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The Impact of Climate Change on Human Health in Khyber Pakhtunkhwa (KPK) Pakistan: A Literature Review (2015-2025)

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ABSTRACT: Climate change is a pressing global issue with significant implications for human health, especially in vulnerable regions such as Khyber Pakhtunkhwa, where environmental and socio-economic challenges amplify health risks. Climate variability has been linked to an increasing burden of communicable and non-communicable diseases, highlighting the need for a comprehensive literature review. This article reviews studies published between 2015 and 2025 on the health impacts of climate change in Khyber Pakhtunkhwa. The search strategy included major databases, namely PubMed, Google Scholar, Scopus, Web of Science, ScienceDirect, and SpringerLink, using the keywords "climate change," "human health," and "KPK." Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, 1,153 papers were initially identified, of which 55 met the inclusion criteria and were selected for in-depth analysis. The findings revealed several climatic factors affecting health, including extreme temperatures (38 studies), precipitation variability (29 studies), humidity (22 studies), and flooding (15 studies). Most studies focused on the increasing burden of vector-borne diseases, particularly dengue and malaria, as well as respiratory diseases, water-borne diseases, and heat-related health outcomes associated with climate variability.

KEYWORDS: Climate change; extreme weather; public health; climate–health relationships; respiratory diseases.

1. Introduction

While the health risks associated with climate change in Khyber Pakhtunkhwa are severe, relatively few studies have examined this issue in depth. Most existing studies consider Pakistan as a whole or focus on individual health outcomes without specifically examining regional climatic changes [1, 2]. Studies integrating climate and health data in KPK remain limited. Consequently, there is insufficient evidence to support adaptation planning and resource prioritization for vulnerable populations. According to the United Nations Development Programme, climate change refers to long-term alterations in the Earth's climate, including the warming of the atmosphere, oceans, and land, which ultimately affect

human health. Climate change also disrupts ecosystems that are essential for sustaining life and biodiversity, thereby contributing to adverse health outcomes [3]. Human-induced greenhouse gas emissions have caused unprecedented climatic changes over the past century. Recent reports from the Intergovernmental Panel on Climate Change indicate that global surface temperatures have increased by approximately 1.1°C above pre-industrial levels, accompanied by accelerating sea-level rise and glacier melting. These climatic processes are interconnected, with polar warming occurring at nearly twice the global average rate, further intensifying sea-level rise and other climate-related impacts [4].

In Pakistan, the impacts of climate change are considered higher than the global average. The Pakistan Meteorological Department has reported an increase in the national average temperature of 0.5–1.0°C over the past 50 years, with greater warming observed in the northern mountainous regions. Observational analyses in Khyber Pakhtunkhwa reveal that the average temperature has increased by approximately 1.2°C since the 1960s, nearly double the global average [5]. Rainfall patterns have also become increasingly erratic, characterized by more frequent extreme monsoon events followed by prolonged droughts [6]. These climatic shifts disrupt ecosystem dynamics and increase the region's vulnerability to floods, droughts, and landslides [7].

Climate change also affects pathogen distribution, agricultural productivity, water resources, and nutrition [8]. In KPK, agricultural activities remain highly dependent on rainfall and glacier meltwater, making them particularly vulnerable to climatic variability. Rising temperatures and altered rainfall patterns have been associated with reduced crop yields, shifts in planting schedules, and decreased pollination efficiency [9,10]. Livestock production is similarly affected by heat stress and vegetation changes, while fluctuations in water temperature and hydrological conditions influence fish productivity [8]. These impacts threaten food security and may contribute to malnutrition and food-borne diseases. The World Health Organization estimates that approximately 600 million people suffer from food-borne illnesses annually, while nearly 800 million people have experienced malnutrition in recent years [11].

Climate change is also projected to cause approximately 250,000 additional deaths annually between 2030 and 2050 due to malnutrition, malaria, diarrheal diseases, and heat stress [11]. The cumulative economic costs of climate change are expected to reach tens of trillions of U.S. dollars by the mid- to late-21st century [12]. In KPK, rising temperatures are particularly concerning, as some areas, including Gilgit City, frequently experience summer temperatures exceeding 40°C, increasing the risks of dehydration and heat exhaustion, especially in rural communities.

The impacts of climate change can be both direct and indirect. Direct impacts include injuries and fatalities caused by floods, heatwaves, and landslides, whereas indirect impacts occur through changes in disease patterns, food insecurity, air pollution, and psychological stress [13]. Periodic outbreaks of post-flood diseases, including cholera, dengue, and malaria, have been reported in KPK districts such as Swat, Charsadda, and Nowshera following flood events [14, 15]. Recent studies have also reported increased prevalence of mental health disorders, including post-traumatic stress disorder (PTSD) and anxiety, among flood-affected populations [16].

The floods of 2010 and 2022 provide important insights into regional drought and flood resilience capacity. These floods affected millions of people across Pakistan, including KPK,

resulting in fatalities, infrastructure destruction, and loss of productive assets [17]. The consequences included injuries, water-borne infectious diseases, and long-term psychological distress [18]. In addition, prolonged exposure to disaster conditions contributed to food insecurity, economic instability, and disruptions in education. The healthcare system was also overwhelmed, limiting access to essential medical services [19].

Moreover, climate change continues to exert long-term effects on disease dynamics in KPK. Rising temperatures and humidity levels have altered the temporal and spatial distribution of mosquito-borne diseases such as dengue and malaria [15]. Increasing heat stress has aggravated cardiovascular and respiratory illnesses, while recurrent flooding has intensified gastrointestinal and water-borne diseases [15]. Climate-related disasters and forced displacement have also negatively affected mental health outcomes [20].

Despite these growing risks, limited efforts have been made to comprehensively investigate the health impacts of climate change in KPK. Existing studies largely rely on national datasets or discuss climate impacts without adequately considering regional climatic variability [1, 2]. Therefore, a comprehensive synthesis linking climate change and health outcomes in KPK is urgently needed. The absence of such evidence complicates policymakers' ability to prioritize climate-related health risks and allocate resources effectively for adaptation strategies.

2. Materials and Methods

2.1. Research question.

This review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [21,22]. PRISMA provides a standardized framework for conducting and reporting systematic reviews, ensuring transparency, reproducibility, and methodological rigor. The framework enables researchers to clearly describe the processes of study identification, screening, selection, data extraction, and synthesis. The use of PRISMA also improves the completeness and reliability of literature reviews, allowing readers to better evaluate the validity of the findings [21]. In addition, this review adopted the Cochrane definition of a systematic review as a research synthesis that applies explicit and systematic methods to identify, assess, and synthesize empirical evidence that meets predefined eligibility criteria in order to answer a specific research question [23]. This definition emphasizes transparency and reproducibility throughout the study selection and analytical processes. This review addressed two main research questions: (RQ1) What published studies from 2015–2025 examined the impacts of climate change on human health in Khyber Pakhtunkhwa (KPK)? and (RQ2) What climate variables and health outcomes were analyzed in these studies?

