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Impacts on Human Health of Climate and Land Use Change in the Hindu Kush–Himalayan Region

Overview of Available Information and Research Agenda

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Mountains are hotspots of climate and land use change. The Hindu Kush–Himalayan (HKH) region features some of the world's most vulnerable ecosystems and is highly susceptible to climate change. Both climate change and land use transition in the HKH region have impacts on human health. A warming trend is driving the geographical expansion of disease outbreaks, whereas ecological changes and economic inequalities influence the spread of diseases. Altered distributions of vector species are early signs of climate change, and pests, pathogens, and parasites are among the first scourges to emerge during periods of transition. The distribution and seasonal transmission of vector-borne infections among humans may be affected by climate change. Information on the impacts of such changes on human health in the region is scanty. This article reviews literature on the impacts of climate change and land use transition on human health in the HKH region, specifically dealing with topics such as the relationship between climate change and health; health sensitivity, vulnerability, and adaptation; health determinants related to climate change; temperature extremes and health issues; air pollution, black carbon, and health; food security, nutrition, and health; land use change and infectious diseases; and population migration and livelihood transition. The article outlines an agenda for future research on climate change and human health for the HKH region.

Keywords: *Black carbon; climate extremes; diseases; health determinants; mountains; vulnerability.*

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Introduction

Mountains have ecological, aesthetic, and socioeconomic significance, not only for people living in mountain areas but also for those living in the adjacent lowlands (Schild and Sharma 2011). Recently, the Hindu Kush–Himalayan (HKH) region has been facing major challenges from climate, socioeconomic, and land use change (Singh et al 2011). A recent climate change study in the eastern Himalaya has also shown direct impacts on ecosystem services, livelihoods, and human wellbeing (Tse-ring et al 2010). Understanding the impacts of these interrelated changes on human health and the uncertainties related to the scales and rapid pace of change is an urgent but difficult task that requires more than fragmented small-scale studies on various aspects of the problems at hand.

Over the past decades, the fact that the world's climate has been changing rapidly has become evident (IPCC 2001). Global climate change poses a number of potential risks to mountain ecosystems, which are particularly sensitive even to small changes (Schild and Sharma 2011). The HKH region features some of the world's most vulnerable ecosystems and is highly susceptible to climate change impacts (IPCC 2007). Such diverse mountainous regions as the HKH have recently been under acute pressure from environmental change and human activities; these pressures are impacting on human wellbeing and especially on human health (Singh et al 2011). Future projections of climate change-related health impacts vary by health outcome and region, with most of the projected disease burden being due to increases in diarrheal disease and malnutrition, primarily among low-income populations already experiencing a large burden of disease (Campbell-Lendrum et al 2003; McMichael 2004). The projected health impacts of climate change are predominately negative, with the most severe impacts being seen in low-income countries, where the capacity to adapt is weakest (IPCC 2001; Regmi et al 2006).

Climate change has both direct and indirect influences on human health in mountain areas, as reviewed earlier (WHO 2006; Ebi et al 2007). Another major driver of change in the Himalaya that affects human health is land use transition (Xu et al 2008a). Generally speaking, however, information about climate change impacts on human health in the HKH region is scanty, as already noted by Ebi et al (2007). Moreover, there is a need for comprehensive and systematic studies embedded in an overall integrative framework. This article provides conceptual information and reviews existing studies on a number of impacts of climate and land use change on human health. It concludes with a proposal for a more integrative research agenda that focuses on human health in the HKH region.

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TABLE 1 Health determinants and health outcomes that currently exist in mountain regions or are related to mountains. (Based on WHO 2006, p 23, slightly modified) [a)]

Health determinants and outcomes	Country					
	Afghanistan	Bangladesh	Bhutan	China	India	Nepal
Heat waves	+	+	−	+	+	+
Glacial lake outburst floods	M	−	M	M	M	M
Flash floods	M	+	M	M	M	M
Riverine (plain) floods	+	+	−	+	+	+
Water scarcity, water quality	M	+	+	M	M	M
Drought-related food insecurity	M	+	−	M	M	−
Diseases						
Water-borne diseases	M	+	M	M	M	M
Malaria	+	+	+	+	+	M
Japanese encephalitis	−	+	−	+	+	+
Kala-azar	+	−	−	−	+	+
Dengue	−	+	+	+	+	−

[a)] +, health determinant or outcome is present elsewhere in the country; −, health determinant or outcome is not present in the country; M, health determinant or outcome present in the mountainous region of the country (and also in the nonmountainous areas).

