionnaires, including age, sex, indicators of socio-economic status, health behaviours (alcohol drinking and smoking), and PM_{2.5} from non-wildfire sources. The authors also assessed mortality among people living in deprived areas according to the Townsend deprivation index, but this was not mapped because it did not meet the inclusion criterion of people experiencing the greatest deprivation used for this review.

Summary of evidence – ethnic minority groups

One cohort study (class B) was identified on the association between wildfire-related air pollution and risk of mortality for ethnic minority groups. While this study was generally well conducted (QCC rating: medium quality), the main limitations of the study were that the sample was not representative of the general population and the description of the exposure was limited.

No studies were identified for other climate change related health risks (changes to vector ecology, changes to food supply and safety, changes to water supply and safety, or environmental degradation) for this population group.

Table 2. Summary table of studies identified on climate change related health risks

Reference	Study methods	Population group	Climate change related health risks	Outcomes	Quality criteria checklist rating
Gao and others (37)	Prospective cohort (study design class B) <ul style="list-style-type: none"> • Total n=492,394 participants • n=57,224 participants of non-white ethnicity Great Britain UK Biobank participants enrolled 2004 to 2010, exposure measured 2000 to 2019, mean follow-up time 11.2 years	Ethnic minority groups: <ul style="list-style-type: none"> • non-white ethnicity (individual-level) 	<ul style="list-style-type: none"> • Changes to air quality Population-level exposure assessment: modelled wildfire-related PM _{2.5} levels within 10km of each participant's address	Mortality: <ul style="list-style-type: none"> • all causes 	Medium quality

Evidence on solutions and responses to address climate change

Five studies (2 retrospective studies, one time series, one before-after study and one modelling study) were identified that assessed the health impacts of the solutions and responses to address climate change ([49](#), [55](#), [56](#), [58](#)) (one paper reported on 2 studies) for populations experiencing social vulnerabilities in the UK (see [Table 3](#)).

All 5 studies assessed the health impacts of the solutions and responses to address climate change for people experiencing the greatest deprivation. Four of the 5 studies reported on the health impacts of climate change mitigation policy or interventions. The other study reported on the health impacts of climate change adaptation policy and interventions.

Four of the 5 studies aimed to investigate the health equity impacts of climate change mitigation policy, including for people experiencing the greatest deprivation. The other study did not focus on health equity, but reported on people experiencing the greatest deprivation in secondary analysis ([56](#)).

No studies were identified for any of the other population groups of interest, or other solutions and responses to address climate change.

People experiencing the greatest deprivation

Mitigation policy and interventions

Mitigation policy and interventions – studies with a focus on health equity

Williams and others ([58](#)) conducted a modelling study that predicted the impact of the Climate Change Act on exposure to air pollution for people experiencing the greatest deprivation. The study predicted changes in air pollution for small geographical areas in Great Britain under various scenarios, stratified by quintiles of deprivation based on the Carstairs Index (an area-level measure of deprivation). The authors used a previously validated model to make predictions about changes in air quality and provided clear justifications for the choice of model used for health impact assessment, including transparent reporting of study limitations.

Kearns and others ([55](#)) reported 2 studies (one before-after study and one retrospective study) in one paper. In the before-after study (study design class D; QCC rating: low quality) 229 interviews were conducted in the winter following installation of external wall insulation. Households that had the external wall insulation fitted between October to February of 2015 to 2017 were sampled from 7,201 properties that had external wall insulation installed between 2013 to 2020 as part of an intervention to reduce fuel poverty. Participants provided self-reported ratings of health-related quality of life (including mental and physical health) before and after installation of the external wall insulation.

The retrospective study by Kearns and others (55) (study design class D; QCC rating: low quality) assessed emergency hospital admissions for respiratory and cardiovascular disease between May 2011 to September 2021 in the Ayrshire and Arran Health Board area of Scotland (10,975 postcodes, 54% of which were in the 2 most deprived quintiles of the Scottish IMD). The study compared the number of hospital admissions between 184 postcode areas (73% of which were in the 2 most deprived quintiles) where at least 50% of properties had undergone external wall insulation, with the remaining postcodes in the Health Board area.

Mitigation policy and interventions – studies reporting on health equity in secondary analysis

Symonds and others (56) (study design class D; QCC rating: low quality) conducted a retrospective study investigating the association between home energy efficiency and self-reported health, using linked administrative datasets. This study covered the whole of Greater London, with subgroup analysis in the most income deprived quartile (measured at area level). Median household energy efficiency for each LSOA was calculated from the most recent score recorded in the energy performance certificate database (data obtained in 2017). Health outcomes were based on estimates of the proportion of people in each LSOA who self-reported good or very good health at the 2011 Census.

Adaptation policy and interventions

Adaptation policy and interventions – studies with a focus on health equity

Tieges and others (49) (study design class C; QCC rating: low quality) conducted a time series analysis to investigate the health co-benefits of a canal regeneration project aimed to improve climate change adaptation (for example, by reducing risk of flooding and improving air quality) in north Glasgow. The study calculated the change in all-cause mortality rates from 2001 to 2017 (before and after canal regeneration) between 114 small areas, approximately half of which were in the 20% most deprived areas based on the Scottish IMD (exact number not reported).

Summary of evidence – people experiencing the greatest deprivation

Four of the 5 studies (3 observational studies and one modelling study) reported on the health impacts of mitigation policy and interventions for people experiencing the greatest deprivation. The 3 observational studies (2 retrospective and one before-after study; all rated as low quality) reported on morbidity (hospital admissions and self-reported health outcomes) and the modelling study reported on proximal determinants of health (exposure to air pollution). The other study was an observational study (time series analysis rated as low quality), which reported on changes in mortality associated with climate change adaptation policy.

The main limitations of the 4 observational studies were that there was no measure of deprivation at the individual level (one study used an area level measure of deprivation and the other 3 studies were conducted in an area experiencing high levels of deprivation). In addition, outcomes were self-reported in 2 out of 4 studies, which is more prone to bias than objectively measured outcomes.

No studies were identified on the health impacts of other solutions and responses to address climate change, such as community resilience and disaster risk reduction, response and recovery.

Table 3. Summary table of studies identified on solutions and responses to address climate change

Reference	Study methods	Population group	Solutions and responses to climate change	Outcomes	Quality criteria checklist rating
Kearns and others (55)	Retrospective study (study design class D) <ul style="list-style-type: none"> • Sample size not reported Ayrshire & Arran Health Board, Scotland May 2011 to September 2021	People experiencing the greatest deprivation: <ul style="list-style-type: none"> • area with high levels of deprivation (area-level) 	Mitigation policy and interventions: <ul style="list-style-type: none"> • UK net zero policy • Clean Growth Strategy 	Morbidity: <ul style="list-style-type: none"> • emergency hospital admissions for cardiovascular and respiratory diseases 	Low quality
Kearns and others (55)	Before-after study (study design class D) <ul style="list-style-type: none"> • n=229 interviews Southwest Scotland Winter following installation of external wall insulation in 2015 to 2017	People experiencing the greatest deprivation: <ul style="list-style-type: none"> • area with high levels of deprivation (area-level) 	Mitigation policy and interventions: <ul style="list-style-type: none"> • UK net zero policy • Clean Growth Strategy 	Morbidity: <ul style="list-style-type: none"> • self-reported health-related quality of life 	Low quality
Symonds and others (56)	Retrospective study (study design class D) <ul style="list-style-type: none"> • Total n=4,835 LSOAs • n=1,442 LSOAs in most income deprived quartile Greater London Study period unclear	People experiencing the greatest deprivation: <ul style="list-style-type: none"> • most income deprived quartile (area-level) 	Mitigation policy and interventions: <ul style="list-style-type: none"> • UK net zero policy 	Morbidity: <ul style="list-style-type: none"> • self-reported health 	Low quality
Tieges and others (49)	Time series (study design class C) <ul style="list-style-type: none"> • Total n=114 small geographic areas • Number of deaths not reported Glasgow 2001 to 2017	People experiencing the greatest deprivation: <ul style="list-style-type: none"> • area with high levels of deprivation (area-level) 	Adaptation policy and interventions: <ul style="list-style-type: none"> • Glasgow smart canal project 	Mortality: <ul style="list-style-type: none"> • all-cause mortality 	Low quality
Williams and others (58)	Modelling study (no study design class) Great Britain 2011 to 2154	People experiencing the greatest deprivation: <ul style="list-style-type: none"> • most deprived quintile of Carstairs Index (area-level) 	Mitigation policy and interventions: <ul style="list-style-type: none"> • Climate Change Act 	Proxy outcome – exposure to air pollution: <ul style="list-style-type: none"> • PM_{2.5} • NO₂ • O₃ 	Not assessed

Evidence gaps

No studies reporting on the health equity impacts that met the inclusion criteria were identified for the following population groups experiencing social vulnerabilities in the UK:

- people in contact with the criminal justice system
- vulnerable migrants
- Gypsy, Roma and Traveller communities
- sex workers
- victims of modern slavery
- people from protected characteristics groups related to gender reassignment
- people from protected characteristics groups related to sexual orientation
- people from protected characteristics groups related to religion or belief

In addition, no studies that investigated health equity impacts in settings of relevance to population groups experiencing social vulnerabilities were identified.