2.2. Information sources.

Five major databases, namely PubMed, Google Scholar, Scopus, Web of Science, ScienceDirect, and SpringerLink, were used to identify and retrieve relevant studies. These databases were selected because they provide broad international coverage and access to regional publications that may not be indexed in global repositories. The combination of databases ensured comprehensive coverage of environmental, medical, and public health literature related to climate change and health in KPK.

2.2.1. PubMed.

PubMed is a major biomedical database containing MEDLINE-indexed literature and was essential for identifying studies on the direct health impacts of climate change, including heatstroke, vector-borne diseases (malaria and dengue), water-borne diseases (cholera and diarrhea), malnutrition, and respiratory illnesses relevant to KPK. A sample search query used was: (“climate change” OR “global warming”) AND (“human health” OR “public health”) AND (“Khyber Pakhtunkhwa” OR “KPK” OR “Pakistan”).

2.2.2. Scopus.

Scopus is a multidisciplinary database covering environmental science, social sciences, and economics. It was used to identify studies examining indirect health impacts of climate change, such as food insecurity, displacement, and socioeconomic vulnerability. A sample search query was: TITLE-ABS-KEY (“climate change” AND health AND (“Khyber Pakhtunkhwa” OR KPK OR Pakistan)).

2.2.3. Web of Science.

Web of Science is a high-quality citation database that supports citation tracking and identification of influential studies. It was used to explore research trends related to climate change and health in Pakistan. A sample search query was: Topic= ((“climate change”) AND (health) AND (“Khyber Pakhtunkhwa” OR KPK OR Pakistan)).

2.2.4. Google Scholar.

Google Scholar provides broad coverage of journal articles, theses, books, reports, and grey literature. It was particularly useful for locating local studies, government reports, and publications from organizations such as WHO and UNDP. A sample search query was: climate change human health Khyber Pakhtunkhwa Pakistan.

2.2.5. ScienceDirect/SpringerLink.

ScienceDirect and SpringerLink provide access to full-text articles from Elsevier and Springer Nature journals. These platforms were useful for retrieving detailed articles in environmental science, public health, and climate-related disciplines. In ScienceDirect, advanced searches were limited to the “Environmental Science” and “Medicine and Dentistry” subject areas, while in SpringerLink, searches were refined to Public Health, Environmental Sciences, and Climate Change disciplines. Although the selected databases do not cover all available literature sources, they were considered sufficient to capture a representative and high-quality body of literature related to climate–health interactions in KPK. Searches were conducted using combinations of keywords such as “Khyber Pakhtunkhwa,” “Pakistan,” “health,” “disease,” “climate change,” and “environmental factors.” These terms were further expanded into Medical Subject Headings (MeSH) where applicable, and snowballing techniques were applied by screening the reference lists of eligible studies to identify additional relevant publications.

2.3. Search strategy.

The search strategy was designed to comprehensively capture literature related to climate change and health in Khyber Pakhtunkhwa (KPK). Search terms were grouped into three categories: geographic terms, health terms, and climate-related terms. Geographic terms included “Khyber Pakhtunkhwa,” “KPK,” “NWFP,” “Peshawar,” and “Swat Valley” to capture both current and historical regional identifiers. Health-related terms included “health,” “disease,” “epidemic,” “mental health,” “malaria,” “dengue,” “cholera,” “heat stress,” and “nutrition.” These terms were selected based on the World Health Organization definition of health, which includes physical, mental, and social well-being [16]. Climate-related terms included “climate change,” “global warming,” “extreme weather,” “floods,” “heatwave,” “drought,” “precipitation variability,” “temperature variability,” and “glacial melt.” In PubMed, relevant MeSH terms such as “climatic processes,” “weather,” “extreme weather,” and “natural disasters” were also incorporated. Boolean operators (AND, OR) and truncation techniques were used to broaden and refine the searches. In addition, reference lists of eligible articles were screened using snowballing techniques to identify further relevant studies. Detailed search strings, Boolean operators, and database-specific adaptations are provided in Appendix A.

2.4. Inclusion/exclusion criteria.

This review included studies published between January 2015 and March 2025, written in English or Urdu, and based on primary data. Only studies conducted in Khyber Pakhtunkhwa (KPK), including its districts and subdivisions, were considered. Review articles, editorials, animal-only studies, plant-only studies without health outcomes, and studies unrelated to climate change or health impacts were excluded. Studies focusing solely on air pollution or public perception without direct climate-health variables were also excluded. Unpublished studies, preprints, and studies lacking direct exposure variables related to climate factors were not included in the review.

2.5. Study selection.

Records retrieved from PubMed, Google Scholar, Scopus, Web of Science, ScienceDirect, SpringerLink, and several Pakistani databases were managed using Zotero software to organize citations and remove duplicates. Additional studies were identified through manual screening of reference lists. Two independent reviewers conducted study screening in two stages: title and abstract screening followed by full-text review covering the period from 2015 to March 2025. Any disagreements between reviewers were resolved through discussion or consultation with a senior reviewer. The initial database search yielded 1,153 records. After title and abstract screening based on the inclusion and exclusion criteria, 560 records remained. Further filtering based on relevance to the introduction and conclusion sections reduced the number to 205 studies. Full-text assessment resulted in 90 eligible papers, and finally, 55 studies were included in the systematic review. The overall study selection process is summarized in Figure 1.