Review

Relationship between climate change and health

The Intergovernmental Panel for Climate Change (IPCC) in their second (1996) and third (2001) assessment reports provided some early evidence of actual health impacts related to changes in the frequency and intensity of extremes of heat and cold, floods, and droughts, and projected increased threats to human health that would manifest themselves particularly in lower-income populations, predominantly in tropical and subtropical countries. In general, climate change can have 3 types of impact on human health:
(i) direct impacts of weather extremes; (ii) the consequences of ecological disruption; and (iii) various health consequences, such as traumata, infections, and nutritional, psychological, and other impacts that occur among displaced populations in the wake of climate-induced dislocation (WHO 2003).

As mentioned above, the relationship between climate change and health impacts has not been studied much in the HKH region. However, there are some scattered anecdotal examples that are indicative of climate change impacts on health (WHO 2006). The main climate-sensitive health determinants and outcomes in the countries of the HKH region (WHO 2006) are summarized in Table 1.

Human health sensitivity, vulnerability, and adaptation

Assessing the potential health impact of climate variability and change requires an understanding of both the vulnerability of populations and their capacity to respond to new conditions. According to the IPCC, the vulnerability of human health to climate change is a function of (i) sensitivity to changes in weather and climate; (ii) exposure to weather- or climate-related hazards, including the character, magnitude, and rate of climate variation; and (iii) adaptation measures and actions in place to reduce the burden of a specific adverse health outcome.

Adaptation measures can greatly reduce many of the potential health impacts of climate change (WHO 2000). The most important, cost-effective, and urgently needed measure is to rebuild public health infrastructure. Many diseases and public health problems that otherwise might be exacerbated by climate change could be prevented substantially or completely with adequate financial and public health resources, research to develop and implement more effective surveillance and emergency response systems, and sustainable prevention and control programs.

The current climatic trends in the HKH region may cause shifts in the geographical range and the seasonality of diseases such as malaria and dengue (Dhiman et al

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TABLE 2 Populations vulnerable to climate-sensitive health determinants and outcomes in the HKH region. (Based on WHO 2006, p 25, slightly modified)

Health determinant or outcome	Vulnerable populations
Heat wave mortality	Slum dwellers, elderly people, children, agricultural and outdoor laborers, urban dwellers, people working in crowded and unventilated workplaces, homeless people
Glacial lake outburst floods	Elderly people, poor people, nomads, children, disabled or infirm people, women, independently living ethnic groups in remote areas
Flash floods	Everyone in the path of floods
Riverine (plains) floods	Elderly people, poor people, nomads, children, disabled or sick people, women, people living in poor housing, in coastal areas, or on isolated islands
Water scarcity, poor quality	Children, women, poor people, people without access to clean water and sanitation, inhabitants of flood areas, people without education regarding health and hygiene
Drought-related food insecurity	Children, elderly people, pregnant women, women in general
Water-borne diseases	Children, women, poor people, people without access to clean water and sanitation, inhabitants of flood areas, people with poor access to health and hygiene
Malaria	Children, pregnant women, slum dwellers, homeless people, migrants, people living in areas with poor environmental hygiene, independently living ethnic groups in remote areas
Japanese encephalitis	Farm workers (especially in paddy fields), children, people living with pigs
Kala-azar	People living on the ground floors of buildings in endemic areas, poor people
Dengue	People in urban areas
Filariasis	Poor people in foothills or high-humidity areas

2011). However, such shifts would also depend on local topographical and ecological circumstances, other determinants of local populations' vulnerability, and the existence and level of public health defenses. Populations, subgroups, and systems that cannot or will not adapt are more vulnerable than those who are more susceptible to weather and climate variability (WHO 2006).

Health determinants specific to climate change in the HKH

An overview of health determinants specific to climate change in the countries of the HKH shows that approximately half of these determinants depend on water supply and half are related to the spread of infectious diseases (Table 1). In mountainous areas, the proportion is different, however, with most health determinants dependent on water. Because the lowlands depend on water from the highlands, climate-related changes in water supply in the highlands will also affect the populations that live downstream of the HKH.

These highland–lowland interactions with regard to health have not yet been sufficiently explored. Indeed, water scarcity, caused either by a reduction in water availability as a result of reduced snowmelt or by increased drought, is likely to increase water-related health hazards in the populations of arid downstream basins such as the Indus.

