BACKGROUND PAPER AND WORKSHOP PARTICIPANT

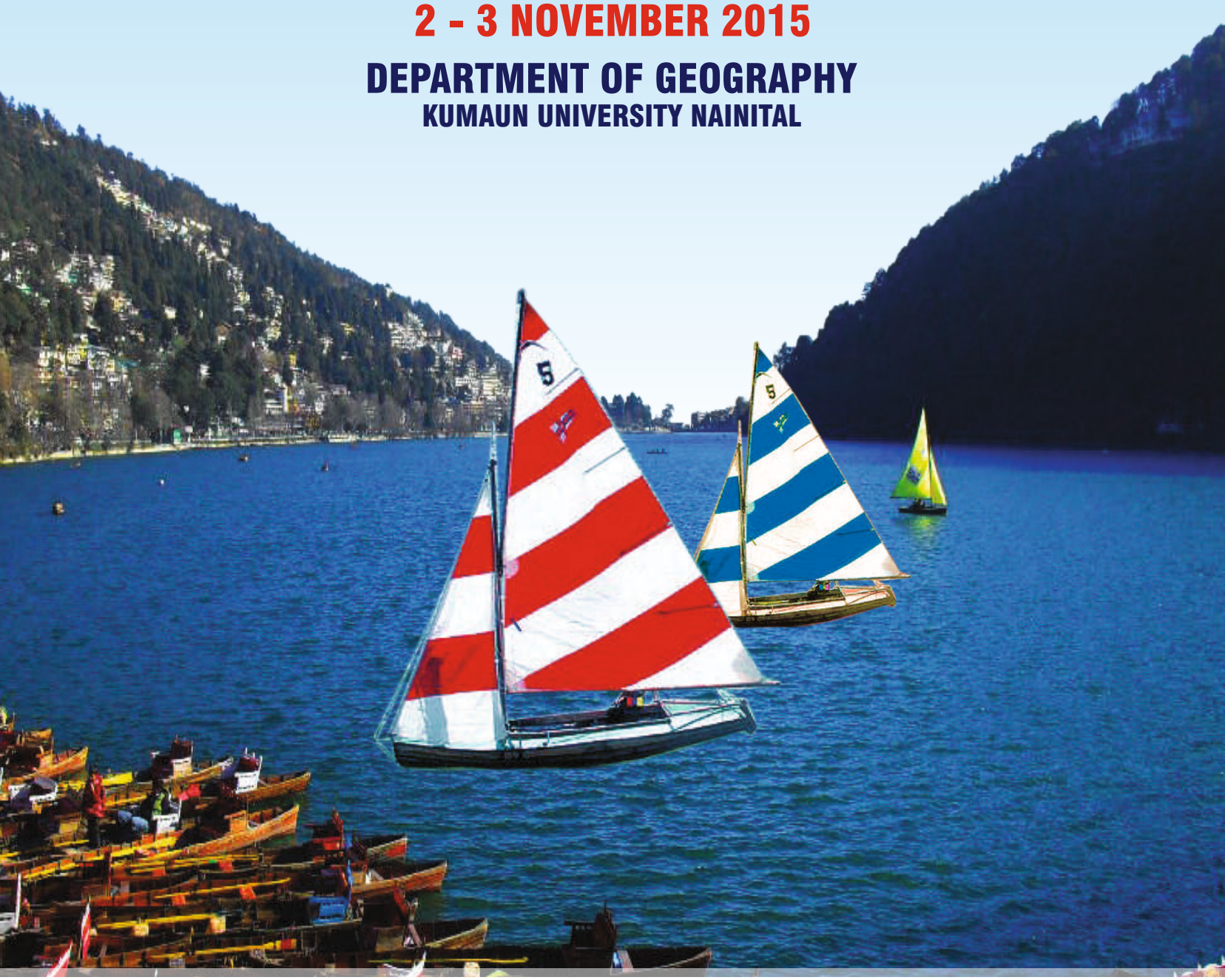
IHCAP INTERNATIONAL WORKSHOP

CLIMATE CHANGE IMPACT AND ADAPTATION IN HIMALAYA: SCIENCE AND POLICY INTERFACE

2 - 3 NOVEMBER 2015

DEPARTMENT OF GEOGRAPHY

KUMAUN UNIVERSITY NAINITAL



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IHCAP Indian Himalayas Climate Adaptation Programme

Department of Science & Technology
Ministry of Science & Technology
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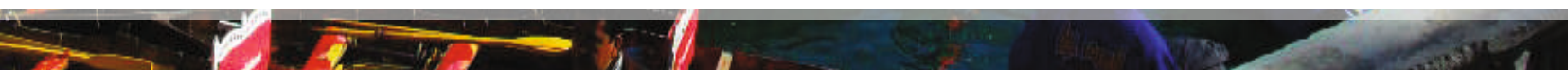
NMSHE NATIONAL MISSION FOR SUSTAINING THE HIMALAYAN ECOSYSTEM



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BACKGROUND PAPER AND WORKSHOP PARTICIPANT

International Workshop

Climate Change Impact and Adaptation in Himalaya: Science and Policy Interface

Supported By:

Indian Himalaya Climate Adaptation Programme (IHCAP)
Swiss Agency for Development and Cooperation (SDC)

National Mission for Sustaining The Himalayan Ecosystem (NIMSHE)
Department of Science and Technology, Government of India

Indian Council of Social Science Research (ICSSR)

Kumaun University, Nainital, Uttarakhand, India

2 - 4 November 2015

Convener:
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Nainital, Uttarakhand, India

Workshop Sponsors

Indian Himalaya Climate Adaptation Programme (IHCAP)
Swiss Agency for Development and Cooperation (SDC)

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Kumaun University, Nainital, Uttarakhand, India

1973

The Workshop

Rationale, Objectives and Expected Outcomes Rationale:

Himalaya constitutes headwaters of some of the largest trans-boundary rivers systems of the planet that sustain 1.3 billion people dependent primarily on subsistence agriculture in South Asia. A variety of changes have emerged in traditional resource use structure mainly in response to population growth and resultant increased demand of natural resources and rapid urbanization in Himalaya during the recent past. These changes have exerted sharply accentuated pressures on local subsistence economy through depletion of land, water, biodiversity and forests resources collapsing conventional production system. The economic globalisation have further increased the vulnerability of mountain communities to environmental risks through exploitation of natural resources even in remote and inaccessible areas. This is likely to sharpen the poverty imbalances between highlands and lowlands.

Moreover, changing climatic conditions have stressed the Himalayan ecosystem through higher mean annual temperatures and melting of glaciers and snow and altered precipitation patterns. These changes are disrupting the hydrological regimes of Himalayan headwaters; affecting adversely the availability of water both for drinking and food production; and increasing frequency, severity and intensity of extreme weather events. Furthermore, climate change is intensifying the impacts of other drivers of global environmental change and resulting into decrease in agricultural production, frequent crop failures, loss of rural livelihood, and consequent decline in community food purchasing power. This is exacerbating region's limited capacity to cope with projected decrease in availability of water for drinking, food production and risks of climate change induced natural disasters. The long-term impacts of these changes are not only of direct relevance to the Himalayan mountains, but they will have serious implications for downstream regions as these will increase the vulnerability of nearly 40% global population which constitutes some of the poorest people of the world with access to less than 5% freshwater resources of the planet, to water, food, livelihood and health insecurity both in mountains and their lowlands. This will have enormous regional implications for fundamental human endeavours ranging from poverty alleviation to environmental sustainability and climate change adaptation, and even to human security across South Asia. However, the exact impacts of climate change on mountain ecosystems, and the interlink-ages with other drivers of global change are yet to be investigated and properly understood. In view of this, the proposed workshop world the opportunity of sharing, exchanging and synthesizing the most critical knowledge to fill up this highly realized gap.

Objective:

The main objectives of the proposed workshop is to provide scientific platform for the synthesis of cutting edge most recent knowledge in climate change impacts assessment and adaptation that could: (i) enrich the knowledge being constructed under the ongoing project on 'Indian Himalayan Climate Adaptation Programme' (IHCAP) being by the Swiss Agency for Development and Cooperation (SDC) and National Mission for Sustaining the Himalayan Ecosystem (NMSHE) of the Department of Science and Technology (DST), Ministry of Science and Technology, Government of India; and (ii) help policy planning agencies to evolve effective climate change adaptation plans for the Himalayan States of India. In order to attain the overall objective of the workshop the following questions will be addressed:

- What is the current magnitude of the impact of climate change on glaciers and snow, hydrological system and water resources, forest and biodiversity?
- How to assess the impact of changing climatic conditions more precisely on socio-ecological systems?
- How to analyze the responses of socio-ecological system to climate change?
- How to assess the vulnerability of socio-ecological systems to climate change
- How to interpret nexus among climate change, water, energy and food security?
- How to evolve appropriate and effective climate change adaptation plans in water, food, livelihood and gender sectors?
- How to interpret linkages between climate change and natural disasters, and how to mitigate the risks of climate change induced natural disasters?
- How to integrate climate adaptation into integrated development plans
- What is the potential role of international, regional, national and local institutions in climate change adaptation governance in Himalaya?
- How the Himalayan States can move ahead with integrated climate change and disaster risk reduction framework ?

Expected Outputs:

The workshop is expected to have the following outputs:

- A document highlighting the recommendations of the workshop.
- A publication synthesizing the most recent cutting edge knowledge in the forms of workshop proceeding and a review of current state of knowledge in the subject with specific reference to the Indian Himalaya
- A Policy framework to evolve effective and specific climate change adaptation action plan/s for the Governments of the Himalayan States and Government of India

Climate Change and Mountains:

Impacts, Responses and Adaptation

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Introduction:

Mountain regions which encompass nearly 24% of the total land surface of the earth (UNEP-WCMC 2002) and constitute home for approximately 12% of the world's population (Huddleston et al. 2003) in addition to nearly 14% global population living in their foothills and adjoining lowlands are highly critical from the view point of marginality, environmental sensitivity, climate change, constraints of terrain, geographical inaccessibility and less infrastructural development (Meybeck et al. 2001). Mountains constitute the sources of a variety of ecosystems services, including water, biodiversity, soils, natural beauty, recreational opportunities, wilderness and cultural diversity which sustains the livelihood and economy of large population both in mountains and their vast lowlands. Mountain headwaters provide freshwater to approximately half of the world population inhabiting the large river basins located far away from mountains (Viviroli et al. 2007). The large mountain regions such as the Himalaya play a pivotal role in monsoonal circulations. The effects of climate change on mountain regions could alter monsoon flow and intensify monsoon precipitation, affecting agricultural conditions for a huge portion of the global population. The largest trans-boundary river systems of the planet have their origin in high mountains, and mountains have still the largest proportion of world's forests which not only constitute global biodiversity hot spots and the pool of genetic resources, but they also regulate and modify climatic conditions and contribute towards mitigating global warming through serving as carbon sinks (ICIMOD 2010). Mountain agriculture and farming systems constitute the principal source of food and livelihood for about half a billion population. The indigenous communities inhabiting mountain regions since time immemorial have evolved diversity of cultures that comprise traditional knowledge, resource development and environmental conservation practices, agricultural and food systems, adaptation and coping mechanism, languages, customs, traditions, costumes, conventions and rituals which have immense relevance and practical significance in environmental restoration, climate change adaptation and ensuring sustained resource productivity in mountain ecosystems (ICIMOD 2010).