The evidence identified mainly reported on the health impacts of climate change related hazards for people experiencing the greatest deprivation: 7 studies reported on increase in ambient temperature, 5 on extreme cold, 4 on extreme heat, 4 on heavy rainfall and flooding. No studies were identified for other climate change related hazards (drought or other extreme weather events) or climate change related health risks for this population group. Importantly, most of these studies only reported on people experiencing the greatest deprivation in subgroup analysis using an area-based measure of deprivation. This means that it is unclear whether the findings of these studies apply to all individuals within those communities. Therefore, there is a need for studies that assess the health equity impacts of climate change at the individual level in the UK in order to improve understanding of the reasons underlying health equity impacts of climate change for this population group.

Only 2 studies were identified for ethnic minority groups, one on heavy rainfall and flooding and one on wildfire-related air pollution. No studies were identified for this population group that reported on other climate change related hazards (increase in ambient temperature, extreme cold, extreme heat or drought) or climate change related health risks.

Only 3 studies were identified on inclusion health groups: 2 reporting on people experiencing homelessness, both on the increase in ambient temperature, and one on people with drug and or alcohol dependence (also reporting on increase in ambient temperature). No studies were identified for these population groups that reported on other climate change related hazards (extreme cold, extreme heat, drought or other extreme events) or climate change related health risks.

Only 5 studies were identified that reported on the health impacts of solutions and responses to climate change. Four of these studies reported on climate change mitigation policy and interventions, all for people experiencing the greatest deprivation. Further research is needed into the health equity impacts of the mitigation policy and interventions in other population

groups experiencing social vulnerabilities in the UK to inform consideration of appropriate mitigation measures to take in the future. The other study reported on climate change adaptation policy and interventions, also for people experiencing the greatest deprivation, highlighting a need for further research into health equity impacts of adaptation measures. More generally, there was no evidence identified on the health equity impacts of other responses to climate change, such as community resilience and disaster risk reduction, response and recovery.

No studies examining the mediating pathways through which climate change exposures may differentially impact groups experiencing social vulnerabilities were identified, either qualitative research or quantitative studies that formally assessed mediating pathways. Further research is needed to understand how wider determinants of health interact to influence climate change vulnerability across population groups experiencing social vulnerabilities and associated settings in the UK.

Limitations of the review process

Our mapping review followed streamlined methodologies: 90% of the records included on title and abstract were screened by only one reviewer, and full text screening and data extraction were done by one reviewer and checked by a second (as per our usual rapid review methodology, see [Annexe B](#)).

For studies reporting on climate change related health risks (such as changes to air quality) and solutions to address climate change, only studies with an explicit link to climate change were included. For instance, the literature on the health impacts of air pollution without an explicit link to climate change was not included as it was beyond the scope of this mapping review. This could mean that some relevant studies may have been missed.

This mapping review included population groups that were considered to experience social vulnerabilities in the UK, identified based on NHS England's Core20PLUS framework which has been adopted by UKHSA ([3](#)). The population group 'people experiencing the greatest deprivation' is defined in the Core20PLUS framework as the most deprived 20% of the population as defined by the IMD, but for the purpose of this review other measures of deprivation, such as household deprivation and low household income, were included. This was to ensure that no relevant papers were missed. However, applying this criterion occasionally required subjective judgement and may have led to inconsistencies. Another limitation related to the included population groups is that there may be other population groups not included in the Core20PLUS framework who may also experience social vulnerability.

Specific search terms relating to climate change and the population groups of interest were included in the search strategy, and a validated UK geographic search filter was used for Medline and Embase in order to limit the evidence retrieved to UK settings ([62](#), [63](#)). There is no validated UK geographical search filter available for Web of Science, so we used a UK search strategy that had been adapted from the Medline filter by an information scientist. As with all search strategies, the evidence retrieved is limited by the search terms used so relevant studies may have been missed.

No studies meeting the inclusion criteria were identified through grey literature searches. While the grey literature search was extensive, including 11 sources identified by the review team and topic experts, it is possible that some relevant sources were not searched. As a result, some relevant reports may not have been retrieved by the literature search. As no studies were identified from the initial grey literature search, we only updated the database search and not the grey literature search, so relevant studies may have been missed.

Critical appraisal was conducted at the study level, whereas for most studies the relevant analyses were conducted in subgroup analysis. Therefore, the quality ratings in this mapping review reflect the methodological quality of the study as a whole, rather than the risk of bias for each individual outcome, which was beyond the scope of this mapping review as it did not include a narrative summary of the findings of each study.

A limitation of mapping the outcomes in the third dimension of the evidence gap map is that the categories were quite broad. For instance, the mortality and morbidity outcomes could have been further broken down into the types of diseases assessed. However, as described in the protocol, the main aim of this mapping review was to identify the evidence gaps for population groups experiencing social vulnerabilities in the UK to inform priority areas for future research, rather than summarising evidence gaps in terms of health outcomes.

Conclusions

Twenty-four studies were identified that reported on the health impacts of climate change and solutions and responses taken to address climate change in population groups experiencing social vulnerabilities in the UK. Most of the studies (18 out of 24) assessed the health impacts of climate change related hazards. The remaining studies reported on either climate change related health risks (one study) or health impacts of solutions to address climate change (5 studies).

Of the 18 studies investigating health impacts of climate change related hazards, 7 studies reported on increase in ambient temperature, 5 studies on extreme cold, and 4 studies each on extreme heat and heavy rainfall and flooding. No studies were identified for drought or other extreme weather events.

The one study that was identified on the health impacts of climate change related health risks reported on changes to air quality (PM_{2.5} from wildfires). No studies were identified for changes to vector borne diseases, changes to food supply and safety, changes to water supply and safety, or environmental degradation.

Four of the 5 studies that reported on health impacts of solutions and responses to address climate change reported on mitigation policy and interventions. The other study reported on climate change adaptation policy and interventions. No studies were identified for community resilience, or disaster risk reduction, response and recovery.

The lack of studies identified for climate change related health risks and responses and solutions to address climate change may be, in part, because studies that did not have an explicit link to climate change were excluded. Since the impacts of climate change on health are wide ranging and cascading, it is sometimes difficult to identify the indirect effects of climate change on health.

In terms of outcomes, most of the evidence identified reported on morbidity (10 studies) and mortality (10 studies). Most of the studies on morbidity were on cardiovascular and respiratory diseases; only 3 studies were identified for mental health. Fewer studies were identified that reported on healthcare usage (2 studies on A&E attendance), and other proximal determinants of health (2 studies; one on access to healthcare and one on exposure to air pollution).

Most studies (20 out of 24) reported on people experiencing the greatest deprivation, of which 14 studies aimed to investigate health equity. However, most studies either used an area-based measure of deprivation (15 out of 20 studies) or were conducted in an area experiencing high levels of deprivation (3 studies). The information provided by these studies on the underlying mechanisms of the health equity impacts of climate change for people experiencing the greatest deprivation was limited.

Evidence was very limited for the other population groups experiencing social vulnerabilities: only 2 studies were identified that reported on ethnic minority groups and 3 studies on inclusion health groups (2 on people experiencing homelessness and one on people with drug and or alcohol dependence). No studies were identified for the following groups:

- people in contact with the criminal justice system
- vulnerable migrants
- Gypsy Roma and Traveller communities
- sex workers
- victims of modern slavery
- people from protected characteristics groups related to gender reassignment
- people from protected characteristics groups related to sexual orientation
- people from protected characteristics groups related to religion or belief

In addition, no studies were identified that were conducted in settings associated with population groups experiencing social vulnerabilities, such as prisons and places of detention, asylum seeker accommodation settings, traveller sites, temporary housing accommodation, homeless shelters, and rehabilitation centres.

Further research is needed to address the evidence gaps identified in this rapid mapping review. In particular, more research is needed to assess the health impacts of climate change for the population groups for whom limited, or no, evidence was identified: people from protected characteristics groups related to gender reassignment, sexual orientation and religion or belief, ethnic minority groups, inclusion health groups and associated settings. Limited evidence was also identified on the health equity impacts of climate change related health risks and the solutions and responses to address climate change. There is also a need to investigate how wider determinants of health interact to influence climate change vulnerability across population groups experiencing social vulnerabilities and associated settings in the UK.

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Disclaimer

UKHSA's rapid reviews aim to provide the best available evidence to decision makers in a timely and accessible way, based on published peer-reviewed scientific papers, unpublished reports and papers on preprint servers. Please note that the reviews: i) use accelerated methods and may not be representative of the whole body of evidence publicly available; ii) have undergone an internal, but not independent, peer review; and iii) are only valid as of the date stated on the review.

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Annexe A. Scoping searches

A scoping exercise was performed before the rapid mapping review was undertaken as part of best practice, in order to identify relevant review-level evidence to inform next steps and avoid duplication of work.

Methods

The aim of this scoping search was to identify existing reviews (systematic or rapid), evidence summaries and protocols relevant to the scoping question ‘what are the disparities in exposure and health outcomes associated with climate change using the Core20PLUS framework in the UK context?’. Umbrella reviews were not included, although the reviews identified in relevant umbrella reviews were checked for inclusion against our criteria.

We searched Ovid Medline, Ovid Embase and the prospective review register PROSPERO on 21 February 2023 (searches limited from 1 January 2010 to 20 February 2023). We additionally searched Web of Science (Science Citation Index and Social Sciences Citation Index) on 6 March 2023 (searches limited from 1 January 2010 to 6 March 2023).

Results were first screened on title and abstract for relevance by an information scientist and were then assessed for eligibility on full text in duplicate by 2 reviewers.

Records were included if they reported on adverse health effects of climate change in populations routinely identified as part of the Core20PLUS framework relevant to the UK context.

