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Review article

Climate change and its environmental and health effects from 2015 to 2022: A scoping review

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A R T I C L E I N F O

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A B S T R A C T

Background: The rise in environmental pollutants has become a pressing global concern of international magnitude. Substantial evidence now demonstrates that escalating global temperatures and rising sea levels might exacerbate release of chemical pollutants into the environment which amplifies their toxicity. Existing research underscores the linkage between climate change and air pollution as driving forces, with increased mortality and morbidity.

Purpose of review: This review explores the reciprocal relationship between climate change and its impact on health, as well as the environment. We conducted an in-depth analysis of all relevant published studies, encompassing studies conducted across various regions worldwide, including the Eastern Mediterranean Regional Office (EMRO)[1] region.

Summary: The environmental consequences of climate change have widespread impacts on various health systems and populations. Knowledge gaps remain in understanding the full scope of climate change effects, particularly through environmental pollution. The findings of this review highlight the need for global strategies to mitigate diverse health risks to protect from the growing threats of climate change.

1. Background

In recent years, the global spotlight has increasingly focused on the profound impacts of climate change and its deleterious effects on air quality [1]. Climate change is a complex phenomenon stemming from both natural processes and human activities, and it significantly contributes to the global burden of disease and premature mortality [2]. The escalating levels of pollutants in the atmosphere has emerged as a critical concern, exerting detrimental influences on both public health and the environment [3] (see Table 1).

Abbreviations: BRACE, Building Resilience Against Climate Effects; CDC, Centers for Disease Control and Prevention; COPD, Chronic Obstructive Pulmonary Disease; CO2, Carbon Dioxide; ED, Emergency Department; EMRO, Eastern Mediterranean Regional Office; GI, Gastrointestinal; HIV, Human Immunodeficiency Virus; HP, Hypersensitivity Pneumonitis; IPCC, Intergovernmental Panel on Climate Change; NPLP3, Neuropeptide-Like Precursor 3; NO2, Nitrogen Dioxide; O3, Ozone; OCP, Organochlorine Pesticides; PAHS, Polycyclic Aromatic Hydrocarbons; PBB, Polybrominated Biphenyl; PCOS, Polycystic Ovarian Syndrome; PFAS, Per- and Polyfluoroalkyl Substances; PM, Particulate Matter; POP, Persistent Organic Pollutants; PTB, Preterm birth; PTSD, Post-Traumatic Stress Disorder; SARS, Severe Acute Respiratory Syndrome; SIDS, Sudden Infant Death Syndrome; SO2, Sulfur Dioxide; TB, Tuberculosis; USA, United States of America; UV, Ultraviolet; and WHO, World Health Organization.

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The consequences arising from climate change are dire, including the potential submergence of coastal cities due to rising sea levels [4]. Furthermore, the intensification of heatwaves has led to increased risk of dehydration, exacerbating heat-related illnesses such as heat stroke, and amplifying the prevalence of cardiovascular and respiratory ailments [5]. Additionally, elevated levels of precipitation and subsequent flooding events have given rise to conditions conducive to the proliferation of waterborne diseases, including cholera, typhoid, and diarrheal illnesses [6,7].

To address these imminent threats, early warning systems have been implemented, with notable initiatives such as the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC) [8]. These systems aim to proactively respond to climate-related emergencies by utilizing risk indices to assess exposure and vulnerability in various regions, thereby prompting the development and implementation of action plans [5].

In 2015, landmark initiatives like the Lancet Commission and the Paris Agreement were established with the primary goal of monitoring and mitigating greenhouse gas emissions to counteract the adverse impacts of climate change [6]. These comprehensive strategies encompassed measures such as reducing fossil fuel combustion, promoting the use of public transportation, cycling, and walking over private vehicles, as well as the implementation of adaptation strategies to manage public health risks associated with climate change [6]. Collaborative efforts have been undertaken, with the involvement of entities like the US Department of Health and various regions, including South Asia, such as Nepal and Bangladesh, and the Eastern Mediterranean Regional Office (EMRO), such as Saudi Arabia, Pakistan, and Iran, where climate change poses significant public health challenges amplified by varying environmental and socio-economic factors [7]. The following review explores how these impacts manifest, affecting health outcomes in diverse ways.

Regrettably, the comprehensive execution of these adaptation strategies has not been realized by the majority of countries. Many nations face challenges, for instance, the absence of a robust monitoring system, resulting in information gaps, limitations in capacity and resources, and a deficiency of sustainable implementation policies. Some of these strategies adopt a structured five-step approach derived from the Centers for Disease Control and Prevention's (CDC) Building Resilience Against Climate Effects (BRACE) program. This framework empowers health authorities to formulate strategies and initiatives aimed at assisting communities in preparing for the health impacts of climate change [9]. These initiatives address existing health conditions stemming from climate change and anticipate future implications.

The primary objective of this paper is to conduct a comprehensive review the available literature spanning the years 2015–2022. This review seeks to investigate the far-reaching effects of climate change on health and the associated environmental consequences, both on a global scale and within the EMRO region.

2. Materials and methods

The identification of articles involved an extensive literature exploration. We employed two prominent search engines, namely PubMed and Google Scholar.

Initially, an advanced search was conducted through PubMed. This involved the utilization of specific Medical Subject Headings (MeSHes) including "climate change", "global warming", "pesticide", "persistent organic pollutant", "environmental pollution", "chemical hazard release", and "chemical terrorism". These MeSHes were organized into concept groups using Boolean operators. For instance, combining "climate change" OR "global warming" yielded a total of 16 614 search results, while "pesticide" OR "persistent organic pollutants" OR "environmental pollution" OR "chemical hazard release" OR "chemical terrorism" produced 449 079 results. The combination of these two concepts using the Boolean operator AND resulted in a total of 3440 search results.

Our literature search focused on publications from the year 2015 and onward. This timeframe was selected to assess recent efforts in investigating the intersection of climate change and health risks, with a particular emphasis on the EMRO region. Given the healthcare perspective of this study, we applied a "Human" filter instead of incorporating specific keywords. As this review aims to explore the connection between a problem (chemical exposure), its impact effect (climate change), and resulting health issues, we employed an Etiology Clinical Query. This approach led to the identification of a total of 137 relevant articles.

In a subsequent search, we extended our inquiry to include EMRO countries. To achieve this, we appended the following countries to our search query using the Boolean operator OR: Afghanistan, Bahrain, Djibouti, Egypt, Iran, Iraq, Kuwait, Lebanon, Libya, Morocco, Palestine, Oman, Pakistan, Qatar, Saudi, Somalia, Sudan, Syria, Tunisia, United Arab Emirates, and Yemen. The search yielded a total of 5 relevant articles.

For the Google Scholar search, we employed a comprehensive set of keywords encompassing climate change (e.g., climate change or global warming), chemical agents (Chemical or Pesticide or POPs, or Air pollutants), and human health (e.g., Human Health or toxicity or poison or disease). Utilizing the same publication years, this approach yielded a total of 36 eligible articles that align with the criteria of our investigation. These selected articles were imported into Rayyan, a purpose-designed web application tailored for systematic reviews. Rayyan streamlines the initial evaluation of article titles and abstracts and facilitates systematic and user-friendly searches to include studies that address specific research inquiries.

Subsequently, we assessed the relevance of the imported papers by carefully reviewing their titles and abstracts. At this stage, we had a total of 178 articles. In instances where uncertainty arose, we diligently scrutinized the full text of the articles. This comprehensive evaluation was carried out actively by project members possessing a medical knowledge and expertise in medical toxicology.

Following the initial filtering process, we proceeded to extract the full text of each article to conduct a thorough examination of manuscripts. The inclusion criteria for this review necessitated that articles meet the following: publication date in 2015 or later and original studies investigating the impact of climate or air pollution on human health. 55 articles involving animals, experimental studies, and those published before 2015 were excluded from our review. This study selection process is outlined below in PRISMA Flow Diagram (Fig. 1).

Table 1
The health effects by system of difference types of climate change and pollutants.