But, mountains have long been marginalized from the view point of sustainable development of their resources and inhabitants. However, our understanding about the problems of mountain regions and approach to their development has undergone drastic changes, during the recent years. Currently, mountain ecosystems as well as mountain communities are particularly threatened by the ongoing processes of environmental global change, population dynamics and globalizing economy and resultant exploitation of mountain resources (Borsdorf et al. 2010). During the recent years, a variety of changes have emerged in the traditional resource use structure in high mountain areas, particularly in developing and underdeveloped regions of the world mainly in response to changing global economic order, transforming political systems, rapid urban growth, increased demographic pressure and resultant increased demand and exploitation of natural resources. As a result, mountain regions of the world are passing through a process of rapid environmental, socio-economic and cultural transformation and exploitation and depletion of their natural resources leading to ecological imbalances and economic un-sustainability both in upland and lowland areas (Haigh et al. 2002, Tiwari 2000).

Moreover, the changing climatic conditions have already stressed mountain ecosystems through higher mean annual temperatures and melting of glaciers and snow, altered precipitation patterns and hydrological disruptions, and more frequent and extreme weather events. In this context, climate change acts as an additional stress which can multiply existing development deficits and may also reverse the process of socio-economic development in mountain regions particularly in underdeveloped and developing countries (UNDP 2010). Mountain people, who have contributed the least to global greenhouse gas (GHG) emissions, and helped significantly in mitigating climate change through promoting carbon sequestration by preserving the largest proportion of forests on the planet are likely to be the worst affected by long-term impacts of climate change (ICIMOD 2010). Further, these changes are likely to undermine the inherent capacity of indigenous mountain communities to respond and adapt to changing environmental conditions including climate change. Besides, the recent food crisis followed by global economic recession has adversely affected the food and livelihood security of mountain communities because of their subsistence economies, constraints of terrain and climate and resultant physical isolation and low productivity, vulnerability to natural risks, poor infrastructure, limited access to markets, higher cost of production, and poor employment and livelihood opportunities. It has been estimated that a large proportion of food insecure population now live in mountain regions of the world (Huddleston et al. 2003, FAO 2008a & 2008b).

It is therefore high time that national as well as international policy and decision making agencies and organizations

must realize the significance of mountain ecosystems is sustaining world population, and evolve framework for the sustainable development of mountain regions and well being of their inhabitants. The world community should come forward to compensate mountain people for the value of the ecosystem services provided by the mountain regions, and facilitate them in the protection of their fragile environment and conservation of natural resources and take benefit from emerging opportunities of globalization. This particularly imperative in the context of the United Nations Framework Convention on Climate Change (UNFCCC) for providing monetary benefits to mountain inhabitants for their contribution towards mitigating climate change through conservation of forests. The developed countries should line up to act as important resource centers for capacity building of developing countries by providing knowledge, technology, and expertise to mountain regions.

The Mountains:

Although mountains constitute very significant phenomena on the earth's land surface with varying altitudinal ranges and heterogeneity of landscape and terrain characteristics and diversity ecosystems, but so far, the mountains of the planet have not been defined very vividly and in a well acceptable manner (Mahat 2006). However, mountains can be characterized by their altitudinal progression across different climatic and vegetation zones, physiographic characteristics and landforms types. "Mountains include all areas of a marked relief with significant ecological differences and slopes which are susceptible to natural hazards and human activities" (Mahat 2006). The mountains and highlands constitute a large part of the planet as nearly 46.7% of the total area of all the continents is above 500 m; 26.9% above 1000 m; and 11.1% is over 2000 m (Mountain Agenda 1997).

United Nations Environment Programme – World Conservation Monitoring Centre (UNEP-WCMC) characterized mountain area as a land mass with slope and elevation which includes both mountains and hills (UNEP-WCMC 2000). However, in several cases mountains are separated from hills on the basis of their higher elevations, steeper slopes and lower temperatures. Food and Agricultural Organization (FAO) of the United Nations has defined mountains as areas with high altitudes and characteristic topography, and all the areas above 2500 m elevation have been included under mountains. Further, the areas having altitude between 300 m and 2500 m can also be categorized as mountain regions if they are marked with steep slopes or wide range of elevation in a small spatial unit (FAO 2002a). However, highland plateaus having elevation below 2500 m that lack surface slope and/or local elevation rate are therefore not included under mountains. But, the hills marked with low altitudes but exhibiting difficult terrain conditions have been classified as mountains (FAO 2002b).

The UNEP-WCMC classified world mountains into six categories ranging from Class – 1 to Class – 6 mountains taking into account elevation from the mean sea level and surface slope. The elevations higher than 2500 m from the mean sea level have been categorized as mountain areas irrespective of the magnitude of slope and topographic characteristics. The Class – 1 mountains are those areas which are situated in an altitudinal range of 300 m and 1000 m with a Local Elevation Range (LER) of 300 m of 5 km (i.e., characterized with 50 slope); , Class – 2 Mountains have an elevation from 1000 m to 1500 m with slope equal to or more than 50 or a Local Elevation Range 300 m of 5 km; Class – 3 Mountains should be located between the altitude of 1500 m and 2500 with a surface slope equal to and above 20; Class – 4 mountains area with elevation between 2500 and 3500; Class – 5 with altitudinal range between 3500 m and 4500 m; and Class – 6 mountains should have altitude above 4500 m. It is interesting to observe that this classification of mountain does not consider regions below the altitude of 2 500 m, high plateaus and large intermountain valleys as mountain areas, despite their showing several features of mountain ecology and being interconnected with mountain ecosystems. However, areas located just at altitude of 300 m above mean sea level but marked with more than 20 of slope have been classified as mountain areas from Class – 1 to Class – 3 Mountains.

As per the UNEP-WCMC classification of world mountains' nearly 29 million km2 area which accounts for about 22% of the total geographical land surface of the world is under different types of mountains. The maximum proportion of World Mountains (22 million km2) is located in in developing countries and only a small proportion (5 million km2) is situated in transition countries. The Asia and the Pacific region of the developing world shares 28%, developed countries 23% and countries in transition have 18% of the world's mountains. The sub-regions of developing and transition countries in which the mountain regions are extend over more than 1 million km2 include East Asia, the Commonwealth of Independent States (CIS), South America, the Near East, Southeast Asia and Oceania, South Asia and East Africa, and mountains in these sub-regions account for approximately 90% of the total mountain areas of the developing and transition countries. However, Huddleston et al. (2003) has classified those countries as mountainous where one-third of their population was living in mountain areas and/or in which mountainous terrain encompass more than one-third of the total geographical area.

However, taking into the proportion of total geographical area the sub-regions in developing and transition countries, East Asia, North America (Mexico), Central America, Southeast Asia and Oceania and the Near East respectively account for 50%, 45%, 41%, 35% and 34% areas of the respective sub-region. Interestingly, 80% of the world's mountains have altitude 2500 m and almost 50% mountains regions have elevation below 1000 m. The high mountains in the planet extend across the Himalaya, Andes mountain ranges and in Tibetan plateau. Geologically, the Himalaya, Andes, Alps and Rockies are considered as the youngest and tectonically active mountain ranges of the world, and owing to their high elevation, steep slope and geo-tectonic instability these mountains are characterized with high environmental fragility as well as socio-economic vulnerability. Nearly 90% of the mountain population live in developing or transition countries (Huddleston et al. 2003); 50% in the Asia-Pacific region and one-third live in China. About 30% of total world's mountain population lives in urban centres even though during the recent years the mountain regions of heavily populated developing countries have been experiencing rapid urban growth (Hassan et al. 2005). Out of the total population living in the mountain regions more than 50% live below 1000 m, and over 70% live below 1 500 m, whereas less than 10% global mountain population live in the mountain area located above 2500 m (Huddleston et al. 2003). However, the distribution of population living in mountain areas varies remarkably from one region to another. The Hindu Kush Himalayan (HKH) mountains ranges extending across the countries of Bhutan, Nepal, Afghanistan, India, Pakistan, the Tibetan Plateau and the Andes Mountains in Bolivia, northern Chile, Ecuador, Peru are virtually the only mountain regions which are inhibited by humans above an elevation of 4500 m even though the population living in these high mountains account for merely less than 1% of total global mountain population (Huddleston et al. 2003).

Mountain Ecosystem Services:

The Millennium Ecosystem Assessment (MA) was carried out between 2001 and 2005 to assess the consequences of ecosystem change for human well-being and to establish the scientific basis for actions needed to improve the conservation and sustainable utilization of ecosystems and their contributions to human well-being (Millennium Ecosystem Assessment 2005a). MA defines ecosystem as a dynamic complex of biotic components of nature that include plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit, and also as 'the benefits people obtain from ecosystems' (MA) (Millennium Ecosystem Assessment 2005a). The MA deals with the full range of relatively undisturbed ecosystems, such as natural forests and landscapes with mixed patterns of human use, and also ecosystems intensively managed and modified by humans, such as agricultural land and urban areas. Ecosystems are natural assets that provide a wide range of services and products that sustain humanity across the planet (Millennium Ecosystem Assessment 2005a). Mountains support many different ecosystems and provide key resources and services for human sustenance far away from mountains as most of the goods and services provided by mountains have their origin in the headwaters, the beneficiaries of these services are mostly in the lowlands (Beniston 2005). Highland and lowland ecosystems are thus highly interactive and inter-dependent in terms of ecology and economy as well as in social and political perspectives. The mountain population have contributed significantly to the conservation and protection of these ecosystem goods and services with their indigenous knowledge and traditional resource management practices. In view of this, mountain people need to be given some tangible incentives and adequate compensation for their most sincere efforts towards supporting the sustainability of large lowland population. The goods and services provided by mountain ecosystems can be divided into the following three primary categories (Hassan et al. 2005; UNEP-WCMC 2002)):

(i) Supporting Services which maintain the essential natural conditions for all forms of life on the earth and are intangible and do not have an explicit market value. These services mainly include soil formation, photosynthesis, and nutrient cycling. (ii) Provisioning Services that provide means of livelihoods and the economy by supplying various natural resources and products, such as, food, water, timber, and fibre. Undoubtedly, the most important good provided by mountain ecosystem is water, and therefore mountains are often known as 'water towers' for the world (Viviroli et al. 2007; UNEP-WCMC 2002) (Table 4, 5, 6 & 7 and Figure 3). Mountains slopes and valleys have the capacity to store a large amount of fresh-water in the forms of glaciers, snow, and ice; as well as in the forms of groundwater and lakes. Almost all the principal rivers of the world besides many a large number of others have their sources in mountains (Messerli and Ives 1997). It has been observed that more than half of the total geographical area of world's mountains is highly crucial for supplying fresh-water to large population inhabiting the lowlands. The freshwater of Hindu Kush Himalayan (HKH) mountain ranges is used by more than 200 million people living in the region and by 1.3 billion people living in the ten downstream river basins of South and East Asia (Viviroli et al. 2007). Besides water, mountains are endowed with high biological and agricultural diversity that includes variety of food and fibre crops and medicinal plants (UNEP-WCMC 2002). (iii) Regulating Services regulate climate, flood and, disease, maintain water quality and recycle wastes. Mountain play vital role in maintaining and supporting a healthy and safe environment and climatic conditions for the survival of human being as well as for other living organism. Mountains contribute significantly in maintaining the hydrological cycle through purification and retention of rainwater in the forms of groundwater, ice, and snow, as well as in lakes and streams. Mountain ecosystems play important role in atmospheric circulation and climate regulation and act as pool for the

storage carbon and soil nutrients. The mountain slopes consisting of nearly 28% of the world's forests provide mechanical support to landscape and hence protect fragile slopes against land degradation and slope instability (IPCC 2007a, b). (iv) Cultural Services that provide opportunities for recreation and education and spiritual and aesthetic inspiration (World Resource Institute 2005). The mountain regions are exhibited by cultural and ethnological diversity including spiritual traits and rich traditional ecological knowledge which besides strengthening the adaptive capacity of mountain communities to global change also provide fascinating attractions to a variety of visitors (Bernbaum 1997).

