Review

The Health Effects of Climate Change in the WHO European Region

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Abstract: The evidence of observed health effects as well as projections of future health risks from climate variability and climate change is growing. This article summarizes new knowledge on these health risks generated since the IPCC fourth assessment report (AR4) was published in 2007, with a specific focus on the 53 countries comprising the WHO European Region. Many studies on the effects of weather, climate variability, and climate change on health in the European Region have been published since 2007, increasing the level of certainty with regard to already known health threats. Exposures to temperature extremes, floods, storms, and wildfires have effects on cardiovascular and respiratory health. Climate- and weather-related health risks from worsening food and water safety and security, poor air quality, and ultraviolet radiation exposure as well as increasing allergic diseases, vector- and rodent-borne diseases, and other climate-sensitive health outcomes also warrant attention and policy action to protect human health.

1. Introduction

As all over the world, the climate in the 53 countries comprising the WHO European Region is changing [1]. Temperatures are increasing, as are the frequency and intensity of extreme weather events including heatwaves, floods, and wildfires, and these trends are projected to continue under the most likely climate change scenarios [2]. Climate change affects health via direct and indirect pathways. Direct health effects of climate change include those attributable to extremes of temperature, extreme weather events, and exposure to ultraviolet radiation. Indirect effects include those mediated through either natural or human systems, such as patterns of certain vector-borne infectious diseases, respiratory diseases from changes in air quality and allergens, diarrheal disease, malnutrition and stunting from worsening food, and water safety and security. The health outcomes attributable to climate include premature mortality, several communicable and noncommunicable diseases, mental health issues, and effects on occupational health, nutrition, and social function [3]. It is predicted that the net effects of climate change on health, in Europe and worldwide, will be negative [3–5].

Certain groups are particularly vulnerable to the health effects of climate change, including the elderly, children, people with chronic diseases, people from low income groups, and workers subject to specific exposure (such as extreme temperatures, fires, and flooding). In addition, the increasing burden of climate change on human health will generate new and growing challenges for health systems, due to increases in care demands relating to increased morbidity and mortality, and additional pressure from extreme weather events. This will generate costs for all of society and exacerbate inequality [6]. Opportunities to both mitigate climate change and protect health have received increasing attention in recent years [7,8]. Countries across the WHO European Region have varying capacities to assess the health effects of climate change [9,10]. This literature review provides an update on observations and projections for various climate change-related health effects in the WHO European Region from 2007 through 2014.

2. Methods

A comprehensive literature search was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology [11]. The search was designed to identify recent research papers relevant to the effects of climate change on health in the WHO European Region. We searched for studies on climate change and health using the PubMed and ScienceDirect databases from January 2007 to 5 September 2014.

Four search algorithms were designed for use in the PubMed and ScienceDirect databases, allowing a basic search as well as searches specific to different health outcomes and risks. The algorithms used incorporate three main elements: country names, climate (exposure), and health effect/s (outcome/s). Countries included the 53 WHO European Region Member States (http://www.euro.who.int/en/ countries) as well as the keywords *Europe* and *central Asia*.

Original research papers were identified, with further material obtained by way of screening the references of identified papers. The reference lists of selected key papers were also reviewed, and relevant citations obtained from the aforementioned scientific databases. Additionally, the website of the

European Commission Community Research and Development Information Service (CORDIS) was used to identify relevant European Commission-funded projects and publications [12].

All identified studies assessing the effects, observed or projected, of climate-related impacts on health in Europe were considered for inclusion in this review. Studies were limited to those published in English from 2007 onwards. Owing to the diverse scale of potential climate-related health effects, considered studies included those assessing health effects dependent on long-term climate change as well as those caused by more acute weather and climate variables, such as extreme weather events.

After screening, identified original research papers were assessed by topic and reference lists and summary tables outlining the characteristics of each study were compiled. To avoid assessor bias, the results of this search were cross-checked with those of a previous, preliminary search performed on 19 January 2014 using the same algorithms and methodology. Significant sources of bias were not identified. A reference management program (Mendeley Desktop 1.13.3®) was used to organize and process search results.

3. Results

The initial search performed using the four search algorithms in PubMed returned, after removal of duplicates, a total of 6550 results, with an additional 2740 identified using ScienceDirect. First screening (by way of automatic filters in PubMed and manual screening of ScienceDirect search results) returned a total of 631 papers. A second screening applying established eligibility criteria, assessment of abstracts, and assessment of full-text versions excluded another 527 articles. An additional 31 studies were identified via a hand search, leaving a final total of 135 studies included for review (see Figure 1).

The search results were grouped as studies relevant to the direct and indirect health effects of climate change. The direct effects encompass:

- high temperature and heat,
- low temperature and cold,
- floods,
- wildfires, and
- UV radiation.

The indirect effects comprise

- Climate sensitive vector-borne infectious diseases (mosquito-, tick- and rodent-borne),
- Food- and water-related health effects;
- those related to air quality, and
- allergic diseases.

A count and classification of the 135 papers identified in the search by topic are provided in Table 1. The findings from these studies are presented in the subsequent sections of this review. Due to the large number of papers and the heterogeneity of studies in each topic, very brief and topic-specific summary tables present the search results at the end of each subsection. In addition, the search results are described and explained in a more narrative way. Several review articles and technical, government, and policy documents were used to provide background information to illustrate the relevance of the sub-topics for public health in Europe.
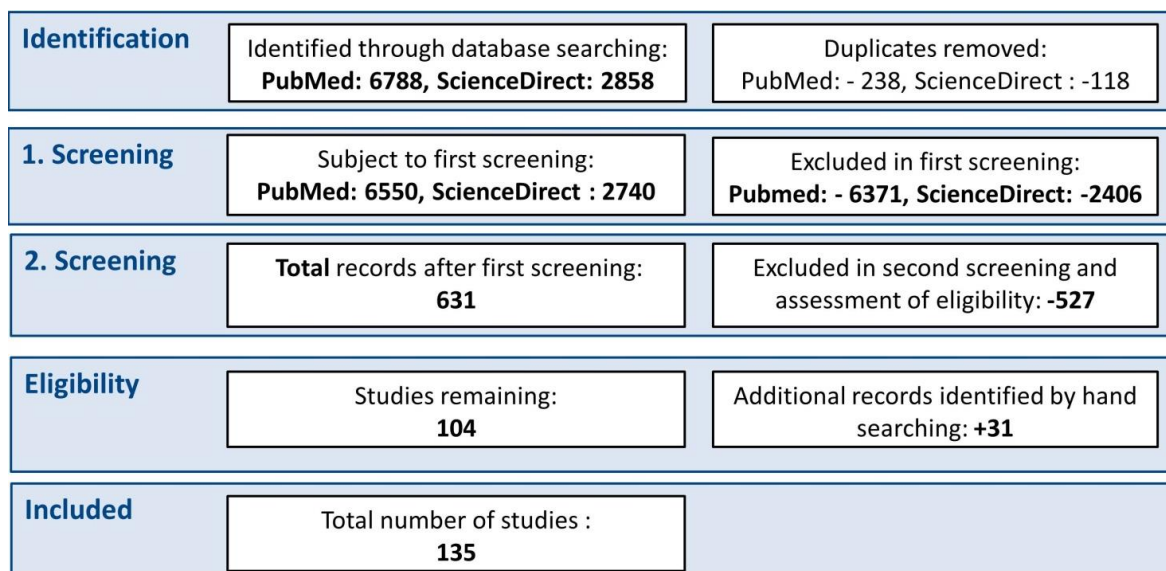
Figure 1. Flow chart.

Table 1. Screened results of literature search.

