Systematic Review

Climate Change and Spatiotemporal Distribution of Major Vector-Borne Diseases in South Asia: A Systematic Review

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Abstract

Background:
South Asia is among the most climate-vulnerable regions globally, experiencing rapid warming, altered precipitation patterns, and increased frequency of extreme weather events. These changes have important implications for vector-borne diseases (VBDs), which remain a major public health burden in the region.

Objective:
This systematic review synthesizes evidence on the relationship between climate change and the spatiotemporal distribution of major vector-borne diseases in restricted South Asia (India, Pakistan, Bangladesh, Sri Lanka, Nepal, and Bhutan), focusing on malaria, dengue, chikungunya, Japanese encephalitis, and visceral leishmaniasis.

Methods:
A systematic literature search was conducted in PubMed, Web of Science, Google Scholar, and relevant government and WHO reports for studies published up to December 2023. The review followed PRISMA guidelines. Studies assessing climatic trends, spatial or temporal distribution of vectors and diseases, or associations between climatic variables and disease transmission were included.

Results:
A total of 24 studies were included in the qualitative synthesis, consistent with the PRISMA flow diagram. Evidence indicates a regional warming trend, increasing temperature extremes, and changing rainfall patterns across South Asia. These climatic changes are associated with altitudinal and latitudinal expansion of malaria, dengue, chikungunya, Japanese encephalitis, and visceral leishmaniasis into previously non-endemic areas, including highland and peri-urban regions. Temperature and rainfall were the most consistently reported climatic drivers, although non-climatic factors such as urbanization, population mobility, land-use change, and vector control interventions strongly modified observed patterns.

Conclusion:
Climate change is contributing to the changing spatiotemporal distribution of major VBDs in South Asia, particularly through expansion into new ecological zones. Integrated surveillance, climate-informed early warning systems, and regionally coordinated public health strategies are urgently needed to mitigate future risks.

Keywords: Climate change, Vector-borne diseases, South Asia, Spatiotemporal distribution

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Introduction:

Vector-borne diseases (VBDs) continue to pose a substantial public health challenge globally, accounting for more than 17% of all infectious diseases and disproportionately affecting low- and middle-income countries[1]. South Asia, home to nearly one-quarter of the world's population, bears a particularly high burden of VBDs, including malaria, dengue, chikungunya, Japanese encephalitis (JE), and visceral leishmaniasis (VL)[2]. These diseases are transmitted by vectors whose survival, reproduction, and vectorial capacity are strongly influenced by climatic conditions [3]

Climate change has emerged as a critical determinant of infectious disease dynamics [4]According to the Intergovernmental Panel on Climate Change, South Asia has experienced above-global-average warming, increased variability in monsoon rainfall, more frequent heatwaves, floods, and droughts [5] These changes are especially pronounced in ecologically sensitive areas such as the Himalayan foothills, river deltas, and rapidly urbanizing landscapes [6] Temperature directly affects vector development rates, survival, biting frequency, and pathogen incubation periods, while rainfall influences breeding site availability and vector population dynamics [7]

Evidence from individual South Asian countries suggests that climate change is altering the geographical range and seasonal transmission patterns of VBDs[8]. Malaria has been reported at higher altitudes in Nepal, Bhutan, and northern India; dengue and chikungunya have expanded into temperate and peri-urban settings; and visceral leishmaniasis has increasingly been reported from areas previously considered non-endemic[9] However, these findings remain fragmented across national and disease-specific studies.

A regional synthesis is essential for several reasons [10] First, climatic systems such as the South Asian monsoon operate across national boundaries, influencing disease ecology at a regional scale. Second, population movement, trade, and cross-border transmission are common in South Asia, necessitating coordinated public health responses. Third, understanding similarities and differences in climate–disease relationships across countries can inform regionally tailored adaptation and mitigation strategies [10].

This systematic review aims to synthesize the available literature on climate change and the spatiotemporal distribution of major VBDs in restricted South Asia. By integrating climatic, epidemiological, and entomological evidence, the review seeks to identify consistent patterns, key drivers, research gaps, and policy-relevant insights.

Methods

Study Design and Reporting Framework

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The review protocol was not registered in PROSPERO or any other systematic review registry. The study selection process strictly followed the PRISMA flow diagram provided by the authors [11].

Search Strategy

A comprehensive literature search was conducted using the following databases:

- PubMed
- Web of Science
- Google Scholar
- Government and WHO reports (WHO SEARO, national surveillance publications)

The search covered publications available up to December 2023. Search terms were applied to titles, abstracts, and keywords and included combinations of:

- *South Asia*, *India*, *Pakistan*, *Bangladesh*, *Sri Lanka*, *Nepal*, *Bhutan*
- *Climate change*, *temperature*, *rainfall*, *precipitation*, *humidity*, *extreme events*
- *Malaria*, *dengue*, *chikungunya*, *Japanese encephalitis*, *visceral leishmaniasis*
- *Vector-borne diseases*, *mosquito-borne diseases*, *sandfly*, *Aedes*, *Anopheles*, *Culex*, *Phlebotomus*

Reference lists of included articles were also screened using snowball sampling to identify additional relevant studies.

