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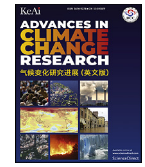

Review

Climate change and its association with the expansion of vectors and vector-borne diseases in the Hindu Kush Himalayan region: A systematic synthesis of the literature

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Abstract

Observed weather and projected climate change suggest an increase in the transmission of vector-borne diseases (VBDs) in the Hindu Kush Himalayan (HKH) region. In this study, we systematically explore the literature for empiric associations between the climate variables and specific VBDs and their vectors in the HKH region. We conducted a systematic synthesis of the published literature on climate variables, VBDs and vectors in the HKH region until the 8th of December 2020. The majority of studies show significant positive associations of VBDs with climatic factors, such as temperature, precipitation, relative humidity, etc. This systematic review allowed us to identify the most significant variables to be considered for evidence-based trend estimates of the effects of climate change on VBDs and their vectors in the HKH region. This evidence-based trend was set into the context of climate change as well as the observed expansion of VBDs and disease vectors in the HKH region. The geographic range of VBDs expanded into previously considered non-endemic areas of highlands (mountains) in the HKH region. Based on scarce, but clear evidence of a positive relationship of most climate variables and VBDs and the observed climatic changes, we strongly recommend an expansion of vector control and surveillance programmes in areas of the HKH region that were previously considered to be non-endemic.

Keywords: Chikungunya; Dengue; Filariasis; High altitude; Himalayas; Leishmaniasis; Mountain; Mosquito; Malaria; Sandfly

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1. Introduction

Climate change is affecting the Hindu Kush Himalayan (HKH) region due to changes in temperature, precipitation patterns and an increase in the frequency and intensity of extreme events (Sun et al., 2017; You et al., 2017; Zhan et al., 2017; Krishnan et al., 2019). From 1901 to 2014, the annual mean temperature of the HKH region significantly increased by 0.104 °C per decade (a mean maximum temperature rate of 0.077 °C per decade, and a mean minimum temperature rate of 0.176 °C per decade) (Ren et al., 2017). In the last two and a half decades (1982−2006), the temperature increased by 1.5 °C (0.6 °C per decade) compared to 0.6 °C at the global level (Shrestha et al., 2012). Precipitation slightly decreasesd over the last 100 years, but with a statistically significant increase of 5.3% per decade over the last six decades, with more rapid increases since the mid-1980s (Ren et al., 2017). Projections suggest that the future will be warmer and wetter in the northwest Himalayas and the Karakoram mountain range, compared to the present, including increases in climatic extremes (Sanjay et al., 2017). The temperature increase is expected to be higher in the Himalayan region than the global average, with a global temperature rise of 1.5 °C, leading to a warming of 2.1 ± 0.1 °C by the end of the 21st century (Shrestha et al., 2015). The Projected precipitation change is 7% for RCP4.5 and 10.6% for RCP8.5 by 2100 (Wu et al., 2017).

Changes in temperature and precipitation are expected to affect all climate-dependent sectors, such as water resources, agriculture, and health (IPCC, 2014; IPCC, 2019; Nie et al., 2021). The health of human populations is sensitive to shifts in weather patterns and therefore, ultimately, to climate change. Health effects can occur directly, due to changes in temperature and precipitation, and indirectly by ecological disruptions brought on by climate change (e.g. shifting patterns of disease vectors) (Woodward et al., 2014).

Major vector-borne diseases (VBDs) endemic to the HKH region include malaria, lymphatic filariasis, Japanese encephalitis, visceral leishmaniasis, chikungunya fever, and dengue fever. These VBDs are caused by pathogens transmitted to or among humans by insect vectors (mosquitoes and sandflies). The geographic range and life cycle of these vectors are sensitive to temperature changes and thus, ultimately, to climate change (Tabachnick, 2010). The distributions of disease vectors and disease transmission are projected to shift to higher elevations (IPCC, 2014). A recent systematic review shows a widespread expansion of VBDs, specifically of dengue and chikungunya in the HKH region with an increasing trend of infection and highly seasonal prevalence (Phuyal et al., 2020).