In addition, erratic precipitation and increased glacial melting might exacerbate the various types of flooding that are already common in mountain areas, such as riverine floods, flash floods, glacial lake outburst floods, and breached landslide dams. Such extreme weather events can increase the risk of diseases via the contamination of water resources, poor hygiene, and other socioeconomic factors. Floodwaters, often accompanied by large amounts of debris, can lead to collateral damage and human catastrophes miles from the outburst source. Vulnerable groups, such as the poorest people, those from a low caste, women and children, and the elderly, are often hit the hardest (Table 2) (WHO 2006). Reductions in the supply of good-quality water are increasing the burden of diarrheal disease in most mountain regions (Pokhrel and Viraraghavan 2004). Cholera may also emerge as a significant health risk given its current incidence in some parts of the Indian Himalaya and Nepal (Sarkar 2010). Moreover, after a climate-related disaster, mountain village communities have to deal with severe damage to their property and livestock, which entails an immediate threat to their livelihoods and food security but can also lead to protracted socioeconomic stress with related health implications, even though this aspect of extreme events is seldom highlighted (Eriksson et al 2008).

A long-term warming trend encourages the geographical expansion of several important

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infections with clusters of disease outbreaks (Epstein 2000). Ecological changes and economic inequities strongly influence the spread of diseases, and the warming and instability of the climate is playing an ever-increasing role in driving the global emergence, resurgence, and redistribution of diseases (McMichael 2004). An altered distribution of vector species may be among the early signs of climate change, and pests, pathogens, and parasites are among the first to emerge during periods of transition. In addition, the distribution and seasonal transmission of vector-borne infections (such as malaria, dengue, and schistosomiasis) may be affected by climate change (Sutherst 1998). In Nepal, outbreaks of kala-azar and Japanese encephalitis have been linked to climate change, particularly in the subtropical and hot regions (Regmi et al 2006). In India, there has been growing concern about the changing pattern of most of these diseases as a result of climate change. The vector *Falciparum* for transmitting malaria is reported to be spreading to higher altitudes in the Himalaya (Bhattacharya et al 2006). Himalayan populations, with no history of exposure to these pathogens, are likely to be more vulnerable than their tropical counterparts (Sarkar 2010). Raina et al (2009) have also reported the possible upward transmission of the leishmaniasis vector beyond 600 m in Garhwal and Himachal Pradesh in India, where it was previously not endemic. Similarly, clinical cases of dengue, as well as larvae of its principal vector, *Aedes aegypti*, have been recorded in the Kumaon hills at elevations higher than previously reported (Shukla and Sharma 1999).

Temperature extremes and health issues

Most of the predictive modeling studies that use climate change scenarios have estimated future temperature-related mortality. Global average temperatures are projected to increase between 1.8°C and 4.0°C by the end of this century (IPCC 2007). Climate change is expected to raise overall temperature distribution and contribute to an increase in the frequency of extreme heat events. Heat-related health impacts include heat exhaustion, heat cramps, heat stroke, and death. However, in temperate countries and mountainous, high-altitude areas, the reduction in winter deaths may outnumber the increase in summer deaths. Without proper research data, the net impact on annual mortality is difficult to estimate, and it will also vary among populations (WHO 2003). Most excess deaths during times of thermal extremes occur in populations with preexisting health problems, such as cardiovascular and respiratory diseases (WHO 2003).

In mountain regions, where the majority of the population is poor, people who have contributed little to climate change in terms of carbon emissions suffer disproportionately from the negative impacts of climate change (Bonasoni et al 2010; ICIMOD 2011). The temperature increase in the Himalayan region has been greater than the global average of 0.74°C over the past 100 years (Du et al 2004; IPCC 2007). The higher the altitude, the more rapid the warming: this can also be noted in temperature records from the HKH region (Shrestha et al 1999; Liu and Chen 2000; Shrestha and Aryal 2011; Singh et al 2011). The regional mean temperature rise in high-altitude areas is almost double that recorded in the foothills in Nepal (Shrestha et al 1999) and the eastern Himalaya (Tse-ring et al 2010). Indications of health hazards occurring predominantly in tropical areas might be observed in the temperate and cooler areas of the Himalaya in the future (Xu et al 2008b). However, the impact of climate change on human health is not always entirely negative. For example, a warm winter may reduce cold-related diseases and deaths. During the past few decades, elderly people living in the high mountains and herders on the Tibetan Plateau have felt more comfortable in the wintertime (Eriksson et al 2008; Xu et al 2008b).