Cardio-respiratory				
Global warming: - [Ground-level ozone, PM] Asthma, lung cancer, cardiovascular disease, stroke, and increased mortality [11] - [Both cold and hot temperature exposure] Increased stroke risk in the elderly [64] - Life threatening asthma attacks, increased risk for respiratory infections, increased need for medical services, and higher rates of death [10]	*Increasing temperature:* - [All forms of pollution] 43 % of lung-cancer deaths [75] - Longer QTc interval [17,63] - Ozone-related asthma emergency department visits for children age less than 17 [22] - Colonization with P. Aeruginosa in patients with cystic fibrosis [25] - Increase mortality in patients with chronic lung diseases [25]	*Droughts & hot summers:* - [Wildfires] Burns and smoke inhalation secondary to wildfires [71] - (PM and other toxic substances) Aggravation of existing respiratory illness [71]	*Floods:* [Overcrowding and overgrowth of mold] Increased the risk of respiratory diseases [71]	*Climate change:* - [Particulate air pollution] 15 % of all lung cancer deaths [75] - Deaths attributable to particulate pollution have increased by 20 % in the past three decades [75] - [PM2.5] Pneumonia, asthma, and COPD [25] - Exacerbation of existing cardiovascular disease [60] - [Dust storms] COPD, asthma, sarcoidosis, and pulmonary fibrosis [96]
Gastrointestinal (GI)				
Increasing temperature [Disruption in food and water supply] GI cancers [75]			*Warm, moist storage environments*: [Fungal mycotoxins] Hepatocellular carcinoma [99]	
Infectious				
Increasing temperature - Pulmonary and systemic melioidosis, and an increase in ED visits for thunderstorm asthma [25] - Avian influenza and coccidioido-mycosis [14]	*Droughts & hot summers:* Increased human susceptibility to infectious diseases e.g., meningitis [71]	*Floods:* Increases in dermatitis and infectious diseases (e.g., cholera and leptospirosis) [71]	*Changes in temperature, precipitation, and soil moisture* Vector-borne diseases, such as Malaria, Dengue, West Nile virus, Lyme [66]	*Warm, moist storage environments:* Ochratoxin in vines and mycotoxins in wine production [69]
Renal and Endocrine				
Global warming: A variety of human health effects, including kidney failure, difficulties with iron absorption, and thyroid issues [121]			*Increasing temperature*: Increased workers' susceptibility to pesticides absorption, endocrine-disrupting chemicals (estrogens, androgens, and thyroid hormones) [107]	
Immunological				
Global warming: - [Polychlorinated biphenyls, chlordanes] No negative impact on biodiversity and human health, but immune disorders in polar bears [46] - [Increased allergens] Exacerbation of pre-existing diseases [67]		*Droughts & hot summers:* [Spore and mycelial antigens exposure] Hypersensitivity pneumonitis [70]	*Global climate variability:* • [Aeroallergens delivered by fungal spores and particles] Modified allergenecity [77] • Thunderstorm asthma, atopic dermatitis, allergic rhinitis, earlier and longer allergic pollen season [76]	
Cutaneous				
Climate change: [UV radiation] Melanoma & keratinocyte cancers [75], epigenetic alterations in skin cells, acute and chronic effects on skin and eye, photodermatoses, phototoxic and photoallergic reactions [89]				
Nutritional				
Global warming: [Carbon dioxide emission] Deficiency in zinc, protein and iron [66], altered rainfall distribution, drought, severe weather events, and snow/polar ice melting [22]			*Rise in global temperature by 1 °C above pre-industrial levels*: [Ocean warming and acidification] Decreased consumption of fish i.e., omega-3 fatty acids, that are protective against some cancers, and increased production of aflatoxins, that are associated with liver cancer [75]	
Morbidity/Mortality				
Increasing temperature: - [Pesticides, ozone] Heat-related morbidity and mortality risks [18] - [Fine PM and O3] Increased mortality secondary to power plants and altered air conditioning demands [105] - Decreased evaporative cooling during heat stress, leading to increases in fever and morbidity [88]			*Climate change:* - [PM10, PM2.5, NO, SO2] Excessive mortality risk, mortality, and child mortality [34]	

(continued on next page)

Table 1 (*continued*)

Cardio-respiratory			
		- Emergence of new diseases with increased morbidity and mortality, secondary to allergens and vectors of infection [67]	
Gestational/Fetal/Neonatal			
Global warming: - [Pesticides, PAHs, PM, and toxic metal] LBW, IUGR, PTB, and pre-eclampsia [20] - [PFOS, PAHs, PFNA] PTB [20] - [PFHXS] Null odds of PTB [20] - [DEHP] Protective against PTB [20] - [POP: OCPs an PFAS] Neurodevelopmental disorders in infants and SIDS [20] - [Tobacco smoke and electronic cigarettes aerosol: co, cyanide, aniline, methanol, hydrogen sulfide, arsenic, lead, cadmium, and other toxins or carcinogens] FGR and PPROM [20] - [Lead, cadmium, mercury, arsenic] PTB, FGR, and pre-eclampsia [20]	*Droughts and hot summers:* [PM, O3, traffic-related air pollution, NO2] Prematurity, LBW, atopic diseases (asthma, aero allergies, and eczema), impaired lung development, neuro-developmental conditions, thinner brain cortex, impaired inhibitory control, cognitive impairment, and malignancy [79]	*Climate change:* - [Mercury] Toxicity in women of childbearing age and their children secondary to fish consumption with high mercury levels [58] - [Warm seasons] PTB risk especially during the second trimester of pregnancy [20] - [Cold temperatures] Protective against PTB, especially during the third trimester [20]	
Occupational			
Global climate variability: [Carbon monoxide, diesel PM, air toxic compound] Occupational health & cancer risk [85]		*Climate change:* - [Heat, hazardous chemicals, UV radiation] Increased risk of injury or lapses in safety [87]	
Physical/Psychological Damage			
Extreme weather (hurricanes/wildfires/floods) - Posttraumatic stress, anxiety, depression, and suicide [66] - Damaged health-care infrastructure, reduced health-care quality and availability, increased risk of disease progression and death [75] - Drowning injuries & hypothermia [71]		*Climate change:* - Pro-inflammatory and pro-coagulatory states in cold, and anti-coagulatory states in heat [61] - Hyperpyrexia, decline in physical strength, fatigue, and reduction in alertness and mental capacity [92] - [Snowfall] Shovel-related injuries and exercise-induced medical emergencies [92]	
Other Neoplastic			
Increasing temperature: [PM with PAHs, benzene, formaldehyde] Lung and breast cancers [75]	*Extreme weather events (hurricanes/wildfires)* Decreased ability to reach or deliver healthcare, hence increased cancer risk and decreased patient survival [75]	*Floods*: Carcinogenic chemicals release from contaminated groundwater or sewage overflow [105]	*Climate change:* [Pesticides] Leukemia, lymphoma, brain, kidney, breast, prostate, pancreas, liver, lung, and skin cancers [107]
Miscellaneous			
Increasing temperature: Effects on the brain, heart, intestine, kidney, liver, lung, and pancreas, such as ischemia, heat cytotoxicity, inflammatory response, DIC, and rhabdomyolysis [12]		*Climate change*: - [Petrochemicals] Liver disease (cirrhosis, ALT/AST abnormalities, fatty liver, liver cancer), COPD, IHD, stroke, blood disorders, lesions, tumors, and morphological abnormalities [103] - [PM] Hyperactivation of the NLRP3 inflammasome, neuroinflammation exacerbation, and SARS mortality [24]	

3. Results

In our analysis, a total of 123 articles were included. As there was a limited representation of studies specifically centred within the EMRO region, with only 5 articles identified, the majority of these studies were conducted in regions outside the EMRO region.

3.1. Air pollution, climate change, and human health

Air pollution, a significant environmental concern, carries profound implications for human health [10]. The World Health Organization (WHO) has declared air pollution as one of the major environmental human health risks. WHO reports that over 7 million individuals are killed annually, predominantly suffering from neurological, cardiac, and respiratory issues [11].