Establishing a relationship between VBDs and climate change requires evidence of: 1) association(s) with weather variables such as temperature and/or precipitation; 2) biological sensitivity of the vector to temperature and/or precipitation; and 3) changes in disease prevalence (VBDs) with changes in temperature and/or precipitation (Kovats et al., 2001). The first two criteria are satisfied, whereas the third needs further research in the HKH region. The potential impacts of climate change on VBDs in the HKH region are beginning to be explored to inform health system preparedness (Confalonieri et al., 2007; Dhimal, 2015; IPCC, 2014). In the present study, we systematically explore the literature for empiric associations of climate variables with VBDs and their vectors in the HKH region. This systematic review allowed us to identify the most significant variables to be considered for evidence-based trend estimates of the effects of climate change on VBDs and their vectors in the HKH region.

2. Materials and methods

2.1. Study area

The HKH region extends over more than 4.3 million km^2 and comprises approximately 18% of the world's mountain areas. The region stretches across 3500 km, encompassing all or parts of eight countries, from Afghanistan in the west to Myanmar in the east, including all of Nepal and Bhutan, and the mountainous areas of Afghanistan, Bangladesh, China, India, Myanmar, and Pakistan (Singh et al., 2011). Precipitation is dominated by the Asian summer monsoon in the central and eastern regions and by the westerlies in the western Himalayas. Temperature follows an altitudinal gradient (Sun et al., 2017). The climate is subtropical to temperate in the lower-elevation areas and sub-alpine to alpine in the higher-elevation areas. The region is undergoing rapid change, driven by climate change and urbanization, threatening economic development, quality of life, and environmental sustainability (Mukherji et al., 2018).

2.2. Search terms

A literature search was conducted following the preferred reporting items for systematic review and meta-analysis (PRISMA) guidelines. All Web of Science databases were searched for peer-reviewed articles published until the 8th of December 2020 including Web of Science Core Collection, Biological Abstracts, BIOSIS Citation Index, Current Contents Connect, Data Citation Index, Derwent Innovations Index, KCI-Korean Journal Database, Medline, Russian Science Citation Index, SciELO Citation Index and Zoological Record. Only peer-reviewed articles published in English were included and reported associations between climatic factors and VBDs in the HKH region were summarized.

The search term was applied to the title, abstract, and keywords (topic search) and was established based on the following inclusion criteria that secure the reference to the region, climate, and vector/pathogen/disease:

A) Names of countries in the HKH region or names of territories of countries as well as river and mountain areas in the HKH region (given by the International Centre for Integrated Mountain Development, ICIMOD) (Eriksson et al., 2009). Additionally, rivers and mountains of the HKH region and their synonyms were added.
B) Weather and climate variables.

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C) VBDs and their synonyms and related insect vectors and pathogens that are relevant for the HKH region.

2.3. Literature database and analysis

A systematic literature search ($n = 928$) was conducted on climate change and VBDs and their vectors in the HKH region following the PRISMA guidelines (Fig. A1). The articles were then screened to determine whether they met the inclusion criteria. The HKH region was defined as outlined above and using a map by ICIMOD (Sharma and Partap, 1994; Eriksson et al., 2009). For final eligibility, the 75 articles that fulfilled all our inclusion criteria were reviewed based on full texts, thematically analysed, and included in the final database.

Each of the included studies was coded with a pre-formulated rating sheet with relevant data extracted and recorded by two reviewers. Further verifications of extracted data were carried out by two independent reviewers. The extracted data included: title of the study, type of study, methods used, and main findings. Most of the articles were case reports and descriptive studies. It was not possible to pool the results using a meta-analysis because of significant heterogeneity in the study designs and the outcome measures. Descriptive summaries were generated.

2.4. Analysis of relationships between VBDs and climatic variables

The included 75 articles were sorted and summarized by VBDs and their vectors: 1) malaria and *Anopheles*; 2) dengue and *Aedes*; 3) chikungunya and *Aedes*; 4) Japanese encephalitis and *Culex*; 5) lymphatic filariasis and *Culex*; 6) Zika and *Aedes*; 7) visceral leishmaniasis and *Phlebotomus*; and 8) multiple diseases and vectors. The 75 included articles mainly addressed epidemiological and entomological aspects of VBDs using predominantly descriptive or model-based methods. Significant associations were reported between temperature, rainfall, and relative humidity and the incidence of VBDs and disease vectors.

