Available online at www.sciencedirect.com
ScienceDirect
Environment International xx (2007) xxx–xxx
ENVIRONMENT INTERNATIONAL
www.elsevier.com/locate/envint

Critical linkages between land-use transition and human health in the Himalayan region

Jianchu Xu [a,b,*], Rita Sharma [b], Jing Fang [b], Yufen Xu [c]

[a] *Kunming Institute of Botany, Kunming, Yunnan, China*
[b] *International Centre for Integrated Mountain Development, Kathmandu, Nepal*
[b] *Wuhua District Hospital, Kunming, Yunnan, China*

Received 6 March 2007; accepted 14 August 2007

Abstract

This article reviews critical linkages between land-use transition and human health in the Himalayan region by applying ecosystem approaches to human health (or EcoHealth). Land-use transition in the Himalayan and similar regions includes sedentarization, agricultural intensification, habitat modification, migration, change of livelihoods and lifestyles, biodiversity loss, and increasing flash floods. These transitions, which can have impacts on human health, are driven by state policies, a market economy, and climate change. Human health is dependent on access to ecosystem services for food, nutrition, medicine, fiber and shelter, fresh water, and clear air. Ecosystem management has been a key means of controlling disease vectors and creating suitable habitats for human well-being. The paper identifies the web of environmental factors that influence human health. Institutional and policy issues for land-use and health transitions are also discussed.

Keywords: Himalayas; Land use; EcoHealth; Human health; Ecosystem services; Diseases; Health risk

1. Introduction

Most emerging human diseases are driven by human activities that modify the ecosystems or otherwise spread pathogens into new ecological niches (Taylor et al., 2001). Human activities through land-use practices generate both 'positive' benefits (increases in food and fiber production) and 'negative' costs (species' extinction, soil erosion, land degradation, water pollution, and global warming). The pace, magnitude, and spatial reach of land-cover and land-use change have increased over the past three centuries, particularly over the last three decades, as a result of human activities, and may go beyond the ecosystem's recovery capacity (Lambin and Geist, 2006). Land use affects human health directly and indirectly. It affects fauna and flora, contributes to local, regional, and global climate changes and is the primary source of soil, water and land degradation (Sala et al., 2000; Pielke, 2005; Sthiannopkao et al., 2007). Altering ecosystem services—i.e., the provisions people obtain from ecosystems (e.g., food, water), regulating services (e.g., predator-prey relationships, flood and disease control), cultural services (e.g., spiritual and recreational benefits), and support services (e.g., pollination, nutrient cycling, productivity)—that maintain the conditions for life on Earth affects the ability of biological systems to support human needs (Vitousek et al., 1997). Alterations lead to large-scale land degradation, changing the ecology of diseases that influence human health and making it more vulnerable to infections (Collins, 2001). Risks to human health are increased also by toxicological risks resulting from bioaccumulation of toxic substances through global and regional environmental degradation (Rapport et al., 1998; Darnerud, 2003) and disease outbreaks resulting from disruption of species' dynamics in disease control (Berrang, 2006). Such changes in part determine the vulnerability of coupled human-environment systems to climatic, economic or sociopolitical perturbations (Turner et al., 2003; Ezzati et al., 2002). Land-use decisions are, hence, human health decisions.

* Corresponding author. Kunming Institute of Botany, Chinese Academy of Science, Kunming, Yunnan 650204 China.
E-mail address: jxu@mail.kib.ac.cn (J. Xu).

0160-4120/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.envint.2007.08.004

Paths and rates of land-use change are often driven by the local political economy, but mostly by the market economy and political control, crosscut by globalization (Xu, 2006; Lambin and Geist, 2001). Land-use transition, therefore, is also socioeconomic transformation. Understanding land-use transition is crucial because the most profound impacts on human health occur during transition between different land-use states (Mustard et al., 2004). Impacts are scale-dependent, some affecting the local environment (e.g., water quality) and others extending far beyond the source from which they arise (e.g., carbon cycle, climate change) (Subramanian, 2004). Not all land-use changes are irreversible; ecosystems have a capacity to absorb disturbances. Additionally, humans can shape and reshape the capacity of ecosystems to generate services.

Human health is dependent on access to ecosystem services through different land-use practices. The health of people and of ecosystems is affected negatively by decreased and inferior agricultural production caused by transformation in physical and human environments; viz., excessive use of chemical pesticides and fertilizers, salinization, contamination by heavy metals, and soil depletion (Lebel, 2003). Many infectious diseases (such as malaria, Japanese encephalitis and schistosomiasis) caused by/contamination from fluoride (Gikunju et al., 2002) and arsenic poisoning (Anawar et al., 2002>; Duker et al., 2005) have known links to the anthropogenic ecosystem, or human land-use activities. Fragmentation of forest habitats for agriculture and settlements leads to edge effects that promote interactions among pathogens, vectors and hosts. This edge effect has been well documented for Lyme's disease (Glass et al., 1995) and Leismaniasis (Weigle et al., 1993). Non-communicable diseases are linked to environmental factors such as imbalanced minerals, diet and nutrition, lifestyle, and environmental pollutants. There are certain indirect linkages of land-use transition to human health in that large-scale deforestation leads to soil erosion, adding mercury (available naturally in the rainforests) to the rivers and contaminating fish (Fostier et al., 2000). The pattern and extent of change in incidences of a particular infectious disease depends on the particular ecosystems affected, type of land use, dynamics of disease-specific transmission, sociocultural change, and human susceptibility. Health risks from increasing mountain hazards (earthquakes and flash floods) and socioeconomic transformation, as well as development displacement such as dam construction (WCD, 2000), need attention. Trends ranging from forest clearance to climate-induced habitat changes appear to have caused certain populations of mosquitoes to alter transmission patterns for diseases such as malaria. Larval development in malaria-transmitting mosquitoes is extremely sensitive to changes in temperature.

These events expose populations to alien environments and health risks without adequate prior knowledge as human health is a reflection of a variety of complex interactions between the internal biological and the external environmental systems.

Impacts on health of each land-use change should be assessed within the context of other concomitant environmental changes such as rapid urbanization, migration and increasing mobility, movement of production, resource exhaustion, desertification, and pollution. Specific population groups are vulnerable to health risks and threats; e.g., certain lifestyles and occupations combined with exposure to hazards may result in increased health risks (Gopalan and Saksena, 1999; Pinheiro et al., 2007). Vulnerable groups, such as indigenous herders, farmers, and shifting cultivators, in changing their lifestyles, carry a double burden of not only battling traditional hazards such as floods, drought, and poor sanitation, but also increasing exposure to HIV/AIDS, atmospheric brown clouds (ABC), industrial pollution, and new influenza strains such as avian flu.