1. Climate change exposure pathways with adverse health effects included (but not limited to) extreme heat and cold, other extreme weather events, changes in vector ecology, respiratory allergens, air pollution, changes in water quality, negative impacts on food safety and supply, and environmental degradation. Any health outcomes (including but not limited to mortality, heat-related illness, cardio-respiratory outcomes, perinatal outcomes and mental health outcomes) were considered for inclusion.
2. Population groups (identified as part of the Core20PLUS framework) included people experiencing the greatest deprivation; ethnic minority groups; people with a learning disability; people with multiple long-term health conditions; groups with protected characteristics; and people from inclusion health groups, including people experiencing homelessness, people with drug and or alcohol dependence, vulnerable migrants, Gypsy, Roma and Traveller communities, sex workers, people in contact with the justice system, victims of modern slavery and other groups with experience of social exclusion. It is worth noting that this list is not exhaustive and that any population group that would fit under the Core20PLUS framework would be included (2).

When assessing reviews for inclusion, overlap of primary studies between reviews was considered as a criterion together with the uniqueness of the review question: for instance, if the UK studies included in a review were also included in a review with a more recent search date

which looked at a similar review question, the older review was excluded. However, if the older review had conducted a meta-analysis but the more recent review had not, both reviews would be included.

This scoping exercise was conducted at review-level and judgement on relevance to the UK context and population groups was on the overall review (primary studies were not assessed). Similarly, criteria regarding the adverse health effects were applied at review-level.

Results

A total of 213 records were included on title and abstract by an Information Scientist and then screened in duplicate. A further 5 records obtained via reference searching were screened on full text by one reviewer and checked by another. Of the 218 records screened on full text, 29 were included: 24 reviews ([4 to 27](#)) and 5 protocols ([64 to 68](#)).

Of the 24 reviews, 6 were systematic reviews with meta-analysis and 4 were scoping reviews. The remaining were systematic reviews with narrative synthesis. In terms of search dates, 7 reviews conducted their searches between 2020 and 2022, 6 in 2019, 3 between 2017 and 2018, 5 between 2014 and 2015, and 3 in 2012 or earlier.

Thirteen of the reviews identified looked at the adverse health effects of climate change in the general population, and although they were not primarily focused on vulnerable groups, they were included because they reported on some vulnerable groups as part of the narrative synthesis or via subgroup analyses ([4](#), [5](#), [7](#), [10 to 13](#), [15 to 18](#), [21](#), [25](#)). The vulnerable groups most reported in these reviews on the general population were older adults (7 reviews), children (6 reviews), people with pre-existing health conditions (6 reviews) and people with mental health conditions (4 reviews). Female sex and socio-economic status were discussed in 3 reviews each.

The remaining reviews focused on specific population groups: 4 on pregnant women: ([6](#), [9](#), [20](#), [23](#)), 2 on older adults ([8](#), [24](#)), 2 on children ([22](#), [27](#)), one on people experiencing homelessness ([14](#)), one on people with diabetes ([19](#)) and one on people with respiratory diseases ([26](#)).

In terms of settings, 2 reviews and one protocol focused on UK settings:

- Arbuthnott and others conducted a systematic review with narrative synthesis (searches up to January 2017) to assess the health effects of hotter summers and heatwaves in the UK ([4](#)) – the population of interest was the general population, although the distribution of the adverse health impacts was reported by geographical areas, age, sex, underlying co-morbidities (including people with mental health conditions and substance misuse) and socio-economic status, people with mental health conditions and people with drug and or alcohol dependence
- Cruz and others conducted a systematic review with meta-analysis (searches up to December 2019) to quantify the prevalence and describe the causes of mental health conditions amongst populations exposed to extreme weather events in the UK ([11](#)) – the population of interest was the general population (findings also discussed for

female sex, older adults, pre-existing health conditions and most deprived population groups), looking at new onset of mental health conditions such as anxiety, depression and post-traumatic stress disorder

- according to their protocol published on Prospero, the review by Kovats and others aimed to examine the evidence of public health effectiveness and health equity implications of measures to address climate risks in England ([65](#))

Two additional reviews, with about one third of studies conducted in the UK and the remaining studies from developed countries, were considered directly relevant to the UK context:

- Tanner and others conducted a systematic review with narrative synthesis (searches up to 2011) to examine and quantify associations between socio-economic, housing or behavioural factors and cold weather-related adverse health or social outcomes ([21](#)) – the inclusion criteria for populations were “any human population groups from economically developed countries” and 14 of the 33 studies included were from the UK (to note that the background and context of this article is also directly relevant to the UK as this review was conducted by researchers from Newcastle University)
- Wang and others conducted a systematic review with narrative synthesis (searches up to 2015) to evaluate the effectiveness of strategies relating to air pollution control on public health and health equity in Europe ([25](#)) – of the 15 studies included, 5 were from the UK (and the remaining from EU countries)

For the remaining reviews, the relevance to the UK context of the overall findings was less clear; each review would need to be critically assessed in order to check relevance of the findings, which was beyond the scope of this initial scoping exercise.

Summary

Only 4 reviews and one protocol reporting on the adverse health effects associated with climate change on population groups (based on the Core20PLUS framework) that were directly relevant to the UK setting were identified. The remaining 20 reviews and 4 protocols identified provided some evidence potentially relevant to the UK setting.

In terms of population groups, the evidence was limited to a few population groups mainly related to certain protected characteristics: older adults (9 reviews), children (7 reviews) and pregnant women (6 reviews). Female sex was reported in 3 reviews, and people with disability in one. However, no evidence was identified on ethnic minority groups, people from protected characteristics groups related to sexual orientation or gender reassignment.

A number of reviews also reported on people with long-term health conditions, especially mental health conditions (5 reviews) and respiratory diseases (4 reviews).

The adverse health effects of climate change on the people experiencing the greatest deprivation were reported in only 3 reviews.

In relation to inclusion health, the evidence identified was limited to people experiencing homelessness (2 reviews), people with drug and or alcohol dependence (2 reviews) and people in contact with the justice system (one review). There was no evidence on the other inclusion health groups. However, it is unclear based on this scoping whether this is due to a gap in review-level evidence or a lack of primary research.

The population groups included in the rapid mapping review was informed by this initial scoping.

2024 update

Following personal communication with the authors, the protocol by Kovats and others ([65](#)), which met our inclusion criteria when identified during the scoping exercise, no longer met the inclusion criteria. Indeed, the authors have confirmed that this project has moved from aiming to examine the evidence of public health effectiveness and health equity implications of measures to address climate risks in England to focusing on the cost-benefit of measures to address climate risks in England.

Limitations and disclaimer

Our scoping exercises follow less stringent methodologies than our rapid reviews so relevant evidence may have been missed.

Our scoping exercises are a way of finding and collating relevant review-level evidence to inform next steps and reduce duplication of work. Scoping exercises are done before a review is undertaken as part of best practice. It is not a final output.

Annexe B. Methods

This report followed streamlined systematic methods to address the review question ‘What is the available evidence on the health impacts of both climate change and the solutions taken to address climate change in population groups experiencing social vulnerabilities in the UK?’.

Our rapid mapping review approach followed streamlined systematic methodologies (28). For instance, full text screening and data extraction were performed by one reviewer and checked by another instead of being conducted in duplicate.

Protocol

A protocol was produced before the literature search began, specifying the review question and the inclusion and exclusion criteria. The protocol was published on the Open Science Framework (OSF) before the review process started (29).

Modifications made to the protocol after the review started are reported below, where relevant.

Inclusion and exclusion criteria

Article eligibility criteria are summarised in [Table B.1](#).

Table B.1. Inclusion and exclusion criteria

	Included	Excluded
Country	UK	Non-UK
Population	<ul style="list-style-type: none"> • Core20PLUS population groups included within this review: <ul style="list-style-type: none"> – people experiencing the greatest deprivation (the most deprived 20% as defined by IMD, also other deprivation measures will be considered) – ethnic minority groups (protected characteristics) – people from protected characteristics groups related to gender reassignment and sexual orientation (including 	<ul style="list-style-type: none"> • Core20PLUS population groups not included within this review: <ul style="list-style-type: none"> – populations with other protected characteristics including age, disability, pregnancy and maternity, and sex – populations with pre-existing health conditions • Place-based vulnerability will be excluded, including: <ul style="list-style-type: none"> – rural versus urban

	Included	Excluded
	<p>LGBTQ+: lesbian, gay, bisexual, transgender, intersex, queer or questioning, asexual and many other terms such as non-binary and pansexual)</p> <ul style="list-style-type: none"> – people from protected characteristics groups related to religion or belief – people experiencing homelessness – people with drug and or alcohol dependence – people in contact with the criminal justice system – vulnerable migrants – Gypsy Roma and Traveller communities – sex workers – victims of modern slavery – other groups with experience of social exclusion <ul style="list-style-type: none"> • Studies conducted in the general population, but which included a focus on sub-group population corresponding to the groups of interest will be considered for inclusion 	<ul style="list-style-type: none"> – coastal settings – regional differences
Settings	<p>All settings with a focus on settings specific to the population groups of interest, including (but not limited to):</p> <ul style="list-style-type: none"> • prisons and places of detention including adult prisons, the children and young people’s secure estate, approved 	

	Included	Excluded
	<p>premises and immigration removal centres</p> <ul style="list-style-type: none"> • asylum seeker accommodation settings (including, arrival centres, bridging hotels) • temporary housing accommodation • homeless shelters and hostels • rehabilitation centres, drug and alcohol treatment facilities • traveller sites (including caravan sites) 	
<p>Intervention or exposure</p>	<p>Climate change induced events and exposure pathways, including:</p> <ul style="list-style-type: none"> • climate change related hazards (with or without explicit link to climate change) <ul style="list-style-type: none"> – increase in ambient temperature – extreme heat – extreme cold – heavy rainfall and flooding – drought – other extreme weather events (such as storms or wildfires) • climate change related health risks with explicit link to climate change <ul style="list-style-type: none"> – changes to vector ecology – changes to food supply and safety 	

