Climate Change and Himalayan Cold Deserts: Mapping vulnerability and threat to ecology and indigenous livelihoods

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Abstract

The remote cold desert stretches of high altitude Himalayas, having a fragile ecosystem are characterized by complex interplay of climatic and geomorphological processes, availability of limited natural resources and economic conditions leading to accelerated resource degradation and associated environmental consequences adversely impacting indigenous communities and their livelihoods. Climate change affects the natural resource base, primarily land, water and vegetation, which essentially pose a big challenge for the natural resource-dependent indigenous population of this region, who are primarily agro-pastoralist.

This paper attempts to quantify the level of environmental threat and adaptive capacity taking watersheds as units of study. Participatory approach (PRAs) blended with scientific field observations was adopted for a detailed analytical study of 82 watersheds across two states in the Trans and Western Indian Himalayas. The exercise focused on charting vulnerable 'hotspot's, identifying the driving factors (both anthropogenic and natural processes) and consequent ecological and socio-economic impacts.

Component indices were devised to include variables related to hydrology, soil conditions, vegetation status, available resources and adequacy gap, developmental pressure, HDI, climate and disaster occurrence, which were further integrated into the composite indices for environmental threat and adaptive capacity. The findings help in understanding the relationship of ecological and economic performance with climate change and anthropogenic pressure and determining the focus areas for interventions.

Keywords: cold deserts, climate change, environmental threat, adaptive capacity

1. Introduction

1.1 Himalayan Cold Deserts

The Himalayas stretches in an arc across northern India and its neighbouring countries between 21°57' - 37°5' N latitude and 72°40' - 97°25' E longitude, covering an area of more than half a million sq. km. At its remote, northern end are pockets that constitute a distinct biome- the Himalayan cold deserts. Formed due to the rainshadow effect of the towering main Himalaya mountain wall and its offshoot ranges whose average elevation is more than 6000 mts, thus creating an effective barrier against the movement of the rain-bearing SW monsoons to the regions lying to the north of it, the cold deserts comprise the trans-Himalaya which lies across the main Himalaya and is part of the vast Tibetan plateau and the inner dry valleys within the main Himalayan range which lie in the rainshadow zone- stretching from Kinnaur at its southern point to Ladakh at its northern point.

Composed of different river valleys amidst high mountain ranges, the elevation of inhabited areas in cold deserts range from 8,000 ft. to 16,000 ft. It is a unique region, with a huge seasonal variation in weather - a short, dry, cloudless, arid summer reaching 36ºC and a long, windy, freezing winter at - 32ºC. It has highly arid conditions with rainfall among the lowest in the country - the annual average rainfall from is 279 mm; in the core zone, it may be restricted to a few showers each year. The bulk of the precipitation received each year is in the form of snow. Cold deserts are characterised by a fragile ecosystem and a complex interplay of climatic and geomorphological processes, limited availability of natural resources and economic conditions leading to accelerated resource degradation and associated environmental consequences, that adversely impact indigenous communities and their livelihoods. Blizzards, snowstorms and avalanches are common. The soil is not very productive and the climatic conditions allow a very short growing season. Water resources are minimal with glacier-fed streams being the only source of irrigation. In terms of habitation, they are usually sparsely inhabited, although this is now changing. Development and modernisation is stepping in. With the growing attraction of the remote frontiers for tourists, the pressure on the environment is also increasing.

1.2 Climate Change and its Impacts on Cold Deserts

The Intergovernmental Panel on Climate Change in its global climate scenarios (Assessment Report, 2001) has indicated that the pattern of global warming will be more pronounced at high altitude zones, especially those in the tropics and sub-tropics (of which the Himalayas is the largest range) - upto 3 to 5 times faster warming than in the rest of the world. Alpine glaciers, such as the ones in the Himalayas, are particularly sensitive indicators of climate change. An observation by the Working Group on Himalayan Glaciology of the International Commission for Snow and Ice (ICSI) in 1999, stated that "glaciers in the Himalayas are receding faster than in any other part of the world and, if the present rate continues, the likelihood of them disappearing by the year 2035 is very high". The glaciers of the Himalayas make up the largest amount of snow and ice outside the polar ice caps (Dannevig, 2005). Investigations have shown an overall reduction in glacier area from 2077 sq. km in 1962 to 1628 sq. km at present (2007), an overall deglaciation of 21% while, the number of glaciers has increased due to fragmentation. Small glaciarates and ice fields have shown extensive melt down. This would mean huge trouble for 500 million people in North India in terms of agricultural output, freshwater reserves, energy production and the overall economy and it would be catastrophic for cold desert communities. Climate change affects the natural resource base, primarily land, water and vegetation, which essentially pose a big challenge for the natural resource-dependent indigenous population of this region, who are primarily agro-pastoralist.

Although these marginal communities walk with a light carbon footprint they have to bear the brunt of unsustainable resource use elsewhere in the world. Climate shocks threaten lives, evoke a feeling of insecurity and also erode long-term opportunities for human development, eroding productivity and human capabilities. Climate change is placing further pressure on already over-stressed coping mechanisms of the Himalayan cold deserts. Adaptive capacity of the human system is low and vulnerability high for the mountain communities, because of limited public services, very little or no economic diversification, and strong dependence on a few resources. Most of the villages in the Himalayan cold deserts are solely dependent on ice melts and springs/streams fed by the glacial melt. The region comprises small valleys with a scatter of villages and a dispersed population amidst high mountain ranges, insulated and dependent on local level resources. Complex terrains, remoteness of the area and extreme weather conditions make the region and its people more vulnerable to the impacts of climate change. Livelihood options are limited, the terrain restricts the stretch of land available for agriculture and other activities, and poverty levels are high.

The region has been historically vulnerable to climatic extremes and the vulnerability is increasing due to climate change. The impacts of climate change in these high altitude terrains could be far-reaching and competition for natural resources will increase. Climate change may induce disturbances and shift hazard zones beyond the known extents of occurrences. The incidence of droughts, snow-storms, blizzards and the like in the Himalayas has risen. Another alarming factor is that increasing stress on cash crops in the Himalayan has allowed soil loss and run-off from the croplands to dramatically increase together with increase in pressure on ecosystem. Upland agriculture was seemingly sustainable till the population pressure was low and the ultimate goal of agriculture was to meet local consumption. A trend of increase in livestock population and changes in composition of livestock population is also common across the region. An increase in livestock population but reduction in fodder production from farmland with changing cropping patterns implies more intensive grazing in already degrading alpine rangelands. Approximately 70% of the pastures are already facing degradation, affecting the livelihoods of thousands of high altitude pastoralists across the region.

The precipitation pattern varies widely across the Himalayas. The monsoon effect decreases to the West, and the Trans-Himalayan region situated in the rainshadow of the greater ranges and massifs are less affected by the monsoon (Dannevig, 2005). Studies indicate a definite reduction in snowfall in the region over time, snowfall events oscillate in 2 important ways: (i) reductions in the amount of snowfall and (ii) changes in the timing of snowfall. There is also a shift in the distribution of rain across time with a significant increase in the number of cloudy days. Local perceptions further reveal that the temperature distribution has undergone a significant shift in addition to an overall increase in temperatures. However, late snowfall has been leading to cooler temperatures in March-April. Cloudbursts and other such phenomena have increased over time (Vedwan and Rhoades, 2001).