Ecosystem and human health issues have long been a focus for research and development, but the linkages between them are inadequately addressed. The 'Ecosystem Approaches to Human Health (or EcoHealth) Program' launched by Canada's International Development Research Centre (IDRC) is an innovative response to human health problems resulting from local and global transformations of ecosystem, environment, and human health (Waltner-Toews, 1996; Forest and Lebel, 2001; Lebel, 2003). The ecosystem and health relationship can be measured by indicators of environmental health-risk exposure, human morbidity or mortality, or human well-being and ecosystem sustainability approaches (Cole et al., 1998; Rapport and Singh, 2006). Much has been learned about environmental health risks in specific sectors (Gabaldon, 1983; Wilson et al., 2002; Ramanathan and Ramana, 2005; Zhang and Wong, 2007; Maharjan et al., 2005; Xiao et al., 2004). The critical linkage between land-use changes and human health risks in mountain ecosystems, however, has not been well understood. A responsive strategy for managing land-use transition and human health risk is imperative for transdisciplinary scientists and policy-makers.

2. EcoHealth approach in the Himalayan region

2.1. Review framework

Human disturbance of ecosystems and their services through land-use changes affect health through biological mechanisms and ecological processes (Fig. 1). Human activities not closely associated with environmental modifications have a role in the production of diseases. Ecosystem management through land-use practices can mediate the influence of anthropogenic activities in changing the epidemiological patterns and reducing or increasing the incidence of human diseases Most ecological systems have a unique set of infectious diseases; but diseases like malaria are ubiquitous and can be found across ecological systems, although with somewhat different dynamics.

Human health is arguably the most complex impact of global change on societies. Understanding how to prepare for these impacts and increasing the resilience of human–environment systems is one of the big challenges ahead. Globalization and environmental change render land-use transition inevitable in the Himalayas. Land-use transition is illustrated by changes in land use and habitat that ultimately change ecosystem services. Land-use and habitat changes can have biophysical and socioeconomic effects that increase or decrease health risks and diseases. Some societies might be more vulnerable than

Please cite this article as: Xu J et al., Critical linkages between land-use transition and human health in the Himalayan region, Environ Int (2007), doi:10.1016/j.envint.2007.08.004

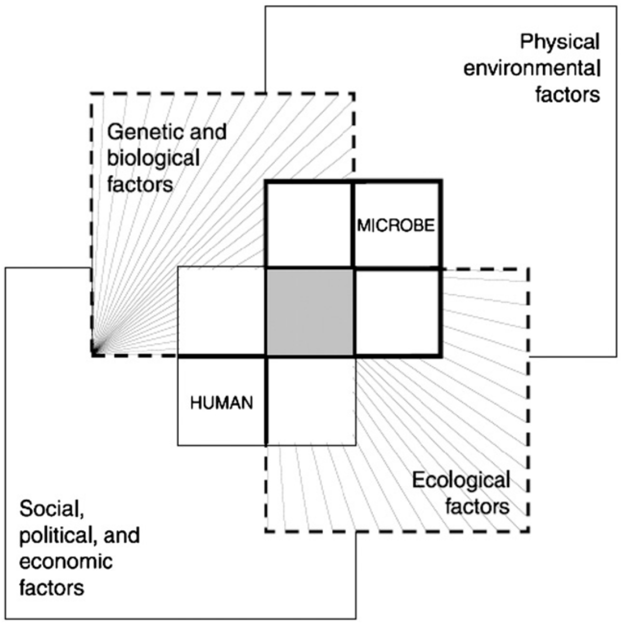

Fig. 1. Multiple factors in human health (Institute of Medicine, 2003, adopted from Millennium Ecosystem Assessment).

others depending upon exposure to health risks and access to health services. A key question is how positive or negative impacts of land-use and habitat changes are distributed among stakeholders including different gender groups. The relationship between land-use transition, ecosystem services, and human health is shown in Fig. 2.

There is evidence that local human–land interactions can be held responsible for some consequences to human health; e.g., the re-emergence of malaria is associated with intensified land use: land-use changes directly affect the habitat of vector-born diseases such as malaria, African trypanosomiasis, and dengue fever. Global warming also has indirect effects on human health.

2.2. The Himalayan mountain perspective

The Himalayan region is the source of nine large river systems in Asia, the basins of which are home to over 1.3 billion people (Xu et al., 2007a). Environmental change in the greater Himalayas affects much of inland China, Central and South Asia, and the mainland of Southeast Asia.. During past decades, conditions in the region have deteriorated substantially. Environmental change is more visible: the retreat of glaciers, increasing irregularity of precipitation, growing carbon dioxide output caused by economic growth in the plains, and increased frequency of natural disasters, are indicators. Globalization and economic liberalization are major factors stimulating the growing economies of India, Pakistan and China which need more land, including steep-sloped mountain areas, for plantation. Competition for water and land has led to growing imbalances resulting in increased migration, poor health and poverty, and unstable land-use patterns. Mountain areas have not received sufficient attention to counterbalance these negative trends. Competition for scarce resources, low per capita availability of productive land, remoteness, and marginalization have increased vulnerability in terms of food security, primary health care, natural hazards, and access to services and productive land. Today, the region is characterized by social and political conflict, poverty, and environmental degradation (Pant, 2003).

2.2.1. Biophysical vulnerability and mountain 'niche'

Changes in mountain environments occur through biogeochemical processes. Slope, aspect, and altitude determine the fundamental characteristics of mountain habitats. Topographic diversity adds to the small-scale variations in the physical environment and ecosystem.

Climates vary according to altitude and exposure; thus, mountain habitats have greater species' richness than similar areas in the lowlands. This richness decreases with altitude and isolation and environmental extremes restrict species' habitats. Biogeographically the Himalayan region is stratified into elevational belts, each with characteristic flora and fauna. The Asian monsoon climate, characterized by seasonal and interannual variability and distinct climate regimes, together with geophysical variability and altitude as well as latitude gradient, predominates. Geophysical fragility and climatic variability have strong impacts on the ecosystem, resulting in the variability of ecosystems and land use that is linked to a monsoon climate, altitude, and fragility and predetermining pastoralism in the high plateau, terraced agriculture in the middle mountains, and forest-based shifting cultivation in the humid tropics. The Himalayan landscape and biota have undergone transformation through human use for centuries.