	Included	Excluded
	<ul style="list-style-type: none"> – changes to water supply and safety – changes to air quality (including air pollution and aeroallergens and due to emissions ozone or particulate concentration) – environmental degradation • solutions and responses to climate change exposure pathways with explicit link to climate change <ul style="list-style-type: none"> – mitigation policy and interventions – adaptation policy and interventions – community resilience – disaster risk reduction, response and recovery 	<ul style="list-style-type: none"> • Climate change related health risks and solutions or response without an explicit mention or link to climate change (for instance, studies reporting on changes to vector ecology without a specific link or mention to climate change would be excluded)
Outcomes	<ul style="list-style-type: none"> • Observed and projected health effects associated with climate change exposure pathways, including (but not limited to): <ul style="list-style-type: none"> – mortality (all-cause and specific) – respiratory disease – cardiovascular diseases – other chronic diseases – maternal and child outcomes – mental health (including but not limited to self-reported or clinical measures of stress, anxiety, depression, obsessive compulsive 	<ul style="list-style-type: none"> • Non-health related outcomes, such as economic outcomes • Studies focusing on climate change without health outcomes • Wellbeing outcomes (happiness and life satisfaction and so on) • Non-human health outcomes • Socio-economic determinants of health

	Included	Excluded
	<p>disorder, phobias, psychological distress, post-traumatic stress disorder, eating disorders, substance abuse disorders, personality disorders, resilience, quality of life)</p> <ul style="list-style-type: none"> – other morbidity outcomes – healthcare usage such as A&E visits or 999 calls – projected health measures such as health impact scores or life-years gained <ul style="list-style-type: none"> • The following proxy outcomes (proximal determinants of health) will be tagged during screening and may be considered for inclusion depending on the level of evidence identified: <ul style="list-style-type: none"> – exposure to air pollution – unsafe working conditions where there is a clear link made to at least one direct health risk – poor nutrition – exposure to infectious diseases and vectors – exposure to poor water quality – poor sanitation – access to healthcare – physical activity – risky health behaviours (such as smoking, alcohol and drugs consumption) 	

	Included	Excluded
Language	English	Non-English studies
Date of publication	1 January 2010 to February 2024	Studies published before January 2010
Study design	<ul style="list-style-type: none"> • Observational studies (cohort, case-control, cross-sectional studies and surveillance studies) • Case reports and case series • Ecological studies • Mixed-method studies • Qualitative studies • Modelling studies that used UK data to project the health effects of climate change exposure pathways on populations in the UK 	<ul style="list-style-type: none"> • Systematic or narrative reviews • Guidelines • Opinion pieces • Modelling studies that use hypothetical data, or non-UK data, to project the health effect of climate change exposure pathways
Publication type	<ul style="list-style-type: none"> • Peer-reviewed • Preprint • Grey literature (including reports published by government agencies, local government, and non-governmental organisations) 	<ul style="list-style-type: none"> • Conference abstracts • News articles

Modifications made to the protocol

In the original protocol, ‘social housing accommodation’ and ‘council housing estates’ were listed as eligible for inclusion as these settings were thought to be relevant for identifying people experiencing the greatest deprivation. However, it became clear during screening that these settings were not reliable indicators of people experiencing the greatest deprivation due to the socio-economic variability among residents (69), leading to these settings being removed from the inclusion criteria.

Our protocol aimed to include evidence for people experiencing the greatest deprivation, based on the most deprived 20% of the population defined by the IMD (in line with the Core20PLUS framework), as well as other measures of deprivation. Once the screening started, we agreed to also include studies that measured deprivation based on quartiles of deprivation (most deprived

25% of the population) to ensure that no relevant evidence on the most deprived populations was excluded.

Two additional proxy outcomes were added to the inclusion criteria for risky health behaviours and physical activity. These were included to capture a broader spectrum of determinants that may influence health outcomes related to climate change.

Other minor refinements were made to the eligible outcomes based on insights gained during the screening process. To provide clarity on the specific mental health outcomes that were eligible for inclusion, some examples of eligible outcomes were added to the protocol: “(including, but not limited to, self-reported or clinical measures of stress, anxiety, depression, obsessive compulsive disorder, phobias, psychological distress, post-traumatic stress disorder, eating disorders, substance abuse disorders, personality disorders, resilience, and quality of life)”. Happiness and life satisfaction were also added as examples for the excluded outcome of well-being. This distinction was made to illustrate the difference between mental health outcomes and broader measures of well-being.

Sources searched

Databases: Ovid Medline, Ovid Embase, Web of Science (Science citation index and Social science citation index), the Finding Accessible Inequalities Research (FAIR) database and the King’s Fund Library. To note that many preprints are now indexed in Medline and Embase – Medline indexes eligible preprints funded by the National Institutes of Health (NIH) and Embase indexes preprints from medRxiv and bioRxiv.

Grey literature sources:

- [Climate Change and Human Health Literature Portal](#)
- [Health Observatory Resource Catalogue](#)
- [the FAIR database](#)
- [King’s Fund Library](#)
- [National Grey Literature Collection](#)
- [Adaptation Scotland](#)
- [Climate and Health \(Wellcome\)](#)
- [Climate Change Just \(Joseph Rowntree Foundation\)](#)
- [Climate Change Committee](#)
- [COP26 university network](#)
- [Environment and climate crisis \(NESTA\)](#)

Citation searching using 22 seed papers from the initial database search (backward, forward and co-citation), including 4 papers that were initially included but subsequently excluded for not meeting the inclusion criteria following discussion between reviewers.

Additional sources: topic experts and reference list of included papers and relevant systematic reviews.

Modifications made to the protocol

The FAIR database and the King's Fund Library were not included in the databases listed in the original protocol. These were added after the protocol was published on the recommendation of 2 information scientists.

We excluded 4 of the grey literature sources listed in the protocol due to their limited evidence in relation to the review question because:

- the Health Inequalities Portal and Institute of Health Equity lacked evidence on climate change
- the Adaptation Clearinghouse focused on US-contexts
- the Collaboration for Environmental Evidence Database provided mostly review-level evidence which was out of scope for this review

Search strategies

Databases searches were conducted for papers published between 1 January 2010 and 17 July 2023 (date search conducted: 18 July 2023) for the initial search. The database search was updated on 19 February 2024.

The search strategies were drafted by an information scientist and peer-reviewed by a second information scientist. The search strategy for Ovid Medline is presented in [Annexe C](#).

Citation analysis

Citation analysis was conducted used 2 sources: backwards and forwards citation analysis was performed using [citationchaser](#) (70) and co-citation analysis was performed using Web of Science. After deduplication, 1,067 citations were obtained from the citation analysis. These were imported into the original Endnote library with the database search results, where further duplicates were removed, leaving 874 results (713 citationchaser, 161 WoS co-citations). A further 12 duplicates were identified and removed in EPPI-R, leaving a final total of 862 unique results for screening.

Screening

Results from the initial database searches were downloaded into Endnote, then duplicates were removed using [Deduklick](#) (an automated artificial intelligence deduplication tool). Final results were imported into EPPI-Reviewer web version (30) in order to conduct the screening. Title and abstract screening of records identified was completed in triplicate by 3 reviewers for 10% of the studies, with the remainder completed by one reviewer. Disagreement was resolved by discussion among the review team. Full text screening was done by one reviewer and checked

by a second using EPPI-Reviewer. The same approach was used for screening of the database search update, except that 10% of records were screened on title and abstract in duplicate by 2 reviewers and Rayyan ([31](#)) was used to complete the screening, rather than EPPI-Reviewer.

Results from the grey literature searches were screened on title and abstract screening by one reviewer. Title and abstract screening was done in Rayyan and Microsoft Excel. Full text screening was done by one reviewer and checked by a second using EPPI-Reviewer.

The reports identified by the citation searching were downloaded into Endnote and imported into EPPI-Reviewer for screening. Title and abstract screening was completed by one reviewer. Full text screening was done by one reviewer and checked by a second using EPPI-Reviewer.

Screening of the list of the included studies and relevant systematic reviews was done by one reviewer.

The PRISMA diagram showing the flow of citations for the initial search is provided in [Figure B.1](#) and for the database search update in [Figure B.2](#).

Data extraction

Summary information for each study was extracted and reported in tabular form. Information included study design, objective, population group, setting, study period, exposure type (climate change related hazards, climate change related health risks, solutions and response), outcomes. Data charting for the mapping of the evidence identified was also extracted at this stage, including Core20PLUS population group, climate change related exposure and outcomes.

The data extraction form was first piloted by 2 reviewers on 4 studies and discussed with the review team.

Data extraction was conducted by one reviewer and checked by a second.

Modifications made to the protocol

The original protocol stated that we would extract data on the mediating pathways underlying the health equity impacts of climate change and, depending on the evidence identified, map the corresponding findings. However, due to the lack of evidence identified (no qualitative studies identified and none of the quantitative studies conducted formal mediation analysis), we decided not to extract data on mediating pathways for this mapping review.