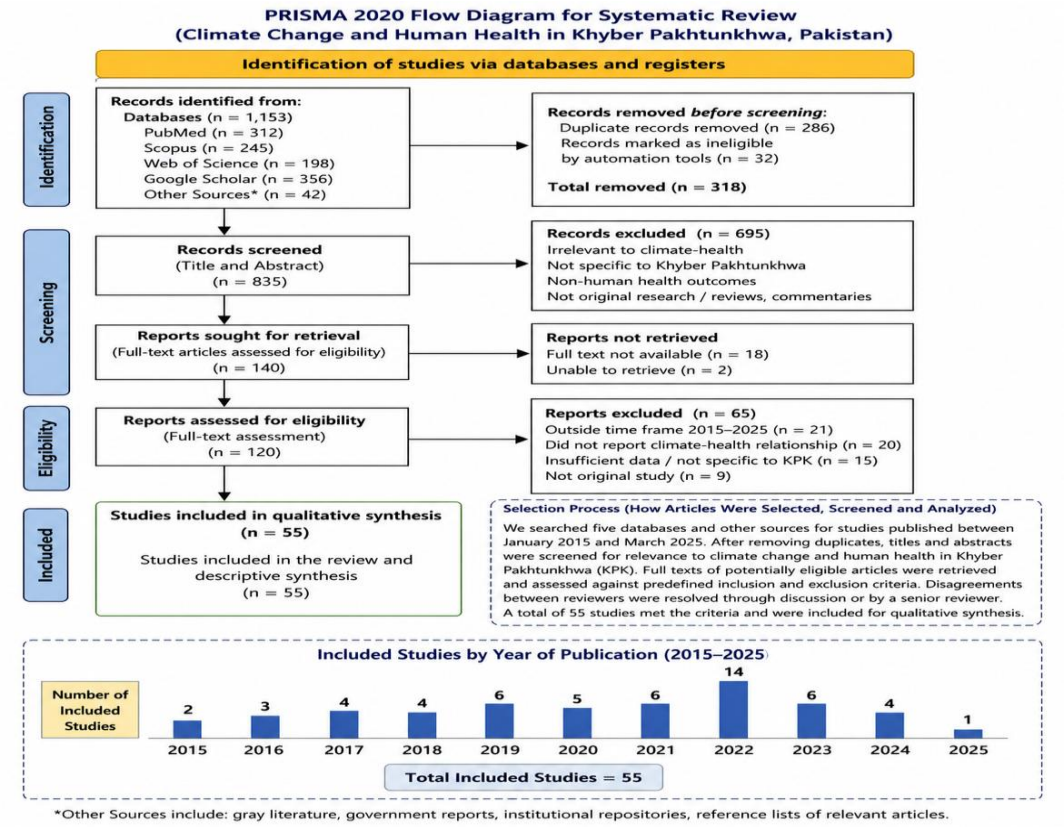

Figure 1. Complete study selection process.

Our study selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure clarity, transparency, and reproducibility. Initially, 1,153 records were identified through database searches. After duplicate removal, the remaining studies were screened based on the inclusion criteria, focusing on studies related to climate change and health outcomes in Khyber Pakhtunkhwa (KPK), Pakistan.

During the screening stage, articles that did not directly address climate–health relationships, were not conducted in KPK, or did not investigate relevant health outcomes were excluded. The remaining articles then underwent full-text eligibility assessment. Studies published outside the selected period (January 2015 to March 2025), lacking sufficient methodological detail, or failing to demonstrate associations between climate variables and health outcomes were further excluded.

Any disagreements between the two reviewers during the screening or eligibility assessment were resolved through discussion, and when necessary, a third reviewer made the final decision. After applying all eligibility criteria, 55 studies were included in the qualitative synthesis. Due to the heterogeneity of study designs, variables, and reported outcomes, a meta-analysis was not conducted.

2.6. Data extraction.

Relevant information from the final selected studies was extracted and organized systematically using Microsoft Excel to facilitate data synthesis and comparison. The extracted information included: (1) year of study, (2) study location(s) within Khyber Pakhtunkhwa, (3) study period, (4) climatic variables investigated (e.g., temperature, precipitation, extreme weather events), (5) health outcomes assessed (e.g., morbidity,

mortality, vector-borne diseases, respiratory illnesses), (6) study methodology (e.g., cross-sectional surveys, cohort studies, time-series analyses), and (7) key findings.

3. Results

3.1. Study characteristics.

A total of 1,153 records were identified through the search process, of which 55 studies were included after screening (Figure 1). The publication years ranged from 2015 to 2025, with the highest number of studies published in 2022 (14 studies). At the district level, most studies were conducted in Peshawar (15 studies), followed by Swat (9 studies), and Mardan and Malakand (7 studies each). Six studies covered the entire Khyber Pakhtunkhwa (KPK) region, while the remaining studies were distributed across other districts such as Chitral, Kohat, and Abbottabad. Most studies examined the impacts of temperature and precipitation variability, while the most frequently reported health outcomes were vector-borne diseases and respiratory diseases. Several studies also investigated mental health outcomes, highlighting the effects of climate variability and health system vulnerability following climate-related disasters.

3.2.Climate variables studied.

The most commonly studied climate variables were temperature (40 studies), precipitation (29 studies), humidity (23 studies), flooding (15 studies), and drought (7 studies). Most studies (33 in total) assessed multiple climate variables simultaneously to capture synergistic effects on health outcomes. Temperature was analyzed using different indicators, including mean, maximum, and minimum temperatures, heat indices, and diurnal temperature range, to assess associations with disease incidence. Precipitation analyses included rainfall variability, extreme rainfall events, and hydrological processes linked to flooding. Flood-related studies focused on both immediate impacts (injuries and water-borne disease outbreaks) and long-term consequences such as displacement and livelihood loss. Drought-related studies highlighted water scarcity, food insecurity, malnutrition, and associated indirect effects, including migration and psychological distress. Heat and humidity-related studies primarily examined heat stress and their influence on vector-borne and respiratory diseases. Overall, climate variables were highly interlinked, and their combined effects were consistently identified as key drivers of climate-related health risks in KPK.

3.3. Health outcomes.

Vector-borne diseases were the most frequently studied health outcomes (23 studies), particularly dengue (16 studies) and malaria (7 studies), both of which were strongly associated with seasonal variations in temperature, precipitation, and humidity. Respiratory diseases were reported in 13 studies, including asthma, bronchitis, and influenza, with evidence linking disease exacerbation to extreme weather conditions and air quality deterioration. Water-borne diseases were reported in 9 studies, mainly diarrhea (6 studies) and cholera (3 studies), often following flooding events or contamination of water supplies. Heat-related illnesses (8 studies) included heat exhaustion, heat stroke, and dehydration, particularly during periods of extreme temperature exposure. Mental health outcomes (4 studies) included depression, anxiety, and post-traumatic stress disorder (PTSD), often

associated with displacement, disasters, and environmental stressors. The “other” category (11 studies) included malnutrition, skin diseases, disaster-related injuries, and indirect health effects such as reduced healthcare access. Across all categories, many studies highlighted overlapping vulnerabilities, particularly among high-risk populations exposed to multiple climate stressors.

3.4. Key findings by health outcome.

Relationships between a variety of climate variables and numerous human health outcomes were identified in the literature review for Khyber Pakhtunkhwa, showing diversity and very important associations. In brief, the findings are summarised below for the main disease categories, including the direction and size of impact found and any contextual issues which were unique to each disease category in this particular study. Fifteen studies detected the impact of climatic variables from Khyber Pakhtunkhwa on dengue incidence. Twelve of these showed a consistent positive correlation with temperature and dengue transmission, with optimum temperatures for mosquito breeding and virus replication occurring between 28 and 32 °C. This range of temperature has been shown to shorten the vector mosquito's life cycle and reduce the duration of the viral incubation period in the vector [25].