2.2.2. History of land use and socioeconomic transformation

Despite the harsh environment, more the 500 million people (ca. 100 ethnic groups) live in these mountains. Most people live in the middle mountains: almost all live in poverty and are vulnerable to food insecurity. Most farmers have no national health care even when they migrate to the cities for work; and yet they have a significant impact on lowland inhabitants because of their influence on the health of the mountain ecosystem — land and resource use in particular. Mountain

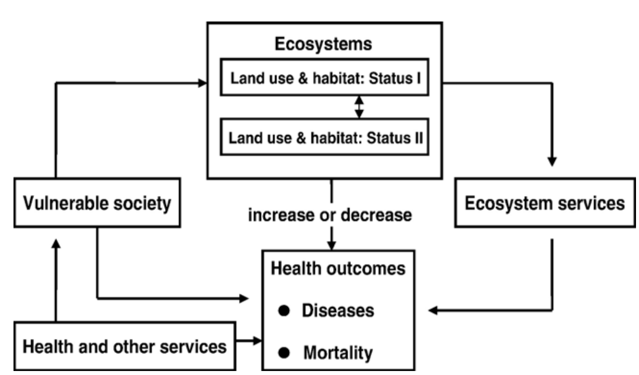

Fig. 2. Causal linkages between land-use transition, ecosystem services and human health.

Please cite this article as: Xu J et al., Critical linkages between land-use transition and human health in the Himalayan region, Environ Int (2007), doi:10.1016/j.envint.2007.08.004

landscapes are heterogeneous, often a mosaic of forests, wetlands, rangeland, and cropland providing habitats for all life forms and a diversity of livelihoods: from nomadic to agro-pastoral (> 3000 m); from sedentary upland agriculture (< 3000 m) to terraced paddy (< 2500 m); from shifting cultivation (< 2000 m) to tea gardens (< 1500 m); and from hunting and gathering to home gardens and aquaculture, or composite livelihoods well adapted to mountain habitats (Xu and Rana, 2005). The prevalence of malaria in the lowland tropics meant that mountain habitats were ideal for indigenous people in the past. There are many examples of flourishing economies based on mountain habitats — the Tibetans in China, hill tribes in India, and the indigenous people in Nepal. Many still survive and some even thrive. Mountain towns and caravan networks linked the mountains with the lowlands for centuries. Mountains were as much pathways of migration and trade as barriers between the highlands and lowlands (Pereira et al., 2005). During the colonial period, plantation economies based on standard industrialization of cotton and later tea predominated (Macfarlane and Macfarlane, 2004). Large-scale application of DDT controlled malaria. The green revolution, plantation economy, and disease control facilitated the population and urbanization of the plains, leading to widespread deforestation and conversion to agricultural land. The lowland economy dominated because of intensive sedentary agriculture, large-scale manufacturing, easy transportation and trade, urbanization, and the consequent access to education, health care, and political power. Mountain people are economically polarized from the plains, and they are more vulnerable to drought and flash floods because of climate change. Mountain people do not receive as much support from the state as lowlanders for social services and development of utilities, nor is their role as rich reservoirs of indigenous knowledge recognized: environmental degradation, poverty, and out-migration are inevitable features of the social landscape (Shrestha, 1989; Körner and Ohsawa., 2005).

Land-use history in the Himalayan region reflects the linkages between settlement history, cultural ecology, and political economy as these relate to resources, marginality, and territory (Zurick, 1989). Land-use changes are responses to changes in ecosystem services and socioeconomic access (Salick et al., 2005).

Mountain people live in steep, uneven terrain and are embedded in an even steeper and unequal political environment. Interaction with the states that govern them is unequal. Land use and property rights in the Himalayas have always been influenced by political perspectives and ideologies. The power bases of decisions about land use are in the lowland, urban areas. Mountain regions are perceived as sources of potential resources; consequently, logging, mining, plantation, and hydropower are operated by state-owned or private enterprises for the benefit of the lowlands. Traditional land-use practices, such as shifting cultivation and nomadic herding, are often portrayed as responsible for deforestation and desertification in the highlands leading to downstream flooding, rather than being seen as sustainable land uses (Ives, 2004). In the case of Nepal, where political power is in the hands of a mid-hill elite, traditional systems of resource protection disappeared and social conflicts increased as a result of unequal access to land and forest resources. Governments in the region often respond by increasing privatization of common resources rather than by improving infrastructure and social services (Yan et al., 2005).

3. Key lessons from land–health linkages

3.1. Environmental health risks

The mountain environment is rich in mineral resources, but also carries the risk of endemic diseases linked to heavy metals (Purohit et al., 2001) and high-level toxic minerals such as fluoride (Rajasthan, 2001; Alarcon-Herrera, 2001; Gikunju et al., 2002), arsenic (Maharjan et al., 2005) and thallium (Xiao et al., 2004). Contaminant convergence is associated with mountain terrain, steep slopes, and sediment transportation and trapping. Human activities have increased exposure to health risks; e.g., extraction of groundwater and coal in fluoride-rich areas. A case study in Yuanmou County, Yunnan Province, China, for example, found fluoride content in underground water ranging from 1.0 to 7.2 mg/L (44 samples higher than 1.0 mg/L in a total of 860 water samples collected in the valley); and, in sampling a total population of 40,686 in 43 villages, found that over 33.3% had a history of dental caries (author's own field work).

Arsenic in groundwater is a serious public health problem in Nepal (Maharjan et al., 2005) and has acute and chronic effects on human health. Paucity of information about improper land-use management and the state of the environment leads to great health risks (Victor and Reuben, 2000). Land-use transitions augment natural processes like weathering of rocks and biological activities are the main, natural processes of arsenic release, whereas smelting of non-ferrous metals; manufacturing arsenic compounds, using pesticides, fertilizers, and so on containing it, as well as burning arsenic compounds and fossil fuels, are anthropogenic causes of the release of arsenic into the environment. Well-functioning ecosystems, however, can absorb and remove contaminants; e.g., wetlands remove excess nutrients from runoff, preventing damage to downstream ecosystems (Jordan et al., 2003).