Inclusion and Exclusion Criteria

Inclusion criteria:

1. Studies conducted in restricted South Asia (India, Pakistan, Bangladesh, Sri Lanka, Nepal, Bhutan). Afghanistan and the Maldives were not included because insufficient eligible literature meeting the review criteria was identified for meaningful synthesis.
2. Studies analyzing climatic trends relevant to VBD transmission.
3. Epidemiological or entomological studies assessing spatial or temporal distribution of VBDs or vectors.
4. Studies evaluating associations between climatic variables and VBD incidence or vector abundance.
5. Peer-reviewed articles and authoritative government/WHO reports.

Exclusion criteria:

- Review articles, commentaries, editorials, conference abstracts, and theses.
- Studies without a clear climate, spatial, or temporal component.
- Studies focusing exclusively on lymphatic filariasis.

Study Selection and Data Extraction

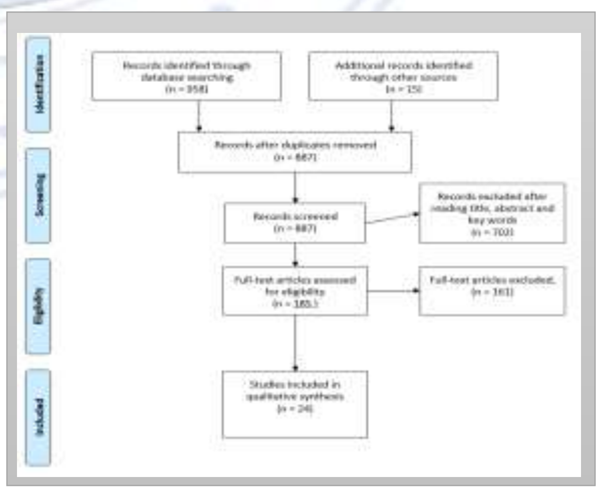
Titles, abstracts, and keywords were screened for relevance. Full-text articles were assessed for eligibility based on the inclusion criteria. As this was a single-author review, screening, eligibility assessment, and data extraction were conducted by the author according to predefined inclusion and exclusion criteria. Data extracted included author, year, country, disease, study design, climatic variables assessed, main findings, and limitations.

Data Synthesis

Due to heterogeneity in study designs, climatic indicators, and outcome measures, quantitative meta-analysis was not feasible. A narrative synthesis was conducted, supported by structured literature matrix tables.

Results

Study Selection



Based on the PRISMA flow diagram, 958 records were identified through database searching, with 15 additional records identified from other sources. After screening and eligibility assessment, 24 studies were included in the qualitative synthesis (Figure 1).

Table 1. Characteristics of Included Studies (Literature Matrix)

No.	Author (Year)	Country	Disease(s)	Study period	Study design	Climatic variables assessed	Key findings
1	Dhimal et al. (2015) [12].	Nepal	Malaria, Dengue, JE, VL	1978–2012	Systematic synthesis	Temperature, rainfall	Expansion of VBDs into hill and mountain regions linked to warming trends
2	Dhimal et al. (2014) [13]	Nepal	Malaria	2004–2012	Time-series analysis	Temperature, rainfall	Rising temperature increased malaria incidence; vector control modified risk.
3	Dhimal et al. (2014) [14]	Nepal	Dengue	2011–2012	Entomological study	Temperature, humidity, rainfall	Climatic factors significantly influenced Aedes abundance
4	Bhandari et al.	Nepal	Malaria	1998–2	ARIMA time-	Temperature,	Positive correlations obs

	(2013) [15]			009	series	rainfall	erved, but climatic variables not sole predictors
5	Siraj et al. (2014) [16]	India	Malaria	1980–2010	Climate–epidemic modelling	Temperature	Temperature rise explained resurgence in malaria transmission
6	Dhiman et al. (2010) [17]	India	Malaria	1986–2006	Ecological study	Temperature, rainfall	Climate variability influenced seasonal malaria
							dynamics
7	Deb Roy et al. (2006) [18]	India	Visceral leishmaniasis	1980–2003	Descriptive epidemiology	Temperature, rainfall	VL incidence increased following warmer and wetter periods
8	Singh et al. (2015) [19]	India	Dengue	2001–2012	Spatial–temporal analysis	Temperature, rainfall	Dengue expansion into new urban and peri-urban regions
9	Sarkar et al. (2019)	India	Dengue, Chikungunya	2010–2	Ecological modelling	Temperature, rainfall,	Climate anomalies