Vulnerability is a subjective concept that includes three dimensions: exposure, sensitivity, and adaptive capacity of the affected system (Smit et al. 2001). The sensitivity and adaptive capacity of the affected system in particular depend on a range of socio-economic characteristics of the system. Here agriculture is the mainstay of the people along with other subsidiary activities such as animal husbandry, horticulture, NTFPs collection - completely dependent on the availability and accessibility of the natural resources of the region. Recent studies reveal that in dry areas, high mountain farming is experiencing an increasingly dry environment (Chalise 1994 in Banskota et al. 2000). This is probably related to less snow in wintertime and retreating glaciers. As a result, the livelihood conditions get harsher in many places and people are migrating out from the mountain valleys and down to urban areas (Banskota et al. 2000).

Across the Indian Himalayas variations in climatic conditions, lack of market linkages, accompanied by small fragmented farms on small terraces on steep slopes have led the farmers to adopt subsistence farming systems characterized by substantial diversity and self-reliance (Maikhuri *et al.*, 1996; Semwal and Maikhuri, 1996; Palni *et al.*, 1998; Rao and Saxena, 1994; Ramakrishnan *et al.*, 1994; Nautiyal et. al., 1998; Nautiyal et. al., 2002-2003). The constraint of the natural scarcity of water were overcome by following age-old institutions and rules governing irrigation based on traditional cultural practices with an inherent flexibility to accommodate practical problems. However, during recent years, the traditional systems are being replaced due to a variety of factors. The changes in livelihood options are also reflected in the changes within the agrarian system and the impact on the traditional irrigation systems (Gupta and Tiwari, 2002).

This paper presents the findings of a study conducted to assess the degree and nature of Environmental Threat in Himalayan cold deserts, as well as the Adaptation Capacity of the region, taking watershed units of study. The study aimed to evaluate the relationships between various geographic, ecological, climatic and socio-economic factors, and helped in understanding the nature of interactions among these. It helped in determining the vulnerability of cold desert watersheds as a composite of multiple parameters, and identifying major causal and mediating factors. The paper also seeks to explore vulnerability-based strategies for livelihood security of cold desert communities.

2. Methodology

In the summers of 2006 and 2007, Pragya, an organisation working for the sustainable development of the Himalayan region in India, carried out a comprehensive study to assess the vulnerability of cold deserts to various environmental and anthropogenic stressors. The key approach features included the collection of data by bio-geographic zones and a composite socio-ecological assessment.

2.1 Study Area

Field studies were carried out across two different bio-geographic zones - the Trans-Himalayas and the Western Indian Himalayas that constitute the cold desert belt in India. The two zones are distinguished by their unique characteristic geological and topographic feature, vegetation and climatic characteristics. The former constitutes the core cold desert zone, while the latter may be defined as a transition zone between the alpine south and the core cold desert north. The region spreads across: three districts of

the state of Himachal Pradesh: Lahaul & Spiti, Kinnaur and Chamba, and one district in the state of Jammu and Kashmir: Leh-Ladakh.
A sample of 82 watersheds were surveyed across 4 different altitude bands:

- 2000-3000m: Threshold Altitude belt for the Himalayan cold deserts
- 3000-3300m: Mid-range Altitude belt for the region
- 3300-3700m: High Altitude belt
- >3700m: Very High Altitude belt

The details are presented in Table 1.

2.2 Sampling of Watersheds

A stratified, nested sampling procedure was adopted. Within each bio-geographic zone (Trans-Himalayas, Western Himalayas), watersheds were delineated using available topographical maps. The watersheds were categorized into four Altitude Bands (as above) and three hydrological levels (given below) for the purpose of the study, based on the source and discharge of the streams and the topographical settings:

- Hydrological Level 1 - catchments higher up in the mountain slopes with streams originating from glacial melt having low volume of water,
- Hydrological Level 2 - catchments located at mid-slopes with streams of highly variable amount of water during different seasons and
- Hydrological Level 3 - catchments that are served by healthy streams and located at their confluence with the major river.

Detailed reconnaissance survey was carried out for selection of the sample watersheds based on the altitude bands and the three different watershed levels. Other key differentiators that were hypothesized to have an impact on the factors being measured/assessed, were aspect and distance from administrative headquarters. A representative sample was selected that included a proportionate representation of watersheds of varying positions on the differentiating factors.

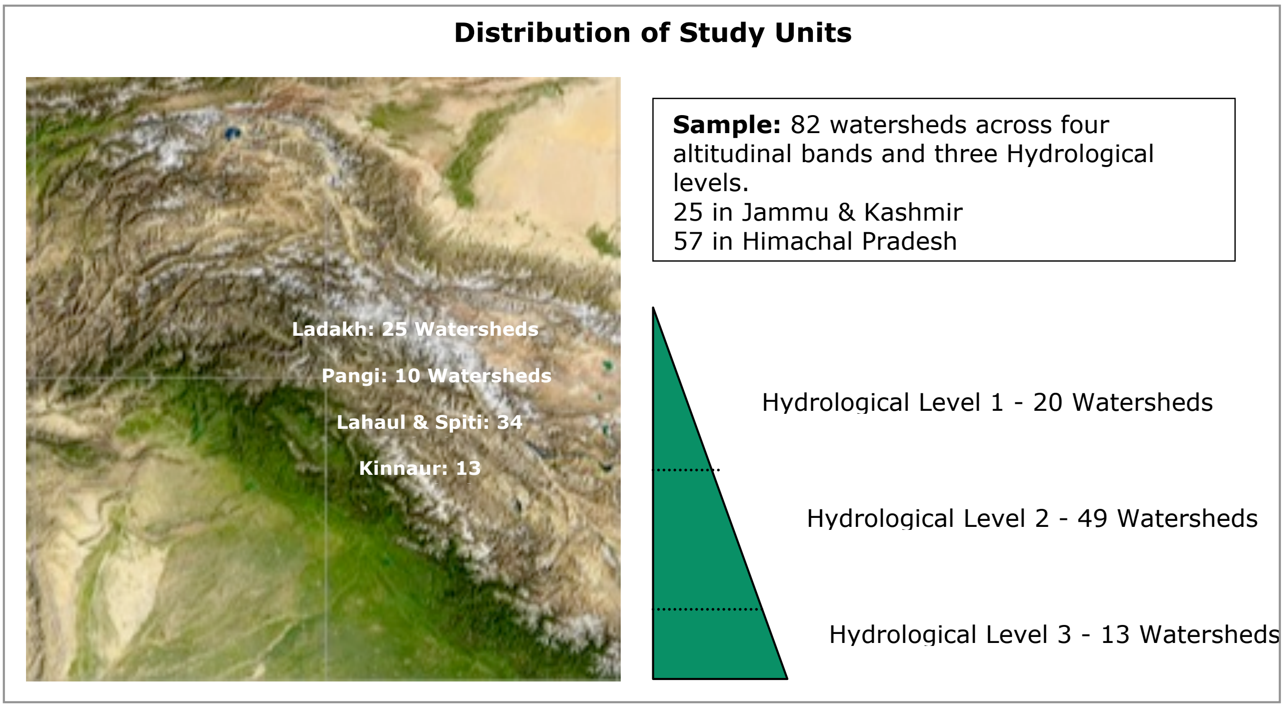

Fig. 1 Sampling distribution of the watersheds

Table: 1 - Sampling Details

Bio-geographic Zones	State	Districts	Watershed Level	No of watersheds surveyed
Trans-Himalayas	J&K	Ladakh	1	8
			2	10
			3	7
Western Himalayas	Himachal Pradesh	Lahaul & Spiti	1	6
			2	24
			3	4
	Himachal Pradesh	Kinnaur, Chamba	1	6
			2	15
			3	2