Critical appraisal

Epidemiological studies were assessed using the quality criteria checklist (QCC) for primary research ([32](#), [33](#)). This tool can be applied to most study designs (observational and interventions) and is therefore suitable for rapid reviews of mixed type of evidence. It is

composed of 10 validity questions to assess the methodological quality of a study (that is, the extent to which a study has minimised selection, measurement and confounding biases). In the QCC tool, 4 questions are considered critical (on selection bias, group comparability and confounding, interventions or exposure and outcome assessment). A study was rated as high quality if the answers to the 4 critical questions were 'yes' (and at least one additional 'yes' for one of the non-critical questions). The study was rated as low quality if less than 50% of the critical questions were answered 'yes' or if less than 50% of the non-critical questions were answered 'yes'. Otherwise, the study was rated as medium quality. Judgements were made on a case-by-case basis for questions answered as 'unclear' to upgrade or downgrade a rating.

In addition to the QCC rating, which provides information about the potential for bias within each study design, we assessed the potential for bias inherent to each study design by using a system of study design class, with studies in class A having lowest potential for bias and studies in class D the highest. The study design classes were based on the hierarchy of evidence in the Academic of Nutrition and Dietetics Evidence Analysis Manual (32), which provides guidance about how to apply the QCC to different study designs. Case-crossover studies were classified as class C based on their similarity to time series analysis (71). Retrospective studies that assessed the association between climate change and health outcomes at the area level were classified as class D. Modelling studies were not assigned to a study design class because the hierarchy is applicable only to observational studies.

Critical appraisal was done in duplicate by 2 reviewers. QCC ratings are reported in [Annexe D](#). According to our protocol, the National Institute for Health and Care Excellence (NICE) Quality Appraisal Checklist for Qualitative Studies (72) would have been used for qualitative studies. However, no qualitative studies meeting the inclusion criteria were identified.

Modifications made to the protocol

The use of study design class to provide an indication of the potential for bias within each study design was not planned in the original protocol. This was done in order to add clarity and support discussion around the level of evidence.

Critical appraisal was done independently in duplicate by 2 reviewers instead of being done by one reviewer and checked by a second as planned in the original protocol.

Synthesis

Narrative synthesis of the evidence identified was not performed, although a description of the evidence identified was provided (including number of studies and breakdown by population group, climate change related exposure and QCC rating).

Visual synthesis was performed by generating an interactive evidence gap map with EPPI- Mapper (35), using the coding extracted to represent the evidence identified on health equity impacts of climate change by population groups and by climate change related exposure, with a third dimension added to represent whether the study was conducted in the population of

interest or conducted in the general population and reported on the population of interest in subgroup analysis.

In terms of population groups, the following codes were used:

- people experiencing the greatest deprivation
- ethnic minority groups
- protected characteristics: sexual orientation or gender reassignment (these groups were combined only for the purpose of creating the evidence gap map for ease of visualisation)
- protected characteristics: religion or belief
- people experiencing homelessness
- people with drug and or alcohol dependence
- people in contact with the criminal justice system
- vulnerable migrants
- Gypsy Roma and Traveller communities
- sex workers
- victims of modern slavery
- other groups with experience of social exclusion

In terms of climate change related exposure, there were 2 levels of coding (parent and child codes):

- climate change related hazards
 - increase in ambient temperature
 - extreme heat
 - extreme cold
 - heavy rainfall and flooding
 - drought
 - other extreme weather events
- climate change related health risks
 - changes to vector ecology
 - changes to food supply and safety
 - changes to water supply and safety
 - changes to air quality
 - environmental degradation
- solutions and responses to climate change exposure pathways
 - mitigation policy and interventions
 - adaptation policy and interventions
 - community resilience
 - disaster risk reduction, response and recovery

For the third dimension of health outcomes, the following codes were used:

- mortality
- morbidity
- healthcare usage
- proxy outcome: access to healthcare
- proxy outcome: exposure to air pollution

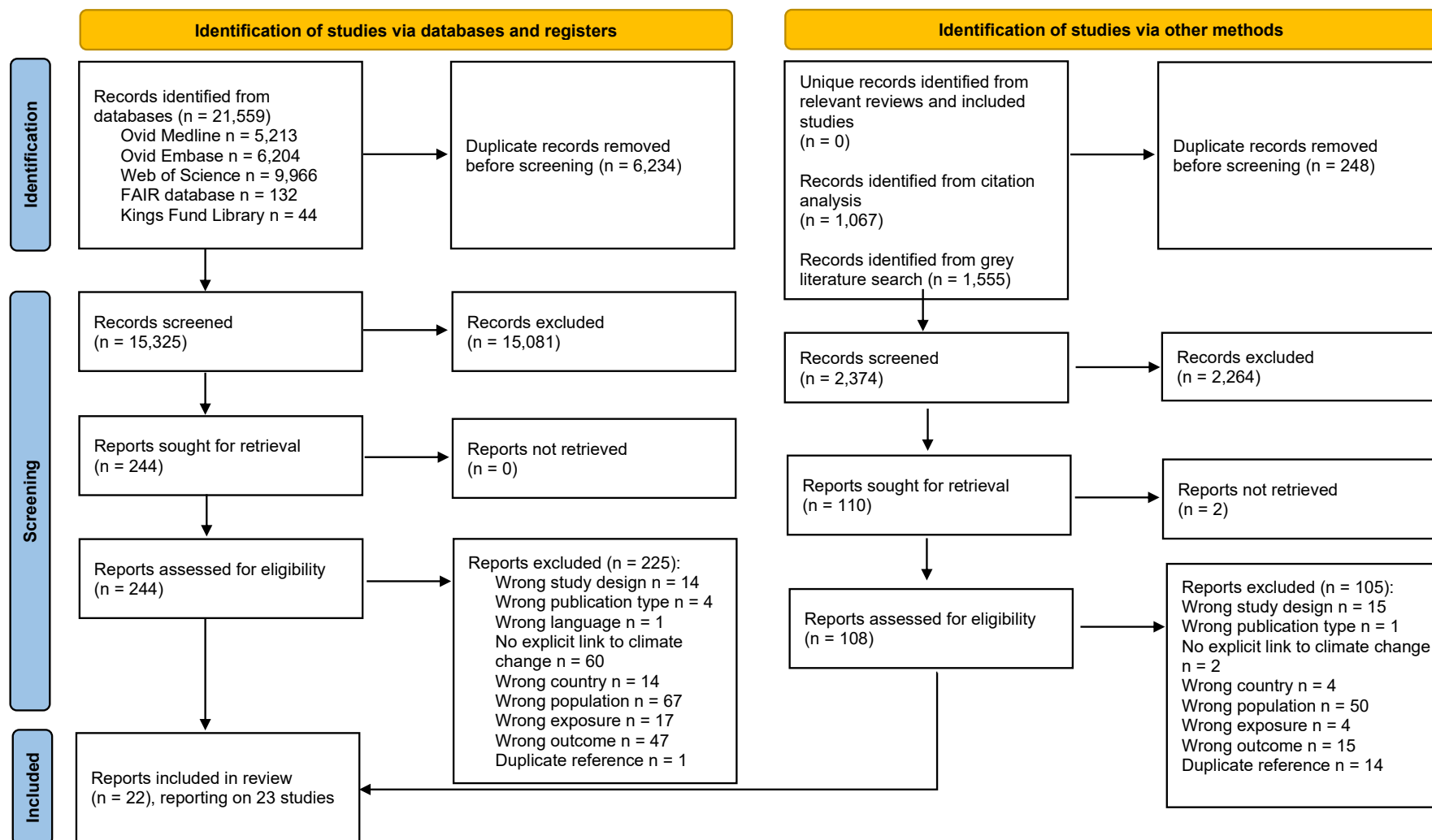
Modifications made to the protocol

In the original protocol, it was suggested that, depending on the type of evidence identified, the third dimension of the evidence gap map would be either the mediating pathways or study quality. Following discussion within the review team, including topic experts, we decided to map the health outcomes in the third dimension as this was deemed to be more informative.

The protocol also stated that 2 maps would be produced: one for climate change related hazards and health risks, and another for solutions and responses to climate change. As the number of studies identified was low (only 24 studies), we decided to create one map containing all of the exposure pathways.

The other visualisations (produced using Microsoft Excel) were not pre-planned in the protocol. However, these were deemed important to demonstrate the evidence gap for studies measuring deprivation at the individual level and the number of studies that were focused on health equity.

Figure B.1. PRISMA diagram for the initial search conducted on 18 July 2023



Text equivalent of the PRISMA diagram showing the flow of studies through this review for the initial search (conducted 18 July 2023)

From searching of databases and registers, n=21,559 records were identified:

- Ovid Medline ALL n=5,213
- Ovid Embase n=6,204
- Web of Science (Clarivate) n=9,966
- Finding Accessible Inequalities Research (FAIR) database n=132
- King's Fund Library n=44

From these, n=6,234 duplicate records were removed before screening.

After removal of duplicates, n=15,325 records were screened on title and abstract, of which n=15,081 were excluded, leaving n=244 papers sought for retrieval.