	[20]			017		humidity	preceded major outbreaks
10	Telle et al. (2016) [21]	Sri Lanka	Dengue	2007–2012	Spatial regression	Temperature, rainfall	Urban heat and rainfall variability increased dengue risk
11	Fernando et al. (2024) [22]	Sri Lanka	Dengue	2000–2018	Time-series analysis	Rainfall, temperature	Lagged rainfall effects predicted dengue outbreaks
12	Hapuarachchi et al.	Sri Lanka	Chikungunya	2006–	Descriptive epidemi	Rainfall, temper	Re-emergence link

	(2019) [23]			2017	ology	ature	ed to monsoon variability.
13	Akram et al. (2023) [24]	Pakistan	Dengue	2011–2018	Ecological study	Rainfall, humidity	Increased dengue incidence following intense monsoon rains
14	Mukhtar et al. (2018) [25]	Pakistan	Dengue	2006–2015	Spatial analysis	Temperature	Warmer urban microclimates supported vector survival

15	Wahid et al. (2017)[26]	Pakistan	Chikungunya	2016–2019	Descriptive outbreak analysis	Temperature, rainfall	Climatic suitability facilitated outbreak persistence
16	Rahman et al. (2022)[27]	Bangladesh	Dengue	2000–2016	Time-series analysis	Rainfall, temperature	Rainfall anomalies strongly associated with outbreaks
17	Lowe et al. (2018)[28]	Bangladesh	Dengue	2000–2015	Climate–health modelling	Temperature, rainfall	Climate variability increased epidemic probability
18	Hossain et al. (2022)[29]	Bangladesh	Chikungunya	2017	Outbreak investigation	Rainfall, temperature	Extreme rainfall preceded nationwide outbreak
19	Uranw et al. (2013)[30]	Nepal	Visceral leishmaniasis	2000–2008	Case–control study	Rainfall, temperature	Urban transmission linked to climatic and ecological factors
20	Pandey et al. (2023)[31]	Nepal	Visceral leishmaniasis	1999–2009	Descriptive analysis	Rainfall	Seasonal peaks followed monsoon

							rainfall
21	Impoinvil et al. (2011) [32]	Nepal	Japanese encephalitis	2004–2008	Spatial regression	Rainfall, land use	JE incidence negatively associated with precipitation
22	Robertson et al. (2013) [33]	Nepal	Japanese encephalitis	2007–2011	Geographically weighted regression	Temperature, land use	JE expanded into hill and mountain districts
23	Thakur et al. (2012) [34]	Nepal	Japanese encephalitis	2010	Serological study	Temperature	Evidence of JEV circulation in high-altitude
							regions
24	Kulkarni et al. (2016) [35]	South Asia (regional)	Multiple VBDs	1961–2098	Climate projection modelling	Temperature, rainfall	Future warming is projected to increase VBD suitability.

Discussion

This systematic review synthesizes evidence on the influence of climate change on the spatiotemporal distribution of major vector-borne diseases in restricted South Asia. Across diverse ecological and socio-economic settings, a consistent pattern emerges: rising temperatures, altered precipitation regimes, and increasing climate variability are reshaping the geography, seasonality, and intensity of transmission of malaria, dengue, chikungunya, Japanese encephalitis, and visceral leishmaniasis. While the magnitude and direction of these effects vary by disease and location, the collective evidence supports the conclusion that climate change is an important, though not exclusive, driver of observed epidemiological shifts.

Regional Climate Trends and Biological Plausibility

South Asia has experienced significant warming over recent decades, with increases in both mean and extreme temperatures reported across lowland, coastal, and highland regions [36].

Temperature is biologically one of the most influential climatic determinants of vector-borne disease transmission, as vectors are ectothermic and pathogen development within vectors is temperature-dependent [37]. Multiple studies included in this review demonstrate that rising temperatures shorten vector development cycles, increase biting rates, and reduce the extrinsic incubation period of pathogens, thereby enhancing transmission potential.

Precipitation patterns across South Asia are becoming increasingly erratic, characterized by intensified monsoon rainfall, prolonged dry spells, and a higher frequency of extreme events such as floods [38]. Rainfall affects vector ecology in complex and sometimes non-linear ways. Moderate rainfall increases breeding site availability, particularly for *Aedes* and *Anopheles* mosquitoes, while excessive rainfall can destroy larval habitats [39]. The heterogeneity of findings related to rainfall observed in this review reflects these complex dynamics, underscoring the importance of local context.

Disease-Specific and Cross-Country Comparisons

Malaria

Malaria provides one of the clearest examples of climate-sensitive disease dynamics in South Asia. Evidence from India, Nepal, and Bhutan indicates that warming temperatures have enabled malaria vectors to survive and transmit at higher altitudes and latitudes than previously documented [40]These findings are consistent with global observations of malaria expansion into highland regions under warming scenarios. However, the review also highlights that declining malaria incidence in several countries is largely attributable to intensified vector control interventions, such as long-lasting insecticidal nets and improved case management. This apparent paradox- declining burden alongside expanding climatic suitability- illustrates how effective public health interventions can temporarily offset climate-driven risks.