2.3 Data Collection

The data requirements were categorised into - (i) watershed-specific data (e.g., resources, incomes, assets, vegetation density, soil quality, hydrology), (ii) area/multi-watershed data (e.g. crop yields, crop value, productivity of crops/animals, perception of threat), (iii) regional/district data (e.g. agricultural land, grassland, forest land, wasteland, climate, disaster occurrence)

2.3.1 Primary data

Detailed questionnaires were developed for collecting information regarding resource and resource sharing, perception of stress and time series data for various critical parameters. A participatory approach blended with scientific field observations and secondary data collection was adopted. Participatory Rural Appraisals were carried out in each village/villages served by a sample watershed in order to collect primary data on socio-economic and resource related factors, as well as to discern trends in climate, ecology and resource availability. Mixed groups of men, women and children participated in each PRA. A participative mapping and ecological study was carried out in which field surveys were conducted in each watershed using scientific measurement of hydrology, soil and vegetation, with the involvement of the resident communities of the watershed. The process involved transect walks for the mapping of resources and study of sample quadrats for a detailed study on vegetation status. Flow, depth and velocity measurements were taken, and channel shape, depositional features, etc., were studied for assessing hydrological conditions in the main stream of the catchments; water samples were collected for chemical analysis. Study of soil conditions involved observation of physical parameters and collection of samples from different habitats and land-use category for detailed analysis in the laboratory.

Group meetings were conducted at the administrative block level with representatives from the villages across the whole block to collect area data on factors that are common across a larger area including multiple watersheds. These meetings helped draw our regional variations in productivity and pricing, variations in local perceptions as well as the reasons behind them.

2.3.2 Secondary data

Secondary data was collected from district census handbooks and various other publications of the Census of India, Meteorological data for Ladakh from FRL Leh, FRL Pratapur, and for Kalpa weather station in Himachal Pradesh from the Regional Meteorological Centre, New Delhi, livestock related figures from the detailed livestock census reports and other compilations of the Sheep Husbandry Department, Govt of Jammu & Kashmir and Directorate of Animal Husbandry, Himachal Pradesh. Some data related to vegetation and ecology was sourced from an earlier survey conducted by Pragya across the Indian Himalayan region for medicinal and aromatic plants in 2003-06.

2.4 Data Analysis

The variables were weighted and combined through principal component analysis into sub-indices related to hydrology, soil conditions, vegetation status, available resources and infrastructure, etc., that were then further integrated into eight composite indices. These indices constituted the Predictive Variables for Vulnerability assessment. They included: (i) *Resource Status* (i.e. availability of biotic resources, water resource, infrastructure for water storage and distribution), (ii) *Ecological Balance* (i.e. hydrology, vegetation, soil conditions), (iii) *Development Status* (i.e. status of health care, education, women, food security, economic capacity, access to services and support from the government and CSOs), (iv) *Eco-degradation* (i.e. soil contamination, soil erosion, water quality, erosion of stream bank, alteration of wetlands, desertification), (v) *Anthropogenic Pressure* (i.e. dependence on natural resources, developmental pressure and increase in pressure), (vi) *Resource Stress* (i.e. supply of water for drinking and irrigation, productive and unproductive resources, per capita availability of NTFPs), (vii) *Disaster Risk* (i.e. frequency of occurrence, perception of threat), (viii) *Climate Change*: (i.e. change in snow amount, rainfall, and availability of water resources).

Analysis of the direction of influence helped determine the Criterion Variables and their component indices:

- *Environmental Threat*: Eco-degradation, Anthorpogenic Pressure, Resource Stress, Disaster Risk and Climate Change
- *Adaptive Capacity*: Resource Status, Ecological Balance, Development Status.

The exercise focused on charting Vulnerability Hotspots of the Himalayan cold deserts, identifying the driving forces (both anthropogenic and natural processes) and consequent ecological and socio-economic impacts. The two Criterion Variables were used to identify the 'Vulnerability Hotspots' while the component indices helped in depiction of the key characteristic features of the study units.

3. Results

3.1 Geographic Determinants of Socio-Ecological Status

Geographic factors were found to be key determinants of the ecological health of and environmental stressors impacting the cold desert watersheds under study, and correlated strongly with socio-economic status of resident communities and the anthropogenic stressors associated with this.

3.1.1 Description of socio-ecological status by altitude belt

(a) Very High Altitude (>3700m):

Watersheds in this altitude belt are primarily of the first and second Hydrological Level. The Ecological Balance of watersheds in this belt is of moderate order with almost all watersheds possessing moderate levels of water resources, soil quality and vegetal growth. Per capita Resource availability is of similar order as a consequence of low population density in the region. However, the population is highly dependent on natural resources for its livelihood and consumption needs and as a result Resource Stress experienced by communities is of a high order- the highest of all altitude belts with 74% settlements facing high to very high Resource Stress. This is strongly associated with the higher impacts of climate change in terms of shrinkage and unpredictability of resources, at this altitude. Glaciers are receding and snowfall patterns have changed and Disaster Occurrence is frequent as well, leading to moderate to high order of related stress. Degradation levels of and Anthropogenic Pressure on the ecosystem range from moderate to high.

It must be noted that the environmental stress trends are amplified for the watersheds of the first Hydrological Level with 3/4ths of them having high to very high levels of Degradation and as much as 88% of them with high to very high levels of Resource Stress. The population in these sites is almost wholly pastoral and owns large heads of cattle, the flock size and hence demand for fodder and pressure on pasturelands, growing with time. Overall Anthropogenic Pressure is low in these watersheds however, as a result of very low population density and human activity; many of the settlements in this belt besides, are of a temporary nature, inhabited by nomadic groups that follow an annual migratory cycle. The highest impacts of Climate Change of all settlements are for those falling in this category with half the settlements reporting impacts of the highest order. As snowfall reduces and temperatures rise, the high altitude plateaux show high levels of climate change associated degradation. Watersheds of the second Hydrological Level are typically on steep slopes and hence more prone to disasters, such as GLOFs, rapid stream responses, etc. As might be expected, Anthropogenic Pressure increases for these watersheds of the second Hydrological level, in comparison to those of the first Hydrological level, with increase in population and human activity in these areas. Inhabitants of these watersheds are of a sedentary nature and undertake both cultivation and pastoralism, leading to a more intensive use of ecosystem resources.