	Topic	Identified Studies
	High temperature and heat-wave	23
	Low temperature and cold	10
Direct health effects (48)	Floods	5
	Wildfires	6
	Ultraviolet radiation	4
	Vector- (mosquito, tick) and rodent-borne infectious diseases	37
Indirect health effects (87)	Food- and water-related diseases	7
	Air quality	26
	Allergic diseases	17
Total: 135		

3.1. Direct Health Effects

3.1.1. High Temperature and Heatwaves

Twenty-three papers assessing the health effects of high temperatures and heatwaves were identified in this search. The papers evaluate the health effects, such as morbidity and mortality, caused by extreme summer heat waves as well as the effects of high temperatures.

High temperatures are a threat to human health in Europe. More than 70,000 additional deaths occurred in Europe during hot periods in summer 2003, in comparison to the reference period of 1998–2002 [13]. The combination of extreme daytime maximum temperatures and warm nocturnal temperatures is particularly hazardous [14]. Mortality can be up to three times higher during long, high-intensity heatwaves [15,16]. In Berlin, higher death rates occur in densely built-up areas compared to rural areas [17]. The effect of heatwaves on different populations is highly variable; for example, mortality increased by 7.6% in Munich compared to 33.6% in Milan. A greater increase in mortality on

heatwave days was observed in Mediterranean cities compared with cities in northern parts of Europe (21.8% and 12.4% mortality increase, respectively) [15]. In contrast, cities with cooler climates have a greater increase in mortality per 1 °C increase above a local temperature threshold, compared to warmer cities [18]. A study in Central Italy found that a 1 °C increase in temperature above a threshold was associated with an increase in mortality of up to 15.97% among people aged 75 years or more, over a lag period of 30 days [19]. A lag effect is evident for heat- and heatwave-related mortality and morbidity, with the maximum death rate and hospital emergency department presentations occurring two to three days after peak temperature [20–22].

Excess deaths during heatwaves may be caused by dementia, renal disease, respiratory disease, and cerebrovascular disease [13]. Hot periods can lead to dehydration, hyperthermia, renal colic and renal failure [23]. Heatwaves have a significant effect on morbidity and mortality due to respiratory diseases [15]. Each 1 °C increase in temperature above local comfort thresholds is associated with an average mortality increase of 12%, compared with the daily mean [16]. Furthermore, for each 1 °C increase above a threshold in maximum apparent temperature, hospital admissions for respiratory disorders increased by up to 4.5% in 12 European cities [24]. Ambulance dispatches increase for every 1 °C increase in mean apparent temperature between 25 °C and 30 °C. The increase is greatest on days when the mean apparent temperature is more than 30 °C, with ambulance dispatches up to 9% higher on these days [25].

Elderly people are more vulnerable to the effects of heatwaves, due in part to poorer physical health and the effects of cognitive impairment on the perception of heat-related health risk [22]. However, temperature-dependent mortality is also high among young populations, particularly in Eastern and Southern Mediterranean cities including Istanbul and Tel Aviv [18]. Increased summer temperatures also have consequences for pregnancy and preterm birth. The risk of preterm birth increased by up to 20% when the maximum apparent temperature exceeded the 90th percentile (36 °C) in the two days prior to delivery. An increase in preterm birth was also observed when the minimum temperature was above the 90th percentile in the week prior to delivery [26].

Summer temperatures, as well as the frequency and severity of heatwaves, are expected to increase in Europe as the climate changes [27]. An increase in the distribution of severe and extreme stress heatwaves is expected in Europe under the SRES A1B scenario, with a northward expansion of affected areas anticipated. Mediterranean countries will be particularly affected by extreme heat events, especially Portugal, Italy, Greece, Turkey, and southern Spain. In these countries, temperatures during severe stress heatwaves may increase by up to 5–7 °C per heatwave day by 2075–2094. Other areas may experience temperature increases of up to 4–5 °C per heatwave day. The frequency and number of severe and extreme heatwave days are expected to increase by up to 45 days per summer by the late 21st century, and heatwaves may occur both earlier and later in the season, including late spring and early autumn, by 2071–2100 [14]. Highly urbanized areas are projected to be at increased risk from heat stress, compared with surrounding areas [28].

Heat-related mortality is expected to increase. A study across 10 cities in central Italy projects increases in heat-related mortality. The greatest increases are predicted in coastal regions, with mortality expected to increase by up to 11.8% by 2031–2050, compared with the baseline for 1999–2008, for each 1 °C increase above the estimated temperature threshold [19]. Heat-related hospital admissions for respiratory conditions are predicted to increase as well. The proportion of heat-related admissions is expected to

approximately double, from 0.18% in the baseline period (1981–2010) to 0.4% in the period 2021–2050. Considering that the number of warm days is also expected to increase, the number of heat-related respiratory hospital admissions is projected to increase from 11,000 per year at baseline to 26,000 per year. The greatest increases are expected in southern European countries, with the proportion of heat-related admissions for respiratory conditions expected to approximately triple in this region [29].

In Europe, the health burden of heat and heatwaves under climate change conditions will decrease in the short term, as warming is likely to avert 50,000 to 100,000 cold-related deaths by the 2020s [30]. However, by the 2080s, heat-related mortality rates in Europe are likely to increase by 12–33 per 100,000 per year, totaling approximately 50,000 to 160,000 additional deaths annually. The greatest increase in mortality is expected in central and southern Europe [30]. The costs of an estimated 26,000 additional heat-related deaths per year by the 2020s, 89,000 by the 2050s, and 127,000 by the 2080s, using a A1B scenario without mitigation or adaptation, amount to €147 billion/year when using the value of statistical life approach [31]. The same study highlights that these impacts can be reduced to a stable 69,000 deaths and €80 billion per year when the EU's 2 ℃ target is adhered to [31].

Table 2 lists the search results by author according to the focus of papers for heatwaves and high temperature: observed mortality, observed morbidity, and projection studies. While most reports about observed mortality or morbidity are related to heatwaves, five studies are about observed mortality or morbidity related to higher temperatures. Four studies assess the future impacts of higher temperature or heat and six studies address multiple or different aspects of this topic.

Table 2. Search results about health effects of extreme heatwaves and high temperature (23).

Health Effect	Related to Extreme Heat	Related to Higher Temperature
Observed mortality	Extreme temperatures are associated with increases in mortality [15–17,22,32]	Mortality increases are associated with temperatures above a local comfort threshold [13,18]
Observed morbidity	Extreme temperature is associated with increases in morbidity [20,23,26]	Morbidity indicators are associated with higher temperatures [24,25,33]
Future projection	Future expected extreme temperatures are expected to increase heat-related mortality [14] Projected effects of heatwaves and high temperature have economic costs [27,30]	Future increases in temperature are estimated to increase health effects of temperatures above a comfort temperature [28,29,31,34]
Other or multiple focus	There is confounding by air pollution for heat and cold effects [35] Heat and cold, mortality and morbidity, observation and projection are relevant in Europe [19] Different population subgroups are at risk [36]	

3.1.2. Low Temperature and Cold Spells

Ten papers identified in this search addressed the health effects of low temperatures and cold spells.