During the last 50 years human interventions have transformed natural ecosystems more rapidly and extensively than in any comparable period of time in human history on the earth. This was primarily to fulfill rapidly growing demands of natural resources, such as, arable land, food, fresh water, timber, grazing areas and energy which resulted into a considerable and largely irreversible loss of biodiversity and ecosystem services on the earth. Although these changes in the natural system have contributed significantly towards betterment of the quality of human life, but they also caused rapid exploitation of natural resources, substantial loss of ecosystem services and imbalanced economic growth in many parts of the planet. The depletion of natural resources and continued disruption and loss of ecosystem services may affect adversely the process of attaining the Millennium Development Goals MDGs) (Millennium Ecosystem Assessment 2005a). The challenge of restoration of ecosystem services and conservation of environment while meeting increasing demands of natural resources would require significant changes in policy plans and decision making processes from local to international levels. There are a number of possibilities and opportunities that may be used to restore certain types of ecosystem goods and services in such a way that they provide positive synergies with other ecosystem services (Millennium Ecosystem Assessment 2005a).

Marginality and Vulnerability of Mountains and their Inhabitants:

Mountains include some of the most fragile ecosystems on the planet (ICIMOD 2010) as they are highly sensitive to a variety of changes caused by natural as well as by anthropogenic factors primarily owing to their high relief, steepness of terrain, high rainfall, thin and shallow soils, sensitive flora and fauna, climatic complexities and geodynamic instability (Sonesson and Messerli 2002). The drivers of changes range from a variety on natural hazards and disasters including, degradation of land, slope instability and landslides, volcanic eruptions and seismic activities, floods and flesh floods, cloud bursts, avalanches, droughts to a series of human induced processes such as, population growth and resultant intensification of land use and depletion of natural resources, forest fires, globalization, urbanization, changing economic policies and orders; political marginalization and cultural dilution. Moreover, changing climatic conditions have stressed the mountain environments through, higher mean annual temperatures and melting of glaciers and snow, altered precipitation patterns, and more frequent and extreme weather events which are likely to intensify the impacts of other natural as well as socio-economic drivers of change and may cause substantial decrease in availability of ecosystem services, and consequently increase the proportion of water, health, food and livelihood insecure people in large part of their lowlands.

However, despite exhaustive debate and discussion on climate change and its possible drivers still there exist vast knowledge gaps in understanding the crucial linkages between climate change and mountain ecosystems. This indicates that the exact impacts of climate change on mountains and its connection with other drivers of global change are yet to be fully understood and interpreted at global as well as regional and local levels. However, it is clear that the changes in mountain landscape and resultant disruption of ecosystem services would directly lead to social un-sustainability and economic insecurity of 30% of world's population living in mountains as well as in their vast lowlands.

This will have particularly severe impacts on the livelihood and economy of mountains and their densely populated plains ecosystems in developing countries dependent primarily on subsistence crop farming (Tiwari 2000). Mountains exhibit very high level of ethno-culturally complexity which reflected in diversity of languages, dialects, food habits, costumes, traditions, and economic systems. The mountain communities and their culture is vast depository of rich traditional knowledge which they have evolved through experimentation with complex natural conditions, and applying it in the conservation, management and governance of natural resources and adapting to impacts of global change including rapidly changing climatic conditions in mountains. The traditional community resource management practices and traditional coping mechanism to environmental changes are now being considered highly relevant and significance in responding to the impacts of global change in mountain environments, and particularly for low-intensity production systems at high altitude (UNEP-WCMC 2002).

This clearly indicates that mountain communities, particularly in developing and underdeveloped countries are highly vulnerable to the impacts of global change (UNEPWCMC 2002). The driving forces of mountain people's vulnerability include unbalanced poverty levels, declining agricultural productivity and increasing food insecurity, poor health

conditions, high dependency on natural resources, socio-economic and political marginalisation, and limited livelihood options. The potency of these factors is likely to be further exacerbated by the process of global change especially in least developed countries. It has been indicated that the impacts of climate change on economic development will be unevenly distributed around the globe (Sanderson and Islam 2009). In order to improve rural livelihood in mountains and reduce poverty, it would be highly imperative to address the issue of climate change and its relationship with economic development through adaptation measures.

Approximately, 2.1 billion people amounting to 40% of the rural population of developing countries live in Less Favored Areas (LFA) which are primarily defined as low productivity regions mainly due geo-environmental constraints, lack of access to infrastructure and market and socio-economic and political marginalization (Ruben et al. 2004). Nearly, 90% mountain-population lives in developing or transition countries; 50% in Asia Pacific region and one third of population of mountains resides in China. Although the mountains, particularly those situated in developing countries have been passing through a process of rapid urbanization, yet majority of mountain population (70%) across the planet live in rural areas. A considerably large proportion of population living in mountain regions of developing countries primarily depends on subsistence agriculture for its food and livelihood even-though the availability of arable land is severely limited and crop productivity is poor. The Food and Agricultural Organization (FAO) of United Nations has identified more than 75% of the land surface of the world's mountain as unsuitable or marginally suitable for practicing agriculture. The mountains due constraints of terrain and climate and lack of access infrastructure and essential services and resultant low level of socio-economic development largely overlap with LFA ; Messerli and Ives 1997). As a result, the mountain ecosystems and their inhabitants are highly vulnerable to the long-term impacts of global change particularly in developing world. Although mountain areas are rich in natural resources, such as biodiversity, water and scenic beauty, but they often presents several challenges because of their subsistence economy, fragile environment, physical isolation, inadequate access to markets and inputs, low resource productivity and resultant vulnerability to risks of a variety of natural hazards and disasters.

Mountain regions, particularly in developing countries are largely inhibited by poor people . The mountain communities are subject to prevailing poverty and lower levels of socio-economic development than those in their adjoining lowland areas in developing countries. The main drivers of mountain poverty include fragility of ecosystems; remoteness; poor accessibility and marginalisation of mountain communities from the mainstream; lack of equity in terms of access to basic facilities such as health care, education, and physical infrastructure, as well as to markets, political marginalization; lack of employment opportunities; and proneness to natural disasters (Tiwari and Joshi 2012b and b; Jodha 1992; ICIMOD 2010). It has been observed that the proportion of poor and vulnerable people increases with elevation, and the ongoing process of globalisation seems to have further strengthened poverty imbalances between highlands and lowlands (Hassan et al. 2005, Huddleston and Ataman 2003). There are indications that poverty inequality between mountain people and those living in other areas is currently increasing in Nepal (ICIMOD 2010).

Approximately, 271 million people which accounts for nearly 40% of the mountain population in developing and transition countries have been estimated to be highly vulnerable to food insecurity; of which about 50% are surviving under chronic hunger. Out of the total of 245 million mountain rural population identified as vulnerable food insecurity as much as 87% live below 2500 m above mean sea level which constitute the most densely populated transact of mountains specifically in Asia and Latin America (Tiwari and Joshi 2012b). Although in higher mountains regions the number of vulnerable rural population is comparatively small, but that accounts for nearly 70% of the population living in high mountains above 2500 m. The lack of balanced diets reduces the supply of micronutrients in mountain people which results in very high level of malnutrition in local population (Huddleston and Ataman 2003). Furthermore, due to very limited and no access to primary health-care and sanitation facilities and increasing food deficiencies the maternal and infant mortality rates have been observed very high in mountain regions, particularly in developing and underdeveloped countries (FAO 2008a).

High dependency on natural resources and increasing marginalisation are some of important factors prevailing poverty, food and livelihood insecurity, poor community health, in mountains of developing countries which are further increasing their vulnerability to long-term impacts of global change (Tiwari and Joshi 2012b). The mountain population is traditionally dependent on natural resources and agriculture constitutes the prime source of rural livelihood in mountain environment (Huddleston and Ataman 2003). At lower mountains, intensive mixed farming systems are the most common form of agriculture, however, due to environmental constraints such as unfavourable climatic conditions, poor-quality or shallow soils, and sloping terrain, productivity is generally low and the produces are not competitive in the global market (Huddleston and Ataman 2003). Whereas, at higher elevations pastoralism is the most common livelihood option as due to rising altitude, declining temperature and steeper slopes restrict agricultural practices.

Global Change and Mountains:

The globalization and climate change are interrelated and interdependent drivers of global change. However, the global change studies in mountains so far dominated by climate change, and the impact of globalization did not received the desired focus (Kohler & Maselli 2009; Borsdorf et al. 2008; Jandl et al. 2009). The climate change has long-term impacts on ecosystem services both in mountains and their downstream, and the process of globalization also exerts a sharp impact on ecosystems and even more severe effect on the socio-economic landscape including agriculture, population structure and its dynamics, as well as the urbanization and marginalization of peripheral mountain communities (Borsdorf et al. 2010). The ongoing global discussion on responses at different spatial scale that might take place under the processes of future global change is generally focussed on fragile environments, such as the Arctic, coastal regions, and mountains (ACIA 2004; IPCC 2007a, b). Mountains consisting a vast repository of a variety of ecosystem services and goods constitute one of the most fragile environments on the planet and they are considered as being highly sensitive to global change (Diaz et al. 2003).

The drivers of global change and process of transformation in mountains are highly complex and multifaceted; hence the understanding of current responses and projecting future changes in these ecosystems is exceedingly difficult (Loeffler et al. 2011). People living in mountain areas are exposed to a series of environmental and non-environmental stressors which are interconnected and have serious implications on the livelihood and quality of life of mountain communities. These stressors include population growth and processes of socio-economic development which are linked to increasing demand of goods and services and globalisation that leads to depletion of natural resources, such as, land, water, forests, minerals and biodiversity (ICIMOD 2010). The global change is referred to the changes caused by both natural and anthropogenic processes and encompass, among other factors, climate change, land use cover change, industrialisation, urbanisation, and changes in atmospheric chemistry (Goudie and Cuff 2002). Becker and Bugmann (2001) have categorized global environmental changes affecting mountain ecosystems into two groups: (i) systemic changes that operate at a global scale (such as climate change) and cumulative changes caused by processes at a local scale but that are globally pervasive (such as land use cover change).