The socio-economic status of communities residing at the highest inhabited altitudes in the cold deserts ranges from moderate to high. Although deprived of basic services and low on welfare indices, the population has a positive economic status as a result of better resource availability. Watersheds in the third hydrological level have lower education and health status but high economic capacity due to higher resource availability and lesser population pressure on these resources. The watersheds of the first hydrological level have better health status as fewer cases of disease are reported, and higher economic capacity as ownership of productive resources are high. All the sample watersheds in this category suffer from poor access to basic services such as transport and communication, electricity, banking and market facilities and access to administrative services at block level.

(b) High Altitude (3300-3700m):

The Ecological Balance in this belt ranges from moderate to high as does the per capita Resource status. 89% of the watersheds have moderate to high hydrological conditions and a majority of the watersheds have moderate soil quality and vegetal growth. The soil condition, vegetal growth and hydrological condition is best in the watersheds of the third Hydrological Level.

Degradation of the ecosystem increases at this altitude with a majority of the watersheds suffering high levels of Degradation. Anthropogenic Pressure though is lowest in this category with 84% settlements with low-moderate pressure levels, since the population density and human activity is predominantly low even at this altitude, while the ecosystem is more robust. Cultivation is the dominant occupation, and organic, multi-cropping systems are followed that have lower impacts on the ecosystem. However, since the less-efficient traditional systems of cultivation are followed, Resource Stress is moderate to high. Impacts of Climate Change are lower than for the Very High Altitude belt and range from moderate to high and Disaster Risk is lowest in this category with 74% of the settlements facing low-moderate risk. Anthropogenic Pressure and Resource Stress in the watersheds in the first Hydrological Level are lower than for the belt as a whole, a result of the lower population levels in these watersheds. The steeper gradients of the second Hydrological Level however, raise the Disaster Risk level with 15% of the settlements in this category having a very high risk of disasters.

The socio-economic conditions in this altitude belt are determined to be of a low-moderate order. Like the Very High Altitude belt, this belt too is characterized by low access to services. Watersheds in the second hydrological level exhibit low educational status; those in the first hydrological level have relatively higher educational status, economic capacity and food security as a result of better sources of nutrition, yield of subsistence crops and per capita availability of animal produce for consumption. This altitude belt also has better health status in spite of low access to health services, as occurrence of diseases is lower.

(c) Mid-range Altitude (3000-3300m):

The Ecological Balance in this altitude belt is the highest among all altitude belts with 67% of the settlements displaying a high to very high status. Majority of the watersheds have good hydrological conditions, moderate quality of soil and good vegetal growth. The hydrological condition and vegetal growth are best for watersheds in the first Hydrological Level, whereas the soil is best in the third Hydrological Level. The Resources status however ranges from moderate to high, as a result of higher population density.

Population and human activity rises steeply in this altitude belt. There is a dense clustering of habitations and several urban/semi-urban centres lie in this area with associated road connectivity and other development. Visitors to the region throng to these centres and population pressure peaks in the summer months. Degradation levels in this altitude belt are therefore the highest among all altitude belts, with 78% showing high to very high degradation. Anthropogenic Pressure is similarly the highest in this belt with 56% of settlements displaying high pressure levels and Resource Stress is the highest following only the Very High Altitude belt. Disaster Risk is the highest among all altitude belts. Settlements in this belt lie mostly on steep slopes or at valley basins, locations that are highly vulnerable to landslides and flashfloods. This altitude belt matches the Very High Altitude belt in the impacts of Climate Change suffered by it- the highest among all altitude belts with 61% of the settlements suffering high to very high levels of climate change associated ecosystem damage.

The watersheds that lie in the third Hydrological Level in this altitude belt have a high to very high level of all negative environmental characteristics- Degradation, Anthropogenic Pressure, and Resource Stress. Development in the Himalayan region has tended to flow along the major river at the valley bottom- hydrological factors have drawn populations to these sites and the ease of construction in relatively lesser gradients, apart from the higher population density, has focused developmental activities in the area. Urbanisation and development, and concomitant environmental pressures, are the highest in this category of watersheds therefore. The impacts of Climate Change are rather severe in this category of watersheds with all settlements suffering high to very high levels of associated stress. Disaster Risk is the highest in this category with all settlements displaying high vulnerability to disasters.

The socio-economic status of the population in this altitude belt is the highest among all altitude belts with 73% of the settlements having relatively high levels of development. The development status is highest for settlements in the third Hydrological level. Welfare facilities and services are by far higher and there is a higher performance on all human development indices therefore. Occupational diversity is greater due to higher urbanisation, as is access to resources and developmental infrastructure and services. However, the belt suffers from lower food security due to excessive dependence on cash crops and lower livestock assets.

(d) Threshold Altitude (2000-3000m):

In this Threshold Altitude belt of the Cold Desert Region, the Ecological Balance is moderate, albeit poorer than those of the High and Mid-range Altitude belts. The Resource status in per capita resource availability is the poorest among all altitude belts, a result of poor ecological conditions and higher population density in the belt. It must be noted however that while the watersheds in the first and second Hydrological Levels display this pattern, those in the third Hydrological Level show a tending towards high Resource status and Ecological Balance.

Although the natural processes of ecological Degradation is lower in the Threshold Altitude belt, all other environmental pressures and stresses in this belt are akin to the levels of the same in the Mid-range Altitude belt. The population and developmental pressures in this belt are similar to that in the Mid-range Altitude, although the degree of urbanisation and related visitor traffic and seasonal pressure is a trifle lower. Hence Anthropogenic Pressure and Resource Stress are just a notch lower than the Mid-range Altitude belt. Watersheds in this belt also display high levels of Disaster Risk and the impacts of Climate Change although mildly lower levels than in the Mid-range Altitude belt.

Watersheds in the first and third Hydrological Levels have lower levels of Anthropogenic Pressure, while those in the second Hydrological Level have a high level of Anthropogenic Pressure. Resource Stress on the other hand is high for watersheds in the first and second Hydrological Levels, but considerably lower for watersheds in the third Hydrological Level. Watersheds in the first Hydrological Level have lower populations, but lower level of Resources as well; those in the second and third have higher populations and higher levels of resources too, although watersheds in the second Hydrological Level have been facing reducing resources and increasing effects of Climate Change and Disasters.

Watersheds in this altitude belt display a moderate to high level of development. These watersheds have easy access to developmental infrastructure and services. However, they suffer from lower food security due to excessive dependence on cash crops and lower per capita ownership of productive resources due to high population density, low health status in spite of better health care facilities and a lower educational status compared to the other altitude belts. The socio-economic conditions do not alter much with different hydrological levels within this altitude belt.