Low temperatures and extreme cold weather pose a significant risk to human health. Low temperatures have an effect on respiratory tract infections [37], myocardial infarction [38], stroke hospitalization [39] and general hospital admissions [40], and mortality [35,41–43]. Extreme cold spells cause increases in morbidity [38] and mortality due to respiratory, cardio-, and cerebrovascular diseases [39,44,45]. The effect of cold weather on mortality increases with age, and is greater in warmer (southern) cities. On average, a 1 ℃ decrease in daily minimum apparent temperature in seven Mediterranean cities during

the cold season was associated with a 1.62% increase in daily total (natural) mortality, and a 2.29%, 2.80%, and 2.03% increase in mortality from cardiovascular, respiratory, and cerebrovascular causes, respectively [35]. A lag effect of up to 23 days was observed, particularly for respiratory mortality, highlighting the prolonged effects of cold weather on health [35]. A study performed in Spain found that each 1 ℃ decrease below a seasonal temperature threshold caused a mortality excess of 10% [45]. An association between lower temperatures and mortality due to cancer, respiratory diseases, and cardiovascular diseases was also found. The strongest effect was seen on cancer mortality among the elderly, particularly on days when the temperature was lower than the 5th percentile for the cold season [41].

As the climate warms, cold-related deaths in the European Union are expected to fall by 50,000 to 100,000 deaths per year by the 2020s and by 100,000 to 250,000 deaths per year by the 2080s, with Ireland, the United Kingdom, and southern Europe likely to experience the greatest reductions in cold-related mortality [30]. In the short term, a reduction in cold-related mortality may be greater than the expected increase in heat-related mortality; however, over time the reduction in deaths due to cold will likely be insufficient to offset increases in heat-related mortality. A study across 10 cities in central Italy has compared projected heat and cold-related mortality for the period 2031–2050. Cold-related mortality shows a variable change, from −1.2% to 0.9% for each 1 ℃ below the estimated cold season temperature threshold. Conversely, in the same region, mortality rates are expected to increase by up to 11.8% for each 1 ℃ increase above the threshold during the warm season [19].

Table 3, [19,30,35,38–46] lists the search results according to the focus of the research. Most of the papers address the observed effects of low temperatures on mortality (4) and morbidity (3). Three papers analyze the effects of extreme cold: two on mortality and one on morbidity. Two papers provide projections of the future impacts of cold in the context of overall assessments of heat and cold.

3.1.3. Floods

The search identified only five recent papers that report the health effects of floods. Only one reported observed health effects from flooding (in the Netherlands), while others report on projection studies (see Table 4).

Flooding is a serious risk in the WHO European Region. The International Disaster Database of the Centre for Research on the Epidemiology of Disasters (EmDAT) reports 173 flood events (including coastal, fluvial/riverine, flash, and ice jam flood) between 2007 and 2014 in the countries of the WHO European Region, causing 1078 deaths and affecting more than 5 million people [47]. Episodes of heavy precipitation are likely to increase in Europe in the face of a changing climate. As a result, the risk of flash flood events with subsequent risk of morbidity and mortality is likely to increase in some areas [48]. Water quality could be compromised as a result of heavy rainfall and variability in rainfall and runoff [49]. However, given the unpredictable nature and relative infrequency of flash floods, accurate forecasts are difficult and subject to wide regional variation [50].

Table 3. Search results about health effects of low temperature (10).

Health Effect	Low Temperature	Extreme Cold
Observed mortality	Low temperature is associated with observed mortality in 15 European cities [35,41]	Temperatures lower than the 5th percentile are strongly associated with mortality in Cantabria, Spain [44]
	Winter excess mortality rate remains a recurring phenomenon that is quantitatively greater than the isolated summer event in France [42]	
	Excess winter mortality of 4597 cases per year for myocardial infarction in Portugal [43]	Extreme cold is associated with observed mortality in La Mancha, Spain [45]
Observed morbidity	Low temperature is associated with respiratory tract infections [46]	
	Cold weather had an effect on hospital admission in 12 cities in Europe [40]	
	Significant negative associations between daily average air temperature and all stroke hospitalizations [39]	
	Thermal environment inversely associated with acute myocardial infarction morbidity during winter [38]	
Projections	[30] *	
	[19] *	

* already included in Table 2.

Modeling exercises project a mixed pattern of change in fluvial flooding risk across Europe [51]. The British Isles, western and central Europe, regions along the Danube, and northern Italy appear to have a significant increase in future flood hazard, largely due to increases in extreme precipitation events and reduced snow [52]. Approximately 300,000 people are expected to be affected by river flooding per year by the 2050s and up to 390,000 people per year by the 2080s under A1B scenario. People in the United Kingdom, Ireland, Belgium, Luxembourg, France, the Netherlands, Austria, Finland, and Italy will be most affected by river flooding scenarios, despite expected population declines [52,53]. Increases in the number of people affected by river flooding will also occur in Denmark, Germany, Hungary, and Slovakia [52]. Other areas may see a reduction in the number of people affected, particularly northeastern countries including Poland, Estonia, Finland, Latvia, Lithuania, and Sweden; this is likely due to both population decline and a reduction in flood hazard [28,30,51,54].

Sea level rise of about 37 cm by the 2080s under a A1B scenario (for details on the scenarios, please refer to [55]) is projected to affect 250,000 people per year in Europe directly through coastal flooding if no adaptation occurs [56]. Southern Europe, the northern part of central Europe, Ireland, and the United Kingdom are likely to be most affected. The number of people affected by coastal flooding is higher when using A2 and B2 scenarios; 775,000 to 5.5 million more people may be impacted by 2085 compared to the baseline year 1995 [30].

The health risks of (often storm-related) fluvial and coastal floods are highly varied. Health effects of floods include mortality and morbidity resulting from cardiovascular accidents, drowning and electrocution, traumatic injuries, infectious diseases, and psychological impacts in both the short and long term. Infectious diseases associated with flooding include skin, eye, and respiratory infections, and food-, water-, and vector-borne diseases [57]. Other health effects result from population displacement, damage

to infrastructure, health service disruption, contamination of drinking water, disruption of food supplies, and the destruction of crops and other agricultural resources [58,59]. Children are at greatest risk of water-borne infectious diseases due to floodwater exposure, with common causative pathogens including *Campylobacter jejuni*, *Giardia*, *Cryptosporidium*, noroviruses, and enteroviruses [60].

Table 4. Search results of literature about health effects from flooding (5).

Region, Type of Flood or Model	Results	Reference
Estimation of future fluvial flood risk in Europe with LISFLOOD model	Flood risk (= product of flood probability (or hazard), exposure of capital and population, and vulnerability to the effect of flooding); decrease of flood risk in northeast Europe, increase in northern Europe.	[51]
Estimation of future fluvial flood risk in Europe with LISFLOOD model	Robust increase in future flood hazard, mainly due to a pronounced increase in extreme rainfall in western and central Europe, the British Isles, and northern Italy.	[52]
	A decrease in future flood hazard is projected in eastern Germany, Poland, southern Sweden, and, to a lesser extent, the Baltic countries.	
Estimation of future fluvial flood risk in Europe with LISFLOOD model	Under the no adaptation trajectory current expected annual damages of €5.5 billion/year are projected to reach €98 billion/year by the 2080s due to the combined effects of socioeconomic and climate change. Under the adaptation trajectory the avoided damages (benefits) amount to €53 billion/year by the 2080s.	[54]
Assessment of coastal and fluvial flood impacts using the Coastal Fluvial Flood (CFFlood) model in Europe	Approximately 6% of the European population lives in a 100-year event coastal/river flood risk area (2010 estimate) = approx. 28.6 million people.	[61]
Observational study about effect of exposure to floodwater in the Netherlands	Mean risk of infection for children who were exposed to floodwater originating from combined sewers was 33%, from storm sewers 23%, and from rainfall-generated surface runoff 3.5%.(For adults—3.9%, 0.58%, and 0.39%, respectively.)	[60]

3.1.4. Wildfires

Six papers on wildfires were identified in the literature search; they are listed in Table 5. The term wildfire is used to describe the uncontrolled and non-prescribed burning of plants in numerous settings, including forest (forest fires), grassland, and tundra [47]. While most fires in Europe result from human activity, extreme fire events are often assisted by severe weather conditions, and available fuel is a significant determinant of fire behavior [62]. On average, approximately 70,000 fire events occur in Europe each year, affecting more than half a million hectares of forested land. Approximately 70% of fires occur in the Mediterranean region, with the most damaging fires occurring in the months of July, August, and September [63].