There are several interconnected relationships between climate change, air pollution, and human health. Air pollution encompasses a mixture of natural elements and those generated by human activities present in the air we breathe [10]. Ozone, noxious gases,

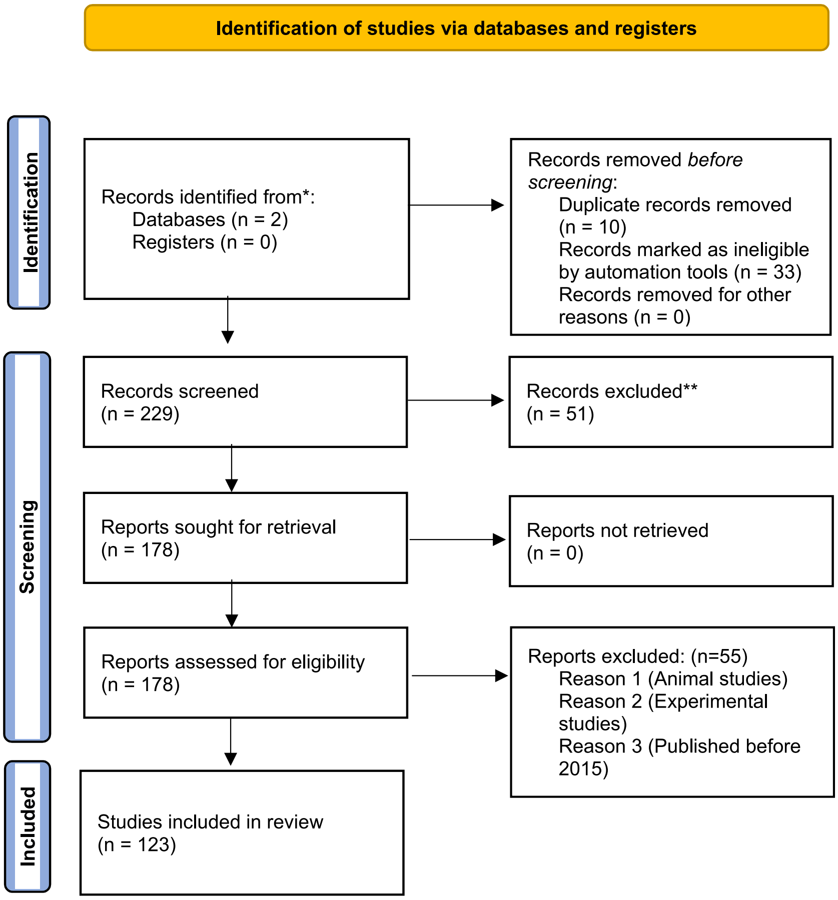

Fig. 1. PRISMA 2020 flow diagram.

and PM constitute the primary components of air pollution on a global scale. The primary source of this pollution is the combustion of fossil fuels (like coal, gasoline, diesel, and natural gas), which serves as the primary energy source. This releases carbon dioxide into the atmosphere, trapping heat and contributing to global warming through a greenhouse effect, resulting in heat waves and warmer summer days [10]. The escalation in global average temperature sets in motion various causal pathways, and the heightened occurrence of extreme heat can exert a multifaceted impact on health. Mora et al. identified five physiological mechanisms triggered by heat exposure: ischemia, heat cytotoxicity, inflammatory response, disseminated intravascular coagulation, and rhabdomyolysis; those mechanisms can critically impact the brain, heart, intestines, kidneys, liver, lungs, and pancreas, and eventually lead to organ failure and death [12].

The literature indicates that our changing climate is driving a rise in the frequency, duration, and intensity of extreme events, and will continue to be for the foreseeable future [6,13,14]. Studies show that since 1960, the frequency of heat waves has increased threefold compared to previous records, particularly in the United States [15]. There has been a substantial surge in hospital admissions related to pulmonary and cardiac conditions [10]. Notably, cases of skin infections, sepsis due to urinary tract infections, and kidney failure have also become more prevalent [10]. Recent research indicates higher mortality rates associated with respiratory infections [16]. Additionally, extreme temperature fluctuations, alterations in rainfall patterns, rising sea levels, and severe weather events have been associated with conditions such as undernutrition, mental health disorders, as well as respiratory, cardiac, and infectious diseases [17].

3.2. Ozone and PM

Fossil fuel combustion releases harmful pollutants like fine particles, nitrogen oxides, sulfur dioxides, and chemical vapors. These pollutants interact with heat and sunlight, especially on hot days, to form ground-level ozone, commonly referred to as smog [10]. The presence of ozone is contingent on temperature and arises from photochemical reactions; this is known as the ozone effect [10,18]. Hence, ozone reactions are more pronounced in warmer climates, particularly with increased exposure to sunlight and heat [19]. While ozone in the upper atmosphere protects us from harmful solar radiation, ozone near the Earth's surface is a major pollutant [10]. The dispersion of ozone's toxic effects in higher quantities leads to a broader reach of pollutants, resulting in more significant health consequences such as higher hospital admission rates, increased emergency department visits, acute respiratory distress syndrome, intractable asthma attacks, life-threatening respiratory infections, and, in severe cases fatalities [19].

Another major pollutant is fine particulate matter (fine PM), or soot, which primarily results from burning fossil fuels, but can also come from natural fires [10]. While soot is sometimes visible, such as from chimneys, vehicles, heat appliances, and factory smokestacks, fine particles are often harder to detect [10]. Of these, cars and trucks contribute the most to air pollution-related fatalities, accounting for an estimated 26.5 % of these fatalities, while the remainder can be attributed to rail transportation, heating, marine pollution, industrial fuels, and other sources [10]. PM consists of various chemical components and is categorized by the size of its particles based on aerodynamic diameter. PM10 and PM2.5, for example, refers to particles with a diameter <10 μm and <2.5 μm, respectively. The toxicity of these particles is closely linked to their size; smaller particles are more harmful, since they can penetrate deeper into the lungs and enter the bloodstream [20]. PM particles with larger sizes are associated with swift, short-term adverse respiratory health effects, particularly when their diameters less than 10 μm [11]. Consequently, these large particles tend to contribute to upper airway diseases, while smaller particles lead to more severe conditions in the alveoli [21].

The harmful effects of PM become more pronounced in warmer temperatures and are closely linked to the development of cardiorespiratory conditions [22]. Elevated ozone levels in the atmosphere are also associated with increased temperatures, resulting in a worsening of allergic diseases [1]. Abel et al. explores the potential health impacts of the increased demand for cooling in buildings, finding that warmer temperatures and more frequent heat waves may worsen air quality through harmful pollutants, notably fine PM and ozone, from electric power plant emissions which can increase respiratory and cardiovascular health issues [23]. Additionally, in recent research, exposure to PM has been connected to lung and neuroinflammation via the NRLP3[1] inflammasome pathway; this inflammation contributes to higher mortality from acute respiratory distress syndrome and SARS[1] [24]. In the Australian population, exposure to PM is primarily associated with lung health conditions, including asthma, COPD, and pneumonia [25]. However, in other countries including South Africa, the leading causes of health issues related to PM exposure are cardiopulmonary conditions [26].

In Europe, there was a notable 19 % increase in the negative health impact of PM in 2000 [27]. Extensive literature has cited multiple morbid conditions associated with PM exposure, including chronic bronchitis, lung cancer, heart failure decompensation, hospital admissions for cerebrovascular and respiratory events, and asthma attacks in children necessitating bronchodilators administration [28,29]. Stewart et al. expanded the list of co-morbidities associated with PM exposure to include diabetes type 2, catecholamine release, thyroid dysfunction, and increased cortisol levels [30]. These additional health concerns further emphasize the wide-ranging impact of PM. Thyroid function also appears to be influenced by exposure to PM2.5, resulting in lower free thyroxine levels in women during early pregnancy [31–33]. Additionally, vitamin D deficiency is another consequence of climate change and air pollution, further compounding the health challenges associated with these environmental factors [31]. The literature also highlights the significant impact of PM on child and respiratory mortality, underscoring this issue [34–36].

3.3. *Persistent organic pollutants (POPs)*

Different types of pollutants exist in various places, with some resisting environmental breakdown and persisting for long periods. These are known as POPs[1], including pesticides, industrial chemicals (PCBs[1], PBDEs[1], PFOS[1]), and industrial by-products. POPs can travel long distances, even crossing international borders, and have been found in remote areas like the poles [37]. They bioaccumulate in the food chain, leading to serious health and environmental risks. In today's polluted environment, nearly everyone carries POPs in their system. Alarmingly, even fetuses and embryos have been found to contain these pollutants. Vizcaino et al. carried out a study describing that POPs transport by active means across the placenta from mother to offspring [38], and newborns continue to accumulate more throughout their lifespan [37]. Exposure to these pollutants can lead to serious health issues, including hormone disruption, cancer, cardiovascular diseases, obesity, reproductive and neurological disorders, learning disabilities, and diabetes [37].