The environmental and economic changes and their impacts are parts of an invariable processes operating in mountain environment. However, during the recent years, the magnitude and rate of these changes and their impacts on natural and social systems have become severe with serious consequences for the sustainability of mountain communities as well as large population living in their catchments in the downstream. Currently, mountain ecosystems are changing more rapidly than at any time in human history on the earth. The long-term impacts of changes caused by deleterious anthropogenic interventions, such as intensification of land use and overexploitation of natural resources are much more deleterious for mountain communities than the affects natural processes, such as volcanic and seismic events, landslides, and flooding that devastate large parts of mountain ecosystems every year (Messerli and Hurni 2000; FAO 2002b; Pratt and Shilling 2002). Currently, mountain ecosystems and their inhabitants are exposed to a variety of drivers of change including globalisation; economic policies; and increasing pressure on land and mountain resources due to economic growth and changes in population and lifestyle (ICIMOD 2010).The major drivers of global change on world's mountain mainly include climate change, population dynamics, economic globalization, land use change, urbanization (Loeffler et al. 2011; Millennium Ecosystem Assessment 2005b). The Andes, covering 33% of the area of the Andean countries, are vital for the livelihoods of the majority of the region's population and the countries' economies. However, increasing pressure, fuelled by growing population numbers, changes in land use, unsustainable exploitation of resources, and climate change, could have far-reaching negative impacts on ecosystem goods and services.

Climate Change:

Global Climate Models (GCMs) have improved our understanding about climate change and its possible impacts in mountains. The mountains across the world, particularly Himalaya and Tibetan Plateau, have shown consistent trends in overall warming during past 100 years and the temperature rise in mountains is faster than in plains (Yao et al. 2006; Du et al. 2004). A number of studies indicated that the increase in temperature in Himalaya has been much higher than the global average of 0.74°C over the last 100 years (IPCC 2007a; Du et al. 2004). The Fifth Assessment Report of IPCC clearly indicated that the globe will warm between 1.5 °C and 4.5 °C by the period of 2085–2100, depending on the prevailing emissions scenario. The future temperature increases are expected to be stronger over land than over the ocean, stronger at high latitudes than in the tropics and, in the tropics, stronger at high altitudes than near the ground. The latter prediction of greater warming at high altitudes, supported by global models, demands further study in individual mountain regions (IPCC 2014). Himalaya has experienced warming between 0.15°C – 0.6°C per decade during the last three decade (Ouyang 2012). The Himalayan ranges in Nepal recorded a temperature increase of 0.6°C per decade between 1977 and 2000. It was observed that the temperature rise in Nepal and Tibet has been progressively higher with elevation (ICIMOD 2007, 2009). Global climate change is expected to exacerbate the impacts of other drivers of change on the mountains.

However, the exact impacts of climate change on mountain ecosystems, and the interlink-ages with other drivers of global change are yet to be investigated and properly understood (ICIMOD 2010). The mountain regions across the world have experienced the effects of global warming which are resulting into the retreat of glaciers, decrease in permafrost, changes in the seasonality of runoff, upward shifts of the vegetation line, and changes in the biodiversity of alpine lakes and streams. The long-term impacts of these changes are not only of direct relevance to the high mountains, but they will have serious implications for downstream regions. Mountain regions have experienced warming of above-average level in the 20th Century (IPCC 2007a, b). The rise in temperature in mountain regions has affected mountain environments and ecological processes across the globe. In case of Himalaya, the progressive warming at higher altitudes has been three times higher in comparison to global average (Eriksson et al. 2008; Xu 2008).

Warming projections for the current century indicate that the mountain systems of the world are expected to be warmer in the 21st century although the rise in temperatures will be disproportionate and in varying magnitude depending both on the altitude and latitude of mountains all over the planet (IPCC 2007a, b). IPCC Special Reports on Emissions Scenarios (SRES) indicates that the highest temperature rise is expected in high and medium-latitude mountains, including the high-latitude mountains of Asia, North America, and Europe and mid-latitude mountains of Asia compared to the mountain ranges of Australia and New Zealand (Rial et al. 2004; Burkett et al. 2005; Nogués-Bravo et al. 2007; Wookey et al. 2009). The high-latitude mountains of Asia are expected to experience the greatest increase in temperature, whereas tropical and mid-latitude mountains in Africa and South America are expected to be less warm with latitudinal gradient of temperature change (Nogues-Bravo et al. 2007). Depending on the different emissions scenario the average temperature in the mountain regions across the globe has been estimated to rise between 2.1ºC and 3.2ºC by 2055, (Nogues-Bravo et al. 2007) which is 2 – 3 times higher than the temperature recorded during the 20th Century in different mountain regions of the earth (Pepin and Seidel 2005).

Mountain ecosystems are expected to react very sharply to climate change (IPCC 2007a), with both natural and social systems being influenced all over the world (Beniston 2000, 2003, 2005, 2006). These changes can be irreversible if they are allowed to go beyond the critical threshold limits (Beniston 2003). Despite long-term predictions about changes in climatic conditions are not practically possible, but scenarios can be used to indicate potential changes (Nogués-Bravo et al. 2007). Climate change affects all spheres of the planet and as well as almost all components of the anthroposphere. However, the changes in the cryosphere are most clearly visible (Borsdorf et al., 2010). The climate change has shown it's most remarkable and significant impact on the glaciers which are retreating fast since the last century (Figure 5). The trend of glaciers melting is global and rapid which may lead to the de-glaciation of large parts of many mountain ranges in the world in the next decades (UNEP WGMS 2002). The Alps are among the most intensely studied mountains on the planet where an intensified retreat of Alpine glaciers has been observed during the previous century (Borsdorf et al. 2010). The Alpine glaciers have reduced by nearly 35% between 1850 and the 1970s, and as much as by 22% by 2000 (UNEP-WGMS 2008). The volume of glaciers in Canadian Rockies has decreased a minimum of 25% during the last century (Luckman and Kavanagh 2000). In the world's highest and largest mountain system – Himalayas, the rate of retreat of glaciers has been relatively faster than the world average and they are thinning at the magnitude of 0.3-1 m/year (Dyurgerov and Meier 2005). Further, it was investigated that the Himalayan glaciers are losing mass faster than European glaciers but slower than those in Alaska (Inman 2010). The rate of retreat of the Gangotri – the largest glacier of Himalaya – has been three times higher than the rate at which it melted during the preceding 200 years (Bhandari and Nijampurkar 1988; Tiwari 1972; Tiwari and Jangpangi 1962; Mukhophadayay 2006; ICIMOD 2007; IPCC 2007a & b; Rawat 2009; Srivastava 2003) (Figure 5). In Nepal Himalaya, a large number of glaciers have observed to be receding rapidly (Seko et al. 1998; Kadota et al. 2000; Fujita et al. 2001). The study indicated that 6% glaciers in the headwaters of Tamor and Dudh Koshi basins in Nepal Himalaya have decreased during 1970 -2000 (Ouyang 2012). As much as more than 82% glaciers in western China have receded during the last half century (Liu et al. 2006; Kang et al. 2010) and as much as 5.5% glaciers receded during 1980-2005 (Ouyang 2012). Further, the area under glaciers in Tibetan Plateau has decreased by about 11.5% over the last 40 years (CNCCC 2007). Similar trends in the responses of glaciers and snow-packed areas have been observed in South African mountains where about 85% of the total ice volume of the plateau glaciers of Mount Kilimanjaro in Africa vanished between 1912 and 2000 (Thompson et al. 2009). In general, the de-glaciation is accelerating in mountains, and consequently, that most snow and ice caps across the world are shrinking at alarming rates. However, exceptionally and interestingly, some of the high altitude glaciers in the Karakorom ranges in Asia have been found either advancing or stable as in the 1970s many of these glaciers showed evidence of short-term thickening and expansion (Hewitt et al. 1989).Out of 42 studied glaciers in Karakoram region, 58% are either advancing or stable and 42% retreating (Scherler et al. 2011; Hewitt 2005). Inman (2010) observed that the remote glaciers of the Himalayan mountains have been a subject of much controversy, but without adequate research. Out of about 12000 to 15000 glaciers in Himalaya and nearly 5000 in Karakorum, very few have so far been monitored on the ground. However, he maintains that Himalayan glaciers have been losing mass, with noticeably greater loss in the past decade (Inman 2010). In all other

mountain regions including Himalaya, Hindukush, West Kunlun Shan, the glaciers are mostly retreating, and the study has observed that the debris cover has a significant influence on glacier terminus dynamics (Scherler et al. 2011). In North American mountains, it was observed that a large number of glaciers were continuously retreating and thinning, and the unconsolidated and unstable sediment is exposed and mobilized into rivers, which causes aggradation downstream. As a result, the rate of sedimentation in most of the river-beds has increased from 7–13 cm up to 1.8 m per decade leading to more frequent catastrophic shifts in the courses of river channels (ASPEN International Mountain Foundation, 2012).

The glaciers have been found retreating in all Andean countries over the last three decades with the complete disappearance of a large number of glaciers. The average rate of retreat of glaciers in Cordillera Blanca of Peru has been observed to be 26% between 1970 and 2003, in Ecuador 27% during 1997 – 2006, 87% reduction in the Mérida Cordillera in Venezuela in the last 50 years, and 2% to 5% annual decrease in glaciers in Colombia over the last 10 years. The annual rate of contribution to sea-level rise from the Patagonian ice-fields has doubled during 2000 – 2005 in comparison to 1975 – 2000. The area of small glaciers has reduced by 50% in the Argentinean Tierra del Fuego. The Northern Patagonian Ice Field in South America lost nearly 140 km² of its snow covered area during1942 and 2001.

These observed changes in the cryosphere are transforming the hydrological regimes of mountain headwaters and disrupting drainage systems all across the basins. Consequently, regime of water resources in mountain headwaters is likely to change rapidly, with respect to discharge, volumes and availability (Tiwari 2000 and 2008; Tiwari & Joshi, 2012a, 2005; Bandyopadhyay et al. 2002 and Viriroli et al. 2003). In Himalaya, as many as 35% of the present glaciers will disappear and runoff will increase with peak flow attaining between 2030 and 2050 with a projected temperature increase of 2ºC by 2050 (Qin 2002). The impacts of retreating glaciers on river-flow s expected to be greater, in small, more highly glaciated headwaters in both the western and eastern Himalayan mountains under the uniform warming scenario of +0.06ºC per year. Water discharge in most of the glacier-fed sub-catchments (glaciation $\geqslant$50%) is likely to attain peak flow of 150% and 170% of initial flow around 2050 and 2070 in the western and eastern Himalayan ranges respectively before decreasing until the respective glaciers vanish in 2086 and 2109 (Rees and Collins 2006). The western Himalayan glaciers are expected to retreat in the next 50 years causing increase of Indus River flows, and then the glacial water-reservoirs will be empty, resulting in decrease of flows by up to 30% to 40% over the subsequent fifty years (World Bank 2005). At the same time, a large number of mountain communities have been severely threatened by the diminishing or disappearance of the small ice-masses and snow fields on which they depend for their water supplies (ICIMOD 2007). It is most likely that most of the mountain regions and their lowlands face a catastrophic water scarcity by the 2050s resulting from population growth, climatic change, and the increase of water demand (Oki 2003).