3.2. Sedentarization in alpine rangeland and tropical forest plural ecosystems

Two distinguishable groups are agro-pastoralists in the semi-arid areas of the Tibetan Plateau and shifting cultivators in the tropical forests of the south-facing Himalayas. Throughout the Tibetan region, nomadic pastoralism with seasonal mobility is a traditional way of life and herders have intricate knowledge of their natural environment. A wide variety of livestock and a flexible and opportunistic approach to searching for pastures and water resources enable them to survive the extremely harsh environment. Nomads often face a different spectrum of health problems than others due to their transient lifestyle and poor access to heath services (Sheik-Mohamed and Velema, 1999) and access to water supplies is crucial as it is essential for life and health. Foggin et al. (2006) report a connection between high rates of miscarriage and infant loss among nomad women and a significant link between general morbidity and the time taken to fetch water. The profile of infectious diseases among pastoralists differs from that of settled populations in that diseases found in cattle, such as tuberculosis or brucellosis and certain sexually-transmitted diseases, are more prevalent (Niamir-Fuller, 1999). Infections, such as leprosy or tuberculosis, requiring long-term treatment are difficult to treat in nomadic populations.

Despite mobile lifestyles and flexible livelihoods, strategies permit land to 'rest' seasonally and thus curb overgrazing or over-harvesting. Settling migratory peoples permanently in terms of land use, property, and settlement, is perhaps the oldest and most continuous project of states (Xu et al., 2007b). Mobility in land use shrinks as farmers use marginal lands and herders settle around infrastructure for water, health, and education (Ellis and Swift, 1988; Niamir-Fuller, 1999). Access to large, diverse landscapes is critical for maintaining productivity of livestock in pastoral systems and reducing vulnerability of pastoral families, particularly during droughts. Recent privatization and sale of rangelands by pastoralists is aptly termed 'selling wealth to buy poverty' (Rutten, 1992). In the mid-1990s, the Chinese government began to privatize rangelands through long-term contracts, either with individual families or groups (Yan et al., 2005). All winter rangelands will be allocated to individual households over the next two to three years, while high-altitude summer pastures will be given to villages or groups of households. In fact, enclosed privatization is not the option preferred by most herders for whom shared labor is still common practice.

Sedentarization in transition to a market economy can lead to social stress, boredom, and reduced physical activity. Rapid increases in livestock population and poor sanitation might contribute to a rise in zoonoses within rural communities (Patz et al., 2004). Increasing barley production can lead to excessive consumption of alcohol. Debilitating diseases such as hepatitis, tuberculosis, heart diseases, and abdominal complaints are common (Xu et al., 2007b).

Long-fallow, rotational shifting cultivation ('swidden agriculture') is a well-documented example of how mobility and flexibility are the basis of sustainable smallholder systems (Conklin, 1957; Ramakrishnan, 1992; Xu et al., 1999; Yin, 2001). Hunter-gatherers (such as the Dulong in Yunnan and the Nagas in Northeast India) in the human tropics may have more diverse diets and nomads on the Tibetan Plateau have a higher protein intake than sedentary farmers. The diet of subsistence farmers appears to be comparatively well balanced. In mountain ecosystems, hunter-gatherers, shifting cultivators, farmers, and herders use mobility as a strategy to acquire food and water and maintain good health. Policies providing mobile services to mobile communities are needed to maintain good health care and educational opportunities while they move livestock to seasonal pastures. Observations and direct evidence imply that the advantages of a sedentary lifestyle may be offset by risks associated with increased intestinal infection, closer spacing, or substitution of starchy gruels for mother's milk and other nutritious weaning foods.

3.3. Intensification of cultivation

The application of biocides and fertilizers triggered large-scale intensification of agriculture and output growth worldwide in general, and in mountain regions in particular. This contributed to food security as outputs doubled, but it had negative consequences on the health of mountain farmers who had neither proper knowledge nor access to health services. Food security does not always provide dietary diversity and balanced nutrition. The environmental consequences of input mismanagement and overuse include destruction of beneficial insects, water logging and salinization of irrigated land, pollution of groundwater and rivers, poisoning of farm workers, and excessive dependence on new, improved crop varieties. Research estimates show that almost half the nitrogen applied is not used by crops, but instead washes away into the forests, wetlands, lakes, and rivers. Over-fertilized trees grow faster than normal and the levels of nutrients in the foliage contain more nitrogen and less calcium and magnesium than normal trees; and about 10% of the added nitrogen is leaking out of the forest as nitrate in groundwater (Nosengo, 2003). In China, nitrate levels are already well above the WHO standard for public health risks, and these may well double over another half-century. Health problems are exacerbated by the impacts of biocide use when agricultural chemicals leak into irrigation canals and drinking water (Geist, 2005). Examples of diseases caused by expansion and changes in agricultural practices are associated with a range of food-borne illnesses globally (Rose et al., 2001).

Health problems are reported from various dryland ecosystems in the Himalayas where land use is intensified to achieve self-sufficiency in food or basic materials for industry. Rice and cotton are the key irrigated crops in the drylands of the western Himalayas. Intensification leads to trade-offs between provision of food, shelter, and clothing and degradation of dryland ecosystems. Intensification expands production, but may increase risks, in both natural and cultural terms, of soil exhaustion in central growing areas and crop failure in marginal areas. Investments in irrigation to increase productivity may help protect food supplies, but can generate new risks and introduce new kinds of instability when production becomes vulnerable to economic and political forces that disrupt or distort the pattern of investment. Similarly, specialized production increases the product range and the overall efficiency of production, but it places large segments of the population at the mercy of fickle systems of exchange or fickle social and political entitlements.

3.4. Habitat modification and development displacement

Humans have transformed natural landscapes into cultural and productive landscapes for millennia. Today, dams and irrigation systems are the most visible symbols of economic development and are the primary drivers of land-cover and land-use changes and fragmentation in the twentieth century (Wu et al., 2003). Building the Three Gorges' Dam along the Yangtze River resulted in the resettlement of 1 million people from their original habitats; however, irrigation and dam construction increased water-related diseases such as schistosomiasis, Japanese encephalitis, and malaria (WCD, 2000).

3.5. Migration, land use and HIV/AIDS

Population growth might not be the prime driver in ecosystem destruction (Tiffen et al., 1994).Human migration spurred by economic liberation and globalization often trigger land-use changes which in turn cause infectious diseases (Patz et al., 2004). Seddon et al. (2002) estimate that the remittance economy provides between 13 and 25% of the national GDP of Nepal, on the one hand, while, on the other hand, outward migration from rural mountain areas leaves the population with insufficient manpower to manage natural resources sustainably. Young men and women, who are the main workforce, migrate to seek employment opportunities. The link between movements of people and the spread of AIDS has been acknowledged. Land-use changes in mountain areas increase the risks of STDs and HIV and rural–urban migration and improved transportation and market connections increase their spread in rural populations. Economic reform in rural China and human migration in a mountainous area of Yunnan province led to an increase in the incidence of schistosomiasis through trade of livestock and exposure to water-borne pathogens (Jiang et al., 2001).