Next, the associations of the VBDs and their vectors with climatic variables were synthesized. The significance of positive, negative, or no associations between the following variables and specific diseases and vectors were documented from the full texts and plotted accordingly: 1) season and weather; 2) temperature; 3) precipitation/rain/rainfall; 4) evapotranspiration/evaporation; 5) humidity; and 6) ice formation.

2.5. Publication bias and quality evaluation of studies

Due to very few studies and historically limited number of cases of VBDs reported in the HKH region, this review considered all available analytical and non-analytical studies including cases reports and case series. Therefore, an assessment of publication bias is not applicable (Morton et al., 2011). The Grading of Recommendations Assessment, Development, and Evaluation (GRADE) is not suitable for this review. For this reason, we did not perform a formal evaluation of the quality of the included studies (Morton et al., 2011).

3. Results

3.1. Expansion of VBDs and their vectors in the HKH region

Dengue virus (DENV) has expanded its geographical range in the HKH region. Namely, dengue fever was not endemic in Nepal and Bhutan before 2004. Since 2004, there was a rapid expansion of the DENV and its vectors, placing the majority of the population at risk (Pandey et al., 2004, 2008; Malla et al., 2008; Dorji et al., 2009; Pandey and Costello, 2019; Dumre et al., 2020; Prajapati et al., 2020). In Nepal, during the first outbreak of dengue fever in 2006, 32 cases were reported from nine districts (Malla et al., 2008; Pandey et al., 2008). During the 2019 outbreak in Nepal, as of September 2019, more than 10000 cases dengue cases from 68 districts were reported, indicating rapid geographical expansion and a drastic increase of cases (Pandey and Costello 2019). Similarly, expansion of DENV vectors was reported from India in the Eastern Himalayas (Aditya et al., 2009). The first autochthonous cases of chikungunya virus (CHIKV; transmitted by *Ae. aegypti* and *Ae. albopictus*) were reported in 2013 in Nepal (Pun et al., 2014) and the first chikungunya fever outbreak in Bhutan was reported in 2012 (Wangchuk et al., 2013). Since 2012, there has been a geographic expansion of the range of CHIKV in the HKH region (Pandey et al., 2015, 2017; Nsoesie et al., 2016; Wahid et al., 2017).

Projections of dengue fever risk in Nepal under different climate change scenarios show that DENV-endemic areas are expected to slightly shift towards higher elevations north of the lowland Tarai and less elevated river valleys in hill and mountain areas. The population exposed to areas suitable for DENV transmission in Nepal is projected to further increase in the 2050s and almost double in the 2070s (Acharya et al., 2018).

Malaria has been endemic in South Asia for many years (Robertson 1941; Issaris et al., 1953; Dhimal et al., 2014a). In accordance, malaria and its vector are increasingly being reported from hills and mountain areas of the HKH region between 1980 and 2010 (Dutta et al., 1991, 2002; Xu et al., 1992; Bouma et al., 1996; Prakash et al., 2000; Sharma et al., 2009a; Dev et al., 2010; Ahmed et al., 2013; Dhimal et al., 2014b; Mutheneni et al., 2014; Vanlalruia et al., 2014b; Wangdi et al., 2020). Projections indicate further geographic expansion of malaria vectors to higher altitudes (Martens et al., 1999; Ebi et al., 2007; Eriksson et al., 2008; Dhiman et al., 2010). Thus, the duration of the malaria transmission window in India is projected to increase in the northern and western states in high altitudes of mountains and hills (Bhattacharya et al., 2006).

In addition, Japanese encephalitis virus (JEV) transmission is established in the hill and mountain areas of the HKH region. Between 1963–1975 it was reported in the mainland of China and in 1995 in the capital of Nepal Kathmandu, which were previously considered as non-endemic for JEV (Zimmerman et al., 1997; Partridge et al., 2007; Bhattachan et al., 2009; Impoinvil et al., 2011; Thakur et al., 2012; Li

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et al., 2014; Baylis et al., 2016). Underlining these findings, the establishment of Culex tritaeniorhynchus, the principal vector of JEV, was reported from the HKH mountain regions (Li et al., 2011; Thakur et al., 2012; Dhimal et al., 2014b).