The 244 papers were assessed for eligibility on full text (n=0 reports not retrieved). Of these, 225 were excluded:

- wrong study design n=14
- wrong publication type n=4
- wrong language n=1
- no explicit link to climate change n=60
- wrong country n=14
- wrong population n=67
- wrong exposure n=17
- wrong outcome n=47
- duplicate reference n=1

A total of 2,622 additional records were identified through additional sources:

- records identified from relevant reviews and included studies: n=0
- records identified from citation analyses: n=1,067
- records identified from through grey literature: n=1,555

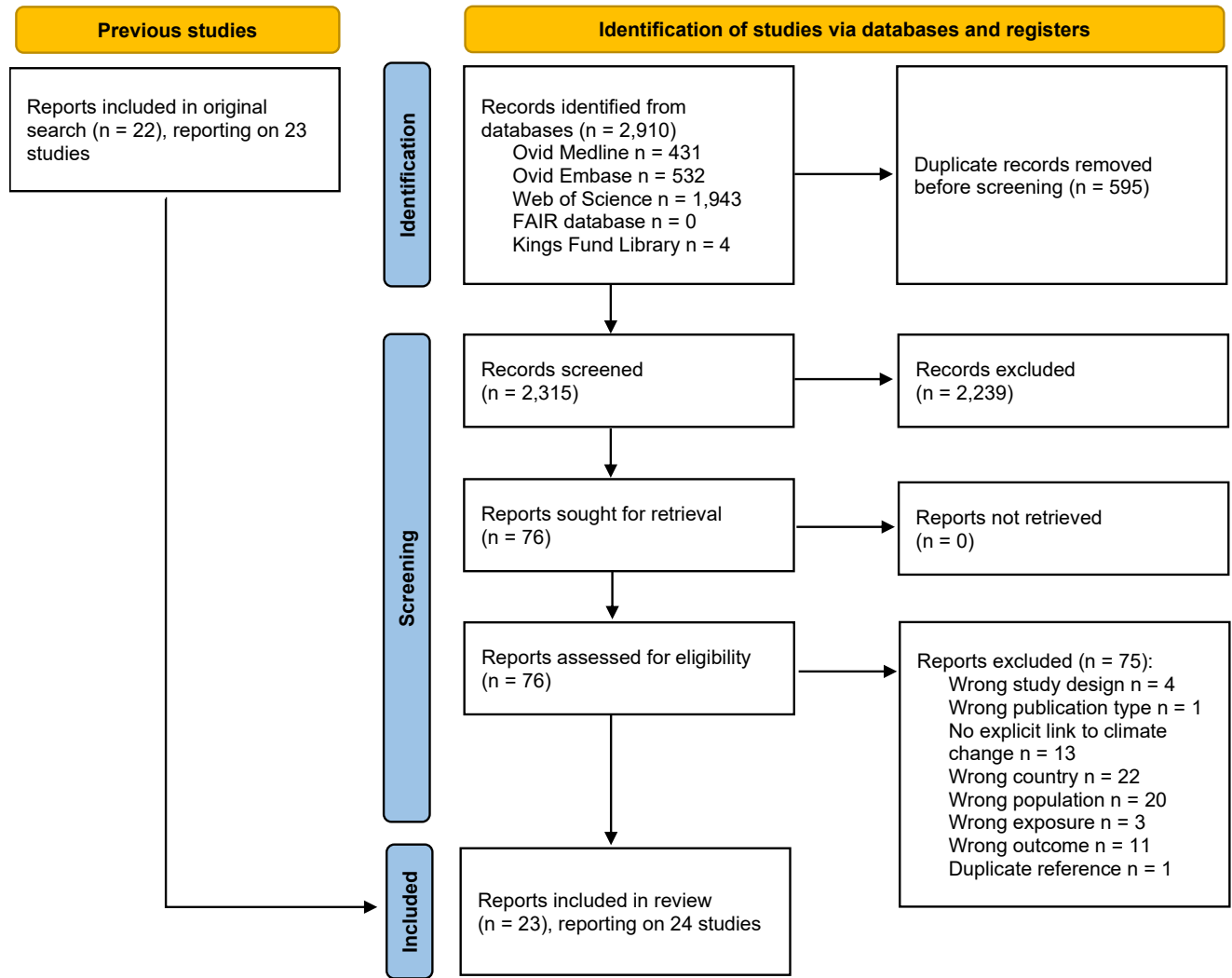
After removal of n=248 duplicate records, n=2,374 papers were screened on title and abstract, of which n=2,264 were excluded, leaving n=108 papers assessed for eligibility on full text (n=2 reports not retrieved). Of these, n=105 were excluded:

- wrong study design n=15
- wrong publication type n=1
- no explicit link to climate change n=2
- wrong country n=4
- wrong population n=50
- wrong exposure n=4
- wrong outcome n=15

- duplicate reference n=14

In total, 22 papers reporting on 23 studies were included.

Figure B.2. PRISMA diagram for the database search update, conducted on 19 February 2024



Text equivalent of the PRISMA diagram showing the flow of studies through this review for the database search update (conducted 19 February 2024)

n=2,910 records were identified during the search update of databases:

- Ovid Medline ALL n=431
- Ovid Embase n=532
- Web of Science (Clarivate) n=1,943
- Finding Accessible Inequalities Research (FAIR) database n=0
- King's Fund Library n=4

From these, n=595 duplicate records were removed before screening.

After removal of duplicates, n=2,315 records were screened on title and abstract, of which n=2,239 were excluded, leaving n=76 papers sought for retrieval.

The 76 papers were assessed for eligibility on full text (n=0 reports not retrieved). Of these, 75 were excluded:

- wrong study design n=4
- wrong publication type n=1
- no explicit link to climate change n=13
- wrong country n=22
- wrong population n=20
- wrong exposure n=3
- wrong outcome n=11
- duplicate reference n=1

In total, one study was included from the database search update.

Combined with the results of the initial search (22 papers, reporting on 23 studies), 23 papers reporting on 24 studies were included in the final review.

Annexe C. Search strategy for Ovid MEDLINE

Search strategy for Ovid Medline ALL:

1. (deprivation or deprived or disadvantage* or vulnerable).tw,kf.
2. social risk*.tw,kf.
3. (sociodemographic* or socioeconomic*).tw,kf.
4. (inclusion health group* or socially excluded).tw,kf.
5. working class*.tw,kf.
6. poverty.tw,kf.
7. house* income*.tw,kf.
8. unemployed.tw,kf.
9. ethnic minorit*.tw,kf.
10. (Asian British or Black British or South Asian* or Afr* Caribbean*).tw,kf.
11. protected characteristic*.tw,kf.
12. (religion or belief*).tw,kf.
13. sexual orientation.tw,kf.
14. LGBTQ+.tw,kf.
15. (lesbian or gay).tw,kf.
16. (bisexual or intersex or queer or asexual or CIS or non-binary or pansexual).tw,kf.
17. gender diverse.tw,kf.
18. transgender.tw,kf.
19. (homeless* or rough sleep* or vagrant*).tw,kf.
20. (substance* adj2 (use* or abuse* or misuse or addict* or depend*)).tw,kf.
21. (drug* adj2 (use* or abuse* or misuse or addict* or depend*)).tw,kf.
22. (alcohol* adj2 (use* or abuse* or misuse or addict* or depend*)).tw,kf.
23. (alcoholic* or alcoholism).tw,kf.
24. (migrant* or immigrant*).tw,kf.
25. (gypsy or gypsies).tw,kf.
26. Roma.tw,kf.
27. (travelling communit* or traveller* or traveler*).tw,kf.

28. (sex work* or prostitut*).tw,kf.
29. justice system*.tw,kf.
30. modern slave*.tw,kf.
31. (forced labour or forced labor).tw,kf.
32. human trafficking.tw,kf.
33. enslavement.tw,kf.
34. (prisoner* or offend* or remand* or incarcerat* or imprisonment or custod*).tw,kf.
35. asylum seeker*.tw,kf.
36. refugee*.tw,kf.
37. displaced person*.tw,kf.
38. social deprivation/
39. Low Socioeconomic Status/
40. Poverty/
41. "Ethnic and Racial Minorities"/
42. exp Socioeconomic Factors/
43. Religion/
44. Minority Groups/
45. Culture/
46. exp "Sexual and Gender Minorities"/
47. Sex Characteristics/
48. exp Homosexuality/
49. Ill-Housed Persons/
50. Substance-Related Disorders/
51. Alcohol-Related Disorders/
52. Drug Users/
53. Alcoholics/
54. Vulnerable Populations/
55. "Transients and Migrants"/
56. Roma/
57. Sex Workers/ or Sex Work/
58. Prisoners/
59. exp Crime Victims/

60. exp Criminals/
61. "Emigrants and Immigrants"/
62. Enslaved Persons/
63. Refugees/
64. Working Poor/
65. Enslavement/
66. Human Trafficking/
67. or/1-66
68. (prison or prisons or jail* or gaol* or detention or correctional).tw,kf.
69. ((camp* or tent or tents) adj2 (transit* or temporary or pitch* or site*)).tw,kf.
70. campsite*.tw,kf.
71. ((asylum or migrant* or refugee* or immigrant* or immigration) adj2 (centre* or center* or camp* or support* or removal*)).tw,kf.
72. caravan*.tw,kf.
73. (park home* or mobile home*).tw,kf.
74. trailer park*.tw,kf.
75. outreach program*.tw,kf.
76. shelter*.tw,kf.
77. (temporary hous* or "no fixed abode").tw,kf.
78. temporary accommodation.tw,kf.
79. (supported hous* or social hous* or half-way house* or council hous*).tw,kf.
80. hostel*.tw,kf.
81. (food bank* or foodbank*).tw,kf.
82. soup kitchen*.tw,kf.
83. (rehabilitation centre* or rehabilitation center*).tw,kf.
84. ((substance or drug* or alcohol*) and treatment clinic*).tw,kf.
85. (detoxification centre* or detoxification center*).tw,kf.
86. (drug* counsel* or alcohol* counsel*).tw,kf.
87. harm reduction program*.tw,kf.
88. sober living home*.tw,kf.
89. needle exchange program*.tw,kf.
90. methadone clinic*.tw,kf.