The Himalaya and Tibetan Plateau – the 'Water Tower of South Asia' sustains livelihood and economy of approximately 200 million people. The observed changes in headwater ecosystems are likely to have significant implications on water availability for mountain as well as downstream population (Stern et al. 2006). The continued melting of glaciers, snow and ice cover will adversely affect the supply of water leading to severe water crisis and potential conflicts in large part of the world. Himalaya, for example, constitutes headwaters of some of the largest trans-boundary basins of planet (e.g. Amu Darya, Brahmaputra, Ganges, Indus, Irrawaddy, Mekong, Salween, Tarim, Yangtze and Yellow River Basins) that sustain one-fourth global population dependent primarily on subsistence agriculture in Pakistan, India, Nepal, Bhutan, China and Bangladesh. Climate change has stressed hydrological regimes of Himalayan headwaters through higher mean annual temperatures, melting of glaciers and altered precipitation patterns causing substantial decrease in water availability. This may increase proportion of health, food and livelihood insecure population in South Asia which includes some of the poorest people of the world with access to less than 5% of planet's freshwater resources. This will have enormous regional implications for fundamental human endeavours ranging from poverty alleviation to environmental sustainability and climate change adaptation, and even to human security (Stern et al. 2006). However, in view of the complexity of inter-linkages between the climatic and non-climatic drivers influencing the mountain freshwater resources and very high improbability regarding changes in precipitation patterns it is extremely difficult to project future changes in mountain freshwater ecosystems.

In the Andes, clean water becomes a critical resource for future sustainable development, taking into consideration the generalized scarcity of resources in the country. Climate change is already decreased the annual average rainfall by 50% in the southernmost section of Chilean Patagonia, mean and minimum temperatures are increasing, snowlines are rising and glaciers are retreating (CONDESAN 2011). There are already serious concerns about decreasing availability fresh-water and reduced supply of hydropower in cities, such as La Paz, Lima and Quito (CONDESAN 2011). The glacier runoff is highly significant for the supply of fresh-water in Peru and Bolivia (Buytaert et al. 2011) where the decreasing glacier runoff is affecting the prime agricultural areas in many of the Andean valleys, particularly in Cordillera Norte and Central in Argentina and Chile (CONDESAN 2011). Decreases in water levels in rivers originating in mountains in the provinces

of Río Negro and Neuquén, probably due to reductions in snowfall in the Andes, have already led to 40% reductions in hydroelectricity generation (República de Argentina 2007).

Mountain ecosystems sustain about 50% of the global biodiversity, and support approximately half of the biodiversity hotspots of the planet (Hassan et al. 2005). Furthermore, nearly 28% of geographical area of world's terrestrial protected areas has their home in the mountains (Kollmair et al. 2005). Nonetheless, mountain biological species are adapted to specific altitudinal zones and microclimatic conditions; hence they are highly sensitive to climate variability (Hassan et al. 2005, IPCC 2007a, b). The high relief, steep terrain, the compression of climatic zones, and landscape fragmentation, increases the biological richness in terms of both species diversity and endemism in mountain ecosystems (IPCC 2007a & b; Körner 2009). The observed trends of changes in temperature are expected to push the vegetation belts upward in higher elevations and the geographical ranges of species may advance northward in the northern hemisphere changing the species composition of communities (Nogues-Bravo et al. 2007; Singh et al. 2010). The advancing unfolding, blossoming, and ripening in the leaves and fruit of wild plants; and of hibernation, migration, and breeding of wildlife have been observed in mountain regions (ICIMOD 2007). In China, the phenology of events has become two to four days earlier than observed in 1980s (Zheng et al. 2002). The climate change also increases the risk of extinction for species with narrow geographic or climatic distributions and also disruption of existing communities. A large number of endemic plant species are unable to respond appropriately to rapidly changing climatic conditions (McCarty 2001). In the Alpine zone the upward movement of tree line and encroachment of woody vegetation has been observed. In the eastern Himalaya, the tree line is moving upward at a rate of 5-10 m per decade (Baker and Moseley 2007). However, some mountain species, such as, territorial animals, late successional plant species, species with small, restricted populations, and species confined to summits are likely to face extinction (Körner 2009).

There is widespread agreement that global warming is associated with the most severe fluctuations, particularly in combination with intensified monsoon circulations that changes the frequency and magnitude of extreme weather events and causes severe natural hazards and disasters. Mountain ecosystems are highly vulnerable to a variety of natural hazards and disasters which now being triggered by rapidly changing climatic conditions. The changes in temperature and precipitation pattern and melting of glaciers and snow alter the frequencies, distribution and magnitudes of natural hazards and disasters in mountains. Mountains are typically exposed to a variety of natural hazards and their multiple impacts, and the incidences and magnitude of hazards and extreme events, such as, floods, windstorms, and droughts, cloud bursts, flash floods will increase with increasing temperature and changes in precipitation pattern (Kohler and Maselli 2009; IPCC 2007a & b).The global warming is to intensify the hydrological cycle in mountain watersheds changing the frequency, intensity and severity of floods and droughts in mountains as well as in their lowlands (Beniston 2005). The high intensity precipitation could trigger flash floods, slope failure and landslides in mountainous terrain having severe impacts on the natural and socio-economic sustainability of fragile mountain ecosystems especially in the tropics and at higher latitudes where an increase in overall precipitation is expected. The more intense precipitation has increased the incidences as well as the spatial scale of floods in the Central Europe during the past some decades. Since the 1990s, an increase in extreme events has been recorded in several river systems with a probability of recurrence in such short succession in large part of Europe (Borsdorf et al. 2008). On the contrary, the risks of droughts are likely to increase in most subtropical and mid-latitude regions. The most dangerous natural disasters in high mountains are associated with the direct consequences of changes in the cryosphere. The changes in cryosphere has led to the formation of a large number of glacial lakes in Himalaya, and many of these high altitude lakes are potentially dangerous. The resulting Glacial Lake Out Flows (GLOFs) can cause catastrophic flooding in lowlands damaging human lives, property, forests, agricultural land, crops and infrastructure. Nepal Himalaya has recorded 25 GLOFs over the last 70 years (Mool 2001; Yamada 1998). In the Hindu Kush-Himalayan region, some 204 critical glacial lakes bearing the high risk of breaching have been identified (Ives et al. 2010). It has been observed that liquid precipitation in combination with excessive melt-water often triggers flash floods and debris flows. In Karakoram ranges, the catastrophic rockslides have a substantial influence on glaciers and have triggered glacial surges which are specific hazards in the Karakoram and Pamir mountains (Hewitt 2005). In the Andes, the frequency of extreme climate or weather events in Andean countries, such as flooding, extreme temperatures, landslides, droughts and wildfires have increased by almost 40% in the period 2001-2010 (CEPAL 2011).

As discussed in the preceding sections, mountain consisting of fragile ecosystems are highly vulnerable to the impacts of these changes that may cause substantial loss of forests, biodiversity and natural habitats, decrease in availability of water for drinking, sanitation and food production, and consequently increase proportion of water, health, food and livelihood insecure population in the entire region. Moreover, the changing climatic conditions are also expected to increase both the severity and frequency of natural disasters in fragile mountains (IPCC 2007 a & b; ICIMOD 2007a). Climate change is particularly threatening sustainable development, especially poverty alleviation and livelihood improvement programmes, in the mountains as critical livelihood resources such as agricultural crops, storage of food and

seeds, and agricultural land have come under increasing threats of climate change triggered natural risks particularly in developing countries. The mountain communities are expected to face more stern impacts in future due to the likelihood of more and more frequent occurrences of extreme events, and their economic development prospects are coming under increased risks of natural calamities. The long-term impacts of climate change may thus further widen the existing socio-economic inequalities between highland and lowland communities. Tourism is emerging as one the most important opportunities in mountains all over the world. However, like agriculture, the tourism industry is extremely susceptible to changes in climatic and other environmental conditions. Picturesque and pristine natural landscapes, twisting rivers, glaciers, diversity of flora and fauna and range of protected areas are some of the major tourist attractions in mountains all over the world. Climate change and the resultant increase in extreme events, fast melting of glaciers, diminishing water flow in streams and rivers have already threatened tourism industry both in developing and developed countries. Winter skiing resorts in the Alps have to made heavy investments into adapting to higher temperatures over the past several years, and in view of this the resort located at lower elevations would no longer be competitive (IPCC 2007a & b).

It is likely that food insecurity could increase more sharp with climate change, and the community health conditions, particularly the sensitive segment of society, such as the old people, infants and children, pregnant women, and the chronically sick may further deteriorate. The declining rainfall and decreasing number of rainy days and the reduced availability of water and increasing incidences and severity of natural disasters may result in crop failure spread of crop and livestock pests and vector-borne diseases to higher elevations with rising temperatures. This may further undermine the sustainability and wellbeing of mountain communities in poor regions. Moreover, the traditional livestock rearing and pastoral practices are becoming increasingly vulnerable due to population growth and the resultant land use intensifications at higher elevations, and also owing to the impacts of more frequent and severe droughts, and the breakdown of traditional trade routes and patterns of exchange (Huddleston and Ataman 2003).

Mountains in International Sustainable Development Agenda:

Mountains have long been marginalized from the view point of sustainable development of their resources and inhabitants. However, our understanding about the problems of mountain regions and approach to their development has undergone drastic changes, during the recent years (ICIMOD 2010). The first UN conference on the 'Human Environment' held in Stockholm in June 1972 figured the subsequent international mountain conferences. This was followed by the pioneering publication of famous report 'The Limits to Growth' by Club of Rome's (Meadows et al., 1972) which initiated research in globalization through bringing into focus the projections of high populations increase and growth of economy and technology in the world. Over the next years a large number of international conferences took place in different mountain regions of the world which was followed by the establishment of the International Centre for Integrated Mountain Development (ICIMOD) involving all eight countries of the Hindu Kush-Himalaya (HKH) in Kathmandu, Nepal in 1983, the African Mountain Association in Ethiopia in 1986, and Andean Mountain Association in 1991 in Chile. This facilitated developing countries to support the proposal of a mountain chapter in the Agenda 21 at the third preparatory conference for Rio in 1991, and consequently, increased awareness and improved understanding of the effects of climate change and globalization on world' mountains (Borsdorf et al. 2010).