POPs are endocrine disruptors, affecting functions of several hormones. For example, organochlorine and organophosphate pesticides, specifically, act as estrogens; exposure during pregnancy alters estrogen and progesterone levels, negatively impacting the fetus and potentially leading to neurodevelopmental complications and SIDS [20]. Porpora et al. also emphasized the potential risk of preterm birth resulting from continuous exposure to these pollutants [20]. These concerns have also been observed in the North American Arctic, where high levels of mercury and POPs circulate, posing a significant risk to the reproductive health of humans and other mammals [20,39]. Furthermore, exposure to perfluoroalkyl substances, organophosphates, or bisphenol A products has been associated with various endocrine conditions such as obesity, polycystic ovarian syndrome, diabetes, infertility, with adverse effects on semen quality [40]. In 2002, Damstra's research described the effects of POPs, such as organochlorine compounds (OCPs) and PFAS, on the reproductive system, including decreased sperm quality and quantity [41,42]. Several studies have supported these findings, indicating that these pollutants can alter sex ratios and contribute to early puberty.

POPs also contribute to worsening cardiovascular events. This is attributed to the lipophilic nature of POPs, leading to their bioaccumulation in high-density lipoproteins [43]. The responsible POPs in cardiovascular disease include OCPs, polychlorinated biphenyls (PCBs[1]) and polybrominated biphenyl (PBB[1]). They have been linked to metabolic syndrome, elevated blood pressure, abnormalities in triglycerides, and glucose intolerance [44]. These effects may be mediated through the aryl hydrocarbon (Ah) receptor, a ligand-activated transcriptional factor [44]. POPs can act as ligands with high binding affinity to AhR. Once activated, downstream AhR signaling interferes with fat metabolism, glucose balance, and insulin secretion [45]. Additionally, excessive activation of this pathway has been found to promote hepatic steatosis, the onset of insulin resistance, causing glucose intolerance, and eventually diabetes [45]. Their lipophilic nature also allows POPs to accumulate in tissues rich in fats. OCPs, for example, have been detected in blood, placental tissue, amniotic fluid, and breastmilk. Exposed mothers can pass them on to their fetus or newborns through either of these means [20].

Global warming has had a notable impact on the spread of POPs, particularly OC and biphenyl products, leading to implications for the immune system [46]. Adult populations with high accidental exposure to PCBs revealed to have a lower IgM and IgA levels, and an increased incidence of respiratory infections [47]. Other adult populations with high consumption of PCB-contaminated fish revealed different immunophenotype distributions, with increases in B cells and decreases in $CD8^{+}$ and natural killer cells [47]. Immune toxicity is ever more apparent in the pediatric population. A Dutch cohort study found that babies exposed to higher prenatal levels of PCB had reduced reactivity to MMR vaccination, increased otitis media infections, and altered lymphocyte distributions [47]. Children in the Faroe Islands exposed to PCB also showed decreased antibody responses to diphtheria toxoid and tetanus toxoid at 18 months and 7 years of age, respectively [47]. Moreover, neonates in Eastern Slovakia were born with a smaller thymic index in mothers with pre-natal exposure to PCBs [48]. The mechanisms underlying PCB pediatric immunotoxicity is yet to be understood, and organs other than the thymus are likely also involved.

3.4. Non-persistent organic pollutants (non-POPs)

A comprehensive examination of non-persistent organic pollutants, including substances like phthalates, phenols, and parabens, delves into their impact on human health [20]. These compounds are commonly present in items such as plastic toys, vinyl flooring, soaps, and shampoos, initiating exposure at a young age and potentially lasting a lifetime through the consumption of food and pharmaceutical products [20]. They belong to a group termed endocrine-disrupting chemicals (EDCs), as they interfere with the production, secretion, transport, binding, and elimination of natural hormones in the body [49]. These compounds have been linked to reproductive and developmental impairments, cancer, metabolic disturbances, and neurological and behavioral disorders [50,51]. While the emergence of these diseases is multifactorial, including both genetic and environmental factors, the latter appears to play a more important role in the initiation and progression of these health issues [49]. Given that individuals are exposed to a mixture of these harmful substances, it is challenging to determine direct casual links between EDC exposure and its adverse effects.

In the case of non-POPs, a clear correlation has been observed with preterm birth (PTB[1]) [52,53]. It is theorized that oxidative stress at the maternal-fetal interface may be a contributing factor early labor. There are several mechanisms through which reactive oxygen species may influence PTB: initiating inflammatory responses leading to early parturition, weakening collagen in the cervical stroma or fetal membranes resulting in preterm premature rupture of membranes, or triggering apoptosis in the syncytiotrophoblast during early pregnancy and impairing effective placentation [53]. Ferugson et al. studied two biomarkers in maternal urine samples, 8-isoprostane and 8-hydroxydeoxyguanosine (8-OHdG), two commonly used markers of oxidative stress [53]. They found that urinary phthalate metabolites are linked to elevated levels of 8-isoprostane during pregnancy [53], and then demonstrated this phthalate–preterm birth relationship by oxidative stress through mediation analysis [52]. This supports the mechanism linking phthalate exposure, oxidative stress, and preterm birth. Unexpectedly, however, higher urinary concentrations of 8-OHdG were protective against spontaneous PTB. One possible explanation for this is the associated of 8-OHdG with unmeasured confounders that can reduce the risk of PTB, such as increased exercise and ferritin levels. Another explanation is 8-OHdG's role in the DNA excision repair process, making it reflect the mother's capacity to repair oxidative damage in addition to its role in provoking it. This implies that mothers with impaired repair mechanisms may have a higher risk of PTB, a hypothesis worth exploration in further research. It's also important to note unmeasured confounders related to 8-isoprostane which may have biased the results of the aforementioned mediation analysis, such as changes in diet; although diet can affect phthalate levels, its link to preterm birth is not well-established. More importantly, both studies assume that phthalates cause oxidative stress; if phthalates are not the direct cause, or if other factors are influencing both phthalates and oxidative stress, then the results might be interpreted differently. However, animal and cell studies suggest that phthalates do cause an increase in oxidative stress during pregnancy, which supports this assumption.

However, when it comes to non-POPs like trihalomethanes and haloacetic acids, the findings from various studies have produced conflicting outcomes [54–57]. Trihalomethanes and haloacetic acids are among the highest in concentration of chlorinated water by-products. A retrospective cohort study in Nova Scotia found an association between exposure to high trihalomethane levels and an elevated risk for stillbirths, but little association with fetal weight or gestational age outcomes [54]. Similarly, Hoffman et al.'s results suggest no adverse effects of haloacetic acids on fetal growth [56]. Another study in Colorado, however, found a large increase in risk for low term birthweight in pregnant women exposure to trihalomethanes in their third trimester [55]. Intrauterine growth retardation was also an increased risk in cases of trihalomethane exposure, according to the results of Kramer et al. [57]. Discrepancies among those studies may arise from several confounding factors. Relying on municipal-level data can inaccurately represent exposures, as individual water usage behaviours, along with measurement methods, can differ. If public health policies rely on inaccurate aggregate data rather than precise individual-level exposure assessments, certain communities may be underserved. Standardized measurement protocols are also essential to ensure that policymakers have confidence in the comparability of research findings. Additionally, residential mobility may cause misclassification, since water quality varies across different areas and pollutant levels can differ between locations. In regions with high residential turnover, such as urban centers, individuals may move in and out of high exposure areas without recognition of their changing exposure; this could lead to an underestimation of health risks, and affect policy making about water quality upgrades. The fluctuation of organic pollutant levels also poses a challenge. If policies are based on average exposure levels, interventions may not be timely nor sufficient. For example, high pollutant concentrations in the summer could require more stringent regulations; without recognition, policies may be delayed, allowing public exposure to persist during peak periods.