Disease is not the only threat to overburdened societies. The United Nations estimates that India's population will increase by 600 million by 2050; and this will alter the land cover and land use and place an added burden on the mountain ecosystem. There is a clear case of stagnation and involution of agriculture in the face of land stress linked to increases in population (Turner and Ali, 1996).

3.6. Biocultural diversity and nutrition

Historic ties to diverse landscapes reveal an inextricable link between biological and cultural diversity. Biodiversity is linked to human health in many ways as it plays a crucial role in controlling disease 'vectors' and micro-organisms(Epstein et al., 1997). Predator/prey relationships are central to biological control. Owls and snakes regulate populations of rodents in the grasslands—opportunistic species involved in the transmission of Lyme disease, hantaviruses, arenaviruses, leptospirosis, and human plague. Habitat loss results in local extinction of predator species and a subsequent increase in the density of their prey. Freshwater fish, reptiles, and bats limit the abundance of mosquitoes, some carrying malaria, yellow fever, dengue fever, and many encephalitides. Rodents, insects, and invasive species represent key biological indicators rapidly responding to environmental change (Epstein et al., 1997).

Diversity and health are linked to agriculture where monoculture is associated with increased vulnerability to food shortages and long-term nutrient deficiencies (Waltner-Toews, 2001; Altieri, 2002). Decreased dietary diversity is one factor contributing to malnutrition (Johns and Sthapit, 2004). Subsistence farmers who consume little or no modern, refined foods appear to have nutritional advantages over more affluent, modernized groups.

Biodiversity loss is occurring at an unprecedented rate in the mountain habitat, driven by over-exploitation, land-cover and land-use changes, global warming, and invasive species and establishment of large-scale infrastructure (Xu and Wilkes, 2004).

3.7. Mountain hazards and floods

Floods and landslides are the principal hazards in the lower valleys and plains. During extreme weather events, the consequences are disastrous. Hundreds of lives and billions of dollars worth of property (agricultural land, public infrastructure) are lost in the region every year due to landslides, debris flows, and floods.

In the case of flash floods, there are health components related to both before and after an event. Before an event, communities living downstream constantly live with the risk (Mool et al., 2001). This continuous risk may cause long-term stress, lack of sleep, and so forth (Eriksson, 2006).

During and after a flash flood, several factors affect human health (Eriksson, 2006). The floods themselves may cause death and injury. Vulnerable groups are often hit hardest because their homes are more exposed or they are marginalized in other ways (Gardner and Dekens, 2007). As it is chiefly communities in rural areas that suffer from flash floods, local communities are often left with severe damage to property causing socioeconomic stress which may lead to health problems.

3.8. Climate change and human health

Climate change can change land use (Kalnay and Cai, 2003; Pielke, 2005) and food security (Parrya et al., 2004) with significant impacts on socioeconomic systems (Winnett, 1998). The economic and physical impacts of climate change on the ecosystem and society directly affect health. Periods of ecological and climate change can lead to extinction of some species and the emergence of new ones (Pimm et al., 1995; Parmesan, 2006). Environmental factors are the most important determinants of schistosomiasis infection in humans (Liang et al., 2007). Periods of change are likely to affect vegetation and agricultural production with some cereal crop yields and plant growth increasing at high latitudes (Ramakrishna et al., 2003; Parrya et al., 2004). Long-term changes in the global climate may cause ill health because of insufficient food supplies, lack of safe and sufficient drinking water, poor sanitation, and insecure habitats.

Altered distribution of vector species may be among the early signs of climate change, and pests, pathogens, and parasites among the first to emerge during periods of transition. In addition, the distribution and seasonal transmission of vector-borne infections (such as malaria, dengue fever, and schistosomiasis) may be affected by climate change (Sutherst, 1998, 2001; WHO, 2000).

4. Ecosystem approach to human health: an imperative

What is the relationship between land-use transition and human health? To arrive at the answers a transdisciplinary group of researchers worked with local people and health workers to develop local health predictors, indicators, and feedback mechanisms for nomadic lifestyle, literacy, mobility, alcohol consumption, access to water, and foraging for Tibetan nomads (Foggin et al., 2006). The ecosystem approach to human health combines biophysical and social indicators (e.g., ecological footprints, access to land and water, natural capital stocks, ecosystem health, healthcare, education, and access to markets and information) to monitor the health of ecosystems (Rapport and Singh, 2006), human behavior, and physical and psychological health (Dovers et al., 2003; Naveh, 2000). It also includes establishing collaborative indicators leading to nonlinear responses together with stakeholders such as local people, resource managers, and health practitioners.

Time scales for interactions among ecosystem, pathogens, humans, and the environment vary and are often more rapid in the contemporary world of global change than comparable evolutionary factors causing nonlinear responses of disease vectors and pathogens. Conventional infectious diseases such as tuberculosis (TB), schistosomiasis, and malaria re-emerge due to the evolution of new strains of pathogens and alteration of habitats. The emergence of new diseases such as HIV/AIDS and avian flu is also related to interaction between humans and ecosystems—including wildlife and livestock (Capua and Alexander, 2002). Chronic diseases, such as diabetes and depression, are often related to changes in lifestyle and social environment. Human actions can promote persistence of ecosystem services that would not persist in the absence of people, as the human component causes nonlinear responses. Human responses allow for more rapid recovery (response) of degrading systems, such as dryland and forestland, by altering the trajectory from negative feedback. Human systems can have long-term effects on biota and physical systems that may not be predictable through short-term analyses; and, hence, the emergence of EcoHealth as an open approach refers to study of the dynamic relationships among people, ecosystem, and human health in the socioecological environment. EcoHealth is transdisciplinary with representatives from a broad range of disciplines. An inclusive vision of ecosystem-related health problems involves each discipline in a process that allows researchers to exceed the limits of their own disciplines to generate new frameworks, methods, and institutions through synergistic collaboration. The diversity and dynamics of the transdisciplinary learning process lead to focusing on complex interactions among various ecological and socioeconomic components of coupled human-environmental systems rather than resorting to simplified, quick-fix and sometimes expensive means of tackling complex problems (Lebel, 2003). Many models of natural resource management assume linear relations that are not applicable to the complexity of interactions between ecosystems and human health. Controls that drive social, cultural and political systems are typically not included in the ecosystem's interactions. We need to overcome the institutional barriers to the EcoHealth approach, as both the health and environment are vertically organized around conventional disciplines and organizations. Implementing an ecosystem approach to human health requires a change in the overarching institutional paradigm and a focus on horizontal integration and cooperation in a transdisciplinary manner.