According to the Em-Dat database, 225 people were killed in wildfires in countries belonging to the WHO European Region between 2007 and 2014 [47]. The health effects of wildfires result from direct exposure to fire and smoke, but also indirectly through damage to health facilities, transport infrastructure and communication systems, ecological change, and social disruption [64]. Given their

highly destructive nature, wildfires and their aftermath may also cause significant psychological distress, both in the short and long term [65].

Fires are also a significant source of air pollutants, including particulate matter [66], volatile organic compounds, and nitrogen and sulfur oxides, products that may be associated with allergic and respiratory diseases. In addition, as more recent studies confirm, these air pollutants promote tropospheric ozone production and radiative forcing, both of which play a role in perpetuating climate change and hence increasing risks to human health [67]. Following forest fires in 2010 near Moscow, the Russian Federation, high levels of PM_{10} were observed in the city of Moscow, the highest 24-h pollution levels exceeding 300 μg/m^3 on several days. The fires occurred in the context of a major heat wave that lasted for 44 days, with 24-h average temperatures ranging from 24 ℃ to 31 ℃. There were close to 11,000 excess deaths from non-accidental causes including high temperatures and air pollution from wildfires [68].

The risk of wildfires is expected to increase in Europe. Projections show an increase in wildfire risk in many areas, including France, Germany, Belgium, Romania, and Bulgaria, plus southern parts of the Netherlands, Sweden, and Finland. Areas of high and very high wildfire risk will increase by the years 2041–2070. Fire risk is expected to increase most significantly in Greece, Portugal, Spain, and southern Italy [28,69]. The projected increase in fire risk is largely due to reductions in summer precipitation [70]. The total burned area in the EU Mediterranean region is expected to increase by 66% by 2071–2100 under the B2 scenario, and 140% under the A2 scenario [69].

Table 5. Search results of literature about health effects from wildfires (6).

Geographical Area	Study Type	Result	Reference
Greece	Cross-sectional case control study following wildfire August 2007	Those exposed to disaster have significantly higher rates of symptoms including somatization, depression, anxiety, hostility, phobic anxiety, and paranoia; they are significantly more distressed than controls.	[71]
Peloponnesus peninsula, Greece	Cross-sectional case control study	400 participants (200 fire-affected, 200 controls). Fire victims have a lower quality of life (physical and psychological health, environment)—but only significant impairment in quality of life in the environmental domain after adjustment for confounders.	[72]
EU-Mediterranean countries	Assessment of recorded fires (1957 to 2007) and projections of future fire conditions	Under scenarios B2 and A2, seasonal severity rating (SSR) expected to rise from 5.3 to 6.64 (+25%) and 7.34 (+38%) respectively (SSR = seasonal rating of fire danger, dependent on fuel moisture and fire behavior potential, designed to correlate with fire control difficulty). Iberian Peninsula (Spain, Portugal) and Greece most affected by increasing fire danger.	[69]
Portugal	Assessment of association between temporal dynamics of fire events in Portugal and several variables—socioeconomic, landscape, climatic	Country-wide increasing trend in numbers of fires from 1980 to mid-1990s, reduction in average area burnt per individual fire (from approx. 20 ha in 1980s to 5 ha in mid-90s). This increase not explained by investigated climatic factors or temperature/precipitation anomalies; not significantly correlated with number of forest fires.	[73]

Table 5. *Cont.*

Europe	Impact assessment and assessment of adaptation strategies	In the Mediterranean region the yearly average burned area is projected to increase by 150–200% by 2090 (relative to 2000). Balkan and eastern European countries will have a 150–560% increase in burned areas by 2090 compared with 2000. Central EU and Baltic countries: increase in burned areas of 120–340% by 2090 (compared with 2000). Overall, 65–67% reduction in burned area with prescribed burnings, compared to the "do nothing" scenario.	[70]
Portugal	Longitudinal observational and comparative study	Highest levels of PM fractions were observed during July and August of 2010, corresponding to the periods when majority (66%) of forest fires occurred and significantly higher than means for the remainder of the year. This may indicate that forest fires are responsible for increased PM levels.	[66]

3.1.5. UV Radiation

Four papers have been identified that analyze the health effects of UV radiation. Stratospheric ozone depletion is a phenomenon that has been noted as one of the first "symptoms" of global environmental change [74]. The emission of ozone-depleting substances had led to a hole in the ozone layer, above Antarctica. However, consequent implementation of measures agreed to in the Montreal Protocol and the substitution of ozone-depleting substances in many items have successfully stopped the increase in ozone-depleting substances and the stratospheric ozone layer is recovering [75]. Currently, the health-relevant effects of stratospheric ozone depletion such as skin cancer and cataracts, through changes in UV radiation, are influenced by climate change and changes in cloudiness [76,77] as well as changes in human behavior and exposure related to living at the coast [78] or changing lifestyles [79] (see Table 6, [78–81])).

3.2. Indirect Health Effects

3.2.1. Climate-Sensitive Infectious Diseases

Temperatures and water availability influence ecosystems and the occurrence of climate-sensitive infectious diseases. Mapping of vulnerabilities to infectious diseases [10] and an assessment of the vulnerability to the risks of infectious disease transmission due to climate change [82] have been undertaken. When researchers studied 2058 outbreaks of 114 infectious diseases occurring in 36 European countries from 1950 to 2009, they found that climatic variations and seasonal changes in the condition of the North Atlantic Oscillation (teleconnection pattern of air pressure leading to warmer/cooler temperatures) influenced the outbreak occurrences of 11 diseases, transmitted through air, water, food, vectors, and rodents [83]. The change in occurrence of infectious diseases in Europe is particularly evident for those transmitted by vectors such as mosquitos, sand flies, and ticks or rodent-borne diseases, and for foodborne diseases as summarized below. Other contributors to changing disease distribution require further assessment, including alterations to vegetation and habitat, human behavior, density and distribution of non-human hosts (such as deer and rodents), and health interventions including vaccination programs [84].

Table 6. Search results about the health effects of UV radiation (4).

Geographical Area	Study Type	Result	Reference
Sweden	Spatial comparison of cancer incidence and sunshine	Coastal communities (high sun exposure) have higher incidence of SCC; this correlates with increased UV radiation exposure.	[78]
Europe (southern Spain, Paris, Berlin, Stockholm)	Modelling of the UV radiation relevant for health risks (skin cancer) and benefits (vitamin D production) for different scenarios	Estimated reduction of UVR daily doses, but not sufficient to provide a protection from erythema. On the other hand, at higher latitudes, UVR reduction possibly contributes to a relevant increase in the exposure time necessary for the synthesis of vitamin D, mainly during the autumn and spring seasons.	[80]
Global	Systematic literature review	UVR exposure is a minor contributor to the world's disease burden, causing an estimated annual loss of 1.6 million DALYs; *i.e.*, 0.1% of the total global disease burden. A markedly larger annual disease burden, 3.3 billion DALYs, might result from reduction in global UVR exposure to very low levels/	[81]
Croatia	Observational comparative study	The incidence of malignant skin melanoma has risen during the last 10 years. Different distribution in two counties could be related to climate changes or different ways of life.	[79]

Vector-Borne and Rodent-Borne Diseases

Vector-borne diseases are those transmitted by infected arthropods such as mosquitoes, sand flies, and ticks. These diseases are associated with significant morbidity and mortality across much of the WHO European Region. Arthropod and rodent survival is highly dependent on climate-related factors, with weather affecting habitat, distribution, reproductive capacity, activity, and biting behavior [84]. Several vector-borne diseases in Europe will likely be affected by climate change [85]. The literature search identified 37 relevant papers: 13 about mosquito-borne diseases, 17 papers about tick-borne diseases, five about rodent-borne diseases, and two that dealt generally with climate-sensitive infectious diseases in Europe (see Table 7).