3.5. Heavy metals

Arctic waters and ecosystems have been discovered to have high levels of heavy metals, particularly mercury, and phenyl-chlorinated biphenyls. The primary health concerns associated with mercury exposure involve increased physiological stress and susceptibility to infectious diseases [39]. A separate study corroborates these findings and underscores the impact of toxic metals on preterm birth; lead, arsenic, cadmium, and mercury are identified as substances that can disrupt bodily systems, affecting various biomarkers like glutathione, catalase, and superoxide dismutase potentially leading to fetal growth restriction [20]. The spread of toxic metabolites, with health effects before and after birth, is predominantly attributed to the consumption of contaminated fish and food products and has consequences for women of childbearing age and their descendants. It is speculated that climate warming will expedite the mobilization and biological amplification of these environmental contaminants [39,58]. A study by Singh et al. corroborates those findings, as the presence of toxic metals– including lead, cadmium, mercury, and arsenic– in the placenta were found to have a positive association with the risk of preterm birth [59]. These metals may contribute to adverse pregnancy outcomes, including oxidative stress, inflammation, and disruption of placental function.

3.6. Cardiovascular and cerebrovascular health

In the context of cardiovascular and cerebrovascular health, extreme heat has been shown to aggravate related conditions, increasing the risk of hospitalization and death [60,61]. Interestingly, a study by Vanasse et al. investigates the association between flood events and acute cardiovascular diseases (CVDs); their findings revealed that floors could potentially trigger acute CVD events due to factors like physical stress, displacements, and limitations in healthcare access during such extreme weather events [62]. Climate change also has the potential to further intensify pre-existing cardiovascular disease, primarily through heat-related stress and heightened exposure to airborne particles, thereby leading to an upsurge in morbidity and mortality [61]. For example, elevated mean temperature and increased temperature variability have been linked to prolonged QTc intervals [63]. Additionally, these diseases are likely to witness an escalation in both their incidence and severity due to elevated temperatures, which enhance the adverse effects of environmental factors like ozone and particulate matter, especially PM2.5 [1,11,13,22,26]. The heightened occurrence of heatwave and wildfire, which are outcomes of climate change, increase the prevalence of cardiovascular diseases, stroke, and mortality, particularly impacting the elderly population due to their heightened vulnerability to both cold and hot temperature exposure. Consequently, this elevated risk of stroke in the elderly results from a multitude of mechanisms, encompassing impaired thermoregulation, multiple medication regimens, and exacerbation of pre-existing medical conditions, such as diabetes mellitus [64]. Another study conducted in China investigated the impact of heat-related issues on the aging population. Their findings revealed that health risks are more pronounced in warmer climates, thus raising concerns about increased mortality in Beijing due to heat [65].

3.7. Respiratory and allergic conditions

Pulmonary and allergic consequences are yet another demonstration of the effects of changing global temperatures. The impact of climate change on allergens has garnered amplified attention, particularly in light of the rising prevalence of respiratory allergic diseases, such as asthma and allergic rhino-conjunctivitis [14,66–69]. This influence can be attributed to various pollutants, including ozone (O3), greenhouse emission, carbon dioxide (CO2), nitrogen dioxide (NO2), sulfur dioxide (SO2), and PM [36]. Prolonged and repeated exposure to substances like spore and mycelial antigens due to droughts and hot summers has the potential to activate the immune system, leading to the development of hypersensitivity pneumonitis (HP) [70]. Extreme weather events such as wildfire, hurricane, and floods have been linked to the exacerbation of asthma and an elevated risk of respiratory infections [1,13,14,17,36,71]. Moreover, climate change-induced phenomena such as wildfires, thunderstorms, tropical cyclones, heat waves, and dust storms secondary have been associated with a rise in allergic disease and lung-damaging wildfire smoke, leading to an increase in asthma exacerbations, wheezes, pneumonia, and bronchitis [72–74]. Liu et al. also conducted a study examining hospital admissions related to wildfires, proposing a possible increase in respiratory-related hospital admissions in the United States (USA) in the presence of moderate climate change scenarios [68]. Higher temperatures contribute to an increased incidence of pulmonary and systemic amyloidosis, along with a surge in Emergency Department (ED) visits [25]. The increase in heatwaves can exacerbate cystic fibrosis and elevate mortality rates in patients with chronic lung diseases [13,25,75]. Moreover, warm weather conditions result in extended and earlier pollen seasons; air pollutants are known to modify the human body's allergic response [76]. This has led to a rise in thunderstorm asthma cases requiring hospital admissions globally, with reports from Australia, the United Kingdom, North America, Europe, the Middle East, and China. Many cases remain unaccounted for in the available data [76]. Suk et al.'s research aligns with these findings, demonstrating the exacerbation of asthma attacks due to increased allergen exposure, exacerbated by air pollution [22,77].

3.8. Impact on the pediatric population and pregnant women

It is essential to acknowledge that climate change and pollutants disproportionately affect vulnerable population. Pediatric patients, for instance, inhale a larger volume of air relative to their body weight compared to adults, which escalates their exposure to air pollutants. Their narrower airways also render them more susceptible to constriction caused by air pollution and allergens [73]. Strikingly, the first documented case of air pollution being certified as the primary cause of death involved a 9-year-old girl named Ella Adoo Kissi-Debrah who tragically succumbed to "asthma exacerbated by excessive air pollution" [78]. Notably, data from New York

City has highlighted higher levels of ozone during the summer, which have been linked to ozone-related asthma attacks, leading to frequent visits to the emergency department among patients under the age of 17 [22].

Intra-uterine exposure to air pollution has been associated with various adverse outcomes, including atopic diseases such as asthma, eczema, allergies, low birth weight, and certain neurodevelopmental conditions like autism, thin brain cortex, cognitive impairment, and even malignancies [79]. Exposure to PM and ozone particularly during pregnancy poses a risk of prematurity for the fetus [79]. Furthermore, exposure to PM, including PM10 and PM2.5, during pregnancy has been linked to elevated blood pressure and an increased risk of preeclampsia [80]. PM2.5 exposure has also been associated with low birth weight and preterm birth [81,82]. Preterm birth has also been reported to result from exposure to polycyclic aromatic hydrocarbons (PAHs) [20]. These compounds are primarily emitted from vehicle and industrial combustion, making these particles accessible through inhalation [20]. Subsequent studies have examined the concentration levels of PAHs in umbilical cord blood at birth, with elevated levels serving as markers of maternal exposure [83].

On another note, major floods and hurricanes can result in drowning, physical injury, and traumatic stress, particularly among younger individuals, disrupting their education and causing mental health problems [73]. Similarly, prolonged periods of drought, which result in food shortages and heightened malnutrition, have had detrimental effects on the physical and mental development of children [73,84]. Anderko et al. demonstrated a strong connection between elevated temperatures, extreme weather events, rising sea levels, and increased carbon dioxide levels, and various health issues in children, including asthma, allergies, vector-borne diseases, malnutrition, low birth weight, and post-traumatic stress disorder (PTSD) [42].

3.9. Occupational health

Ozone poses an occupational health hazard especially for outdoor workers. Additionally, it can increase the likelihood of exposure to cardiopulmonary carcinogens and infectious diseases among this population [18,85]. Individuals working outdoors experience elevated ventilation rates due to increased work of breathing required to compensate for their physical activity. Exposure to dust and forest fires can also enhance ozone inhalation. Consequently, substantial amounts of ozone can potentially enter their respiratory system [18]. Immediate consequences of such exposure encompass symptoms like intractable cough, wheezing, shortness of breath, as well as irritation of the eyes and throat [18]. Over time, prolonged exposure can lead to chronic health issues, such as pneumonia and COPD [18]. A wealth of data underscores the connection between occupational ozone exposure and outcomes, including increased ED visits, hospital admissions for asthma and COPD exacerbations, as well as a heightened likelihood of mortality and decreased productivity [18,86].