3.1.2 Ecological and resource status and climatic characteristics

The Ecological Status of the 2000-3000m level for the cold desert region is at a moderate level. It improves at the 3000-3300m altitude belt, peaking at 3300 mtrs., dropping with increase in altitude thereafter through the 3300-3700m and the >3700m altitude belts. Resource Status, in terms of per capita availability, as a function of the interaction of resources and population, is at the highest in the >3700m altitude belt, dropping steadily as population increases (with reducing altitude) to be at its lowest in the 2000-3000m altitude belt. Resource Stress however, is highest for the >3700m altitude belt, followed by 3000-3300m, and then by 3300-3700, with the lowest Resource Stress being experienced by communities in the 3300-3700m altitude belt. The impacts of Climate Change is at the highest at the highest altitude belt of >3700m as well as at the altitude belt 3000-3300m, with the 2000-3000m belt coming next in intensity of impacts, followed by the 3300-3700m altitude belt.

3.1.3 Socio-economic and settlement patterns

Most settlements in the area lie in the second Hydrological Level. The areas under the first and the third Hydrological Levels were considered not feasible for settlement- the former because they are climatically harsh and have limited resources and development, and the latter because these areas are more prone to disasters like floods. Population density reduces with altitude but development is at its relative best in the 3000-3300m altitude belt, since maximum urbanisation and infrastructure and facilities access is in this belt. The 2000-3000m belt is next in development status, followed by the >3700m belt (primarily as a consequence of a better per capita resource and asset ownership) with the 3300-3700m belt displaying the poorest performance in terms of development.

3.2 Causal Relationships between Social and Ecological Factors

3.2.1 Climate Change and Development, Resource Stress, Disaster Risk

The impacts of Climate Change on the high altitude cold deserts is recognised to be very high. The study findings helped bring out the associations between Climate Change and other social and ecological factors. The level of Development was found to have a positive correlation (0.3) with the impacts of Climate Change, indicating areas with higher levels of development tend to show higher scores on the indicators of Climate Change, such as enhanced pressure on the hydrology, increased drying up of water resources and growing distance from glaciers. The nature of impacts of Climate Change was also brought out by the study. Climate change is causing a reduction in natural resources available for use by resident communities, as indicated by a positive correlation (0.38) between Climate Change and Resource Stress. It is leading to a decline in snow cover and a reduced availability of water for drinking and irrigation, as well as a shrinkage of the natural vegetation such as grasslands and forests that communities depend on, and rendering waste the lands that were productive. Climate Change was also found to be responsible for the increase in Disaster Occurrence in the study region. Change in climate is found to have a concomitant change in the frequency of floods, droughts, avalanches and landslides (correl coeff- 0.3) and threat to the livelihood and property of the people living in the region.

3.2.2 Resource Stress and Anthropogenic Pressure, Climate Change, Resource Status

Apart from Disaster Risk, Resource Stress is the most critical issue facing natural resource dependent communities such as those living in the Himalayan cold deserts. The study brought out a strong correlation (0.35) between Anthropogenic Pressure and Resource Stress. Rise in the density of agriculture, increase in population, development of the region and large amount of tourist inflows, cause an impact on the available resources and the per capita share of these resources. Overuse and inappropriate use of resources to accommodate the increasing population and resource demands is causing resource degradation and stress. As mentioned earlier, a similar positive correlation and causal relationship was also found between Climate Change and Resource Stress.

3.3 Vulnerability Criteria and their Predicators

3.3.1 Factor contribution to Environmental Threat

Analysis reveals that Climate Change and its close associate Disaster Occurrence together constitute the highest contributor to Environmental Threat (39.06%) in the Himalayan cold deserts. Human needs and practices may be deemed to be the second highest contributor with 34.01% share of Environmental Threat. This comprises the impacts of Anthropogenic Pressure (15.45%) on the ecosystem as a result of development and resource use practices, as well as Resource Stress or the overuse of resources and the increasing demand-supply gap in resources (18.56%). The natural process of Environmental Degradation that is being caused by desertification, erosion, wetland alteration, etc., follows at third place with a contribution of 26.92%.

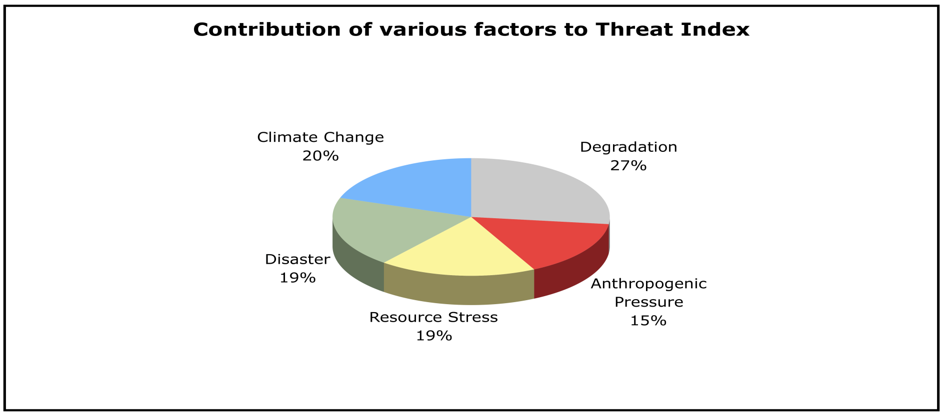

Fig.2 Percentage contribution of various sub-indices to the threat index

3.3.2 Factor contribution to Adaptive Capacity

The Ecological characteristics and health of a watershed is the single biggest contributor to the Adaptive Capacity of the watershed. A healthy ecological state will enable the ecosystem itself to adapt to stresses induced by the climate, natural degradation processes, as well as anthropogenic pressures, and in turn enabling the community dependent on the ecosystem services as well to adapt to the changes that occur, evidently because the resource stress would be by far lesser than in the case of a less healthy ecological state. Hydrology (23.9%) is the highest contributor within the Ecological characteristics, and this is followed by Soil (20.96%) and Vegetation (16.06%). Per capita Resource Availability, a factor of the Ecological status and the population dependent on it, is also a key contributor to the Adaptive Capacity, to the extent of 22.45%. The Development status of the population of a watershed, although a lesser contributor to the adaptive Capacity of a cold desert watershed, is significant as well at 16.62% contribution.

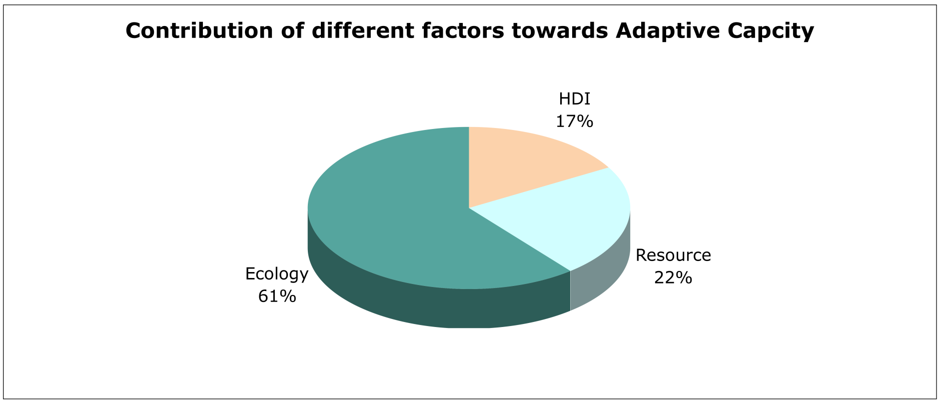

Fig.3 Percentage contribution of various sub-indices to the adaptation index

3.4 Threat and Adaptation Patterns

3.4.1 Impacts of Altitude and Hydrological Level on Environmental Threat

Environmental Threat levels are the highest for watersheds in the Very High Altitude belt. More than half the watersheds have high to very high levels of Environmental Threat, and 17% experience the highest level of threat. Watersheds in the first Hydrological level in this altitude belt have the second highest threat levels with 76% having high to very high threat levels; watersheds in the second Hydrological level in this altitude belt have moderate to high Threat levels.