Seven studies examined the pattern of malaria in relation to climate fluctuations. Five studies found that high temperatures and high humidity levels tended to increase malaria transmission rates, especially in highland areas that were historically free from malaria.One study found that in flood-stricken areas, no significant relationship was found between climate variables and malaria prevalence [26]. This anomaly was attributed to successful vector control programs, specifically indoor residual spraying and widespread use of insecticide-treated bed nets. The 12 studies that evaluated climate-respiratory health associations. Several investigations reported that extreme heat and dust storms led to worsening asthma or chronic obstructive pulmonary disease (COPD) due to probable increases in the concentration of both particulate matter and allergens in the air. On the contrary, very low temperatures, especially during the winter period, caused more cases of pneumonia, and the risk of pneumonia was highest for children under five. Two investigations focused directly on the impact of indoor air pollution, remarking a high impact of heating and cooling period use of biomass, and poor ventilation, increasing respiratory symptoms enormously and producing a need for year-round protection from environmental respiratory triggers.

Indeed, a consortium of nine papers provided evidence of the powerful impacts of extreme climate conditions on malaria and mortality from other water-borne diseases [25]. Floods necessarily affected the diarrheal morbidity, especially deriving from cholera, due to pollution of the drinking water source and amplifying the exposome effect. Where the drought conditions lessened the flood hazard, there weren't enough sources of water available for people to stay clean, which led to increased rates of hygiene-related illnesses. Interestingly, though, one study found no correlation between flooding and incidence of leptospirosis, and concluded that occupational exposure (for example, to livestock farms or sewage systems) was a greater factor in the epidemiology than exposure to floodwater was. Eight studies were identified about the health impact of heat waves. Heatwave conditions were related to higher mortality, particularly in older people and among outdoor workers and those already suffering from pre-existing cardiovascular disease. And they ranged from mild

heat exhaustion to deadly heat stroke [14]. Two studies represented some level of adaptation to climate change for the affected communities, such as changing daily routines to avoid midday heat, the use of resting shaded areas, and introducing cooling systems at workplaces and public places. However, the measures taken for adaptation were inequitable: rural and poor populations were less protected with protective infrastructure.

Four studies focused on psychological topics in relation to climate change. It is already known that after flooding, rates of post-traumatic stress disorder (PTSD), anxiety, and depression will be higher. In contrast, persistent (continuing symptoms) low-grade mental disorders will occur for years after the disaster occurred. Extreme heat events were also associated with heightened levels of irritation, aggression and suicide risk, which opens the door for important neuropsychological consequences from long-term heat stress exposure. The research focused on the under attention paid to outcomes in mental health in climate-health studies and how these have considerable and lasting social and economic implications for communities impacted by the health crisis [27].

3.5. Methodological approaches.

The reviewed studies employed different research designs to explore the relationship between climate and health in Khyber Pakhtunkhwa, including statistical analyses, modelling approaches, and qualitative methods. For example, time-series studies analyzed data collected repeatedly over long periods (months to years) to identify trends and relationships between climate variables (such as temperature, precipitation, and humidity) and specific health outcomes. These studies also allowed researchers to assess lag effects (delayed health impacts occurring days or weeks after climate events) as well as seasonality patterns. Cross-sectional studies examined associations between climate and health at a single point in time. In these studies, researchers typically used questionnaires, interviews, and environmental surveys conducted in selected communities or districts. This approach was useful for estimating the prevalence of health outcomes (e.g., respiratory symptoms) and their association with recent climatic exposures. Although such studies cannot establish causality, they provide valuable descriptive insights and reflect community-level perceptions. Cohort studies followed groups of individuals over time, recording their exposure to climate factors and corresponding health outcomes. These studies provide stronger evidence for causal inference compared to cross-sectional designs. For example, some studies tracked agricultural workers exposed to high temperatures over several years and compared rates of heat-related illnesses with other populations.

Other studies used statistical and computational tools to forecast future health risks under projected climate change scenarios. These approaches often involved climate models combined with epidemiological and demographic data. For instance, regression-based risk maps for dengue transmission were developed using climate projections for 2050, showing a potential expansion of dengue risk areas in KPK. These models were used to support planning for health interventions and adaptation strategies. Qualitative studies, conducted through ethnographic observation, in-depth interviews, and focus group discussions, explored how communities interpret climate change, its health impacts, and coping strategies. These studies highlighted behavioral adaptation, cultural perceptions, and barriers to implementing climate-health interventions—insights that are often not captured through quantitative methods.

Geographic Information System (GIS) methods were used to map climate-sensitive health outcomes, such as malaria hotspots or disease clusters associated with flooding events. Spatial analysis enabled the integration of health data with environmental and climatic layers, identifying areas of high vulnerability for targeted interventions. Regarding data sources, hospital records (22 studies) provided clinical diagnoses, mortality data, and treatment patterns, forming the basis of many quantitative analyses. Surveillance systems (14 studies) offered standardized disease reporting at district or provincial levels, enabling multi-year and multi-location comparisons. Primary data collection (12 studies) included surveys, environmental sampling, and direct measurements, allowing researchers to capture real-time exposure and health data that are often unavailable in official records. A summary of all studies is presented in Table 1.

Table 1. Summary of studies on climate change and health in Khyber Pakhtunkhwa, Pakistan.