Moreover, outdoor workers exposed to heat, hazardous chemicals, and ultraviolet (UV) radiation are at an increased risk of vector-borne diseases, skin cancers, ocular complications, immune dysfunction, heat stroke, and heat exhaustion [87,88]. Prolonged exposure to UV radiation has been a subject of apprehension in the context of ongoing climate change for numerous years [87]. The eyes and the skin are the primary organs that are vulnerable to phototoxic and photo-allergic adverse effects [89]. Such exposure can potentially result in epigenetic alterations and variations within skin cells [89]. Hyperkeratosis is another condition associated with prolonged exposure to ultraviolet radiation [89]. Regarding skin health, several documented conditions include autoimmune photo dermatoses, photogenodermatoses, photo-aggravated dermatoses, and photosensitization reactions [76]. Furthermore, there is an associated risk of ocular melanoma, skin cancers such as melanoma, basal cell carcinoma, and squamous cell carcinomas, along with actinic keratosis [89]. UV radiation can indirectly subject individuals to gene mutations and immunosuppression in subtle way [75].

Kjellstrom, Tord, et al. also explores occupational health in South-East Asia within the context of climate change and highlights the increasing risks of heat-related health issues and decreased productivity for workers due to rising temperatures [90]. They call for targeted adaptation strategies to mitigate these effects, such as reducing emissions from transportation and industry (e.g., vehicles, factories, and other industrial sources) especially during peak heat periods and designing urban planning and green infrastructure in cities (e.g., green roofs, tree planting, and promoting sustainable construction practices) to reduce the overall temperature in urban areas and improve air quality. Similarly, findings from Guangzhou, China suggest that higher temperatures are associated with an increased risk of work-related injuries, highlighting the need for preventive measures during hot weather conditions [91]. Specifically, it explores how increased cooling demand due to rising temperatures can lead to changes in air-quality, especially as it relates to energy consumption from air conditioning. The study highlights that adaptation strategies, such as improving building energy efficiency and transitioning to cleaner energy sources, can mitigate the negative air-quality impacts associated with increased cooling demand. These strategies are crucial for balancing both climate adaptation and minimizing air-quality-related health impacts.

The underlying mechanisms by which cold and hot weather impact mortality and morbidity might vary significantly. Cold temperatures can trigger pro-inflammatory and pro-coagulatory responses, whereas evidence from patients experiencing heat stress or heat strokes suggests that anti-coagulatory states are activated to facilitate sweating and reduce body temperature [61]. Hot weather can lead to hyperpyrexia, a decline in physical strength, fatigue, and a reduction in alertness and mental capacity [92]. These effects tie with findings in South Australia, where Xiang et al. investigates workers' perceptions related to climate change and reveals significant concerns among workers about the impacts of extreme heat exposure on their health and safety, highlighting the need for improved workplace policies and interventions to mitigate these heat-related illness or injuries [93]. It is important to note, however, that cold weather can also lead to work-related health issues as snowfall can result in shovel-related injuries and exercise-induced medical emergencies [92].

A separate study by D'Ovidio et al. highlights how rising global temperature and environmental changes are intensifying biological pollution, leading to increased exposure to allergens in the workplace [77]. This includes allergens from plants, molds, and pollens, which thrive in warmer, more humid conditions. Both indoor and outdoor working environments, such as agriculture, construction, and healthcare, are particularly considered high risk.

3.10. Water contamination, food safety, and patterns of infectious disease

Climate change can influence the prevalence of infectious diseases [67,77,94]. Alterations in temperature, precipitation patterns, and soil moisture levels alter the habitats, life cycles, and feeding behaviours of disease vectors [14,66]. Consequently, this can increase the incidence of various diseases, encompassing Malaria, Dengue fever, Lyme, Hay fever, Tuberculosis (TB), as well as Human Immunodeficiency Virus (HIV) [26], and indirectly contribute to the proliferation of precursors for waterborne diseases such as cholera, typhoid, and diarrhoeal diseases [7,75]. Floods, for example, have been linked to infections such as cholera and leptospirosis, dermatitis, as well as incidents of drowning and hypothermia [95]. Elevated humidity and increased precipitation may lead to heightened levels of ochratoxin A in grapevines, thereby increasing the potential for mycotoxin contamination in wine production [69]. Dust storms enhance the risk of contracting influenza A virus infection, pulmonary coccidioidomycosis, bacterial pneumonia, meningococcal meningitis, chronic obstructive pulmonary disease, asthma, sarcoidosis, and pulmonary fibrosis [96]. As temperature rise, there is also an increased likelihood of heat wave exposure and heightened colonization by Pseudomonas aeruginosa in patients with cystic fibrosis, consequently escalating mortality rates among those with pre-existing lung diseases [25].

The industrialization of food production has had a significant impact, including the occurrence of malnutrition due to the manufacturing of nutrient-deficient and extensively processed food items [97]. In addition, ozone's carries the ability to infiltrate the stomatal pores in plant leaves, ultimately impacting wheat yields [98]; this provides it an indirect involvement in soil contamination. This contamination concern extends its reach to a broad population because ozone can travel over considerable distances. This issue is directly tied to global food insecurity and undernutrition since wheat constitutes a significant portion of dietary protein and caloric intake, accounting to 20 % [98]. The use of chemicals in food production and water contamination negatively impacts the quality of water, exposing populations to infections and toxins like Vibrio Cholerae, hepatitis A and E, and schistosomiasis [99]. Moreover, sewage inundation can exert an impact on human well-being through the creation of extensive septic zones and contamination of pre-existing potable water sources, as seen in the Republic of Macedonia [100]. Water scarcity and contamination also contribute to waterborne diseases and gastrointestinal cancers [75]. Furthermore, this scarcity of easily accessible clean water, compounded by air pollution and chemical hazards stemming from extreme weather conditions, has also been identified as contributing factors to conditions like of asthma, malnutrition, and PTSD [101].

Fungi typically metabolize mycotoxins, which have been linked to various conditions such as hepatocellular carcinomas and gastrointestinal (GI) diseases, including inflammatory bowel diseases [99]. Other organisms, such as cyanobacteria, produce nephrotoxic and hepatotoxic metabolites [99]. Another study conducted on the Portuguese population raised concerns about a potential increase in hepatocellular carcinoma cases due to aflatoxin exposure, highlighting food safety [102]. Liver diseases in general, however, are frequently linked to exposure to petrochemicals, particularly in cases of oil pollution [103].

3.11. Environmental carcinogens and pesticide pollution

Climate change exerts its influence on cancer through a diverse array of mechanisms [104]. Notably, the occurrence of natural disasters, like flooding, can release potentially carcinogenic chemicals into the environment as a result of contaminated groundwater [105]. Additionally, rising temperatures have been linked to lung cancer due to exposure to carcinogens found in wildfire smoke, including particulate matter containing polyaromatic hydrocarbons, benzene, and formaldehyde.

The study by Nkanga et al. provides a detailed exploration of how aging, environmental pollution, and climate change contribute to the development of hematologic malignancies in the Democratic Republic of Congo [106]. The researchers analyzed the interaction between these factors, particularly focusing on how oxidative stress, induced by pollution and exacerbated by climatic variations and seasonal changes, acts as a key driver of cancer formation. Aging was found to be a crucial factor, as it naturally increases oxidative stress within the body, which is further amplified by external pollutants. The study also underscored how pollution, particularly from industrial and urban sources, contributes to a higher burden of oxidants, which can lead to DNA damage and cancer development. A fluctuating seasonal climate, influenced by broader climate change trends, created conditions that intensified the oxidative stress experienced by individuals, especially in areas with higher pollution exposure.

Pesticide pollution, specifically, has increasingly become a global concern in contemporary times, posing threats to both agriculture and human well-being [99]. Agrochemicals exert a profound impact on the human body's responses [99]. The necessity for pesticide usage has grown, particularly due to rising temperatures and warmer climates, which heightens the risk for workers and consumers to be exposed to the harmful effects of these chemicals through increased pesticide dissipation [107]. This elevated exposure can lead to an increased risk of various cancers, such as leukemia, lymphoma, brain, kidney, breast, prostate, pancreas, liver, lung, and skin cancers [30,108]. Additionally, there exists a positive correlation between neurodevelopmental disorders, including sudden infant death syndrome (SIDS), and exposure to organochlorine and organophosphate pesticide exposure [109]. Exposure to these compounds can occur through dermal contact, inhalation, or oral ingestion, and they are recognized for their carcinogenic, neurotoxic, endocrine, and immune system-disrupting agents [107].

3.12. Regional and global health concerns

Climate change and pollutants pose significant threats to both regional and global health, exacerbating existing health challenges and creating new risks for populations across all continents.