Similarly, autochthonous visceral and cutaneous leishmaniasis cases and their vectors are being reported from new areas that were considered non-endemic, mostly in hilly and mountain areas of the HKH region (Joshi et al., 2006; Sharma et al., 2009b; Pandey et al., 2011; Pun et al., 2011, 2013; Schwarz et al., 2011; Yangzom et al., 2012; Uranw et al., 2013; Raina et al., 2016; Shrestha et al., 2018, 2019).

3.2. Association of weather and climate variables with VBDs and their vectors in HKH region

Publications reporting associations between climate variables (temperature, precipitation, and relative humidity) and diseases or vectors in the HKH region most commonly focused on malaria and its vectors, *Anopheles* mosquitoes ($n = 82$; 60%). Among these studies, the prevalence of malaria and its vectors were positively associated with climate change/global warming ($n = 5$), temperature ($n = 19$), season/weather ($n = 18$), precipitation ($n = 14$), humidity ($n = 7$), and evapotranspiration/evaporation ($n = 1$) (Fig. 1a). In contrast, a few studies reported no association with temperature ($n = 3$), precipitation ($n = 3$), and humidity ($n = 2$), and negative associations with temperature ($n = 3$), humidity ($n = 1$), and climate change/global warming ($n = 1$) (Fig. 1a).

Compared to malaria, there were few studies of the associations between weather variables and other VBDs (Fig. 1b–d). Dengue fever, chikungunya fever, and their vectors were positively associated with humidity ($n = 6$), precipitation/rain ($n = 7$), temperature ($n = 9$), and season/weather ($n = 3$; Fig. 1b). In contrast, three articles reported negative associations with humidity and precipitation/rain. Almost all studies (4 out of 5) show a positive association of temperature, rainfall, and humidity with JE and its vectors. Only two articles reported associations of weather variables with visceral leishmaniasis and its vectors.

Temperature and precipitation/rain appear to be key determinants of outbreaks of VBDs in the HKH region. For example, one modelling study (Vanlalruia et al., 2014) concluded that rainfall and relative humidity are positively correlated to mosquito larval density in Mizoram, North Eastern Himalayan region. Another study (Shrestha et al., 2017) projected a 10.1% rise in VBD cases per 1 °C rise in average temperature in Nepal. Similarly, a 1 °C increase in minimum and mean temperatures were projected to increase malaria incidence by 27% and 25%, respectively, in Nepal (Dhimal et al., 2014c).

4. Discussion and future perspectives

The review of observed changes and future climate projections indicate a conducive environment for the transmission of VBDs in the HKH region, with an expansion of VBDs and their vectors in the eye of climate change. This literature synthesis shows weather and climate variables are associated with VBDs in the HKH region. Most of the studies (39.5%) reported a positive association between temperature and incidence of malaria, while very few studies (13.9%) reported a negative or no association with temperature. All studies showed a positive association with precipitation, while relative humidity had positive and negative associations. Studies projected an increasing trend of the epidemic potential and transmission season of malaria in temperate regions, i.e. highlands, due to climate change (Jetten et al., 1996; Mordecai et al., 2013; Caminade et al., 2014; Siraj et al., 2014). This is consistent with reports from other regions, such as Ecuador and the Andean valleys, where vector species are projected to shift their geographic range to highland areas, potentially affecting new regions and human populations (Escobar et al., 2016; Pinault and Hunter, 2011).

More literature focused on the association between malaria and weather/climate variables because malaria is the oldest known VBD in the HKH region, so long-term time-series data are available. Malaria elimination is a priority target of every country in this region (Sachs, 2005), and has received wider attention. However, despite these efforts, malaria is still a public health problem in all countries of the HKH region. Support from global funds in the last two decades (Feachem et al., 2010) have eliminated malaria foci in previously defined high risk areas. However, malaria outbreaks continue to occur in the highlands of Nepal, where malaria intervention programmes were not in place (Himalayan Times, 2019).