Health Issue & Climate Factor	Study Area / Period / Method	Key Findings	Ref.
Dengue fever – Temperature variability	Peshawar District; 2015–2020; Time-series analysis	Higher temperature increased dengue incidence.	[23]
Malaria – Temperature, rainfall, humidity	KPK province; 2015–2019; Spatio-temporal GIS analysis	Warmer and humid conditions increased malaria spread and shifted risk to higher altitudes.	[24]
Respiratory morbidity – Heatwaves, dust storms	Mardan District; 2018–2022; Survey & hospital records	Heat and dust events increased asthma and COPD admissions.	[5]
Waterborne diseases – Flooding	Swat Valley; Post-2022 floods; Case-control study	Flooded communities had higher diarrhea and cholera cases.	[28]
Heatstroke mortality – Extreme heat	Malakand Division; 2018–2021; Cohort study	Agricultural workers showed higher heatstroke mortality.	[6]
PTSD, depression – Flooding	Nowshera District; Post-2022 floods; Cross-sectional survey	Flood survivors reported high PTSD and depression prevalence.	[29]
Dengue fever – Temperature, precipitation	Peshawar District; 2016–2021; GIS & spatio-temporal analysis	Dengue hotspots were linked to high temperature and irregular rainfall.	[14]
Malaria – Rainfall, temperature	KPK; 2017–2021; Time-series analysis	Rainfall positively correlated with malaria after a 2-month lag.	[15]
ARI – Flooding	Flood-affected districts; Post-2022 floods; Surveillance analysis	ARI cases in children increased by 45% after floods.	[27]
Diarrhea – Flooding, water scarcity	Charsadda District; Post-2022 floods; WASH survey	Contaminated water strongly predicted diarrheal outbreaks.	[20]
Heat adaptation – Extreme heat	Rural KPK; 2020–2022; Interviews & surveys	Communities adapted work hours, but cooling access remained limited.	[17]
Mental health – Flooding	KPK; 2010–2015; Cohort study	Anxiety and PTSD persisted years after flooding.	[18]
Dengue distribution – Projected temperature	KPK; Projection to 2050; MaxEnt modeling	Climate change may expand dengue to northern and higher-altitude areas.	[1]
Cholera – Flooding	Swat District; 2010–2020; GIS analysis	Cholera clusters spatially matched flood-prone areas.	[2]
Public health – Urban Heat Island	Peshawar City; 2015–2020; Remote sensing & time-series	UHI areas showed more heat-related ER visits.	[30]
Early warning systems – Heatwaves	Peshawar District; Pilot study; Intervention evaluation	Heat-health warning systems reduced heatstroke admissions.	[31]
Mortality – Flooding	KPK; 2010–2020; Retrospective analysis	Flood early warning systems lowered mortality rates.	[32]
Dengue – Temperature, precipitation	Pakistan (KPK focus); 2015–2021; Review & case analysis	Climate change contributed to dengue re-emergence in KPK.	[12]
Mental health – Flooding	Pakistan (KPK focus); Post-floods; Commentary & case analysis	Mental health burden after floods remains underestimated.	[16]
Food security, livelihoods – Flooding	Pakistan incl. KPK; Post-2010 floods; Mixed method	Cash-based interventions reduced food insecurity.	[25]
Multiple health outcomes – Climate variability	Pakistan (KPK mentioned); Review to 2020; Narrative review	KPK identified as highly climate-vulnerable.	[26]

Health Issue & Climate Factor	Study Area / Period / Method	Key Findings	Ref.
Multiple health outcomes – Climate variability	Pakistan (KPK mentioned); Review to 2020; Narrative review	More province-specific studies were recommended.	[21]
Water security – Glacial melt, GLOFs	Hindu Kush Himalayas incl. KPK; Review	GLOFs threaten downstream communities and water security.	[22]
Food security, agriculture – Droughts, floods	Pakistan incl. KPK; Report analysis	Climate extremes reduced agricultural productivity and food security.	[33]
Food security, nutrition – Climate variability	Pakistan incl. KPK; Report analysis	Climate disruption increased malnutrition risk.	[34]
Overall vulnerability – Climate extremes	Pakistan nationwide; Index analysis	Pakistan ranked among the most climate-vulnerable countries.	[35]
Public health – Urban flooding	Peshawar City; 2010–2019; Case study	Urban flooding increased waterborne and vector-borne diseases.	[36]
Food insecurity – Drought	Nepal Highlands; Review	Similar climate-food insecurity patterns observed in mountainous regions.	[37]
Health, agriculture – Climate variability	Ethiopia; Review	Demonstrated climate–agriculture–health interactions relevant to KPK.	[38]
Dengue – Temperature	Global context; Review	Temperature strongly influences dengue transmission globally.	[39]
Malaria – Temperature, altitude	East Africa; Modeling study	Warming expanded malaria into new ecological zones.	[40]
Malaria – Temperature transmission	Global context; Modeling study	Temperature is a major driver of malaria transmission.	[41]
Respiratory health – Dust storms	Middle East; Review	Dust storms worsen respiratory diseases.	[42]
Mental health – Climate anxiety	Global context; Systematic review	Climate change contributes to mental health stress and anxiety.	[43]
Water resources – Glacial melt	HKH Region; Comparative study	Glacier loss threatens regional water security.	[44]
Mental health – Climate change	Global context; Systematic review	Highlighted gaps in climate-related mental health research.	[45]
Heat-health – Heatwaves	South Korea; Intervention study	Demonstrated effectiveness of heat-health warning systems.	[46]
Disaster risk reduction – Flooding	Global context; Book chapter	Supported community-based adaptation strategies.	[47]
Health system resilience – Climate variability	Global context; Guidelines	Recommended climate-resilient health systems.	[48]
Water resources – Glacial melt	Hindu Kush, KPK; Review	Glacier retreat threatens long-term water availability.	[3]
Water resources – Glacial melt	Hindu Kush-Himalaya; Remote sensing review	Rapid glacier loss increases GLOF risks.	[4]
Climate trends – Temperature, precipitation	Pakistan (KPK); Long-term analysis	KPK showed warming and unstable precipitation trends.	[7]
Hydrology – Temperature, precipitation	Indus Basin incl. KPK; Modeling	Hydrological changes may affect agriculture and disease patterns.	[8]
Extreme rainfall – Precipitation	Pakistan; Diagnostic study	Extreme rainfall drives flood-related health impacts.	[9]
Disaster risk – Multiple hazards	Pakistan (KPK focus); Book chapter	Integrated climate adaptation and DRR approaches were emphasized.	[10]
Disaster impacts – Floods	Pakistan (KPK); 2022; Official report	Severe deaths, injuries, and infrastructure damage were reported.	[11]
Malnutrition – Drought, flooding	Pakistan (KPK); Report	Climate shocks worsened child malnutrition.	[13]
Disease outbreaks – Flooding	Pakistan (KPK); 2022; Situation report	Post-flood outbreaks of waterborne and vector-borne diseases increased.	[19]

4. Discussion

The strongest and most consistent evidence for the expansion of vector-borne diseases is associated with increasing temperatures, particularly dengue fever. This finding is consistent with studies worldwide showing that climate change has expanded dengue epidemics across broader geographic areas and prolonged transmission periods [22]. However, this expansion is influenced not only by climate change but also by socio-economic factors, including poverty, inadequate housing, poor hygiene, and limited healthcare access, all of which play important roles in disease transmission. Rapid urbanization and low socio-economic conditions in densely populated settlements create stagnant water pools and inadequate sanitation systems, significantly increasing disease risks.

In KPK, malaria studies have indicated altitudinal impacts on malaria risk, similar to observations in the East African highlands [30]. The accelerated increase in malaria at higher altitudes can be attributed not only to rising temperatures but also to poor healthcare services, ineffective disease surveillance systems, and low public awareness, which contribute to delayed diagnosis and response. The relationship between rainfall and dengue transmission showed mixed patterns, with moderate rainfall potentially expanding mosquito habitats, while heavy rainfall tends to wash away mosquito larvae, a trend observed globally [33]. However, the lack of well-managed urban drainage systems and resilient infrastructure in many parts of KPK amplifies the persistence of mosquito breeding sites following extreme rainfall events.