Concerning the North American region, there is an increased incidence of hay fever in the United States as a result of pollen production during extreme heat events [110]. Moreover, a study conducted in Canada and Northern America found that the combination of heat waves and air pollution, including particulates, could lead to substantial stress on individuals, resulting in adverse health outcomes. This combined exposure increases the risk of condition such as stroke, cardiovascular diseases, and respiratory illnesses [33]. One study highlighted a higher rate of aeroallergen exposure and allergic sensitization in Quebec, Canada, secondary to the combined effects of greater carbon dioxide concentrations and warmer temperatures which stimulate pollen production from allergenic plants [92]. Shindell et al., showed that effective climate mitigation action in the United States could significantly decrease rate of premature deaths resulting from exposure to aerosols and ozone precursors [110].

Geels and colleagues have underscored the population-level health ramifications of climate change and air pollution, with particular attention to the impact of ozone [111]. They have noted high morbidity and mortality levels in Europe, aligning with findings from studies conducted in the United States. These same findings concerning trends have also been observed in China, where studies have reported a substantial increase in mortality rates, ranging from 5 to 8 times, due to respiratory illnesses attributed to pollution [112]. In eight different regions of China, another recent study highlighted the worrisome levels of mortality associated with air pollution and climate change, specifically concerning ozone and particulate matter [16].

The presence of PM in the atmosphere is known to harm epithelial cells, promote cytokine release, and induce cell inflammation [94]. A retrospective study conducted in Pusan, Korea explored the relationship between sun exposure, PM, and the occurrence of chronic actinic dermatitis, revealing significant findings that supported causal connection [113]. Another study in Northern Mexico shed light on elevated mortality in areas with high levels of particulate matter, especially among seniors aged over 60 [114]. However, a study in Buenos Aires, Argentina, investigated particulate matter concentration in the climate and their correlation with increased pediatric emergency department visits but did not yield significant conclusive data [111]. In contrast, another study in Argentina, conducted by Carreras and colleagues, explicitly detailed the consequences of daily temperature increases in conjunction with exposure to particulate matter. The study underscored the socioeconomic disruptions in the country and designated particulate matter as a predictor for upper and lower respiratory tract infections leading to hospital admissions [94].

The EMRO region experiences various health impacts as a consequence of climate change. Some of the key areas affected are depicted in Fig. 2. In Saudi Arabia, the hot climate and heat exposure during outdoor activities increase the risk of indoor and outdoor heat stress, with compliance to the midday outdoor work ban proving ineffective in reducing this risk [115]. Additionally, there is a potential risk of developing renal abnormalities upon exposure to heat stress, potentially lead to acute kidney injury [116]. Saudi Arabia, located in the subtropical zone with 50 % desert sand, is one of the hottest countries in the world [116]. The findings suggest that the harsh climate may contribute to the development of health consequences among workers in this region. Ensuring proper hydration and healthy habits could help lower that risk. However, the most effective measure may be reducing work hours, as this would decrease heat exposure and improve sleep quality, both of which are crucial for preventing heat-related issues.

The study by Mehmood et al. examines pollution levels of toxic in an urbanized city in Pakistan, revealing significant concentrations of contaminants PM and toxic metals, like lead, cadmium, and arsenic, that exceed safety limits [117]. This research indicated a heightened likelihood of adverse health effects, particularly for vulnerable populations. Key risks include respiratory diseases, such as asthma and COPD, cardiovascular issues, including hypertension and myocardial infarctions. Exposure to heavy metals also poses neurological threats, particularly in children, potentially leading to cognitive deficits and behavioral problems. They also note increased cancer risks, reproductive, and developmental conditions, from long-term exposure to carcinogenic metals. Additionally, rising temperatures and changing rainfall patterns, along with fluctuations in temperature and humidity, result in a scarcity of freshwater for drinking, a lack of water for agriculture, and in turn, significant food shortages. An increase in deaths secondary to

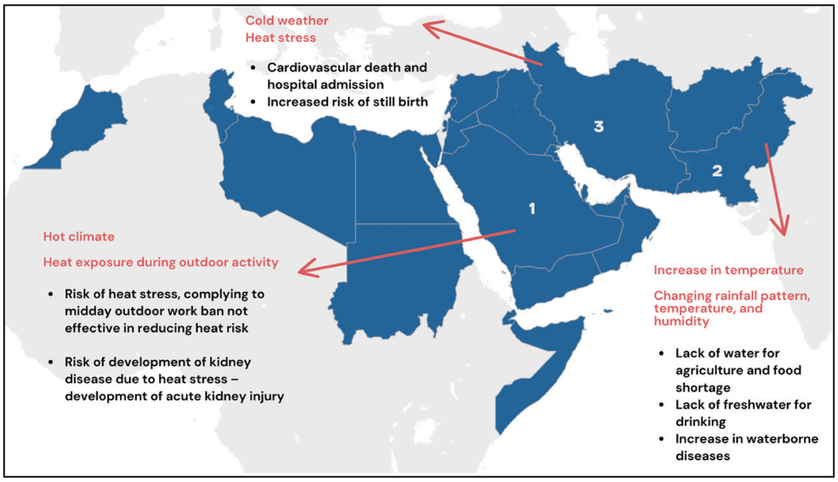

Fig. 2. The health effects associated with difference types of climate change within the EMRO region. *1. Saudi Arabia* [115,116]. *2. Pakistan* [117] *3. Iran* [118,119].

waterborne diseases is observed as a result of this lack of access to safe drinking water [117]. This aligns with broader findings in climate change literature, which indicate that global warming significantly impacts water availability, agricultural productivity, and public health. The authors advocate for stricter emissions regulations and public education campaigns to mitigate these health risks and improve environment quality.

Also, health challenges due to both cold weather and heat stress are seen in Iran. These conditions contribute to cardiovascular deaths and hospital admissions [118]. Khodadadi et al. investigated a relationship in which increased thermal stress, indicated by the Universal Thermal Climate Index (UTCI), is associated with adverse pregnancy outcomes, such as preterm birth and low birth weight [119]. They stressed on the application of public awareness campaigns aimed at educating pregnant women about the dangers of extreme heat and the importance of preventative measures, as well as the implementation of mitigation strategies to protect them from excessive temperatures, such as creating shaded areas and access to cooling centers, along with regular monitoring of environmental conditions. Dastoorpoor et al., on the other hand, studied the Physiological Equivalent Temperature (PET) index as an indicator of thermal stress, and found that higher PET values correlate with a rise in cardio-vascular-related hospital admissions [118]. Here, the need for establishing heat health alters was emphasized, to inform the public about extreme heat events and their associated health risks. Furthermore, the recommendation was to train healthcare providers during heat waves to effectively recognize and manage heat-related health issues, particularly among patients with pre-existing cardiovascular conditions.

3.13. Policy implications of findings on climate change and health

As illustrated in Fig. 3, the health effects are analyzed across various regions, emphasizing geographical variability in impact. The findings highlight the urgent need for both shared and region-specific policy measures to address the health impacts of climate change. A multifaceted approach is essential, including strengthening early warning systems by enhancing data collection and collaborating with international organizations. Public awareness and education campaigns are crucial to inform communities about climate-related health risks and preventive measures. Additionally, improving healthcare infrastructure and capacity—such as investing in climate-resilient facilities and training healthcare professionals—is necessary to manage the increasing burden of climate-related illnesses.