The most relevant climate-sensitive mosquito-borne diseases are malaria, West Nile Fever, Chikungunya, and Dengue. In Europe, most malaria cases are imported and not autochthonous: in 2013 around 5000 imported malaria cases with origin specified were reported, although it is assumed additional cases went unreported [86]. In France and the Netherlands, a few malaria cases without recent travel history were reported [87,88]. The observed and projected risk of malaria was explored for Portugal [89], Turkey [90], Spain [91], and Germany [92]. Although transmission risk may theoretically increase with warming temperatures and provided that suitable mosquito breeding grounds are available, other factors (health system functionality, building and development regulations, and patterns of land use) make the re-emergence of malaria in most countries in Europe unlikely [84] (see also Table 7).

Human West Nile fever (WNF) has been described in Europe since 1950. The transmitting vector is the mosquito species *Culex*, which is widely distributed in Europe. WNF has high rates of asymptomatic infections that make it difficult to monitor [84]. Studies in Israel [93], Hungary, and Austria [94] of neuroinvasive WNF infections indicate that warmer temperatures cause increased mosquito breeding

activity, which is associated with higher incidence. Increased awareness and increased diagnostic testing have also contributed to the increasing incidence of WNF observed over the last 20 years within 20 countries in the WHO European Region [95].

In 2007, more than 200 cases of Chikungunya (characterized by fever and joint pain, and often causing severe illness in older people with concomitant diseases) were reported in Italy [96]. This viral disease is transmitted by the mosquito *Aedes albopictus*. Originating in southeast Asia, *Aedes albopictus* is spreading globally and was reported in Albania in 1979 [97]. The mosquito is now established in southern parts of Europe [98,99] and can transmit not only Chikunguya, but also, among others, Dengue fever [100–103].

The first sustained transmission of Dengue in Europe since the 1920s was reported in 2012 in Madeira, Portugal. A population of the mosquito *Aedes aegypti* on the island of Madeira led to an outbreak of Dengue fever with 2168 cases, of which 1080 were confirmed. No severe clinical variants or deaths were reported [102,104]. In addition, one autochthonous case was reported in southern France in October 2013 [105]. While *Aedes aegypti* is re-emerging in Europe, *Aedes albopictus* is emerging [106,107] and an overall increase in Dengue risk is predicted, with the greatest increase expected in coastal areas of southern Europe [103]; see Table 7.

Table 7. Search results (13) of literature about climate change and mosquito-borne infectious diseases.

Observed Effect (7)	Observed and Projected Effects (6)
Malaria in Portugal [89]	Malaria in Germany [92]
Malaria in Turkey [90]	*Aedes albopictus* in Europe [98]
Malaria in Spain [91]	Recent and future *Aedes albopictus* suitability [99]
WNF in Israel [93]	Dengue in Europe [100]
WNF in Hungary and Austria [94]	Dengue in Europe [103]
Chikungunya in Italy [96]	Dengue and Chikungunya in Europe [101]
Dengue in Madeira 2012 [102]	

Ticks transmit climate-sensitive infectious diseases including Crimean Congo hemorrhagic fever [108,109], Lyme borreliosis [110–112], tick-borne encephalitis [113–120] and Tularemia [121]. Several studies identified in the literature review do not report on climate change and tick-transmitted diseases, but instead describe changes in tick distribution, specifically in the United Kingdom [122], Slovenia [123], and the Czech Republic [124]. Climate modeling suggests that the geographic range of *Ixodes ricinus* ticks will increase during the 21st century. Projections show an increase in the vegetation period and associated tick activity by 2071–2100, with likely increase in tick distribution across Norway, Sweden, and Finland by 2100, resulting in a potential increase in tick-borne diseases [125]. Figure 2 maps the countries with studies on tick-borne diseases retrieved in this search.
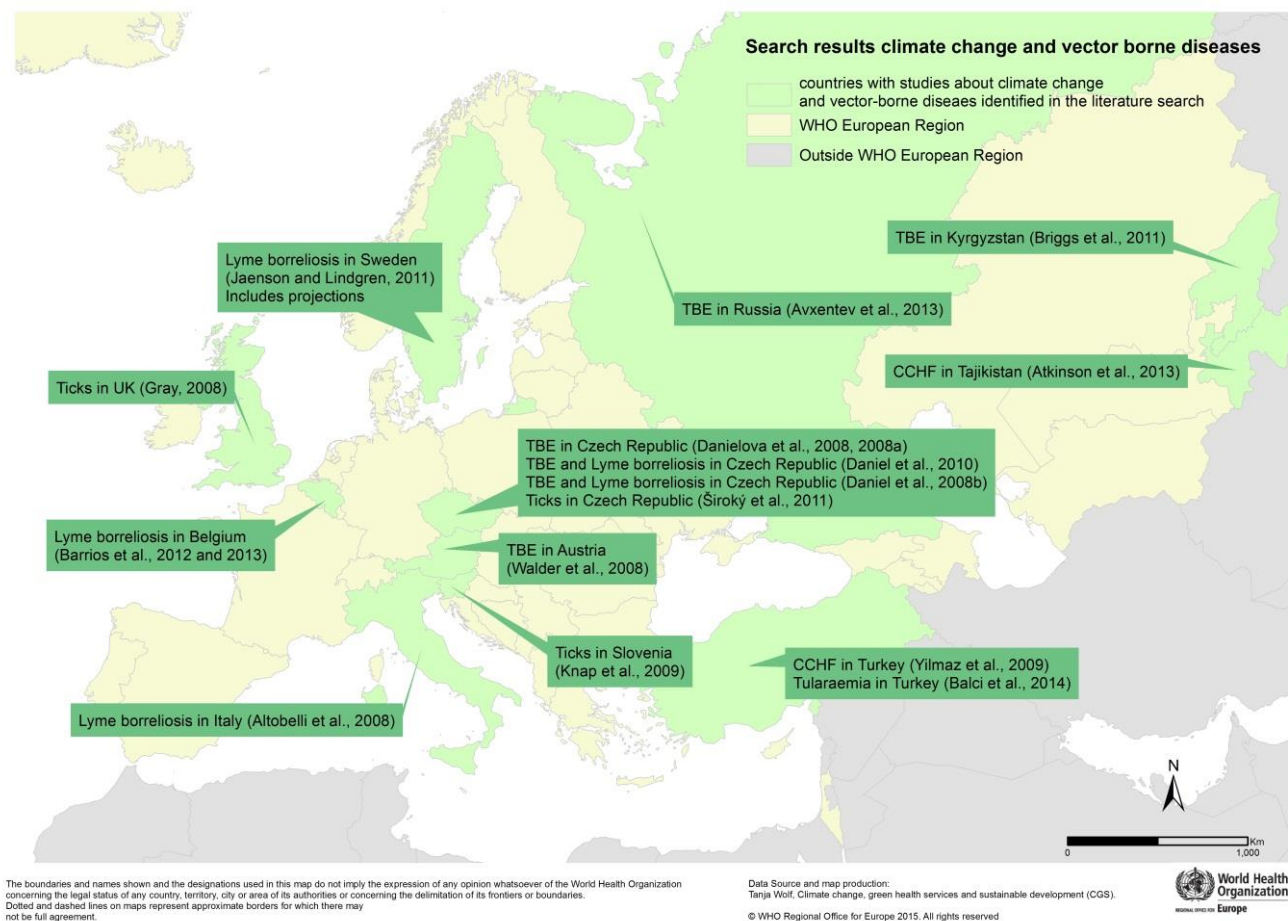
Figure 2. Search results (17) of literature about climate change and tick-borne infectious diseases ([108–111,113–115,117–119,121–128]).