For watersheds in the High Altitude belt, threat levels are the lowest among all altitude belts, with all watersheds having low to moderate threat. Most watersheds at all Hydrological levels in this altitude belt have low-moderate Threat levels.

For the Mid-range Altitude, threat levels are moderate to high. Threat levels are low to moderate for a majority of the watersheds in the first and second Hydrological levels. In the third Hydrological level however, Threat levels of watersheds are the highest of all altitude belts and hydrological levels, with all watersheds suffering high to very high threat levels.

Threat levels in the Threshold Altitude belt are similar to that of the Very High Altitude, with ½ the watersheds having moderate degrees of threat and another ½ having high to v. high degree of threat. The pattern is different however among watersheds. Watersheds in the first and the third Hydrological Levels have moderate Threat levels, while those in the second Hydrological Level have high Threat levels.

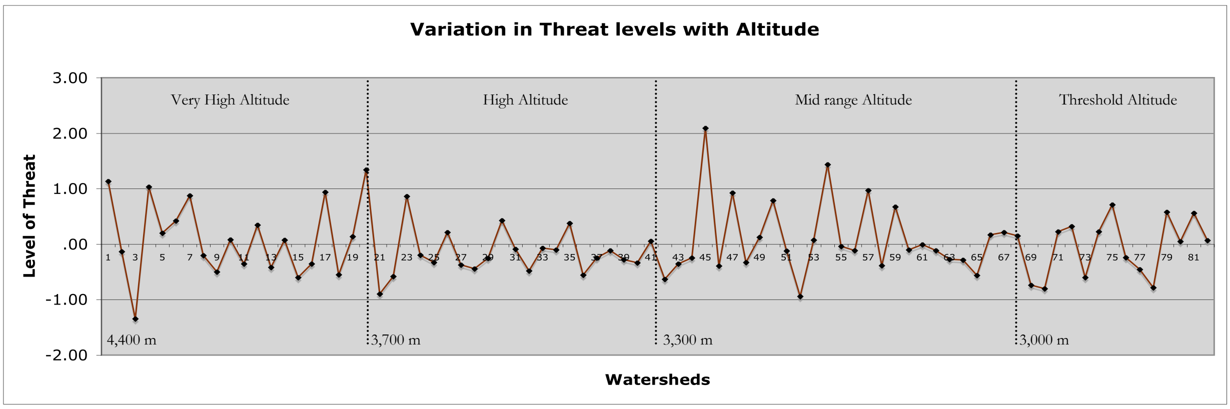

Fig.4 Change in level of threat with altitude

- *High Threat Characteristics*: High Threat watersheds are mostly in the >3700m and 2000-3000m altitude belts (first Hydrological Level in the Very High Altitude; second Hydrological Level in the Threshold Altitude) of the cold desert region. They are characterised by moderate-high levels of Degradation and Disaster Risk, high Anthropogenic Pressure and Resource Stress, and high to very high impacts of Climate Change.

- *Low Threat Characteristics*: Low Threat watersheds are found at all altitude belts in the cold desert region, although predominantly in the 3300-3700m (High Altitude) belt. They are characterised by moderate-high levels of Degradation, Resource Stress, Disaster Risk and impacts of Climate Change, and moderate levels of Anthropogenic Pressure.

3.4.2 Impacts of Altitude and Hydrological Level on Adaptive Capacity

Adaptive Capacity of watersheds in the Very High Altitude Belt ranges from moderate to high, 61% of the watersheds being in the low-moderate range though. Higher levels of Adaptive Capacity are shown by watersheds in the first and second Hydrological Levels. This may be attributed to the higher per capita resource availability in this altitude belt.
In the High Altitude belt, the Adaptive Capacity of watersheds increases slightly, with the highest increase in the watersheds in third Hydrological Level, a change in the Ecological Balance.
In the Mid-range Altitude belt, Adaptive Capacity of watersheds climbs steeply up. The Adaptive Capacity is the highest for watersheds in the altitude belt with 67% of the watersheds having high to very high levels of Adaptive Capacity; it also climbs with increase in Hydrological level with the highest Adaptive Capacity being at the third Hydrological Level.
The Adaptive Capacity of watersheds in the Threshold Altitude belt is lower than that of the Mid-range Altitude belt with 50% of the watersheds in the high to very high capacity range. The Adaptive Capacity is the lowest for watersheds in the first Hydrological Level in this altitude belt.

- *High Adaptation Characteristics*: Watersheds with high Adaptive Capacity are found mostly at the 3000-3700m altitude belt, comprising the Mid-range Altitude and the High Altitude belts, in the Himalayan cold deserts, and predominantly in the second Hydrological level. They are characterised by high Ecological Balance and Development status, as well as moderate to high Resource status.
- *Low Adaption Characteristics*: Watersheds with low Adaptive Capacity are predominantly found at >3700m (Very High Altitude) and 2000-3000m (Threshold Altitude) altitude ranges; majority of them lie in the first and second Hydrological Levels. They are characterised by moderate levels in all contributing factors of Resource status, Ecological Balance and Development status.

4. Discussion

Vulnerability is a measure of the dynamic interplay between *Environmental Threat* and *Adaptive Capacity*. While Threat is a factor of environmental trends with the additional effects of geographic factors (altitude, hydrological level), in association with human interventions, including demographics and patterns of use, Adaptation is a measure of the capacity of the ecology and resource users to respond to shifts in environmental patterns with changes in behaviour, with least damage to quality of ecology/life.

Vulnerability of cold desert watersheds comprises the following kinds of threats:

i. Threat to Livelihood
ii. Threat to Life and/or Nature of Life

4.1 Threat-Adaptation Dynamics

a. *High Threat-High Adaptation* (HT-HA) watersheds are typically located in the >3700m (Very High Altitude) and 3000-3300m (Mid-range Altitude) altitude belts in Himalayan cold deserts. They are characterised by high levels on all Threat factors, viz Degradation, Anthropogenic Pressure, Resource Stress, Disaster Risk and impacts of Climate Change. They are also characterised by a moderate to high level of Resources and high Ecological Balance, as well as a high Development status.
b. *High Threat-Low Adaptation* (HT-LA) watersheds are typically located in the >3700m (Very High Altitude) and 2000-3000m (Threshold Altitude) altitude belts. These watersheds are characterised by moderate to high levels of Degradation and Disaster Risk, and high levels of Anthropogenic Pressure,

Resource Stress and impacts of Climate Change. They are also characterised by moderate to high Resource status, and moderate Ecological Balance, as well as a moderate level of Development.

c. *Low Threat-Low Adaptation* (LT-LA) watersheds are found in the >3700m (Very High Altitude) and 3300-3700m (High Altitude) altitude belts in Himalayan cold deserts. They are characterised by moderate to high levels of Degradation and Resource Stress, but moderate levels of Anthropogenic Pressure, Disaster Risk and impacts of Climate Change. Although moderate to high on Resources, they tend towards moderate levels of Ecological Balance and Development.

d. *Low Threat-High Adaptation* (LT-HA) watersheds are found at all altitudes in the cold desert region, from 2000m to 5000m altitude range. Their characteristics on Threat factors are the same as all Low Threat sites. Although moderate to high on Resources, they are characterised by high Ecological Balance and Development levels.