The significance of mountain social-ecological systems was acknowledged for the first time on a global scale in Agenda 21 of the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro, Brazil, in 1992. The Chapter 13 titled 'Managing Fragile Ecosystems: Sustainable Mountain Development' of Agenda 21 recommends two priority programmes for the sustainable development of the world mountains. These include: (i) generating and strengthening knowledge about the ecology and sustainable development of mountain ecosystems; and (ii) promoting integrated watershed development and livelihood opportunities in mountains. The Food and Agriculture Organization (FAO) of the United Nations was assigned with the responsibility of facilitating and reporting if the implementation of these two programmes.

This resulted in several specific initiatives by different governments of mountainous countries, international organizations, NGOs and scientific agencies across the world during the decade following the UN Conference on Environment and Development. Establishment of Mountain Forum in 1995 was one the important initiatives taken for a global network for information exchange, mutual support, and advocacy towards equitable and ecologically sustainable mountain development and conservation of mountains ecosystem across the world. This was followed by designating 2002 as the International Year of Mountains (IYM) by United Nations General Assembly which was followed by Global Mountain Summit in Bishkek, Kyrgyz Republic in the same year. The International Year of Mountains provided with the great opportunity for raising awareness about the importance of mountains for sustainability of global environment. This resulted in the manifestation of several new initiatives, including the Adelboden Group which lead to the creation of Sustainable Agriculture and Rural Development in Mountains (SARD-M), Global Change in Mountain Regions

(GLOCHAMORE) and the Mountain Research Initiative (MRI). Further, Mountain Partnership was launched at the World Summit on Sustainable Development held in Johannesburg in 2002 to promote, strengthen and facilitate closer collaboration between governments, civil society organizations, inter-government agencies, and the private sector toward achieving sustainable mountain development. All these initiatives and actions have been quite successful in raising awareness of the importance of mountains, and some of them also initiated successful interventions for sustainable mountain development.

On the other hand, in spite of all these successful initiatives and actions and the UN General Assembly continued emphasis on the sustainable mountain development, the mountain regions of the world have never received the desired consideration in the global development agenda (Mountain Partnership 2015). One of the important reasons for mountains not receiving adequate attention was the international developmental agenda is always dominated by the sustainable development agenda, such as the Millennium Development Goals (MDGs) and the Poverty Reduction Strategy Papers (PRSP), which were largely implemented as national programmes ignoring the ecology and specific developmental requirements of mountain areas (Mountain Partnership 2015). Furthermore, the outline of United Nations Framework Convention on Climate Change (UNFCCC) still lacks a mountain perspective, largely because of substantial knowledge gaps and an uncoordinated approach by the countries that are most affected by climate change in their mountains (Mountain Partnership 2015). In view of this, several critical issues related with sustainable mountain development, particularly, management of water resources; conservation of biological and cultural diversity; infrastructure development, access to health services and markets; proper recognition and valuation of mountain ecosystem services and the aesthetic, recreational and spiritual significance of mountains need to be fully addressed (Sonesson and Messerli 2002). The Second UN Conference on Environment and Development (Rio+20) did not adequately and satisfactorily addressed the critical issues related to sustainable mountain development (Mountain Partnership 2015). However, mountains have been as one of the important thematic areas under the framework for action and follow-up (United Nations 2012).

It is therefore highly imperative to place sustainable mountain development in developing countries and the increasing socio-economic vulnerability of their population at the centre of climate change mitigation and adaptation strategy (UN 2014, 2015). Further, in view of increasing demands for fresh-water and hydro-power and other mountains ecosystem services, it would also necessary to realize the need of integrated framework for addressing upstream-downstream interlink-ages, as well as comprehensive trans-boundary river-basin management approaches. The emerging need of adaptation to climate change, particularly in developing countries, calls for further redefining the global sustainable development agenda focusing on eco-region based integrated development (UN 2015). With the rapid retreat of mountains glaciers across the planet and its potential serious long-term impacts on the fresh-water ecosystem and availability of water resources in large part of the world, the mountains regions have suddenly gained global attention, which need to be seized into concrete actions and effective programmes for sustainable development of mountain regions and improvement of the livelihood of their inhabitants, particularly in developing countries.

Conclusion:

Mountains despite their marginality and remoteness are changing rapidly under increasing pressure from globalization and climate change. These changes have unlocked the natural resources of mountains for exploitation without serious concern for sustainable development of mountain and well being of their inhabitants. Consequently, mountain ecosystems as well as mountain communities, specifically in developing and underdeveloped countries are particularly threatened by a series of drivers and processes of global change and emerging new international economic and political orders. However, we are experiencing an emergence of responsiveness of the ecological significance of mountain systems and their importance for the sustainability of global community, particularly after the United Nations Conference on Sustainable Development – the Rios Earth Summit in 1992. As a result, our understanding about the dilemmas of mountain regions and approach to their development has undergone drastic changes, during the last two decades. The climate change has emerged as one of the major drivers transforming consistently the natural environment, society and economy of the mountains regions in all parts of the world, and mountains ecosystem being highly sensitive are extremely vulnerable to these changes. However, there is still a high degree of uncertainty about the trends and magnitude of climate change and its impacts on mountain systems (Mountain Partnership 2015). It is therefore highly imperative to improve our understanding of the trends of changes in temperature and variability in precipitation pattern at local level through downscaling of regional climate models. This would require establishment of a comprehensive networks of hydro-meteorological monitoring stations in mountain areas across the world, particularly in the mountains of developing countries where currently, such monitoring is extremely lacking. Furthermore, a sharp focussed and comprehensive research on climate change impacts assessment, vulnerability and adaptation to climate change would be necessary at micro-regional scale.

An effective mechanism for the sharing of information, data, experience and knowledge generated from local, regional to international levels and international level transfer of knowledge would be crucial for better understanding of changing climatic conditions and evolving appropriate strategies for mitigation of climate change and responding to its impacts in an amicable manner. Since mountains constitute headwaters of some of the largest trans-boundary basins on the earth, it would also be indispensable to establish and strengthen international research collaboration, and develop international mechanisms on knowledge and data sharing. A regional geo-political cooperation framework among riparian countries is therefore highly crucial not only for evolving framework of adaptation to climate change and improved governance of headwaters resources, but also for security and peace in the entire world. The international conventions, initiatives and organization can play an effective role in initiating trans-boundary climate adaptation diplomacy in different mountain regions. All mountain regions across the world are currently facing the common threats from climate change and economic globalization in the backdrop of the similar constraints of terrain, fragility; geographical isolation and socio-political marginalisation. In many developing countries, policy decisions and planning processes have plains perspective largely ignoring the disproportionate vulnerability of social-ecological systems of mountains. Hence, effective mountain-specific policies need to be designed not only at the national level but also at global scale, as these challenges are independent of national territories. In order to address the challenges posed by climate change, the mountain countries and regions should develop mountain specific adaptation and mitigation policies, programmes, institutions and think tank which would be necessary to enhance their resilience and ensure socio-economic and ecological sustainability in mountain areas.

Reducing Emissions from Deforestation and Degradation (REDD) and Enhancement of Carbon Stocks (REDD+) are other important opportunities under the United Nations Framework Convention on Climate Change (UNFCCC) which offer incentives for developing countries to reduce emissions from forested lands and invest in low carbon activities for their sustainable development. Mountains accounting for nearly 28% of the world's forests bear a huge potential for carbon storage and sequestration and are therefore in a privileged position to attract such funds for climate change mitigation bear a huge potential for carbon storage and sequestration and are therefore in a privileged position to attract such funds for climate change mitigation. Hence, the mountain forest-ecosystems are one of the most vital mainstays of Green Economy and in attaining the goals of both REDD and REDD+. The forests conservation in mountains therefore needs to be linked with climate change mitigation and adaptation, poverty alleviation and food and livelihood security of local people. In view of this, the recent experiences of Forest Pnchayats and lessons learned from Joint Forest Management (JFM) in Indian Himalaya and Community Forestry (CF) in Nepal can best be replicated and used for institutionalizing forests and for their community oriented conservation and development. This would provide mountain people with the opportunity of getting involved in global carbon credit process and enhancing their quality of lives through reduction of poverty, improvement of livelihood and restoration of ecosystem services. In addition, several ecological benefits, such as conservation of biodiversity, increased forest productivity, erosion control, slope stabilization and hydrological restoration, could be obtained by integrating participatory forest management with existing carbon markets.

A considerably large proportion of population in mountain regions of developing countries depends for its livelihood on severely limited arable land symbolizing distress husbandry of land. Paradoxically, on the other hand, nearly large forest area put together with water-bodies, high altitude pastures etc. characterized with charismatic landscapes, natural splendor, variety of flora and fauna, enthralling wilderness and rich biodiversity have so far been utilized to provide livelihood to small percentage of rural population. The situation therefore calls for looking beyond the traditional agricultural system and generation of rural employment opportunities in off-farm and non-traditional sectors in the mountains area of less developed countries. This brings out the fact very clearly that restoration of ecosystem services through sustainable utilization and conservation of critical natural resources, such as, land, water, forests, and biodiversity, and generating economically viable options of rural livelihood other than agriculture, and ensuring food security would constitute the critical components of the process of climate change adaptation in mountain areas of less developed countries (UN 2014). The strategy should have wider scope for the generation of off-farm livelihood employment opportunities particularly through the promotion of local rural enterprise in different sectors of tourism. Hence, tourism presents great potential for the inclusive development of the region (UN 2015).

However, the agriculture will remain as one of the important economic activities in the mountains of developing countries, and thus will constitute one of the core components of overall climate change adaptation strategy in the mountains in times to come. This is primarily because, the agriculture is not merely an important economic activity and fundamental source of livelihood of local rural communities, but also constitutes an integral part of their culture, history and traditions, and an invaluable treasure of traditional ecological knowledge required for adapting to climate change. Secondly, mountains have some of the highly productive and agriculturally prosperous valleys and mid-slopes which have still potential of contributing towards the food as well as livelihood security. Thirdly, the potential of varying agro-climatic

zones from valleys to higher elevation can be utilized for growing variety of crops and producing seasonal as well off-season agricultural products. Fourthly, for making tourism ecologically conducive, economically viable and pro-poor livelihood and adaptation strategy it need to be linked with local agricultural and food systems (UN 2014, 2015). Lastly, integration of tourism with local production system will create local viable market for the agricultural products and thus make local agriculture economically viable. In view of this, 'Ecological Tourism' which is now popularly known as 'Ecotourism' has immense potential to be developed as potential adaptation strategy to climate change in mountain areas of less developed countries. Ecotourism capitalizing upon both the socio-cultural and biophysical strength of the mountain landscape would contribute significantly towards securing viable alternative livelihood opportunities, particularly for the poor and marginalized mountain communities in the mountains.