Air pollution, black carbon, and health

Studies that examined the links between climate change, air pollution, and health focus on impacts of weather and air pollution on health outcomes as well as on future air pollution levels. Patz et al (2000) reported that climate change may increase the concentration of ground-level ozone, but the magnitude of the effect remains uncertain. A large part of the change observed in the HKH region's climate has been driven by the presence of aerosols that contain black carbon (Colombo and Decesari 2010; Bonasoni et al 2012, in this issue). This black carbon arises from the burning of fossil fuels, biofuels, and biomass. Black carbon deposited on the snow is likely to increase the melting rate due to increased absorption of solar radiation (Ramanathan and Carmichael 2008). In China, deposition of black carbon on glaciers has accelerated their melting by 5% (ICIMOD 2011). The bulk of black carbon worldwide is emitted in the developing world (Bond et al 2004), and results of the most recent research has shown that upward transport of pollutants constituting the northern rim of the South Asian atmospheric brown cloud are affecting the southern side of the Himalaya (Bonasoni et al 2012, in this issue). Recently, the HKH region has been experiencing forest fires after long dry seasons, which adds to the haze that increases black carbon deposition in mountain areas, on the one hand, and reduces photosynthetically active solar radiation on the other hand; a decrease in photosynthetically active radiation, in turn, is expected to reduce agricultural yields. Based on real-time measurements and satellite data, results of recent studies have

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inferred that black carbon mass concentration contributes 5–10% of the total aerosol optical depth over the central Himalaya (Pant et al 2006). Ramanathan and Carmichael (2008) underlined that an increase in the atmospheric concentration of black carbon and its deposition on snow surfaces can decrease the snow albedo, which lead to increased melting of the Himalayan glaciers; this has been confirmed by Menon et al (2010).

A detailed understanding of the chemical composition of aerosols is of utmost interest for assessing aerosol radiative forcing and air quality over the Himalayan region (Ram et al 2010). In addition, scale interactions associated with small-level (<100 km) dynamics might also play a crucial role in the distribution of aerosols in the Himalayan foothills (Prabha et al 2012). These complex dynamics and the interrelated impacts of air pollutants on the environment and on human health in the HKH require further study.

Food security, nutrition, and health

Climate and weather are key factors in agricultural productivity. Changes in temperature, moisture, and rainfall can affect plant physiology. There is also a risk of changes in plant pests and pathogens. Hence, climate change represents an additional pressure on agricultural systems. The IPCC's third assessment report (IPCC 2001) considers agriculture to be one of the systems most vulnerable to climate change in the South Asian region. In Bangladesh, where the majority of people in the Chittagong Hill Tracts are poor and at higher risk, the agriculture sector contributes a major share, of approximately 30%, to the Gross Domestic Product (GDP) and employs more than 60% of the working force (Rahman 2008). The country is vulnerable to many environmental hazards, including frequent floods, droughts, cyclones, and storm surges that damage life, property, and agricultural production. Limited studies indicate a large impact on agriculture, which would make the poor more vulnerable with regard to food security and nutritional aspects of food. In most developing countries, where a majority of the population is already under- or malnourished, additional impacts of climate change on food security and nutrition would increase the vulnerability of those affected by infectious as well as water- and vector-borne diseases (Rahman 2008); the HKH region is no exception, and it has been shown that vulnerability increases with elevation (Ebi et al 2007).

Land use change and infectious diseases

Climate change can precipitate land use change (Kalnay and Cai 2003), thereby impacting food security as well as socioeconomic systems (Parry et al 2004). Most emerging human diseases are driven by human activities that modify ecosystems or otherwise spread pathogens into new ecological niches (Taylor et al 2001). Such modifications or alterations in ecosystems lead to large-scale land degradation, changing the ecology of the diseases that influence human health and making people more vulnerable to infections (Collins 2001). Land use change decisions, whether in response to climate change or otherwise, are thus human health decisions (Xu et al 2008b). There are several examples of the direct effects of deforestation on human diseases. It is clear that habitat alteration can affect the prevalence and incidence of human malaria; the effects of deforestation on the vectors of human malaria are complex and can be influenced by the nature of agricultural development and specific local ecological characteristics (Yasuoka and Levins 2007).