Rodent-borne diseases such as plague, leptospirosis, and hantavirus infections are also sensitive to climatic changes. Rodents can host vectors or act as an intermediate infected host. Plague is endemic in parts of central Asia, particularly Kazakhstan. Rodent populations, and subsequently rates of *Yersinia pestis* infections, are sensitive to climate factors, owing to effects on food and habitat availability, flea density, and plague transmission [129]. A predicted increase in the aridity of the region may result in an increase in the risk of plague in Europe, particularly in the setting of warmer winters and springs [129,130]. Rodent populations are expected to increase across many parts of Europe and in consequence, rodent-borne diseases are expected to increase [84]. In Europe, leptospirosis occurs mostly in the Mediterranean region and in eastern European countries. Risk factors for human infection include close contact with animals, especially among farmers, abattoir workers, and veterinarians [131]. Heavy precipitation and flooding increase the risk of leptospirosis, a result of increased contact between humans and both *Leptospira* and their reservoirs related to clean-up after inundation [132]. The number of hantavirus infections has increased significantly in recent years, to over 4000 cases across 24 countries in Europe in 2012 [133]. As for other diseases, it remains unclear whether this increase is a true reflection of disease transmission, or rather the result of improved diagnostic and reporting methods [134].

3.2.2. Food- and Water-Related Diseases

Climate change can significantly affect basic determinants of good health. Seven papers have been categorized as dealing with health effects related to food and water. This includes communicable diseases and risk related to intoxication from cyanobacteria and mycotoxins (see Table 8).

A study in Kazakhstan confirmed previous knowledge [135] about climate change and the risk of salmonella [136]. In this study an increase in precipitation was associated with an increase in the incidence of salmonellosis, with a lag time of up to two months [136]. Under the SRES A1B climate change scenario, up to 17,000 additional cases of salmonellosis are expected across the European Union by the 2080s, assuming incidence continues at its current level [31]. The incidence of campylobacteriosis in humans is positively associated with mean monthly temperature, with a lag time to disease onset of up to one month [137]. Accordingly, with warming temperatures an increase in the risk of campylobacter infections is also predicted [138].

Flooding and other extreme precipitation events pose a risk to the supply of safe water. Both low and excessive rainfall may be associated with infectious disease outbreaks caused by contaminated drinking water. Droughts are predicted to increase, threatening fresh water supplies, particularly in southern areas of Europe [27]. An increase in extreme precipitation events is expected in Europe as the climate changes [27], with associated increased risks of water-borne diseases such as cryptosporidiosis [138]. Disease outbreaks are also associated with low rainfall in the preceding three weeks [139]. The exceptionally hot summer of 2010 in some parts of Europe may have played a role in an observed increase in Legionnaires' disease [140].

Apart from extreme precipitation, other factors affect food- and water-related diseases; for example, the number of pathogenic *Vibrio* spp. bacteria is dependent on water salinity and temperature. *Vibrio vulnificus* infections in Israel correlate with increasing coastal water temperatures [141]. A positive correlation also exists between temperature and cyanobacteria biomass; warmer temperatures produce an increase in the amount of potentially toxic cyanobacteria, with heatwaves therefore increasing the risk of toxic exposure. A corresponding reduction in cyanobacteria biomass occurs during extreme cold events [142].

Table 8. Search results (7) of literature on climate change and diseases related to food and water.

Related to food	Campylobacter in northern Europe [137]
	Salmonellosis in Kazakhstan [136]
Related to water	Vibrio in Israel [141]
	Rainfall and outbreaks in the United Kingdom [139]
	E. coli in water and mussels in Norway [143]
	Toxic cyanobacteria in peri-Alpine lakes [142]
	Mycotoxins in maize in the Netherlands [144]

3.2.3. Air Quality

Air quality is an important health threat in Europe [145]. Evidence shows that air pollution at current levels in European cities is responsible for a significant burden of deaths, hospital admissions and exacerbation of symptoms especially for cardiorespiratory disease. Air contains emissions from motor

vehicles, industry, heating and commercial sources, as well as tobacco smoke and household fuels. Air pollution harms human health, particularly in those already vulnerable due to age or existing health problems. Exposure to air pollutants is largely beyond individuals' control and requires action by public authorities at the national, regional, and even international levels. Most pollutants are related with those emissions that contribute to climate change. The links between climate change and air pollution are manifold:

(1) Those emissions leading to climate change often also pollute the air. Accordingly the air quality benefits from reducing greenhouse gases.

(2) The impacts of climate change on the atmosphere, temperature, precipitation, and extreme events have a variable effect on the level of air pollution.

(3) Warmer temperatures worsen the health effects of some air pollutants.

The search identified 26 papers, more than was found for other climate change health effects. Not all of them strictly address the links between climate change, air pollution, and health or relate to one of the three mechanisms above. Nonetheless, the findings of the papers are summarized here in the text and in Table 9.

The number of days with ozone concentrations exceeding human health thresholds is expected to increase. This applies particularly to Austria, Belgium, France, Germany, Luxembourg, Italy, and the Netherlands [146]. Regional projections indicate a 10%−14% increase in ozone-related morbidity and mortality by 2021–2050 in several countries including Belgium, France, Spain, and Portugal; a decrease in ozone-related morbidity and mortality is predicted in some countries in northern Europe. By 2041–2060 morbidity and mortality are predicted to increase by up to 34% in some areas [147]. A positive association between high temperatures, ozone, and PM_{10} concentrations with mortality has been observed, especially on heatwave days [21,148]. A 1.66% mortality increase for each 1 °C increase in temperature was found on low-ozone days, and 2.1% on high-ozone days [149]. In a metropolitan area in Portugal, a 10 μg/m^3 increase in daily eight-hour maximum moving-average ozone is associated with a 0.95% and 1.58% increase in non-accidental and cardiovascular mortality, respectively. The effects of ozone are greater among elderly people, and multiple days of increased exposure produce greater effects than only single days [150,151]. In addition, it is thought that a proportion of recurrent ischemic cerebrovascular events and myocardial infarction may be triggered by short-term exposure to ozone, the levels of which may increase during heatwaves [152].

Emissions of air pollutants including nitrogen oxides, sulfur dioxide, carbon monoxide, and particulate matter are associated with numerous conditions including respiratory disorders [153], cardiovascular disease, and allergies [154,155]. A significant association is seen between the concentration of PM_{10} and summer mortality [151,156]. A positive relationship has also been found between cardiovascular mortality and concentrations of $PM_{2.5}$, nitrogen dioxide, and total suspended particulates [157–159].