Regional initiatives, including the Mountain Research Imitative (MRI), Mountain Forum (MF), Alpine Convention (AC) and the recent global Mountain Initiative (MI) floated by the Government Nepal need to be strengthened. The Mountain Partnership sponsored by FAO play significant role in inter-connecting these various regional and global initiatives. Regional information networks need to be established which would act as effective learning and awareness generation forums between specialists, civil society organizations, and government agencies and to support capacity building activities through focussed education, training and research. Further, in order to build resilient mountain social-ecological systems, the support and cooperation of civil society, including Non-Government Organisations (NGOs), Civil Society Organisations (CSOs), the private sector, educational and research institutions would be inevitable. These institutions play effective role in sensitising policy planners, decision makers and society at large about the importance and significance of mountain eco-systems in sustaining global society as well as about their fragility, marginality, vulnerability and the emerging opportunities.

References:

ACIA 2004. Impacts of a warming Arctic: Arctic climate impact assessment. Cambridge. ASPEN International Mountain Foundation 2012. Sustainable Mountain Development: North American Report – Report Submitted for Rio+20, ASPEN International Mountain Foundation

ASPEN International Mountain Foundation. 2012. Sustainable Mountain Development: North American Report—Report Submitted for Rio+20, ASPEN International Mountain Foundation.

Baker, B.B., Moseley, R.K. 2007. Advancing Tree-line and Retreating Glaciers: Implicatiions for Conservation in Yunnan, P.R. China. In Artic, Antarctic and Alpine Research, 39 (2):200-209

Bandyopadhyay, J. and V. Shiva. 2002. Conflict over limestone quarrying in Doon Valley, Himalaya. Environmental Conservation, 12(2): 1319.

Beniston, M. 2000. Environmental change in mountains and uplands. London.

Beniston, M. 2003. Climatic change in mountain regions: a review of possible impacts. In: Climatic Change 59, 5–31. DOI: 10.1023/A:1024458411589

Beniston, M. 2006. Mountain weather and climate: a general overview and a focus on climatic change in the Alps. In: Hydrobiologia 562, 3–16. DOI: 10.1007/s10750-005-1802-0

Beniston, M. 2005. Mountain climates and climatic change: An overview of processes focusing on the European Alps. Pure and Applied Geophysics, 2005, Vol. 162, p. 1587-1606.

Bernbaum, E. 1998. Sacred Mountains of the World. University of California, Press, Berkeley, Los Angeles, London, 291 pp.

Bhandari, N. and Nijampurkar, S. 1988. Himalayan Glaciers: our neglected Water Banks. In: Chadha SK (ed) Himalayas: ecology and environment. Mittal Publications, New Delhi, pp 76–92

Borsdorf, A., Tappeiner, U. and Tasser E. 2010. Mapping the Alps. In: Challenges for mountain regions. Tackling Complexity, Borsdorf, A., Grabherr, G., Heinrich, K., Scott, B. and Stötter, J., pp. 186-191, Böhlau, Vienna

Borsdorf, A. and Braun, V. 2008. The European and Global Dimension of Mountain Research – An Overview. Revue de Géographie Alpine, 96:4, pp. 117–129, ISSN 1760-7426

Bugmann, H. and Pfister, C. 2000. Impacts of inter-annual climate variability on past and future forest composition. In: Regional Environmental Change 1, 112–125. DOI: 10.1007/s101130000015

Burkett, V. R., Wilcox, D. A., Stottlemyer, R., Barrow , W., Fagre, D., Baron, J., Price, J., Nielsen, J. L., Allen, C. D., Peterson, D. L., Ruggerone, G. and Doyle, T. 2005. Nonlinear dynamics in ecosystem response to climatic change: case studies and policy implications. In: Ecological Complexity 2, 357–394. DOI: 10.1016/j. ecocom.2005.04.01

Buytaert, W., Cuesta-Camacho, F. and Tobón. C. 2011. Potential impacts of climate change on the environmental services of humid tropical alpine regions. Global Ecology and Biogeography 20:19-33.

CEPAL 2011. Climate Change: A Regional Perspective. Report. UN Economic Commission for Latin America and the Caribbean (ECLAC), IDB

CNCCC 2007. China national report on climate change 2007 (in Chinese). Beijing: China National Committee on Climate Change

CONDESAN 2011. 20 years of Sustainable Mountain Development in the Andes - from Rio 1992 to 2012 and beyond – Draft Regional Report, prepared for Lucerne World Mountain Conference

Diaz, H., Grosjean, M. and Graumlich, L. 2003. Climate variability and change in high elevation regions: past, present and future. In: Climatic Change 59, 1–4. DOI: 10.1023/A:1024416227887
Du, M. Y., Kawashima, S., Yonemura, S., Zhang, X. Z. and Chen, S. B. 2004. Mutual influence between human activities and climate change in the Tibetan plateau during recent years. Global and Planetary Change 41: 241-249
Dyurgerov, M. D. and Meier, M. F. 2005. Glaciers and Changing Earth System: A 2004 Snapshot. Boulder (Colorado): Institute of Arctic and Alpine Research, University of Colorado, p117
Eriksson, M., Fang, J., and Dekens, J. 2008. How does climate affect human health in the Hindu Kush-Himalaya region? Regional Health Forum 12(1):11-15
Food and Agricultural Organization 2008a. Soaring Food Prices: Facts, Perspectives, Impacts and Actions Required, High-level Conference on World Food Security: The Challenges of Climate Change and Bio Energy. Hlc/08/Inf/1, Rome, 3–5 June 2008
Food and Agricultural Organization 2008b. Food Security in Mountains – High time for action. Brochure of the International Mountain Day 2008. http://www.mountaineering.ie/documentbank/uploads/IMD08%20brochure.pdf
Food and Agricultural Organization 2002a. International Year of the Mountains. Food and Agriculture Organisation of the United Nations, Rome.
Food and Agricultural Organization 2002b. Land-water linkages in rural watersheds. Land and Water Bulletin 9. Food and Agriculture Organisation of the United Nations, Rome
Fujita, K., Kadota, T., Rana, B., Shrestha, R.B. and Ageta, Y. 2001. Shrinkage of Glacier AX010 in Shorong Region, Nepal Himalayas, in the 1990s. In Bulletin of Glaciological Research, 18: 51-54
Goudie, A. S. and Cuff, D. J. (eds.) 2002. Encyclopedia of global change, Environmental change and human society, Oxford.
Haigh, M. 2002. Headwater control: integrating land and livelihoods, paper presented at the International conference on Sustainable Development of Headwater Resources. United Nation's International University, Nairobi, Kenya, September, 2002.
Hassan, R., Scholes, R. and Ash, N. (eds) 2005. Ecosystems and human well-being: Current state and trends. Volume 1: Findings of the condition and trends, Working Group of the Millennium Ecosystem Assessment. Washington: Island Press
Hewitt, K. 2005. The Karakoram Anomaly? Glacier Expansion and the 'Elevation Effects,' Karakoram Himalaya. Mountain Research and Development, 25(4): 332-340
Hewitt, K., Wake, C.P., Young, G.J. and David, C. 1989. Hydrological Investigation at Biafo Glacier, Karakoram Himalaya: An Important Source of Water for the Indus River'. Ann. Glaciol, 13: 103-108
Huddleston, B., Ataman, E. and d'Ostiani, L. 2003. Towards a GIS-based analysis of mountain environments and populations. Environment and Natural Resources Working Paper No. 10. Food and Agriculture Organization of the United Nations, Rome
ICIMOD 2010. Mountains of the World –Ecosystem Services in a Time of Global and Climate Change: Seizing Opportunities – Meeting Challenges. Framework paper prepared for the Mountain Initiative of the Government of Nepal by ICIMOD and the Government of Nepal, Ministry of Environment
ICIMOD 2009. The Changing Himalayas: Impact of Climate Change on Water Resources and Livelihoods in the Greater Himalayas. ICIMOD, Kathmandu, Nepal
ICIMOD 2007. Melting Himalayas: regional challenges and local impacts of climate change on mountain ecosystems and livelihoods. ICIMOD, Kathmandu, Nepal
IFAD 2001. Rural Poverty: The Challenge of Ending Rural Poverty Report. Oxford University Press
Inman, M. 2010. Settling the Science on Himalayan Glaciers. Nature,
http://www.nature.com/climate/2010/1003/full/climate.2010.19.html March 2, 2010
IPCC 2014. Climate Change Impacts, Adaptation, and Vulnerability, Part A: Global and Sectoral Aspects, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Summary for policymakers, Cambridge University Press, Cambridge, United Kingdom and New York, USA, 2014, 1-32
IPCC 2007a. Climate change 2007: The scientifi c basis. Working Group I contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report. Cambridge: Cambridge University Press
IPCC 2007b. Climate change 2007: Impacts, adaptation and vulnerability. Working Group II contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report. Cambridge: Cambridge University Press
Ives, J. D., Shrestha, R. B. and Mool, P. K. 2010. Formation of glacial lakes in the Hindu Kush-Himalayas and GLOF risk assessment. ICIMOD, Kathmandu, Nepal
Jandl, R., Borsdorf, A., van Miegroet, H., Lackner, R. and Psenner, R. (Eds.) 2009. Global Change and Sustainable Development in Mountain Regions. COST Strategic Workshop, Innsbruck University Press, ISBN 978-3-902571-97-7, Innsbruck
Jodha, N. S. 1992. Mountain perspective and sustainability, a framework for development. In Jodha, N. S., Banskora, M. and Partap, T. (eds) Sustainable Mountain Agriculture, pp 41-82. New Delhi: Oxford & IBM Publishing.
Kadota, T., Seko, K., Aoki, T., Iwata, S. and Yamaguchi, S. 2000. Shrinkage of the Khumbu glacier, east Nepal from 1978 to 1995. In Debris Covered Glaciers, IAHS Publication No. 264:235-243. Wallingford (UK): IAHS
Kohler, T. and Maselli, D. (eds) 2009. Mountains and climate change – From understanding to action. Berne: Geographica Bernensia and Swiss Agency for Development and Cooperation
Kollmair, M. Gurung, G.S., Hurni, K. and Maselli, D. 2005. Mountains: Special places to be protected? An analysis of worldwide nature conservation efforts in mountains. International Journal of Biodiversity Science and Management 1: 181-189