5. Conclusion

Healthy ecosystems and good health are vital to the continued 'virtuous cycle' of human–environmental systems. Where environmental disruption leads to poor health and poverty, the consequences are 'vicious cycles' of poor health and poverty (Woodward et al., 2000). Land degradation and soil loss lead to crop failure, famine, and health problems. Changes in the physical environment affect the subsistence economy, resources become scarce, and the consequent struggle for minimum needs poses a threat to the health of the community, especially the weakest members (Reddy, 2004).Populations with high levels of chronic health problems have less energy and time for growing crops, preventing erosion, and managing land and water resources, leading to decreased sustainability.

Ecosystem approaches can prevent disease emergence (Lebel, 2003): controlling disease vectors contributes to the functioning and structure of ecosystems. The difference between direct and indirect effects applies to the temporal and spatial scales over which these effects occur. One result is that effects of ecosystem disruption on health are often displaced geographically. The impact of over-consumption by rich countries on climate change is one example as many of the adverse health effects are likely to appear first in low carbon-emitting areas such as the Himalayas and over the long-term can cause desertification. The links between land-use transition and human health are most evident among impoverished communities which lack the 'buffers' available to the rich. Owing to the intermediate factors involved, there are considerable time lags between changes in the ecosystem and effects on health. Loss of biodiversity may lead to higher mortality and morbidity by diminishing supplies of biopharmaceuticals, but this becomes apparent only after some years. In spatial terms, we are most familiar with local effects (such as flooding and mudslides on steep denuded hillsides). More difficult to identify, but perhaps more important for human health in the long term, are the impacts of socioeconomic transformation of the landscape in mountain ecosystems in light of regional and global climate changes, including biogeochemical cycles, hydrologic processes, and landscape dynamics. Ecosystem approaches that link land-use transition and human health define important pathways of feedback from coupled human-environment activities at the local and regional scale in the Himalayas with global significance. Improved understanding of how human actions affect the natural processes of mountain ecosystem services is needed, and the consequences of these changes on the humanhealth of indigenous people should be evaluated.

Acknowledgments

This research was supported by Canada's International Development Research Centre (IDRC). This paper was improved vastly by preliminary discussions with Liz Fajber, formal program officer, IDRC, New Delhi, by professional editing from Greta Rana.

References

Alarcon-Herrera T. Well water fluoride, dental fluorosis, and bone fractures in the Guadiana Valley of Mexico. Fluoride 2001;34(2):139–49.

Altieri MA. Agroecology: the science of natural resource management for poor farmers in marginal environments. Agric Ecosyst Environ 2002;1971:1–24.

Anawar HM, Akai J, Mostofa KMG, Safiullah S, Tareq SM. Arsenic poisoning in groundwater: health risk and geochemical source in Bangladesh. Environ Int 2002;27(7):597–604.

Berrang FL. Malaria. In: Geist HJ, editor. Our Earth's changing land: An encyclopedia of land-use and land-cover change, 2006. 2 (L–Z). Westport London: Greenwood Press; 2006. p. 400–4.

Capua I, Alexander DJ. Avian influenza and human health. Acta Trop 2002:1–6.

Cole DC, Eyles J, Gibson BL. Indicators of human health in ecosystems: what do we measure? Sci Total Environ 1998;224:201–13.

Collins AE. Health ecology, land degradation and development. Land Degrad Dev 2001;12:237–50.

Conklin H. Hanunoo Agriculture. Rome: FAO; 1957.

Darnerud PO. Toxic effects of brominated flame retardants in man and in wildlife. Environ Int 2003;29:841–53.

Dovers S, Stern DI, Young MD. New dimensions in ecological economics: Integrated approaches to people and nature. Edward Elgar Publishing; 2003.

Duker AA, Carranza EJM, Hale M. Arsenic geochemistry and health. Environ Int 2005;31:631–41.

Ellis J, Swift DM. Stability of African pastoral ecosystems: alternative paradigms and implications for development. J Range Manag 1988;41:450–9.

Epstein PR, Dobson A, Vandermeer J. Biodiversity and emerging infectious diseases: integrating health and ecosystem monitoring. In: Grifo F, Rosenthal J, editors. Biodiversity and Human Health. Washington: Island Press; 1997.

Eriksson M. Climate change and its implication for human health in the Himalaya. Sustainable mountain development in the greater Himalayan region. Int Cent Integr Mt Dev1013-7386 2006;50:11–3 summer.

Ezzati M, Lopez AD, Rodgers A, Hoorn SV, Murry CJL. Selected major risk factors and global and regional burden of disease. Lancet 2002;360 (2):1347–60.

Foggin PM, Torrance ME, Dorje D, Xuri WZ, Foggin JM, Torrance J. Assessment of the health status and risk factors of Khan Tibetan pastoralists in the alpine grasslands of the Tibetan plateau. Soc Sci Med 2006;63: 2512–32.

Forest G, Lebel J. An ecosystem approach to human health. Int J Occup Environ Health 2001;7(2):s1–s38.

Fostier AH, Forti MC, Guimaraes JR, Melfi Aj, Boulet R, Aspirito Santo CM. Mercury fluxes in a natural forested Amazonian catchment (Serra do NAvio, Amapa State, Brazil). Sci Total Environ. 2000;260:201–11.

Gabaldon A. Malaria eradication in Venezuela: doctrine, practice, and achievements after twenty years. Am J Trop Med Hyg 1983;32:203–11.

Gardner GS, Dekens J. Mountain hazards and the resilience of social–ecological systems: lessons learned in India and Canada. Nat Hazards 2007;41(2):317–36.

Geist HJ. The causes and progression of desertification. Ashgate studies in environmental policy and practice, Ashgate Publishing Ltd./Co. Aldershot: Burlington; 2005. 258 pp.

Gikunju JK, Simiyu KW, Gathura PB, Kyule M, Kanja LW. River water flouride in Kenya. Flouride 2002;35(3):193–6.

Glass GE, Schwartz BS, Morgan III JM, Johnson DT, Noy PM, Israel E. Environmental risk factors for Lyme disease identified with geographic information system. Am J Public Health 1995;85:944–8.