91. (GUM or genitourinary medicine clinic*).tw,kf.
92. (red light district or brothel*).tw,kf.
93. sexual health clinic*.tw,kf.
94. Refugee Camps/
95. Emergency Shelter/
96. Prisons/
97. Correctional Facilities/
98. Public Housing/
99. Rehabilitation Centers/
100. Substance Abuse Treatment Centers/
101. Counseling/
102. Harm Reduction/
103. Needle-Exchange Programs/
104. or/68-103
105. 67 or 104
106. climat*.tw,kf.
107. extreme heat.tw,kf.
108. (temperature adj increase*).tw,kf.
109. ambient temperature*.tw,kf.
110. (high* temperature* or extreme* temperature*).tw,kf.
111. (winter or summer or season*).tw,kf.
112. flood*.tw,kf.
113. (climate adj2 chang*).tw,kf.
114. (climate* adj2 event*).tw,kf.
115. (meteorological varia* or meteorological chang*).tw,kf.
116. rain*.tw,kf.
117. snow*.tw,kf.
118. drought*.tw,kf.
119. extreme cold.tw,kf.
120. freezing temperature*.tw,kf.
121. (storm or storms or rainstorm*).tw,kf.
122. sea-level*.tw,kf.

123. wildfire*.tw,kf.
124. (cyclon* or hurricane* or typhoon*).tw,kf.
125. (air pollut* or air quality).tw,kf.
126. pollen.tw,kf.
127. ozone.tw,kf.
128. particulate*.tw,kf.
129. emissions.tw,kf.
130. global warming.tw,kf.
131. greenhouse effect*.tw,kf.
132. heatwave*.tw,kf.
133. (extreme weather* or severe weather*).tw,kf.
134. extreme event*.tw,kf.
135. (weather-related or weather damag*).tw,kf.
136. Hot Temperature/
137. Extreme Heat/
138. Floods/
139. Droughts/
140. exp Climate Change/
141. Greenhouse Effect/
142. exp Rain/
143. Meteorological Concepts/
144. Extreme Weather/
145. Extreme Cold Weather/
146. Cyclonic Storms/
147. Wildfires/
148. Tornadoes/
149. Tidal Waves/
150. Landslides/
151. exp Ozone/
152. Particulate Matter/
153. Air Pollution/ or Air Pollutants/
154. Carbon Footprint/

155. vector-borne disease*.tw,kf.
156. lyme disease.tw,kf.
157. yellow fever.tw,kf.
158. zika.tw,kf.
159. malaria.tw,kf.
160. (tick* or mosquito* or midge* or flea*).tw,kf.
161. airborne disease*.tw,kf.
162. aeroallergen*.tw,kf.
163. environmental degradation.tw,kf.
164. (greenspace* or green space*).tw,kf.
165. Vector-Borne Diseases/
166. Tick-Borne Diseases/
167. Lyme Disease/
168. Malaria/
169. Yellow Fever/
170. Zika Virus Infection/
171. Ticks/
172. Culicidae/ or Siphonaptera/
173. or/106-172
174. exp Great Britain/
175. (national health service* or nhs*).ti,ab,in.
176. (english not ((published or publication* or translat* or written or language* or speak* or literature or citation*) adj5 english)).ti,ab.
177. (gb or "g.b." or britain* or (british* not "british columbia") or uk or "u.k." or united kingdom* or (england* not "new england") or northern ireland* or northern irish* or scotland* or scottish* or ((wales or "south wales") not "new south wales") or welsh*).ti,ab,jw,in.
178. (bath or "bath's" or ((birmingham not alabama*) or ("birmingham's" not alabama*) or bradford or "bradford's" or brighton or "brighton's" or bristol or "bristol's" or carlisle* or "carlisle's" or (cambridge not (massachusetts* or boston* or harvard*)) or ("cambridge's" not (massachusetts* or boston* or harvard*)) or (canterbury not zealand*) or ("canterbury's" not zealand*) or chelmsford or "chelmsford's" or chester or "chester's" or chichester or "chichester's" or coventry or "coventry's" or derby or "derby's" or (durham not (carolina* or nc)) or ("durham's" not (carolina* or nc)) or ely or "ely's" or exeter or "exeter's" or gloucester or "gloucester's" or hereford or "hereford's" or hull or "hull's" or lancaster or "lancaster's" or leeds* or leicester or "leicester's" or (lincoln not nebraska*) or

- ("lincoln's" not nebraska*) or (liverpool not (new south wales* or nsw)) or ("liverpool's" not (new south wales* or nsw)) or ((london not (ontario* or ont or toronto*)) or ("london's" not (ontario* or ont or toronto*)) or manchester or "manchester's" or (newcastle not (new south wales* or nsw)) or ("newcastle's" not (new south wales* or nsw)) or norwich or "norwich's" or nottingham or "nottingham's" or oxford or "oxford's" or peterborough or "peterborough's" or plymouth or "plymouth's" or portsmouth or "portsmouth's" or preston or "preston's" or ripon or "ripon's" or salford or "salford's" or salisbury or "salisbury's" or sheffield or "sheffield's" or southampton or "southampton's" or st albans or stoke or "stoke's" or sunderland or "sunderland's" or truro or "truro's" or wakefield or "wakefield's" or wells or westminster or "westminster's" or winchester or "winchester's" or wolverhampton or "wolverhampton's" or (worcester not (massachusetts* or boston* or harvard*)) or ("worcester's" not (massachusetts* or boston* or harvard*)) or (york not ("new york*" or ny or ontario* or ont or toronto*)) or ("york's" not ("new york*" or ny or ontario* or ont or toronto*))))).ti,ab,in.
179. (bangor or "bangor's" or cardiff or "cardiff's" or newport or "newport's" or st asaph or "st asaph's" or st davids or swansea or "swansea's").ti,ab,in.
180. (aberdeen or "aberdeen's" or dundee or "dundee's" or edinburgh or "edinburgh's" or glasgow or "glasgow's" or inverness or (perth not australia*) or ("perth's" not australia*) or stirling or "stirling's").ti,ab,in.
181. (armagh or "armagh's" or belfast or "belfast's" or lisburn or "lisburn's" or londonderry or "londonderry's" or derry or "derry's" or newry or "newry's").ti,ab,in.
182. or/174-181
183. (exp africa/ or exp americas/ or exp antarctic regions/ or exp arctic regions/ or exp asia/ or exp oceania/) not (exp great britain/ or europe/)
184. 182 not 183
185. 105 and 173
186. 184 and 185
187. limit 186 to yr="2010 - 2023"

Annexe D. Quality criteria checklist for observational studies

List of quality criteria checklist questions:

- Q1. Was the research question clearly stated?
- Q2. Was the selection of study subjects or patients free from bias?
- Q3. Were study groups comparable?
- Q4. Was the method of handling withdrawals described?
- Q5. Was blinding used to prevent introduction of bias?
- Q6. Were intervention or therapeutic regimens or exposure factor or procedure and any comparison(s) described in detail? Were intervening factors described?
- Q7. Were outcomes clearly defined and the measurements valid and reliable?
- Q8. Was the statistical analysis appropriate for the study design and type of outcome indicators?
- Q9. Are conclusions supported by results with biases and limitations taken into consideration?
- Q10. Is bias due to study's funding or sponsorship unlikely?

Table D.1. Results of quality criteria checklist critical appraisal of studies

Reference	Study design class	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Overall rating
Bennett and others (52)	Class C	Yes	Yes	NA	NA	NA	Yes	Unclear	Yes	Yes	Yes	Medium quality
Brown and others (54)	Class D	Yes	Yes	NA	NA	NA	Unclear	Yes	Unclear	Yes	Yes	Medium quality
Corcuera Hotz and others (38)	Class C	Yes	Yes	NA	NA	NA	Yes	Yes	Yes	Yes	Yes	High quality
Gao and others (37)	Class B	Yes	No	Yes	Unclear	NA	Unclear	Yes	Yes	Yes	Yes	Medium quality
Gasparrini and others (42)	Class C	Yes	Unclear	NA	NA	NA	Yes	Yes	Yes	Yes	Yes	Medium quality
Gong and others (43)	Class C	Yes	Unclear	NA	NA	NA	Yes	Yes	Yes	Yes	Yes	Medium quality
Hajat and others (44)	Class C	Yes	Unclear	NA	NA	NA	Yes	Yes	Yes	Yes	Yes	Medium quality
Kearns and others (retrospective study) (55)	Class D	Yes	Unclear	No	NA	NA	Unclear	Yes	No	Yes	Unclear	Low quality
Kearns and others (before-after study) (55)	Class D	Yes	Unclear	NA	NA	NA	Yes	Unclear	No	Yes	Unclear	Low quality
Konstantinoudis and others (53)	Class C	Yes	Unclear	NA	NA	NA	Yes	Yes	Yes	Yes	Yes	Medium quality
Lambourg and others (39)	Class C	Yes	Yes	NA	NA	NA	Yes	Yes	Yes	Yes	Yes	High quality
Lamond and others (57)	Class D	Yes	No	NA	NA	NA	Yes	No	Yes	No	No	Low quality
Milojevic and others (48)	Class C	Yes	Unclear	NA	NA	NA	No	Yes	Yes	Yes	Yes	Low quality
Milojevic and others (45)	Class C	Yes	Yes	NA	NA	NA	No	Yes	Yes	Yes	Yes	Medium quality
Murage and others (50)	Class C	Yes	Yes	NA	NA	NA	Yes	Yes	Yes	Yes	Yes	High quality
Page and others (40)	Class C	Yes	Yes	NA	NA	NA	Yes	Yes	Yes	Yes	Yes	High quality
Rizmie and others (46)	Class C	Yes	Yes	NA	NA	NA	Unclear	Yes	Yes	Yes	Yes	Medium quality
Symonds and others (56)	Class D	Yes	Unclear	NA	NA	NA	Unclear	Unclear	Yes	Yes	Unclear	Low quality
Tammes and others (51)	Class C	Yes	Yes	NA	NA	NA	Yes	Yes	Yes	Yes	Yes	High quality

Reference	Study design class	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Overall rating
Tieges and others (49)	Class C	Yes	Unclear	NA	NA	NA	Unclear	Yes	Yes	Yes	Yes	Low quality
Wan and others (47)	Class C	Yes	Yes	NA	NA	NA	Unclear	Yes	Yes	Yes	Yes	Medium quality
Zafeiratou and others (41)	Class C	Yes	Yes	NA	NA	NA	Yes	Yes	Yes	Yes	Yes	High quality

Acronyms: NA = not applicable

Scoring system

Studies were rated as:

- low quality if the answer to less than 50% of the critical questions was 'yes' and or 50% or less of the non-critical questions were answered 'yes'
- medium quality if the answer to 50% or more of the critical questions was 'yes'
- high quality if the answer to all of the 4 critical questions (Q2, Q3, Q6 and Q7) was 'yes', plus at least one of the non-critical questions

Judgements were made on a case-by-case basis for questions answered as 'unclear' to downgrade or upgrade a rating.