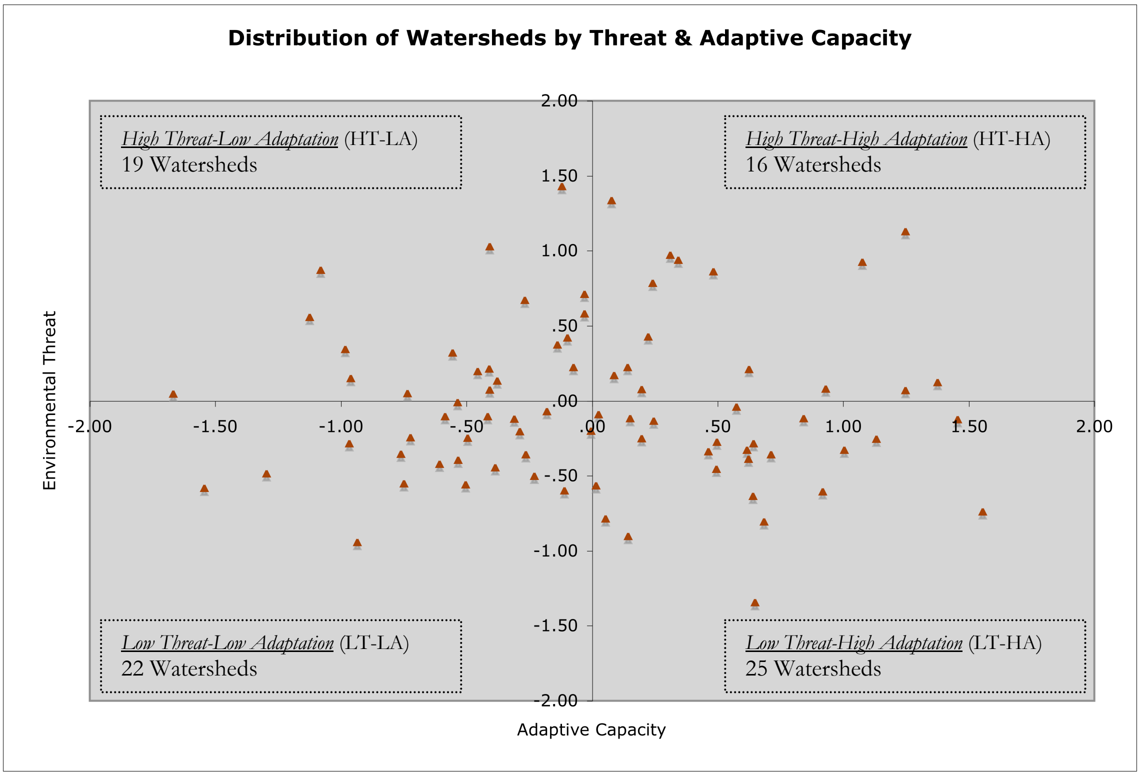

Fig.5 Distribution of watersheds according to Threat and Adaptation dynamics

<u>*High Threat-Low Adaptation*</u> (HT-LA) >3700m (Very High Altitude) and 2000-3000m (Threshold Altitude Moderate to high *Degradation* & *Disaster Risk* High *Anthropogenic Pressure* & *Resource Stress* High impacts of *Climate Change* Moderate to high *Resource* status Moderate *Ecological Balance* Moderate level of *Development*	<u>*High Threat-High Adaptation*</u> (HT-HA) >3700m (Very High Altitude) and 3000-3300m (Mid-range Altitude) High *Degradation, Anthropogenic Pressure, Resource Stress, Disaster Risk* High impacts of *Climate Change* Moderate to high *Resources* base High *Ecological Balance* High *Development* status
<u>*Low Threat-Low Adaptation*</u> (LT-LA) >3700m (Very High Altitude) and 3300-3700m (High Altitude) Moderate to high *Degradation* & *Resource Stress* Moderate *Anthropogenic Pressure, Disaster Risk* Moderate impacts of *Climate Change* Moderate *Ecological Balance* & *Development status*	<u>*Low Threat-High Adaptation*</u> (LT-HA) 2000m to 5000m Moderate to high on *Resources* Moderate levels of *Anthropogenic Pressure, Disaster Risk* Moderate impacts of *Climate Change* High *Ecological Balance* and *Development* levels

Watersheds with high scores on Environmental Threat and low scores on Adaptive Capacity (HT-LA) are the most vulnerable, followed by those with high scores on Environmental Threat and high scores on Adaptive Capacity (HT-HA), as well as those with low scores on Environmental Threat and low scores on Adaptive Capacity (LT-LA) at the second place. The least vulnerable of all watersheds are those determined to have low scores on Environmental Threat and high scores on Adaptive Capacity (LT-HA).

4.2 Implications for Interventions to Address Vulnerability

The Vulnerability Hotspots of the Himalayan Cold Deserts may thus be determined to be the High Threat-Low Adaptation watersheds. These are typically located in the altitude belts of 2000-3000m and >3700m and the first and second Hydrological Levels. They are deemed to be severely affected by environmental stressors without the leavening factors that make for adaptation of the ecology and human population to these stressors. This indicates the need for focussing development interventions to address vulnerability at the specific altitude belts - 2000-3000m and >3700m - in which such vulnerability is especially intense.

The key contributors to Environmental Threat and Adaptive Capacity can serve as the cues to the nature of interventions that may be designed to address vulnerability of cold desert watersheds. Interventions could seek to - (a) Build Adaptive Capacity, and (b) Reduce Environmental Threat. An appropriate weaving of transforming structures can alter the causal relationships for environmental threat identified by the study and help address vulnerability of the region in a sustainable manner. It is imperative that an approach that aims for the equitable achievement of human and environmental rights is followed, blending social justice with conservation.

We propose a two-pronged strategy for addressing vulnerability:
I: the creation of alternatives – in livelihoods, technologies, materials, sources of supply - to address overuse/ inappropriate use of natural resources.
II: conservation and protection - protection of the environment through positive and motivating modes, as well as through coercive controls - and protection against disasters through measures that reduce risk and those that mitigate impacts.