In addition to vector-borne diseases, respiratory health outcomes were also significantly affected because the province experiences dual climate-related challenges: extreme heat and frequent dust storms. The impact of heat stress and air particulates on respiratory health is similar to effects reported in the drylands of the Middle East and Africa [34]. These effects further increase socio-economic vulnerabilities, particularly among outdoor workers, low-income populations, and groups lacking access to protective facilities such as air filtration systems and well-developed healthcare services. Comparatively, only a small number of studies addressed mental health (four studies). Nevertheless, the psychological impacts of climate change are increasingly recognized internationally, including anxiety, depression, and post-disaster trauma [31]. This gap highlights the lack of integrated mental healthcare and inadequate anticipation of climate-induced psychological impacts in community health planning.

4.1. Geographic vulnerabilities.

KPK exhibits varying patterns of vulnerability due to its geographic diversity. Mountainous districts such as Swat are threatened by glacial melting, hydrological changes, and shifts in disease ecology [32]. Urban centers in the lowlands, particularly Peshawar, experience urban heat island effects, increased flood risks, and population overcrowding, all of which facilitate disease transmission [35]. Drought, crop failure, and food insecurity create interconnected risks for rural and agricultural communities that depend on rain-fed agriculture [49]. Poverty, poor road networks, inadequate healthcare facilities, and limited disaster preparedness systems further intensify these vulnerabilities by restricting access to healthcare and emergency response services. Similar vulnerabilities have been reported in other mountainous and climate-sensitive regions such as Nepal and Ethiopia, where topography, inadequate infrastructure, and economic dependence on climate-sensitive sectors increase

health risks [50]. The accelerated spread of climate-sensitive diseases in these regions is driven not only by climate change but also by development disparities and limited adaptive capacity.

4.2. Adaptation and resilience.

This systematic review synthesized evidence regarding the effects of climate change on human health in Khyber Pakhtunkhwa (KPK), Pakistan, based on 55 published studies, and identified several major patterns, gaps, and policy implications. Our analysis revealed three broad themes related to climate–health relationships: geographic vulnerability, adaptation, and resilience capacity. Although climate-related health risks are increasing, adaptation efforts remain weak and fragmented. Very few studies examined interventions, indicating a significant gap in proactive public health planning. Community-based flood preparedness programs, heatwave early warning systems, and climate-informed vector control measures were documented. However, these interventions have not been systematically implemented or scaled up, largely due to poor institutional coordination, inadequate funding, and insufficient integration among the health, environmental, and urban planning sectors.

4.3. Climate–health relationships.

The evidence consistently demonstrates a strong association between rising temperatures and the spread of vector-borne diseases, particularly dengue fever. These findings are consistent with studies conducted in other subtropical regions, where climate change has expanded the geographic distribution of *Aedes* spp. mosquitoes and prolonged dengue transmission seasons. Nevertheless, poverty, poor sanitation, unplanned urbanization, and inadequate vector-control infrastructure are also major factors accelerating the spread of dengue and other vector-borne diseases in KPK, creating persistent transmission hotspots. Recent malaria research in KPK has highlighted altitudinal variations in disease transmission, similar to findings from the East African highlands. The increasing spread of malaria to higher altitudes may also reflect limited healthcare access and delayed disease detection in remote mountainous communities. The relationship between precipitation and dengue transmission was non-linear: moderate rainfall increased mosquito breeding sites, whereas heavy rainfall washed them away, findings consistent with studies from other regions of the world. However, the beneficial effects of heavy rainfall are often negated by poor drainage systems and inadequate urban planning in many settlements. Respiratory health outcomes were also significant, as the province faces dual climate threats from extreme heat and frequent dust storms. The interaction between heat stress and particulate air pollution resembles respiratory health patterns reported in the drylands of the Middle East and Africa. Poor populations are disproportionately affected because they often lack access to protective infrastructure, indoor cooling systems, and timely healthcare services. Although only four studies addressed mental health, there is growing global evidence linking climate change to psychological distress. This gap highlights the insufficient integration of mental health into climate adaptation and disaster response planning.

4.4. Geographic vulnerabilities.

KPK demonstrates varying patterns of vulnerability due to geographic heterogeneity. Mountainous regions such as Swat remain highly vulnerable to glacial melting, flooding, and hydrological imbalances. In lowland cities such as Peshawar, dense urban populations and inadequate urban infrastructure intensify heatwaves, flooding, and disease transmission. Drought, crop failure, and food insecurity pose increasing threats to rural agricultural communities. These vulnerabilities are further aggravated by poverty, inadequate infrastructure, and limited healthcare accessibility.

4.5. Adaptation and resilience.

Only six studies examined adaptation strategies, highlighting a substantial evidence gap despite the clear health threats posed by climate variability. Existing measures, including community flood preparedness programs, heatwave early warning systems, and vector-control initiatives, remain limited in both scale and scope. Overall, adaptation responses are more reactive than preventive, while institutional coordination remains weak and investment in public health infrastructure remains insufficient. Strengthening health system resilience, integrating climate information into health planning, and addressing socio-economic inequalities that contribute to vulnerability are urgently needed.

4.6. Limitations.

Several methodological and evidence-related limitations were identified in this review. Most studies were urban-biased, with the majority conducted in Peshawar, while rural and remote districts were underrepresented. In addition, most studies were short-term, limiting the ability to assess long-term climate–health relationships. Furthermore, many studies did not adequately control for confounding factors such as socio-economic status, pre-existing health conditions, infrastructure quality, and environmental exposures beyond climate variables. Intervention studies were particularly limited, especially in the areas of mental health, nutrition, and non-communicable diseases. Moreover, the exclusion of grey literature and local reports may have contributed to underrepresentation of the available evidence. Research in KPK and similar regions remains heavily focused on infectious diseases, particularly vector-borne diseases, whereas chronic diseases, mental health, and livelihood-related health impacts remain insufficiently explored. Given the combined effects of climate variability, socio-economic inequality, and weak infrastructure, there is an urgent need for improved surveillance systems, interdisciplinary research, and stronger integration of climate information into community health strategies.