Population migration and livelihood transition

Population growth interfaces with climate change in ways that intensify several other mechanisms, especially in relation to shelter, food, and water scarcity. There have been attempts to examine the ecosystem, health, and poverty nexus in fragile environments (Woodward et al 2000). Population growth leads to both increasing urbanization and more competition for resources such as food, water, and land, and results in even greater environmental degradation. On the Tibetan Plateau, for example, changes in land cover and land use have occurred at an unprecedented rate (Lambin et al 2001; Du et al 2004); the Tibetan lifestyle of nomadic pastoralism has become sedentary, with an observed increase in emerging infections and noncommunicable diseases (Xu et al 2008b).

Rising sea levels due to climate change will be a major factor that contributes to populations' displacement; this may have an impact on the HKH region because displaced populations from lower areas move to the hills and mountains, for example, from the low-lying river deltas of Bangladesh to the Chittagong Hill Tracts (Haughton 2004). In terms of deaths and populations affected, floods and tropical cyclones have the greatest impact in South Asia (Schultz et al 2005). At the same time, Nicholls (2003) has found that the major storm surges in the past 100 years have been confined to a limited number of regions, with many events occurring in the Bay of Bengal, particularly Bangladesh.

Thus, in the HKH region, large-scale population movement is likely to intensify as climate change leads to the abandonment of flooded or arid and inhospitable environments. The resulting mass migration could lead to many serious health problems in connection with the various physiological and psychological stresses of the migration process. Population growth will also increase overall emissions, expand the number of vulnerable individuals (Lancet and University College 2009), and place

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additional stress on already weak health systems.

Conclusion and recommendations

The HKH region is facing major challenges from climate change and its impacts. The natural ecosystems, land use change, and human health are intricately linked. There is very little understanding of the health outcomes and diseases related to climate and land use change. Human health-related sensitivity, and populations' vulnerability, and their adaptive capacity in the changing climate context in the HKH region are areas that warrant special attention. Indeed, extreme climatic events, natural disasters, the emergence of infectious diseases, and impacts on human health are becoming increasingly evident in the HKH region.

In general, climate change can have 3 types of impacts on human health, as elaborated above in the section on the relationship between climate change and health, and it is necessary to consider these impacts from a systemic point of view. Interdisciplinary research helps to gain a better understanding of the complex linkages between the various impacts of climate change on health determinants. For example, climate science should be linked with an analysis of the impacts of weather pattern changes on human health. In addition, research should also address the social and economic aspects of climate-related health issues to contribute the knowledge necessary for developing solutions at the local level. Indeed, although climate change mitigation could reduce health impacts, it is an extremely complex and costly venture because it addresses the issues at the source and requires global-level policies. Instead, enhancing the adaptive capacity of populations and the environment may be a more feasible approach for the developing countries in the HKH region.

New areas for research in the context of the HKH region are air pollution and particulate matter such as black carbon. Both of these have implications on agricultural production, glacier melting, a longer-term water supply, and human health. Much of the biomass burning as well as natural and man-made forest fires in the region contribute to black carbon, which intensifies the brown cloud effect, especially in winter. In addition, biomass burning in mountain households and the related black carbon and gaseous emissions are the source of many health problems and contribute to air pollution. Thus, understanding household and agricultural biomass burning as a contributor to air pollution in mountains, and thinking about technologies to reduce such emissions, should be on the research agenda for the region, in addition to the much-needed further exploration of black carbon and its complex impacts on the environment and human health.

Generally speaking, good environmental health is a precondition for safe and healthy human societies. As this review makes clear, climate change, land use transition, food security and nutrition, and migration and livelihood transition are interrelated and have direct implications on potential health hazards. Understanding the issues and linking research on environmental processes, ecosystems, and human health requires an interdisciplinary approach. Based on the research gaps presented here, the key interdisciplinary research priorities for the HKH region in future should address the major challenges of climate change, land use change, and health in the areas of:

1. Developing methods to quantify the current impacts of climate and weather on a range of health outcomes for people living in the mountains as well as downstream;
2. Improving health impact models for projecting health impacts of climate and land use change under different ecological and socioeconomic conditions; and
3. Valuating the costs of the projected health impacts of climate change and the effectiveness of adaptation for policy inputs.

Most countries of the HKH region have recently prepared either national action plans or adaptation programs to meet the challenges of climate change. However, these programs have not considered human health as a priority. Human health should be seen in an integrated manner and should be considered as a priority area in national adaptation or action plans.

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