Children are especially vulnerable to air pollutants. Higher mean annual concentrations of sulfur dioxide, carbon monoxide, nitrogen dioxide, and total suspended particulates have been found to be significantly associated with allergic and respiratory symptoms in children, including rhinitis, rhinoconjunctivits, atopic eczema, and recent severe asthma [160]. Children are particularly vulnerable to changes in air quality, with weekly ozone and sulfur dioxide concentrations associated with the reporting of respiratory symptoms and impaired respiratory function [161]. Exposure of toddlers to ozone and PM_{10} is associated with an increased likelihood of bronchitis and other respiratory diseases, while intra-uterine

exposure to carbon monoxide, nitrogen dioxide, sulfur dioxide, and particulate matter have significant negative effects on fetal growth and anthropometric parameters at birth [162,163].

Emissions of numerous pollutants, including sulfur dioxide, nitrogen oxides, and black carbon (an important contributor to particulate matter) have declined in Europe in recent years, owing to both improvements in technology and stricter regulations [164]. This could also lead to a reduction in PM mass concentration [165], although the relation between PM and nitrogen oxides is not fully clear yet. However, other sources of pollutants exist, such as wildfires. A dramatic increase in particulate matter is observed on wildfire days compared with background summer levels [66,166].

Table 9. Search results of literature about climate change, air quality and health (26).

Place	Study type	Result	Reference
Oporto, Portugal	Observational study	Ozone and PM 10 have adverse effects on health	[151]
Eskisehir, Turkey	Survey; cross-sectional study	Elevated ozone levels were associated with upper respiratory tract complaints in schoolchildren.	[161]
22 cities in the Mediterranean and Europe		Synergistic effects of heat and air pollution (ozone and PM_{10}) on mortality	[148]
Dijon, France	Case-crossover study	Short-term exposure to even low levels of ozone has an effect on ischemic cerebral and cardiac events.	[152]
Germany	Descriptive, observational	Exposure to several air pollutants (ozone, PM_{10}, CO, NO_2, SO_2) significantly affects infant and toddler health.	[162]
Northern Italy	Descriptive, observational study	$PM_{2.5}$, ozone and NO_2 are estimated to reduce life expectancy in two towns by 4% (in people aged 30 years) to 20% (in people aged 85 or more years)	[167]
Italy (ten cities)	Time-stratified, case-crossover analysis	PM_{10} exposure is associated with respiratory mortality, especially in summer. More respiratory deaths occur in the cold season.	[156]
Helsinki, Finland	Observational	Daily air pollution levels ($PM_{2.5}$, NO_2 and CO) is associated with asthma emergency room visits. There is a 3–5 day lag effect in children, but more immediate effect in the adults and elderly.	[168]
Czech Republic	Observational, cross-sectional study	Association between bronchitis and NO_x in children increases with child's age in the under-2 age group	[160]
Kotka, Finland	Cohort study	Even low levels of air pollution ($PM_{2.5}$) are associated with higher inflammatory markers in the blood of elderly people.	[169]
Volos, Greece	Time series study	Air pollutants have a significant effect on hospitalization for respiratory and cardiovascular causes.	[153]
Israel	Cohort study	When adjusted for socio-demographic factors, cumulative chronic exposure to $PM_{2.5}$ is positively associated with reoccurrence of cardiovascular events in patients after a first myocardial infarction.	[170]
Italy	Descriptive, observational	PM_{10} has significant impact on COPD hospitalization for children; ozone has significant influence on hospitalization of the elderly.	[150]

Table 9. *Cont.*

Place	Study type	Result	Reference
Romania	Observational, time series	Dry air aggravates the adverse effects of total suspended particles on chronic bronchitis.	[171]
Madrid, Spain	Ecological longitudinal time-series study	PM is the primary pollutant that showed a statistically significant association with hospital admission among people over 75 years of age.	[172]
Madrid, Spain	Longitudinal ecological time-series	$PM_{2.5}$ concentrations are an important risk factor for daily circulatory-cause mortality.	[157]
England, Belgium, Germany and France	Simulation/climate modelling	Simulation of climate change effect on ozone indicates an increase in ozone concentrations. Higher temperatures are associated with increased biogenic emissions, less precipitation, fewer clouds, and increased photolysis.	[146]
Norway	Cohort study	NO_2, $PM_{2.5}$, and PM_{10} have effects on mortality for cardiovascular causes, lung cancer (threshold effects), and chronic obstructive pulmonary diseases (linear effects).	[173]
Vienna, Austria	Time series analysis	Particulate matter and NO_2 were associated with mortality from non-trauma causes, even at relatively low levels.	[158]
Tuscany, Italy	Time-stratified case-crossover approach	Evidence for an association between air pollutants (PM_{10}, NO_2, CO) and hospitalization for acute myocardial infarction was found.	[174]
Tuscany, Italy	Time series and case-crossover	Ozone exposure is associated with an increase in out-of-hospital coronary death but not hospitalized acute myocardial infarctions.	[159]
12 European countries	Pooled data from 14 population-based mother-child cohort studies	Exposure to ambient air pollutants and traffic during pregnancy is associated with restricted fetal growth in Europe.	[163]
Dresden, Germany	Observational and modelling	PM mass concentrations are higher in winter and estimated to decrease in future due to a decrease in sulfate and soot mass concentrations.	[165]
12 countries in Europe	Cohort study	Long-term exposure to constituents of particles not found to be statistically significantly associated with total cardiovascular mortality.	[175]
Emilia-Romagna region, Italy	Time series analysis	In Emilia-Romagna, Italy, there is a positive relationship between PM_{10} and emergency ambulance dispatches (non-traumatic diseases).	[176]
Europe	Modelling	Increase in ground-level ozone and related health impacts is estimated for Belgium, France, Portugal, and Spain (plus 10–14% by 2050), with similar decrease in Nordic and Baltic countries. By 2041–2060, a strong increase in deaths and morbidity is expected in Belgium.	[147]

3.2.4. Allergic Diseases

Seventeen eligible papers were identified in this search (see Table 10). It is estimated that between 44 and 76 million people living in the European Union suffer from an allergic disease of the respiratory tract or skin, with up to 90% of these individuals receiving no or inadequate treatment. Pollens and spores produced by plants are common allergens and trigger allergies. The role of pollen in the development of allergic disease depends on numerous factors, including the duration and intensity of exposure, the annual volume of pollen produced, and the tendency of particular pollen types to trigger allergic responses [177,178]. Climate change is likely to trigger further changes in pollen concentration, volume, and distribution, with an associated increase in the prevalence and severity of allergic diseases in many parts of Europe. While increasing temperatures may prompt earlier flowering and hence prolongation of the pollen season, rising atmospheric carbon dioxide concentrations will result in increased plant growth and pollen production. Furthermore, changing weather patterns may prompt an increase in the geographic range of many allergenic plants, with increasing population risk of allergic disease [177,179,180]. Episodes of acute allergic conditions, including severe asthma, may increase in some areas, owing to an increase in the frequency of thunderstorms known to trigger pollen release [181].

Symptoms of allergic diseases result in absenteeism from work and school and significant productivity loss; it is estimated that allergic diseases generate avoidable costs of €55–151 billion per year across the European Union [182]. Significant associations have been identified between springtime pollen concentrations and emergency calls for asthma exacerbations among children [183]. Furthermore, an increase in the concentration of Ambrosia pollen by 10 grains/m^3 may increase hospital admissions for respiratory disorders by 25% [184].

An increase in the annual pollen index (a measure of average daily pollen concentration) has been observed for many taxa of pollen-producing species across Europe [185]. Furthermore, in some areas, pollen and spore concentrations have been found to be positively associated with mean air temperature [186–188]. However, the pattern of change is highly heterogeneous by species, season, and geography [187,189–191]. In northern Italy, an increase in the overall incidence of asthma has been observed [192].