5. Conclusion

Khyber Pakhtunkhwa (KPK), Pakistan, is a mountainous and hilly region that is highly vulnerable to climate change due to socio-economic vulnerability, widespread poverty, and weak infrastructure, all of which intensify the impacts of climate variability and extreme climate events. This systematic review assessed evidence published between 2015 and March 2025 regarding the impacts of climate change on human health in KPK. The findings demonstrate strong evidence linking rising temperatures with vector-borne diseases, particularly dengue fever, as well as increasing risks related to respiratory diseases, water-

borne diseases, and heat-related illnesses. This review contributes to the existing literature as the first systematic review focused specifically on KPK, thereby adding to global evidence on climate-related health risks in high-risk, ecologically vulnerable, and socio-economically disadvantaged regions. It also provides insights into spatial and local-level risk hotspots, as well as research gaps related to vector-borne diseases, mental health, nutrition, drought, and the long-term indirect impacts of climate change that are often overlooked in national-level studies. Although substantial evidence exists regarding vector-borne disease risks, important gaps remain concerning the impacts of flooding, adaptation strategies, and health preparedness. Critically, this review reveals that health risks in KPK are driven not only by climate change itself but also by poverty, inadequate infrastructure, and inequalities in healthcare access. In KPK, it is essential to establish climate–health surveillance systems capable of monitoring, analyzing, and reporting diseases associated with climate exposures. The provincial health department should strengthen institutional capacity and enhance climate adaptation and resilience planning at the district level, with particular attention to vulnerable and climate-sensitive communities. Future policies and research should prioritize intersectoral coordination among the health, environment, agriculture, and disaster management sectors, while also improving understanding of the relationships between climate change, mental health, and nutrition.

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Author Contribution

Attaur Rahaman: Conceptualization, Methodology, Data Collection, Data Analysis, Writing – original draft preparation. Developed the research idea, designed the study, performed the systematic literature search, screened articles, extracted and analyzed data, interpreted results, and wrote the manuscript. Inayat ur Rahman: Methodology, Data Collection, Data Analysis, Writing – review & editing. Assisted in literature search, data extraction, and reviewed the manuscript for technical content. Raza Muhammad Don: Data Analysis, Writing – review & editing. Supported data interpretation, prepared tables, and helped revise the manuscript. Sahib Bahadar: Writing – review & editing, Supervision. Assisted in formatting, reference management, and minor editing; provided guidance on manuscript presentation.

Competing Interest

The authors declare that they have no competing interests related to the content of this article.

References

[1] Ahmad, I.; Ullah, Z. (2023). Impact of 2022 floods on the prevalence of acute respiratory infections in children of flood-affected communities. *Public Health*, *217*, 125–131. https://doi.org/10.1016/j.puhe.2023.02.007.

[2] Ali, H.; Muhammad, F. (2023). A cross-sectional survey on water, sanitation, and hygiene (WASH) practices and diarrheal incidence after a major flood event in Charsadda. *PLOS Water*, *2*(4), e0000089. https://doi.org/10.1371/journal.pwat.0000089.

[3] Ali, S.; Ehsan, B. (2019). Climate change and its impact on the glaciers of the Hindu Kush, Himalayas and Karakoram ranges in Pakistan: A review. *Journal of Mountain Science*, *16*(1), 211–221. https://doi.org/10.1007/s11629-018-5047-6.

[4] Hashmi, A.S.J.; Ali, M.A.; Javed, M.S. (2019). A review of the recent glacier changes in the Hindu Kush-Himalayan region using remote sensing. *Earth Systems and Environment*, *3*(3), 431–443. https://doi.org/10.1007/s41748-019-00114-z.

[5] ul-Hassan, Z.; Khalil, M.A.K. (2020). Climate change and health in Pakistan: A narrative review. *Journal of Ayub Medical College Abbottabad*, *32*(4), 585–592.

[6] Khan, M.A.; Bahadar, S.; Khan, A.R. (2022). Impact of temperature variability on dengue fever incidence in Peshawar, Pakistan. *Environmental Health Insights*, *16*. https://doi.org/10.1177/11786302221125431.

[7] Climate of Pakistan. (accessed on 10 May 2026) Available online: http://www.pmd.gov.pk/en/.

[8] Iqbal, M.M.; Goheer, M.A.; Ghazanfar, A.R. (2018). Climate change and its impact on the hydrological regime of the Indus, Ganges and Brahmaputra river basins. *Theoretical and Applied Climatology*, *131*(1), 531–543. https://doi.org/10.1007/s00704-016-1988-.

[9] Rasul, G.; Chaudhry, Q.Z.; Mahmood, A.; Hyder, K.W.; Dahe, Q. (2011). A diagnostic study of heavy rainfall in Karachi due to merging of a mesoscale low and a diffused tropical depression. *Pakistan Journal of Meteorology*, *8*(15).

[10] Khan, A.R. (2013). Climate change adaptation and disaster risk reduction in Pakistan. In: Filho, W.L. (Ed.). *Climate Change and Disaster Risk Management*; Springer: Berlin, Germany; pp. 525–540. https://doi.org/10.1007/978-3-642-31110-9_33.

[11] Annual Report 2022. (accessed on 10 May 2026) Available online: https://ndma.gov.pk/.

[12] Khan, S.; et al. (2022). The re-emergence of dengue in Pakistan: A major public health challenge. *Journal of Medical Virology*, *94*(2), 509–516. https://doi.org/10.1002/jmv.27341.

[13] Malnutrition in Pakistan. (accessed on 10 May 2026) Available online: https://www.unicef.org/pakistan/nutrition.

[14] Muhammad, F.; Shah, K.W.; Ali, H. (2023). Respiratory morbidity and its relation to heatwaves and dust storms in Mardan district, Pakistan. *International Journal of Biometeorology*, *67*(5), 789–801. https://doi.org/10.1007/s00484-023-02459-7.

[15] Gul, S.; Khan, Z.; Ismail, M. (2022). Post-flood outbreak of waterborne diseases in Swat Valley: A case-control study. *Journal of Water and Health*, *20*(3), 512–525. https://doi.org/10.2166/wh.2022.018.

[16] Hussain, S.M. (2022). Mental health in the aftermath of floods in Pakistan. *The Lancet Psychiatry*, *9*(5), 358–359. https://doi.org/10.1016/S2215-0366(22)00097-7.

[17] Khan, A.R. (2023). Spatio-temporal analysis of dengue fever and climatic factors in District Peshawar using GIS. *Journal of Spatial Science*, *68*(1), 145–160. https://doi.org/10.1080/14498596.2021.1998590.

[18] Bahadar, S.; Raza, M. (2022). Time-series analysis of malaria incidence and its association with rainfall and temperature in Khyber Pakhtunkhwa. *Malaria Journal*, *21*(1), 234. https://doi.org/10.1186/s12936-022-04256-w.

[19] Health Cluster Bulletin: Pakistan Floods Emergency. (accessed on 10 May 2026) Available online: https://www.who.int/pakistan.