A few studies reported negative associations of malaria with maximum temperature. This is plausible because high maximum temperatures increase the mortality of anopheline vectors before the development of the malaria parasites is completed in the mosquito (Martens et al., 1995; Patz et al., 2000). Several other studies reported impacts of weather, climate variability, and climate change on malaria transmission in the highlands (Hay et al., 2002; Patz et al., 2002; Caminade et al., 2014; Siraj et al., 2014).

Plasmodium vivax is the predominant malaria parasite in South Asia (Gething et al., 2012), and *P. vivax* malaria is recognized as a neglected disease in terms of research and interventions because it is generally associated with low mortality outside the HKH region, but with high morbidity in this region (Price et al., 2007; Carlton et al., 2011). The expansion of malaria into the highlands due to climatic and environmental changes threatens the malaria elimination goals of the countries in the HKH region (Cotter et al., 2013).

There are seasonal patterns in the effects of temperature on vectors and VBDs in the HKH region. Although precipitation and humidity also affect the transmission of VBDs, seasonal temperature variation played a predominant role in explaining the geographical distribution of VBD (Sachs and Malaney, 2002). The local adaptation of disease vectors to micro-climatic variation (local set of atmospheric conditions variations that differ from those in the surrounding areas, often with a slight difference but sometimes with a substantial one) may modulate the effects of short- and long-term changes in weather and climate (Sternberg and Thomas, 2014). The duration of the mosquito season may increase with climate change in the HKH region because more

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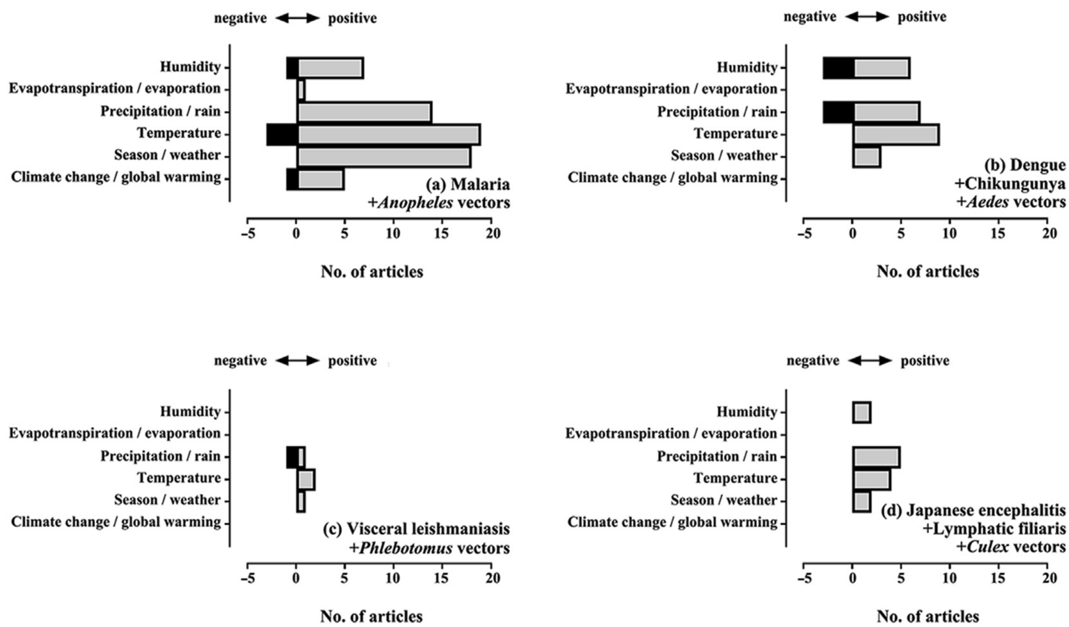

Fig. 1. Associations of six climatic variables and (a) malaria and its vectors, *Anopheles* mosquitoes; (b) dengue fever and chikungunya fever and their vectors, *Aedes* mosquitoes; (c) visceral leishmaniasis and its vectors, *Phlebotomus* sandflies; and (d) Japanese encephalitis, lymphatic filariasis and their vectors, *Culex* mosquitoes. Light grey bars indicate the number of publications reporting positive associations, and black bars those reporting negative associations.