It is important to note that the association between allergic diseases and climate change is not mediated purely by pollen. Increasing air pollution (both as a cause and consequence of climate change), elevated ground-level ozone concentration, and extreme weather events such as thunderstorms and wildfires may all interact with environmental allergens, increasing the frequency and severity of allergic diseases [177]. Links between air pollution and allergic sensitization to common aeroallergens have been assessed, but with mixed results. The European Community Respiratory Health Survey (ECRHS), performed across 29 countries in Europe, found a positive but non-significant association between pollutants, including $PM_{2.5}$ and sulfur, and sensitization to allergens including pollens [193]. In contrast, a significant increase in asthma symptoms has been observed among pollen-allergic patients, in association with higher concentrations of PM_{10}, sulfur dioxide and ozone [194]. A recent study of Timothy grass (*Phleum pratense*), commonly found across Europe and a frequent cause of seasonal allergies, found that exposure to elevated concentrations of carbon dioxide increased the amount of pollen produced by each flower by approximately 50% [195]. Furthermore, studies of Ragweed (*Ambrosia artemisiifolia*) suggest that both recent and projected increases in atmospheric carbon dioxide concentration may increase the amount of allergenic pollen produced [196,197].

Table 10. Search results (17) on climate change and allergic diseases.

Place	Study Type	Result	Reference
7 centers in Spain—Asturias, Barcelona, Bilbao, Cartagena, La Coruña, Madrid, Valencia	Semi-individual population-based study based on International Study of Asthma and Allergies in Childhood (ISAAC) cross-sectional study	Higher mean annual concentrations of SO_2 and CO are associated with higher prevalence of symptoms of allergic diseases (rhinitis, rhino conjunctivitis, eczema, and asthma).	[198]
29 countries across Europe	Cross-sectional survey	No statistically significant associations between regional air pollution with allergic sensitization among adults in Europe.	[193]
Portollano, Spain	Cohort study	Air pollution levels were associated with an increased risk of pollen-allergic asthma symptoms, especially ozone, when exceeding the health threshold.	[194]
Szeged region, Southern Hungary	Descriptive, observational, longitudinal	Daily mean concentrations in chemical air pollutants and Ambrosia and other pollen have joint effects on allergic asthma emergency room visits.	[199]
Szeged, Hungary	Observational, longitudinal study	In Southern Hungary, Ambrosia, PM_{10}, and ozone are associated with admissions across all age groups; increased wind speed may result in admission reduction by 45%.	[184]
Porto, Portugal	Observational, cross-sectional study	Inconsistent correlations between PM_{10} and pollen, and reduced pollen when ozone increases were observed.	[191]
Mainland Portugal—278 municipalities	Retrospective ecological study	In Portugal, positive associations between asthma hospital admission rates and temperature, NO_2, and PM_{10} (summer only); negative associations with vegetation density.	[200]
Ankara, Turkey	Observational cross-sectional study	A small sample of people suffering from allergic rhinitis were shown to be sensitive to mainly tree pollens (95%) compared to grasses (3%) and weeds (2%).	[201]
Spain	Descriptive, observational	Presence of Amaranthacaea pollen is correlated to maximum spring temperature and rainfall and can change with climate.	[188]
Cartagena, Spain	Descriptive, observational	Air pollutants (SO_2 and NO_2) and Urticaria and Poaeceae pollen increase the risk in asthma hospital emergency room visits; NO_2 and SO_2 also increase the risk in ER visits due to chronic obstructive pulmonary disease.	[202]
Thessaloniki, Greece	Descriptive, observational, time series	Pollen levels, mainly of woody plants, are almost doubling each decade in Thessaloniki, Greece and this coincides with a rise in air temperature.	[190]

Table 10. *Cont.*

Place	Study Type	Result	Reference
Hungary	Observational	Total annual pollen counts have increased. The changes in pollen season characteristics were in accordance with risk and expansion potential due to climate change.	[189]
Poland	Observational, comparative	The spore count of two species of fungal spores is mainly determined by air temperature.	[186]
Hungary	Descriptive, observational	Pollen amount increases with mean temperature and rainfall; little change in duration of pollination season.	[187]
Parma area (northern Italy)	Longitudinal descriptive study	In Parma, Italy, a significant increase in the incidence of allergy (to mites, pets, and birch family pollens) and asthma was observed, while allergic reactions to grasses and rhino conjunctivitis decreased and were correlated to a decrease in pollen count, pollen concentration peaks, and pollination period.	[192]
Genoa, Italy	Descriptive observational study	In Genoa, Italy, asthma exacerbations have seasonal peaks in spring and autumn and are associated with pollen concentration, wind speed, and rainfall as well as chemical pollutants (SO_2, NO, and NO_2).	[203]
13 countries across Europe	Time series analysis	Increases in airborne pollen for many taxa in Europe.	[185]

4. Discussion

This literature review for 2007 to 2014 has identified a large amount of research in the area of climate change and health. The large number of papers identified in the initial search was reduced to 135 original research papers that contribute to evidence following the known attribution pathways of climate change. In addition to the observed evidence, studies project that:

- Heat-related mortality is likely to increase, particularly in southern parts of Europe, owing to an increase in the frequency and severity of heatwaves.
- The threat of extreme weather events will grow, with river floods and coastal flooding and associated health effects.
- Wildfire risk is likely to intensify significantly in countries such as Greece, Spain, Portugal, and Italy, with associated threats to life, agriculture, and property.
- The distribution of tick-borne diseases may grow as temperatures increase, and conditions may favor the reintroduction of mosquito-borne diseases including Dengue fever and malaria into parts of Europe.
- Morbidity and mortality caused by air pollution, particularly rising levels of ground-level ozone, may increase, as may allergic diseases due to changes in pollen and aeroallergen production, distribution, and allergenicity.
- The interaction of climate change and changing weather conditions with stratospheric ozone concentration, their joint impacts on UV radiation and human exposure to it is under exploration. The health effects (on the skin, eyes, immunity, *etc.*) are also determined by lifestyle and behavior.

There are some limitations to this review. Firstly, the search is limited to the already known attribution pathways of climate change. There may be further unknown associations between climate and health and it is difficult to draw the line for inclusion. Further, the increasing number of papers on climate change and health makes it extremely difficult to maintain an adequate overview of emerging evidence. It was very difficult to create a search algorithm that would fit the research question, and a very labor-intensive manual selection process was required. This made the paper outdated by the time it was ready for submission. In addition, it is very difficult to decide how much evidence is required to determine the attribution of health effects to climate change. In this review, and in particular in the areas of air quality and allergies, a rather broad definition of issues and papers that may be relevant to known pathways of climate change and health has been applied. Accordingly, the number of papers identified was relatively high. For other sections, for example regarding the health effects of flooding and changes in food and water, the number of studies identified was fewer.

5. Conclusions

This literature review shows that evidence about the direct and indirect health effects of climate change and future health risks for the WHO European Region is emerging. Acknowledging the multitude of contributors to human health, the literature is increasingly reflective of multidisciplinary approaches and comprehensive, integrated assessments of environment and health. However, the science clearly demonstrates that significant changes are occurring; robust policy is now required to push for effective mitigation and adaptation actions in all sectors. Climate change threatens human health, but may be considered a challenge and a strong argument for a transition to more sustainable and healthy societies with "climate-resilient" health systems.

Acknowledgments

Author Contributions

Tanja Wolf planned the literature search, with the support of Marina Ostheimer and Yorck Adrian. Gerardo Sanchez took over and re-did the literature search with Katrina Lyne, who wrote summaries of the selected papers. Tanja Wolf drafted the manuscript and Vladimir and Gerardo helped shorten it substantially.

Conflicts of Interest

The authors declare no conflict of interest.

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