Körner, C. 2009. Conservation of mountain biodiversity in the context of climate change. In Proceedings of the International Mountain Biodiversity Conference, Kathmandu, 16-18 November 2008, ICIMOD, Kathmandu, Nepal
Löffler, J., Anschlag, K., Baker, B., Finch, Oliver-D., Diekkrüger, B., Wundram, D., Schröder, B., Pape, P. and Lundberg, A 2011. Mountain Ecosystem Response to Global Change. Erdkunde, 65(2):189–213
Luckman, B. and Kavanagh, T. 2000. Impact of climate fluctuations on mountain environments in the Canadian Rockies. Ambio 29: 371–380
Mahat, T. J. 2006. Issues in Sustainable Mountain Development: The Himalayan Experience. "Hamro Kalpabrikshya", 17 (189), a monthly magazine of the Department of Forest (Ministry of Forest and Soil Conservation), Government of Nepal, Kathmandu, NEPAL. Unedited version is available from http://www.mtnforum.org/oldocs/486.doc
McCarty, J. P. 2001. Ecological Consequences of Recent Climate Change. Conservation Biology, 15(2):320-331
Messerli, B. and H. Hurni, 2000. African Mountains and Highlands: Problems and Perspectives. African Mountains Association, Walsworth Press, Missouri.
Messerli, B. and Ives, J. D. (eds) 1997. Mountains of the world – A global priority. A contribution to Chapter 13 of Agenda 21. New York: Parthenon
Meybeck, M., Green, P. and Vörösmarty, C. 2001. A new typology for mountains and other relief classes: An application to global continental water resources and population distribution. Mountain Research and Development 21: 34-45
Millennium Ecosystem Assessment 2005a. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.
Millennium Ecosystem Assessment 2005b. Ecosystems and Human Well-being: Current State and Trends: Findings of the Condition and Trends Working Group, Mountain Systems, Island Press, Washington, DC.
Mool, P. 2001. Glacial Lakes and Glacial Lake Outburst Floods. ICIMOD Mountain Development Profile, MDP 2. Kathmandu: ICIMOD
Mountain Agenda 1997. Mountains of the World: Challenges for the 21st Century. United Nations. Switzerland.
Mountain Partnership 2015. International Petition on Mountain Ecosystems and Peoples affected by climate change, letter to UNFCCC - United Nations Framework Convention on Climate Change Ensure that Mountain Peoples and Ecosystems are protected in the new climate deal. 22 September 2015, Mountain Partnership Secretariat, FAO Headquarters, Rome
Mukhophadayay, S. C. 2006. Glaciers and water source appraisal of Himalaya with special reference to Central Himalaya, Uttaranchal. In: Rawat MSS (ed) Resource appraisal, technology application, and environmental challenges in Central Himalaya, Vol 1. Transmedia, Srinagar, Uttarakhand, pp 106–119
Nogués-Bravo, D., Araújo, M. B., Errea, M. P. and Martinéz- Rica, J. P. 2007. Exposure of global mountain systems to climate warming during the 21st century. Global Environmental Change, 17, 420–428. DOI: 10.1016/j.gloenvcha.2006.11.007
Oki, T. 2003. Global Water Resources Assessment under Climatic Change in 2050 using TRIP'. Water Resources Systems – Water Availability and Global Change (Proceedings of symposium HS02a held during IUGG2003 in Sapporo, July 2003). IAHS Publ. No. 280. Fontainebleau (France): IAHS
Pender, J., and P. Hazell. 2000. Promoting Sustainable Development in Less-Favored Lands: Overview. In Promoting Sustainable Development in Less-Favored Lands, edited by J. Pender and P. Hazell. Washington, DC: International Food Policy Research Institute.
Pepin, N. C. and Seidel, D. J. 2005. A global comparison of surface and free-air temperatures at high elevations. Journal of Geophysical Research 110: D03104
Qin D.H. 2002. Glacier Inventory of China (Maps). Xi'an: Xi'an Cartographic Publishing House, Science Press, Beijing, China
Ouyang, H. 2012. Climate Changes and Water Resources Management in the HKH region: Strategy and Implementation. Paper Presented at ICIMOD-MAIRS joint International Workshop on Climate Change Impacts on Water/Land and Adaptation Strategies in the Tibet-Himalayan Region, Pokhara, Nepal, 27 – 29 June, 2012
Rawat, J. S. 2009. Saving Himalayan Rivers: developing spring sanctuaries in headwater regions. In: Shah BL (ed) Natural resource conservation in Uttarakhand. Ankit Prakshan, Haldwani, pp 41–69
Rees, G. H. and Collins, D.N. 2006. Regional Differences in Response of Flow in Glacier-fed Himalayan Rivers to Climate Warming. In Hydrological Processes, 20:2157-2167
República de Argentina 2007. 2da Comunicación Nacional de la República Argentina a la Convención Marco de las Naciones Unidas sobre Cambio Climático
Rial, J. A., Pielke, R. A., Beniston, M., Claussen, M., Canadell, J., Cox, P., Held, H., De Noblet-Ducourde, N., Prinn, R., Reynolds, J. F. and Salas, J. D. 2004. Nonlinearities, feedbacks and critical thresholds within the earth's climate system. In: Climatic Change 65, 11– 38. DOI: 10.1023/B:CLIM.0000037493.89489.3f
Ruben, R., Pender, J. and Kuyvenhoven, A. (eds.) 2004. Sustainable Poverty Reduction in Less Favoured Areas: Problems, Options, Strategies. CAB International, Oxfordshire UK
Scherler, D., Bookhagen, B. and Strecker, M. 2011. Spatially variable response of Himalayan glaciers to climate change affected by debris cover, Nature Geoscience, Vol.4
Seko, K., Yabuki, H., Nakawo, M. Sakai, A. Kadota, T. and Yamada, Y. 1998. Changing surface features of Khumbu glacier, Nepal Himalayas revealed by SPOT images. Bull Glaciol Res 16:33-41
Singh, S. P., Singh, V. and Skutsch, M. 2010. Rapid warming in the Himalayas: Ecosystem responses and development options. Climate Change and Development 2:1-13
Sonesson, M. and Messerli, B (eds.) 2002. The Abisko Agenda: Research for mountain area development. Ambio Special

Report 11, Stockholm: Royal Swedish Academy of Sciences
Srivastava, D. 2003. Recession of Gangotri glacier. In Srivastava, D. Gupta, K.R. and Mukerji, S. (eds.) Proceedings of a workshop on Gangotri glacier, Lucknow, 26 - 28 March 2003, special Publication No. 80, Geological Survey of India, New Delhi
Stern, N., Peters, S., Bakhshi, V., Bowen, A., Cameron, C., Catovsky, S., Crane, D, Cruickshank, S., Dietz, S., Edmonson, N., Garbett, S.-L.., Hamid, L., Hoffman, G., Ingram, D., Jones, B., Patmore, N., Radcliffe, H., Sathiyarajah, R., Stock, M., Taylor, C., Vernon, T., Wanjie, H. and Zenghelis, D. 2006. Stern Review: The Economics of Climate Change, HM Treasury, London.
Thompson, L. G., Brecher, H.H., Mosley-Thompson, E, Hardy, D. R., Mark, B. G. 2009. Glacier loss on Kilimanjaro continues unabated. Proceedings of the National Academy of Science of the United States of America,107 (35):1-6
Tiwari, A. P. 1972. Recent changes in the position of the snout of the Pindari Glacier, Kumaon Himalaya, Almora District, UP India. In: Proceedings of the symposium on role of snow and ice in hydrology. UNESCO-WHO-IAHS, Canada, pp 1144–1149
Tiwari, A. P. and Jangpangi, B. S. 1962. The retreat of the snout of the Pindari Glaciers. In: Proceedings of the symposium of Obergurage. International Association of Hydrological Sciences, pp 245–248
Tiwari, P. C. 2008. Land use changes in Himalaya and their impacts on environment, society and economy: A study of the Lake Region in Kumaon Himalaya, India. Advances in Atmospheric Sciences (an international journal of Chinese Academy of Sciences, Beijing), 25(6):1029-1042, 2008.
Tiwari, P. C. 2000. Land Use Changes in Himalaya and their impact on the plains ecosystem: need for sustainable land use, Land Use Policy 17:101-111.
Tiwari, P. C. and Joshi, B. 2012ba. Environmental changes and sustainable development of water resources in the Himalayan headwaters of India. International Journal of Water Resource Management, 26 (4):26:883–907. DOI 10.1007/s11269-011-9825-y.
Tiwari, P. C. and Joshi, B. 2012b. Natural & Socio-economic Drivers of Food Security in Himalaya. International Journal of Food Security, 4 (2):195-207. DOI 10.1007/s12571-012-0178-z
Tiwari, P. C. and Joshi, B. 2005. Environmental changes and status of water resources in Kumaon Himalaya. In: Libor, J., Haigh, M. and Prasad, H. (eds.): Sustainable management of headwater resources: research from Africa and Asia. United Nations University, Tokyo, pp 109–123
UNDP 2010. Summary of implications from the East Asia and South Asia consultations: Asia Pacific human development report on climate change. Colombo: UNDP Asia Pacific Regional Centre, Human Development Report Unit
UNEP-WCMC 2002. Mountain Watch: Environmental change and sustainable development in mountains. UNEP, Nairobi. www.unep-wcmc.org/mountains/mountainwatchreport/ (accessed 11 March 2012)
UNEP-WGMS 2008. Global glacier changes: Facts and figures. UNEP, Nairobi http://www.grid.unep.ch/glaciers/ (accessed 22 June 2010)
UN 2015. Realizing the Future We Want for All: Report of the UN System Task Team on the Post-2015 UN Development Agenda, UN headquarters, New York
UN 2014. The Road to Dignity by 2030: Ending Poverty, Transforming All Lives and Protecting the Planet, Synthesis Report of the Secretary-General On the Post-2015 Agenda, UN Headquarters, New York, December 2014
UN 2012. Outcome of the Conference, Agenda Item – 10. Rio+20: United Nations Conference on Sustainable Development, Rio de Janeiro, Brazil, June 2012
Viviroli, D., Dürr, H. H., Messerli, B., Meybeck, M. and Weingartner, R. 2007. Mountains of the world, water towers for humanity: Typology, mapping, and global significance. Water Resource Research, 43: W07447
Viviroli, D., Weingartner, R. and Messerli, B. 2003. Assessing the Hydrological Significance of the World's Mountains. Mountain Research and Development, 23: 32-40
Wookey, P. A., Aerts, R., Bardgett, R. D., Baptist, F., Brathen, K. A., Cornelissen, J. H. C., Gough, L., Hartley, I. P., Hopkins, D. W., Lavorel, S. and Shaver, G. R. 2009. Ecosystem feedbacks and cascade processes: understanding their role in the responses of arctic and alpine ecosystems to environmental change. In: Global Change Biology 15, 1153–1172. DOI: 10.1111/j.1365- 2486.2008.01801.x
World Resources Institute 2005. Millennium Ecosystem Assessment – Ecosystems and Human Well-being: Synthesis, Island Press, Washington, DC.
World Bank 2005. Pakistan's Water Economy Running Dry: Pakistan Water Strategy, World Bank Report 2006
Xu, J. C. 2008. The highlands: a shared water tower In a changing climate and changing Asia. Working Paper No. 67. Beijing: World Agro-forestry Centre, ICRAF-China
Yamada, T. 1998. Monitoring of Glacier Lake and its Outburst Floods in Nepal Himalaya. In Japanese Society of Snow and Ice, Monograph No. 1. Tokyo: Japanese Society of Snow and Ice
Yao, T., Duan, K., Xu, B., Wang, N., Guo, X. and Yang, X. 2008. Ice core precipitation record in Central Tibetan plateau since AD 1600. Climate of the Past Discuss. 4: 233–248
Zheng, J.Y., Ge, Q. S., Hao, Z. X. 2002. Impact of Climate Warming on Plant Phenology during Recent 40 years in China. In Scientific Bulletin, 47(20): 1582-1587 (in Chinese)

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