generations of vectors may be produced each year (Sutherst, 2004). Therefore, the greatest effect of climate change on VBD transmission may be observed in the cooler areas of the HKH region, where the minimum temperature is limiting disease transmission, and in warmer areas where temperatures above 34 °C have a negative impact on the survival of vectors and pathogens (Watts et al., 1987; Rueda et al., 1990; Githeko et al., 2000). Moreover, as the warming rate is higher at higher latitudes and in highlands compared with the tropics and lowlands (IPCC, 2007, 2013), vectors and pathogens experience more differential warming (Epstein, 2010). IPCC (2014) highlighted the alterations of the distribution of the disease vectors from climate change and projected an increased risk of VBDs in highlands based on the current trend in greenhouse gase emissions and the consequent changes in climate (Woodward et al., 2014; IPCC 2014).

Studies on dengue fever and chikungunya fever and the abundance of their vectors (*Ae. aegypti* and *Ae. albopictus* mosquitoes) always reported a positive association with temperature; results on the associations with precipitation and relative humidity were mixed. Two studies of weather and climate on dengue fever (Bouzid et al., 2014; Liu-Helmersson et al., 2014) indicated that the effect of rainfall on dengue was mixed because DENV vectors are container-breeding mosquitoes, and too much and too little water can adversely affect their development, growth, and virus transmission. There were only a few studies, mostly case reports, on the association between weather variables and dengue fever and chikungunya fever because they emerged in the HKH region only recently (Pandey et al., 2004; Dorji et al., 2009; Wangchuk et al., 2013; Pun et al., 2014).

A second reason for the low number of publications might be that dengue fever and chikungunya fever are neglected tropical diseases, research funding for which has been limited globally and especially so in the HKH region. The establishment of their vectors at locations higher than 2000 m above sea level (Aditya et al., 2009; Dhimal et al., 2014b, 2015) and the positive association with temperature indicate there will likely be early effects of climate change in the HKH region. For example, *Ae. aegypti* and *Ae. albopictus* sampled in Nepal survived cold temperatures for a short period. With increasing temperatures due to climate change, both species may spread to higher altitudes; a cold winter may no longer be preventative for the establishment of the dengue vector (Kramer et al., 2020). Furthermore, *an Ae. albopictus* population originating from a higher altitude shows high ecological plasticity in overwintering capacity compared to lowland populations and *Ae. aegypti* can survive winter cold especially when acclimated and will probably further spread to colder ecoregions (Kramer et al., 2021). The expansion of disease vectors and the increasing number of autochthonous cases of DENV and CHIKV infections have been reported in Europe and the highlands of Mexico, and both weather and non-climatic factors are contributing factors (Lindgren et al., 2012; Lozano-Fuentes et al., 2012; Tomasello and Schlagenhauf, 2013). A systematic review and meta-analysis shows that minimum temperature, mean temperature, and maximum temperature were positively associated with dengue transmission, and temperatures between 22 °C to 29 °C are strongly correlated to a higher dengue fever incidence (Fan et al., 2014).

In our study, only two articles were found to report associations of climate/weather variables with visceral leishmaniasis and its vectors. However, expansions and outbreaks of visceral leishmaniasis have been reported for many countries of the HKH region in recent years and are correlated with the warming of highland regions in recent decades (Joshi et al., 2006; Pandey et al., 2011; Schwarz et al., 2011; Pun et al., 2013; Mathur and

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Arya, 2014; Ahmad et al., 2016). Despite the low number of studies, research in other parts of the world show impacts of climate and climate change on the occurrence and transmission of leishmaniasis (Cardenas et al., 2006; Ready, 2008; Gonzalez et al., 2010; Salomonet al., 2012).