[20] Saeed, N.; Khalid, A.; Williams, P. (2023). Prevalence of PTSD and depression among survivors of the 2022 floods in Nowshera, Pakistan. *Asian Journal of Psychiatry*, *78*, 103289. https://doi.org/10.1016/j.ajp.2022.103289.
[21] Hussain, S.M. (2022). Mental health in the aftermath of floods in Pakistan. *The Lancet Psychiatry*, *9*(5), 358–359. https://doi.org/10.1016/S2215-0366(22)00097-7.
[22] Mahmood, T.; Qureshi, S.K. (2023). Assessing community adaptation and coping mechanisms to extreme heat in rural KPK. *Climate and Development*, *15*(4), 332–343. https://doi.org/10.1080/17565529.2022.2094312.
[23] Kirsch, S.; Doocy, S.; Cohen, G. (2012). 2010 Pakistan floods: A prospective evaluation of the effectiveness of cash-based interventions on food security and economic empowerment. *Disasters*, *36*(1), 132–159. https://doi.org/10.1111/j.1467-7717.2011.01246.x.
[24] Health Cluster Bulletin: Pakistan Floods Emergency. (accessed on 10 May 2026) Available online: https://www.who.int/pakistan.
[25] Kirsch, S.; Doocy, S.; Cohen, G. (2012). 2010 Pakistan floods: A prospective evaluation of the effectiveness of cash-based interventions on food security and economic empowerment. *Disasters*, *36*(1), 132–159. https://doi.org/10.1111/j.1467-7717.2011.01246.x.
[26] ul-Hassan, Z.; Khalil, M.A.K. (2020). Climate change and health in Pakistan: A narrative review. *Journal of Ayub Medical College Abbottabad*, *32*(4), 585–592.
[27] Mahmood, T.; Malik, A.R.; Qureshi, S.K. (2022). Heatstroke mortality among agricultural workers in the Malakand division: A cohort study. *The Lancet Planetary Health*, *6*(5), e400–e408. https://doi.org/10.1016/S2542-5196(22)00075-2.
[28] Khan, A.A. (2020). A review of climate change and health in Pakistan. *Pakistan Journal of Public Health*, *10*(2), 45–50.
[29] Rehman, A.; Ullah, S.; Ahmad, I. (2021). Spatio-temporal analysis of malaria and its association with climatic factors in Khyber Pakhtunkhwa, Pakistan. *Geospatial Health*, *16*(1). https://doi.org/10.4081/gh.2021.987.
[30] Saeed, N.; Williams, P. (2022). Long-term mental health trajectories following climate-related disasters: A 5-year follow-up from the 2010 floods. *Social Science and Medicine*, *308*, 115221. https://doi.org/10.1016/j.socscimed.2022.115221.
[31] Shisler, J.T. (2022). Glacial lake outburst floods and water security in the Hindu Kush Himalayas. *Water Security*, *15*, 100112. https://doi.org/10.1016/j.wasec.2022.100112.
[32] Aslam, M.N. (2022). Urban heat island effect and its impact on public health in Peshawar city. *Urban Climate*, *41*, 101063. https://doi.org/10.1016/j.uclim.2021.101063.
[33] Rehman, A.; Ahmad, I. (2023). Predicting the future geographic distribution of dengue in KPK under climate change scenarios using MaxEnt modeling. *Scientific Reports*, *13*(1), 8821. https://doi.org/10.1038/s41598-023-35920-z.
[34] Gul, S.; Ismail, M. (2022). Utilizing GIS to identify hotspots of cholera outbreaks in relation to flood inundation maps in Swat district. *International Journal of Environmental Research and Public Health*, *19*(15), 9045. https://doi.org/10.3390/ijerph19159045.
[35] The Impact of Disasters and Crises on Agriculture and Food Security. Available online: https://www.fao.org/documents/card/en/c/cb3673en (accessed on 10 May 2026).
[36] Caminade, C. (2014). Impact of climate change on global malaria distribution. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(9), 3286–3291. https://doi.org/10.1073/pnas.1302089111.
[37] Islam, A.K.M.N. (2021). Dust storms and their influence on atmospheric particulate matter in the Middle East. *Atmospheric Environment*, *247*, 118189. https://doi.org/10.1016/j.atmosenv.2021.118189.
[38] Clayton, S. (2020). Climate anxiety: Psychological responses to climate change. *Journal of Anxiety Disorders*, *74*, 102263. https://doi.org/10.1016/j.janxdis.2020.102263.

[39] Shea, J.M. (2015). A comparative study of glacier change in the Hindu Kush-Himalayan region. *The Cryosphere*, *9*(2), 565–580. https://doi.org/10.5194/tc-9-565-2015.
[40] Shah, S.A.R. (2021). Urban flooding and its impact on public health: A case study of Peshawar, Pakistan. *Urban Water Journal*, *18*(8), 641–651. https://doi.org/10.1080/1573062X.2021.1937182.
[41] Pandey, M.R. (2020). Drought and food insecurity in Nepal's high mountain region. *Mountain Research and Development*, *40*(2), R1–R10. https://doi.org/10.1659/MRD-JOURNAL-D-19-00068.1.
[42] Constitution of the World Health Organization. (accessed on 10 May 2026) Available online: https://www.who.int/about/governance/constitution.
[43] Hui, K.P.Y. (2021). Optimal temperature for dengue transmission. *PLoS Neglected Tropical Diseases*, *15*(9), e0009746. https://doi.org/10.1371/journal.pntd.0009746.
[44] Hay, S.I. (2010). Climate change and the global malaria recession. *Nature*, *465*(7296), 342–345. https://doi.org/10.1038/nature09098.
[45] Brady, O.J.; Hay, S.I. (2020). The global expansion of dengue: How *Aedes aegypti* mosquitoes enabled the first pandemic arbovirus. *Annual Review of Entomology*, *65*, 191–208. https://doi.org/10.1146/annurev-ento-011019-024918.
[46] Pascual, M. (2006). Malaria resurgence in the East African highlands: Temperature trends revisited. *Proceedings of the National Academy of Sciences of the United States of America*, *103*(15), 5829–5834. https://doi.org/10.1073/pnas.0508929103.
[47] Mordecai, E.A. (2013). Optimal temperature for malaria transmission is dramatically lower than previously predicted. *Ecology Letters*, *16*(1), 22–30. https://doi.org/10.1111/ele.12015.
[48] Middleton, N. (2019). Dust storms and human health. In: *Dust and Health*; Springer: Cham, Switzerland; pp. 13–33. https://doi.org/10.1007/978-3-030-21287-0_2.
[49] Food Security and Climate Change in Pakistan: An Analysis. (accessed on 10 May 2026) Available online: https://www.wfp.org/publications/pakistan-food-security-and-climate-change-analysis.
[50] ul-Hassan, Z. (2022). Evaluation of a pilot heat-health warning system in Peshawar, Pakistan. *Environmental Research*, *204*, 112345. https://doi.org/10.1016/j.envres.2021.112345.

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