Dengue and Chikungunya

Dengue and chikungunya exhibit particularly strong associations with climate variability in South Asia. Both diseases have expanded rapidly over the past two decades, with outbreaks increasingly reported outside traditional endemic zones [41]. Urban heat islands, rising temperatures, and monsoon-associated rainfall have collectively enhanced the suitability of urban and peri-urban environments for *Aedes aegypti* and *Aedes albopictus*. The concurrence of dengue and chikungunya outbreaks in several countries further suggests shared climatic and ecological drivers. Importantly, climate change interacts with rapid urbanization, inadequate water management, and population density, making dengue and chikungunya quintessential examples of climate–society–disease interactions.

Japanese Encephalitis

Japanese encephalitis has traditionally been associated with rural agricultural landscapes, particularly rice-growing areas. However, evidence from Nepal and India indicates a gradual shift toward peri-urban and higher-altitude transmission [42] Temperature increases and changes in precipitation patterns, combined with irrigation practices and livestock rearing, appear to facilitate this expansion. The role of land use and agricultural intensification highlights that climate change acts synergistically with environmental modification rather than in isolation.

Visceral Leishmaniasis

Visceral leishmaniasis remains geographically concentrated in the Indo-Gangetic plains but is increasingly reported from areas previously considered non-endemic [43]. Rising temperatures and altered rainfall patterns influence sandfly abundance and seasonal activity, yet socio-economic determinants such as housing quality, poverty, and human mobility remain critical [44] The emergence of urban and peri-urban VL in South Asia suggests that climate change may lower ecological barriers, allowing transmission in settings where socio-economic vulnerabilities already exist.

Role of Non-Climatic Drivers

A central finding of this review is that climate change alone does not fully explain observed spatiotemporal patterns of VBDs in South Asia. Non-climatic drivers frequently modify, amplify, or mask climatic effects. Urbanization creates artificial breeding habitats and alters microclimates; population mobility facilitates pathogen introduction into climatically suitable areas; land-use change affects vector ecology; and public health interventions can significantly reduce disease incidence even under increasingly favorable climatic conditions [14]

These interactions complicate attribution analyses and partly explain inconsistencies across studies. For example, some time-series analyses report weak or non-significant associations between climatic variables and disease incidence after adjusting for control measures. This does not negate the role of climate change but rather emphasizes that disease outcomes are the product of multiple interacting determinants.

Methodological Limitations in the Evidence Base

The reviewed literature reveals several methodological limitations that constrain inference. Many studies rely on short time series, coarse spatial resolution, or aggregated climatic data, limiting their ability to capture local heterogeneity and long-term trends. Few studies explicitly assess extreme climatic events, despite their growing importance under climate change scenarios. Additionally, integrated models that simultaneously incorporate climatic and non-climatic variables remain scarce.

There is also a notable geographic imbalance in research output, with India and Nepal disproportionately represented, while Bhutan and parts of Pakistan and Bangladesh remain under-studied. This uneven evidence base may obscure regional patterns and bias conclusions.

Additionally, the literature search was conducted up to December 2023. Consequently, studies published after this period were not included and may provide further evidence regarding the effects of climate change on vector-borne diseases in South Asia.

Furthermore, no formal risk-of-bias assessment was performed because of the substantial heterogeneity in study designs and outcome measures across the included studies. This should be considered when interpreting the findings.

Implications for Surveillance, Policy, and Research

The findings of this review have several implications. First, disease surveillance systems in South Asia must be strengthened and climate-informed to detect early signals of transmission shifts. Second, public health adaptation strategies should move beyond historical endemicity maps and account for future climatic suitability. Third, cross-border collaboration is essential, given shared climatic systems and porous national boundaries.

From a research perspective, there is an urgent need for long-term, high-resolution climate–health datasets and interdisciplinary approaches that integrate epidemiology, climatology, entomology, and social sciences. Predictive modeling frameworks that incorporate both climatic projections and intervention scenarios would be particularly valuable for policy planning.

Conclusion and Policy Implications

Climate change is increasingly influencing the spatiotemporal distribution of vector-borne diseases in South Asia, particularly through expansion into new ecological and geographical zones. While public health interventions have reduced disease burden in some settings, rising climatic suitability poses future risks.

Policy responses should prioritize climate-integrated disease surveillance, regional data sharing, and adaptive vector control strategies. Strengthening interdisciplinary research at the climate–health interface is essential to safeguard vulnerable populations in South Asia.

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Ethical Approval: Not applicable, as this study involved analysis of previously published data.

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