Gopalan HNB, Saksena S. Domestic Environment and Health of Women and Children. United Nations Environment Program; 1999.

Institute of Medicine. Microbial Threats to Health: Emergence, Detection, and Response. Washington: National Academy Press; 2003.

Ives JD. Himalayan Perceptions: Environmental change and the well-being of mountain peoples. London: Routledge; 2004. p. 60–7.

Jiang Z, Zheng QS, Wang XF, Hua ZH. Influence of livestock husbandry on schistosomiasis transmission in mountainous regions of Yunnan Province. Clin Microbiol Rev 2001;14(2):270–95.

Johns T, Sthapit BR. Bicultural diversity in the sustainability of developing-country food systems. Food Nutr Bull 2004;25(2):143–55.

Jordan T, Whigham D, Hofmockel K, Pittek M. Nutrient and sediment removal by a restored wetland receiving agricultural runoff. J Environ Qual 2003;32:1534–47.

Kalnay E, Cai M. Impact of urbanization and land-use on climate. Nature 2003;423:528–31.

Körner C, Ohsawa M. Mountain system. Ecosystems and Human Well Being, Current states and trends. Millennium Ecosystem Assessment WHO report; 2005.

Lambin EF, Geist HJ. Global land-use/land-cover changes: what have we learned so far? IGBP Glob Change Newsl 2001;46:27–30.

Lambin EF, Giest HJ, editors. Land Use and Land Cover Change: Local Processes, Global Impacts. Springer; 2006.

Lebel J. Health: an ecosystem approach. Published by the International Development Research Centre. Ottawa: Canada; 2003.

Liang S, Seto EYW, Remais JV, Zhong B, Yang CH, Hubbard A, et al. Environmental effects on parasitic disease transmission exemplified by schitosomiasis. PNAS 2007;104(17):7110–5.

Macfarlane A, Macfarlane I. The Empire of Tea: the remarkable history of the plant that took over the world. Woodstock and New York: The Overlook Press; 2004.

Maharjan M, Watanabe C, Ahmad SKA, Ohtsuka R. Arsenic contamination in drinking water and skin manifestations in lowland Nepal: the first community-based survey. Am J Trop Med Hyg 2005;73(2):477–9.

Mool PK, Bajracharya SR, Joshi SP. Inventory of Glaciers, Glacial Lakes and Glacial Lake Outburst Floods: Monitoring and early warning systems in HKH region. Kathmandu: ICIMOD; 2001.

Mustard JF, DeFries RS, Fisher T, Moran E. Land-use and landcover change pathways and impacts. In: Gutman G, Janetos AC, Justice CO, Moran EF, Mustard JF, Rindfuss RR, Skole D, Turner II BL, Cochrane MA, editors. Land change science: Observing, monitoring and understanding trajectories of change on the Earth's surface. Remote Sensing and Digital Image Processing. Dordrecht: Kluwer Academic; 2004. p. 411–29.

Naveh Z. The total human ecosystem: integrating ecology and economics. Bioscience 2000;50(4):357–61.

Niamir-Fuller M. International aid for rangeland development: trends and challenges. In: Freudenberger D, editor. International rangelands congress. Townsville: Australia; 1999. p. 147–52.

Nosengo N. Fertilized to death. Nature 2003;425(30):894–5.

Pant BR. Degrading environment and growing population of the India Himalaya. Envis Bull Himal Ecol Dev 2003;11(1):23–34.

Parmesan C. Ecological and evolutionary response to recent climate change. Ann Rev Ecolog Syst 2006;37:637–69.

Parrya ML, Rosenzweigb C, Iglesiasc A, Livermored M, Fischere G. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Glob Environ Change 2004;14:53–67.

Patz JA, Daszak P, Tabor GM, Aguirre AA, Pearl M, Epstein J, et al. Unhealthy Landscapes: Policy recommendations on land use change and infectious disease emergence. Environ Health Perspect 2004;112 (10):1092–8.

Pereira E, Queiroz C, Pereira HM, Vicente L. Ecosystem services and human well-being: a participatory study in a mountain community in Portugal. Ecology and Society 2005;10(2):14.

Pielke RA. Land use and climate change. Science 2005;310(9):1625–6.

Pimm SL, Russell GJ, Gittleman JL, Brooks TM. The future of biodiversity. Science 1995;269:347–50.

Pinheiro MCN, Crespo-López ME, Vieira JLF, Oikawa T, Guimarães GA, Araújo CC, et al. Mercury pollution and childhood in Amazon riverside villages. Environ Int 2007;33:56–61.

Purohit KK, Mukherjee PK, Khanna PP, Saini NK, Rathi MS. Heavy metal distribution and environmental status of Doon Valley soils, outer Himalaya, India. Environ Geol 2001;40(6):716–24.

Rajasthan D. Endemic Fluorosis in Southern Rajasthan, India. Fluoride 2001;34 (1):61–70.

Ramakrishnan P.S. Shifting Agriculture and Sustainable Development: An Interdisciplinary Study from North-East India, Man and the Biosphere Series vol. 10. Paris and Carnforth, U.K.: UNESCO and Parthenon, 1992.

Ramakrishna RN, Keeling CD, Hashimoto H, Jolly WM, Piper SC, Tucker CJ, et al. Climate-driven increases in global terrestrial net primary production from 1982 to 1999. Science 2003;300:1560–3.

Ramanathan V, Ramana MV. Persistent, widespread, and strongly absorbing haze over the Himalayan foothills and the Indo-Gangetic Plains. Pure Appl Geophys 2005;162:1609–26.

Rapport DJ, Costanza R, McMichael AJ. Assessing Ecosystem Health. Tree 1998;13(10):397–402.

Rapport DJ, Singh A. An EcoHealth-based framework for state of environment reporting. Ecol Indic 2006;6(22):409–28.

Reddy S. Ecosystems Approach to Human Health: a case of Konda Reddi Tribes and Women's Health. J Hum Health 2004;16(4):271–82.

Rose JB, Epstein PR, Lipp EK, Sherman BH, Bernaud SM, Patz JA. Climate variability and change in the United States: potential impacts on water and food borne diseases caused by microbiologic agents. Environ Health Perspect 2001;109(suppl 2):211–21.

Rutten MMEM. Selling wealth to buy poverty: The process of individualisation of land ownership among the Maasai pastoralists of Kajiado District, Kenya 1890–1990. Saarbrücken: Breitenbach Publishers; 1992.