For Q6, measurement of temperature at the area level was not considered a limitation because temperature does not vary substantially within a region (the largest geographical area used to measure temperature in the evidence identified). Conversely, for heavy rainfall and flooding, studies were downgraded if there was no measure of whether individuals had experienced flooding because this is likely to be an important factor influencing health outcomes.

Annexe E. Additional visualisations

Figure E.1. Bar chart showing the number of studies that focused on health equity and the number of studies that did not focus on health equity but reported on a population of interest in secondary analysis

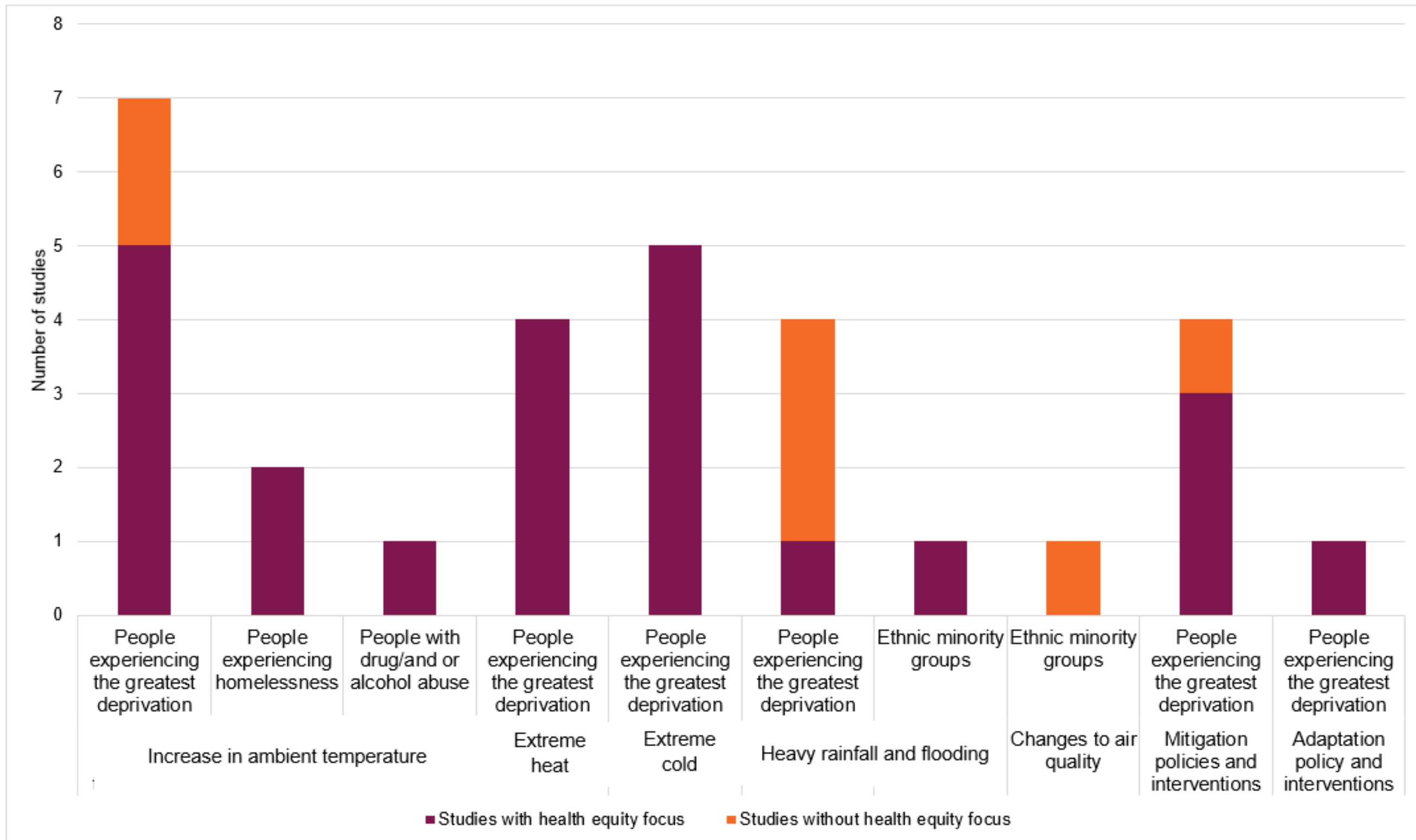
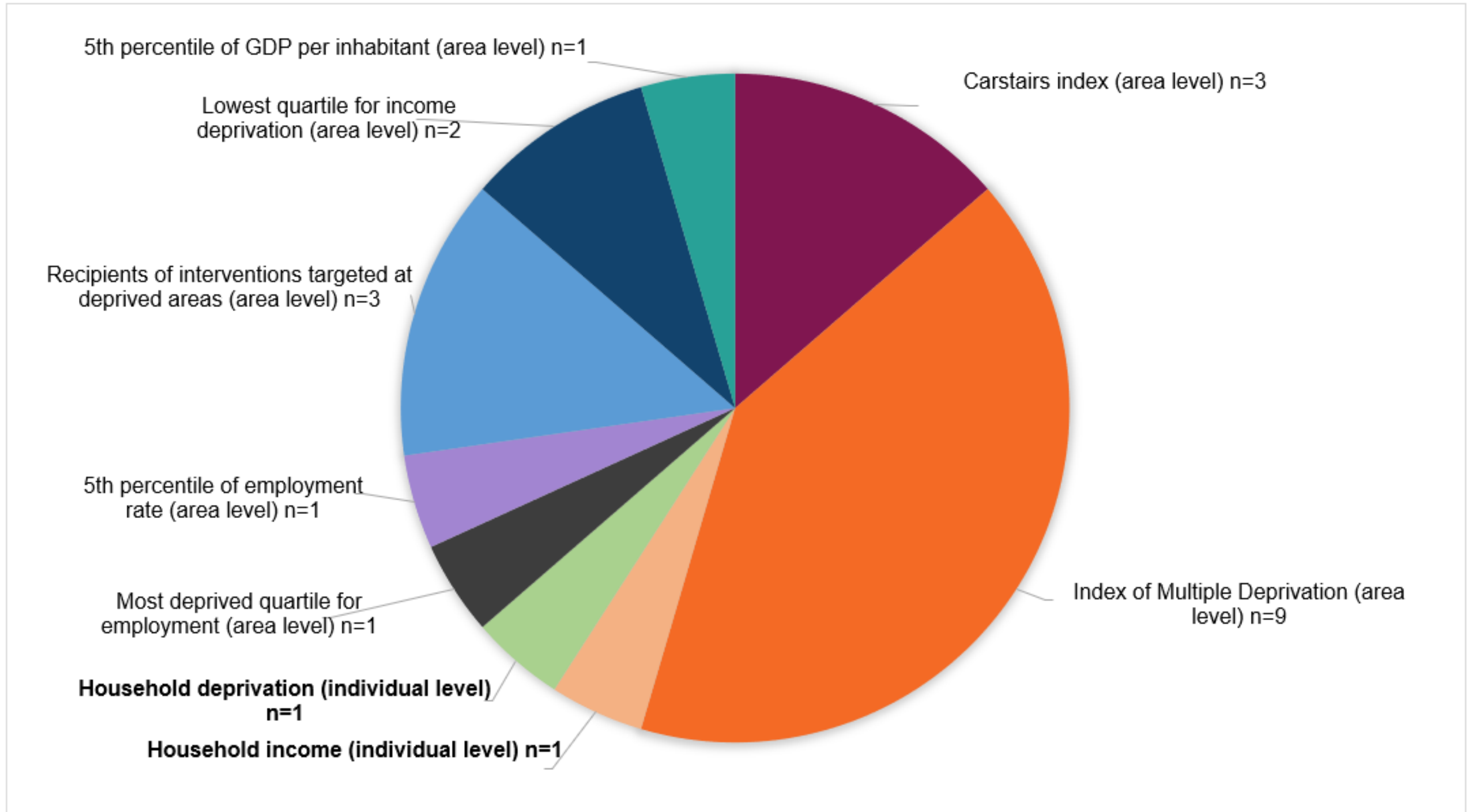


Figure E.2. Pie chart showing the number studies that used an area-level or individual-level measure of deprivation [A]



[A] Two studies used more than one measure of deprivation and have been counted more than once.

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