Adaptation strategies, including developing national plans based on frameworks like CDC's BRACE, are vital for managing both direct and indirect health impacts. Mitigating climate change through significant reductions in greenhouse gas emissions is also critical, with strategies such as promoting renewable energy and sustainable practices. Global cooperation, participation in international agreements, and addressing social determinants of health are essential for equitable and effective climate responses. Finally,

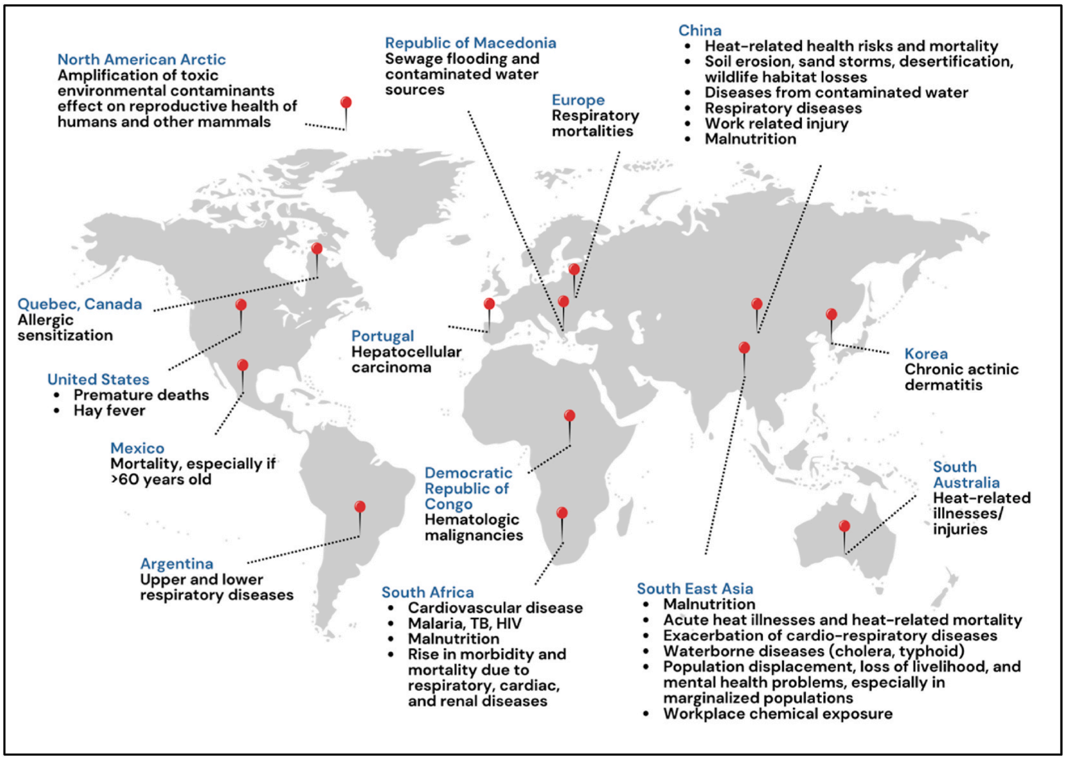

Fig. 3. The health effects as a consequence of climate change across different regions worldwide.
References: Canada [92], United States [110,122], North American Arctic [39,58], Mexico [114], Argentina [94], Europe [28], Portugal [102], Republic of Macedonia [100], China [16,36,65,93], Korea [113], South- East Asia [7], Democratic Republic of Congo [106], South Africa [26], South Australia [12].

developing sustainable implementation policies, including robust monitoring and securing resources, is crucial for achieving long-term health benefits.

4. Strengths and limitations of the literature

The reviewed studies on the health impacts of rising global temperatures present several strengths and limitations.

Strengths include their comprehensive analysis of diverse health outcomes such as cardiovascular, cerebrovascular, respiratory conditions, infectious diseases, and air pollution effects, providing a multifaceted understanding of climate change's impact on health. The studies offer a global perspective by incorporating research from various regions, broadening the relevance of findings across different geographical contexts. They employ diverse methodologies, including epidemiological studies, clinical trials, and retrospective analyses, enhancing the robustness of conclusions by mitigating methodological biases. Many studies include longitudinal data, essential for understanding long-term health impacts and identifying trends. Furthermore, there is a focus on vulnerable populations like the elderly, children, pregnant women, and outdoor workers, which is crucial for developing targeted interventions.

On the other hand, the quality and availability of data vary significantly, especially in regions with limited healthcare infrastructure, leading to potential skewing of results. There is a significant geographical bias, with most studies conducted outside the EMRO region, limiting the applicability of findings to this area and highlighting the need for localized research. Without accurate, localized data, there is a risk that policies or interventions based on these findings may not effectively address regional needs. Overcoming this challenge requires investing in better healthcare systems and data collection methods in underrepresented areas. International collaborations and the establishment of more robust health monitoring systems could also help improve data quality. Moreover, many studies struggle to account fully for confounding factors, such as socioeconomic status, access to healthcare, residential mobility, and individual practices. Incorporating multidisciplinary data that goes beyond health indicators and includes social, economic, and geographic variables can greatly enhance the understanding of how these confounders influence health outcomes. Collaborations between epidemiologists, economists, and social scientists can provide a more comprehensive dataset. Encouraging community-based research with local populations can help account for specific confounding variables that are unique to certain regions as well.

Research on the mental health effects, particularly related to climate anxiety and stress from extreme weather, is also underexplored. Mental health should be integrated into climate impact studies, and more resources should be allocated to studying the psychological effects of extreme weather changes, especially in regions more vulnerable to these changes. Collaborations between mental health professionals and environmental scientists could address this issue. Additionally, many studies focus on immediate health impacts rather than long-term chronic effects, and few thoroughly explore adaptation and mitigation strategies, which are crucial for comprehensive public health policy development. This highlights the need for developing a robust climate-health monitoring system that integrates environmental and health data over extended periods that can help track the evolution of climate-related health impacts. These systems should be publicly accessible and updated regularly, allowing policymakers to make evidence-based decisions on long-term adaptation strategies. It also signifies the importance of funding long-term cohort studies, especially when measuring chronic health diseases, such as COPD and cardiovascular disease. Besides, heterogeneity in study designs and outcomes complicates synthesizing results, and some studies may not capture the most recent data, creating potential gaps in understanding current impacts. Hence, there is a need to evaluate the health impacts of adaptation and mitigation strategies more in depth, and to understand the economic and social determinants that mediate these health outcomes.

5. Limitations of this review

Our study has several limitations that should be considered when interpreting the findings. Firstly, the review was limited to a specific time frame, from 2015 to 2022, which may exclude relevant studies published outside this period and impact the comprehensiveness of our analysis. Additionally, the language restriction to English-only publications potentially introduced language bias, excluding important research published in other languages. As this is a scoping review, we did not conduct a critical appraisal of the quality of the included studies, which could affect the reliability of the conclusions drawn. Furthermore, we excluded grey literature, such as expert opinions and unpublished data, which may have omitted valuable insights and perspectives. Finally, the limited number of studies included may restrict our ability to make comprehensive comparisons across different regions, potentially impacting the generalizability of our findings.

6. Summary and conclusion

This review analyzed studies published between 2015 and 2022 to provide a comprehensive overview of the health challenges posed by climate change. Climate change's health impacts are profound and multifaceted, with a notable increase in heat-related deaths—68 % over recent years, as highlighted by the Lancet's 2022 report [120]. Global warming, increasing temperatures, wildfires, floods, droughts, and hurricanes, and climate variability are all precursors to environmental pollutants that directly and indirectly affect a wide range of conditions. Worldwide, populations of all demographic backgrounds are faced with an increased prevalence of respiratory, cardiac, and infectious diseases, undernutrition, mental health disorders, gestational and neonatal consequences, and increased hospital admissions and mortality rates are only a few examples of further repercussions. The health effects are further complicated by the presence of hazardous chemicals and the environmental consequences of natural disasters, highlighting the critical intersection between climate change, environmental factors, and public health. These findings underscore the urgent need for targeted interventions and comprehensive policy measures to mitigate these environmental health risks globally. Strengthening early warning systems, promoting public awareness, enhancing healthcare infrastructure, and implementing adaptation strategies are crucial. Additionally, reducing greenhouse gas emissions, fostering international collaboration, addressing social determinants of health, and developing sustainable implementation policies are essential to mitigate the health impacts of climate change. These measures are particularly vital for vulnerable regions like EMRO, where climate change effects are increasingly severe. The WHO's adaptation and mitigation strategies reflect the urgency of addressing the growing frequency and intensity of extreme weather events and their repercussions, highlighting the need for proactive measures as more countries face the impacts of floods and rising sea levels. Global cooperation and addressing social determinants of health are also critical to managing these health risks effectively.

CRediT authorship contribution statement

Sarah S. Abdul-Nabi: Writing – original draft, Data curation. **Victoria Al Karaki:** Writing – original draft. **Aline Khalil:** Investigation, Writing – review & editing. **Tharwat El Zahran:** Writing – review & editing.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Data availability

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2025.e42315.

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