There were only a few studies on associations between weather and climate variables and Japanese encephalitis and lymphatic filariasis and their vectors (mosquitoes of the genus *Culex* such as *C. quinquefasciatus* and *C. tritaeniorhynchus* in the HKH region), with all showing positive correlations. Several studies reported temperature and precipitation as major environmental factors influencing JEV transmission in Asia (Bi et al., 2003; Hsu et al., 2008; Murty et al., 2010; Impoinvil et al., 2011; Bai et al., 2014). Thus, climate change may alter the spatial and temporal distribution of JEV transmission in the region. Several studies reported transmission of JEV at high altitudes in the HKH region (Partridge et al., 2007; Bhattachan et al., 2009; Li et al., 2011). The establishment of *Culex* vector mosquitoes at altitudes higher than 2000 m above sea level poses a threat to the lymphatic filariasis elimination goals of countries in the HKH region. Model projections indicate that climate change and population growth were the dominant factors for projecting the risk of infection and spread of lymphatic filariasis on the African continent (Slater and Michael 2012, 2013); there are no comparable studies for the HKH region.

Socio-economic development, access to healthcare, and vector control measures can reduce the impact of climate change on VBDs in some areas where health systems are strong (Gething et al., 2010; Beguin et al., 2011; Astrom et al., 2012). The challenges are expected to be higher in the poorest and most vulnerable regions with the least economic growth (Beguin et al., 2011; Astrom et al., 2012; Woodward et al., 2014). Against a background of weak healthcare systems, difficult geographic terrain, lack of vector control interventions, especially in the highlands, and a continuous influx of infected people from disease endemic areas, climate change could intensify the potential risk of VBD epidemics in the HKH region.

Consequently, there is an urgent need for increasing the capacity of research groups from all HKH countries. South−South and South-North research collaborations must be enhanced to generate more evidence of the impacts of climate change in the HKH region, including through sentinel sites of climate change, long-term biodiversity monitoring sites, and heavily frequented tourist destinations. Only concerted transnational and multidisciplinary research actions that embrace a 'One Health' concept and strengthen regional, as well as South-North collaborations, hold sufficient promise for improving evidence-based decision-making fast enough to impact the prevention and control of VBDs in the fragile and highly vulnerable HKH region. Further research using long-term data records and controlling for possible confounders in analyses is needed for all countries of the HKH region.

It is unequivocal that climate change is happening, the warming rate is much higher in the HKH region and as a result of this, the geographical expansion of several VBDs, including malaria, dengue, Japanese encephalitis, leishmaniasis, etc. and their vectors to higher altitudes and latitudes of HKH region is observed. However, there are very limited studies to show causal relationships between climate change and VBDs in the HKH region using long term time series data. Over the years, there has been a reduction in the incidence of almost all the diseases in previously considered high endemic areas but an expansion of diseases in highland areas that were previously considered non-endemic is a great challenge for the elimination and control of these VBDs due to geographical difficulties and high risk of environmental damage due to insecticides and chemical sprays in a pristine environment that is rich in biological diversity. There is an urgent need to increase surveillance and monitoring of VBDs in highland areas, sharing data among member countries of the HKH region, and assessing the detailed impacts of climate change on VBDs. Finally, early case detection, prompt treatment, and vector control are needed to prepare for and prevent outbreaks of VBDs.

5. Conclusions

The study demonstrates positive associations between weather and climate variables and VBDs in the HKH region and the expansion of VBDs and disease vectors. There are positive associations between weather/climate variables and malaria, dengue fever, chikungunya fever, Japanese encephalitis, lymphatic filariasis, and visceral leishmaniasis. Observed and projected rise in temperature and precipitation patterns are conducive for the transmission of VBDs in the HKH region, especially in parts that have previously been considered non-endemic for these diseases. Most epidemiological and entomological studies reported VBDs to have expanded their geographical ranges over the years, especially in the highlands of the HKH region. Heterogeneous distributions and spatial−temporal variations of VBDs with trends of weather variables across the HKH region suggest that well-designed long-term regional studies are needed to assess the effects of climate change on the transmission and distribution of VBDs into new areas. Therefore, vector and VBD monitoring, surveillance, and research should be strengthened in areas with limited VBD control programmes. National and international cooperation in the monitoring, surveillance and scientific research of vectors and VBDs should consider the extent to which climate change could lead to the expansion of vectors and VBDs in the HKH region.

Declaration of competing interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

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