Sala OE, Chapin III FS, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, et al. Biodiversity: Global biodiversity scenarios for the year 2100. Science 2000;287:1770–4.

Salick J, Yang YP, Amend A. Tibetan Land use and change near Khawa Karpo, Eastern Himalayas. Econ Bot 2005;59(4):312–25.

Seddon D, Adhikari J, Gurung G. Foreign labor migration and the remittance economy of Nepal. Crit Asian Stud 2002;34(1):19–40.

Sheik-Mohamed A, Velema JP. Where health care has no access: the nomadic populations of sub-Saharan Africa. Trop Med Int Health 1999;4(10): 695–707.

Shrestha NR. Frontier settlement and landlessness among hill migrants in Nepal Tarai. Ann Assoc Am Geogr 1989;79(3):370–89.

Sthiannopkao S, Takizawa S, Homewong J, Wirojanagud W. Soil erosion and its impacts on water treatment in the northeastern provinces of Thailand. Environ Int 2007;33(5):706–11.

Subramanian V. Water quality in South Asia. Asian J Water Environ Pollut 2004;1(1-2):41–54.

Sutherst RW. Implications of Global change and climate variability for vector-borne disease: generic approaches to impact assessments. Int J Parasitol 1998;28:935–45.

Sutherst RW. The vulnerability of human health to parasites under Global Change. Int J Parasitol 2001;31:933–48.

Taylor LH, Latham SM, Woolhouse MEJ. Risk factors for human disease emergence. Philos Trans R Soc Lond B 2001;356:983–9.

Tiffen M, Mortimore M, Gichuki F. More People, Less Erosion: environmental recovery in Kenya. Nairobi: ACTS Press; 1994.

Turner BL, Ali AMS. Induced intensification: agricultural change in Bangladesh with implications for Malthus and Boserup. Proc Natl Acad Sci 1996;93: 14984–91.

Turner BL, Matson PA, McCarthy JJ, Corell RW, Christensen L, Eckley N, et al. Illustrating the coupled human-environment system for vulnerability analysis: three case studies. Proc Natl Acad Sci 2003;100(14):8080–5.

Victor TJ, Reuben R. Effects of organic and inorganic and inorganic fertilizers on mosquito populations in rice fields of southern India. Med Vet Entomol 2000;14:361–8.

Vitousek PM, Mooney HA, Lubchenco J, Melillo JM. Human domination of Earth's ecosystems. Science 1997;277(5335):494–9.

Waltner-Toews D. Ecosystem health: a framework for implementing sustainability in agriculture. Bioscience 1996;46(9):686–9.

Waltner-Toews D. An approach to health and its applications to tropical and emerging diseases. Debate, Department of population medicine and network for ecosystem sustainability and health. Ontario, Canada: University of Guelph; 2001.

Weigle KA, Santrich C, Martinez F, Vaiderrama L, Saravia NG. Epidemiology of cutaneous leishmaniasis in Columbia, environmental and behavioral risk factors for infection, clinical manifestation and pathogenecity. J Infect Dis 1993;168:709–14.

Wilson MD, Cheke RA, Flasse SP, Grist S, Osei-Ateweneboana MY, Tetteh-Kumah A, et al. Deforestation and the spatio-temporal distribution of savannah and forest members of the Simulium damnosum complex in southern Ghana and south-western Togo. Trans R Soc Trop Med Hyg 2002;96:632–9.

World Commission on Dams (WCD). Dams and development: a new framework for decision-making. Report of the World Commission on Dams. London: Earthscan Publications; 2000. WCD, Cape Town, South Africa.

WHO. Climate change and human health: Impact and adaptation, Prepared by the Protection of the Human Environment, Geneva and European Centre for Environment and Health. Rome: World Health Organization; 2000.

Winnett SM. Potential effects on climate change on U.S. forests: a review. Clim Res 1998;11:39–49 2002.

Woodward A, Hales S, Litidamu N, Phillips D, Martin J. Protecting human health in a changing world: the role of social and economic development. Bull WHO 2000;78(9):1148–55.

Wu JG, Huang JH, Han XG, Xie ZQ, Gao XM. Three-Gorges Dam-experiment in habitat fragmentation? Science 2003;300:1239–40.

Xiao TF, Guha J, Boyle D, Liu CQ, Chen JA. Environmental concerns related to high thallium levels in soils and thallium uptake by plants in southwest Guizhou, China. Sci Total Environ 2004;318:223–44.

Xu JC. The political, social and ecological transformation of a landscape: the case of rubber in Xishuangbanna, China. Mt Res Dev 2006;26(3):254–62.

Xu JC, Wilkes A. Biodiversity impact analysis in northwest Yunnan, southwest. China. Biodivers Conserv 2004;13:959–83.

Xu JC, Rana GM. Living in the mountains. In: Jeggle Terry, editor. Know Risk, UN Inter-agency secretariat of the International Strategy for Disaster Reduction; 2005. p. 196–9.

Xu JC, Fox J, Lu X, Podger N, Leisz S, Ai X. Effects of swidden cultivation, population growth, and state policies on land cover in Yunnan, China. Mt Res Dev 1999;19(2):123–32.

Xu JC, Shrestha AB, Vaidya RA, Eriksson M, Hewitt K. The Melting Himalayas: Regional Challenges and Local Impacts of Climate Change on Mountain Ecosystems and Livelihoods. Kathmandu: ICIMOD Technical Paper; 2007a.

Xu JC, Sharma R, Yang Y, Tashi N, Li ZQ, Fang J. Understanding land use, livelihood and health transition of Tibetan nomads: Case from Gangga Township, Dingri County, TAR of China, EcoHealth; 2007b. (in review).

Yan ZL, Wu N, Yeshi D, Ru J. A review of rangeland privatization and its implications in the Tibetan Plateau, China. Nomad Peoples 2005;9 (1&2):31–51.

Yin ST. People and Forests: Yunnan Swidden Agriculture in Human-Ecological Perspective. Kunming: Yunnan Education Publishing House; 2001.

Zhang L, Wong MH. Environmental mercury contamination in China: sources and impacts. Environ Int 2007;33:108–21.

Zurick DN. Historical links between settlement, ecology, and politics in the mountains of west Nepal. Hum Ecol 1989;17(2):229–55.

Please cite this article as: Xu J et al., Critical linkages between land-use transition and human health in the Himalayan region, Environ Int (2007), doi:10.1016/j.envint.2007.08.004