4.2.1 Creation of Alternatives

(a) Alternative livelihoods with a competitive advantage:
The overuse of resources in the Himalayan cold deserts is primarily rooted in the nature of livelihoods of the region. Most of the natural resource rich/unique areas, being far from the mainstream, are also far from technologies and from markets, and hence totally primary produce producing economies; while some do trade this primary produce to distant markets, most tend to trade internally and are closed valley economies. The burgeoning population could therefore take recourse to only more intensive use of the existing natural resources, for their livelihoods. The study found that occupational diversity has an association with the Adaptive Capacity of watershed units. Low occupational diversity is strongly related with low development status and lower or negative Adaptive Capacity. In 77% of cases where less than 10% of the population is engaged in secondary and tertiary occupations, the Adaptive Capacity is low. Occupational diversity is higher in settlements at lower altitudes, as 43% and 36% of the samples in very high and high altitude categories respectively, have low occupational diversity (less than 10% engaged in secondary and tertiary sectors), leaving them more dependent on natural resources, and hence suffer from low Adaptive Capacity. A prime concern is that, in all the cases where the respondents perceive a higher threat to livelihood, more than 55% of the population is

engaged in primary occupations. A corollary is that the level of degradation is higher in watersheds in which the majority population is engaged in primary occupations. In other words, dependence on primary occupations increases the degree of Environmental Threat.

A shift in occupational pattern can reduce the threat to the natural environment and livelihoods and also increase the Adaptive Capacity of the population. Alternate non-farm livelihoods that could absorb the growing population and their growing needs, would need to be introduced so that the pressure on the natural resources could be eased. Ideally, livelihoods that the area/people have a competitive advantage in, would yield results faster, and enable an effective 'livelihood rehabilitation'. High mountain regions have the potential to produce a variety of niche products for which latent markets exist; additionally, the burgeoning tourist market in these regions have substantial consumption capacity for a range of goods & services. These could be developed as alternate livelihood avenues with a high income and employment-generating potential. Ecotourism, handicrafts and culture-based products, are examples of some such alternate livelihood avenues.

(b) Alternative, high-contribution uses of natural resources

Extent of resource use is also mediated by the nature of use and its revenue yield. Hence, alternative natural resource uses, those that have a higher contribution in terms of incomes per unit of natural resource used, could also be introduced. This would help retard the trend of ever intensifying use of natural resources. There are of course, typically, some inherent blocks to such high-contribution uses, technical or financial or even related to markets for the resulting produce, which have hindered their application. Efforts would need to be made to remove these blocks.

(c) Value-addition to primary produce and a better share of revenues

The margins on primary produce are always low and those on value-added products higher. The NR intensive use/overuse syndrome could be considerably ameliorated by bringing in value-addition to local produce that would increase incomes per unit of NR used. For primary produce dependant Himalayan communities, this would necessitate a move up the value chain, to include at their point, some or all processing that the primary produce undergoes before purchase by the end-buyer. These processes would enable retention of more parts of the margins on the final products within the Himalayan valleys, and enable some of the Himalayan people to move out of the farm-based activities to working on or managing these processes. A likely spin-off of value-addition is the development of secondary industries to support it, which in turn generate additional employment. A direct access to buyers or even an enhanced strength through cooperatives and the like, could also help reduce channel losses in terms of margins to middlemen, and enable the Himalayan producers to retain more of the margins.

(d) Alternate materials and technologies

The demand-supply gap in resources and the resultant overuse of resources is a key contributor to Environmental Threat and a result of it as well. Climate Change and associated pressure on resources is further enhancing resource stress levels. In the cold deserts, communities follow traditional techniques of resource use and management. Some of these, such as organic cultivation methods, have and continue to contribute to improved Ecological Balance, by protecting soil and water quality. Some others, such as the water management techniques-in-use, have however been rendered less efficient with time and the change in ecological parameters, such as distance from water sources and reduced availability of water.

Progress is effected all over the world through technologies that enable us to achieve more through lesser effort and (sometimes) lesser resources. Adoption of improved technologies, such as drip and sprinkler irrigation techniques, that enable more efficient use of water resources, and life irrigation techniques that allow accessing alternate water sources, would improve productivity of and access to resources and thus reduce resource stress. At the same time, drought-resistant varieties of crops need to be identified and introduced in the highly water-stressed watersheds.

In the context of the growing shrinkage of available natural resources for the domestic and occupational uses of cold desert communities, alternates would need to be found for the modes of satisfying the needs that are currently satisfied through the use of natural resources. This would call for the development/harnessing of technologies and/or materials that can replace the current NR-greedy practices. Many of the needs that are today satisfied through natural resources, do have alternates available, for instance, renewable forms of energy as against fossil fuels; for others technologies need to be developed or adapted to the specific socio-ecological conditions of Himalayan cold deserts.

(e) Alternatives for improved resource availability

In very high altitudes especially, threat to livelihoods is strongly connected with Environmental Threat. People's perception of threat levels to their present indigenous livelihoods has revealed that 41% and 43% of the villages in the sample watersheds in high and very high altitude levels experience a higher degree of threat. These are areas in which there is a near total dependence on wild resources for livelihood inputs and for supplementary inputs for consumption needs as well. Apart from more efficient methods of resource use, supplementary sources of supply must be created for the NTFPs used by indigenous communities. Captive production of such NTFPs may be promoted. Such methods would not only reduce NR overuse and degradation, they would also reduce the pressure for resources and the associated insecurity that the Himalayan communities face today, with its undoubted psychological benefits as well. Fodder farms, seed banks, plantations for timber and fuelwood, etc., could greatly reduce this dependence on NTFPs.

4.2.2 Protection and Conservation

(a) Eco-development interventions

The study found that watersheds facing a higher degree of resource stress have a greater amount of unproductive or less productive resources (i.e. wastelands, fallow lands, un-irrigated land). Improving the quality of these resources and sustainable utilization for better economic returns, will also improve the adaptive capacity of the watersheds. Targeted interventions for reducing erosion, improving soil quality, moisture conservation, afforestation, etc., need to be undertaken in watersheds that have a poor Ecological Balance. Wasteland reclamation needs to be undertaken using soil and water conservation techniques and planting of appropriate crops. Erosion and desertification are critical issues in the area, and communities should be mobilised to address these through appropriate conservation and watershed development measures.

(b) Provision of basic services and rights

Provision of adequate public goods and basic welfare services, have multidimensional impacts on the recipients. At the most basic level, they reduce insecurity and enhance the perception of support from the state among the recipient communities. They also reduce the struggle for survival and raise the capacity of the people to access a better quality of life for themselves; provision of certain services would further reduce their dependence on natural resources and with it the possibility of resource starvation. For the Himalayan people, the reach of these services would have the benefit of enabling communities to adopt the vulnerability addressing strategies that call for higher human resource capacity. For instance, in 83% of the cases where occupational diversity is low (<10% of the population are engaged in secondary and tertiary occupation), the literacy rate is less than 50%. This acts as a hurdle to open new employment avenues that can improve their economic conditions and standard of living and reduce dependence on natural resources. Therefore, strengthening the educational systems would need to be a precursor to introduction of alternate livelihoods.

(c) Protection against disasters

Disasters that stare cold desert communities in the face, in the wake of the intense effects of Climate Change, are of both the slow onset (desertification) and rapid onset (flash floods) types. As has been mentioned, Climate Change and Disaster Risk together are the highest contributors to Environmental Threat in Himalayan cold deserts. It is imperative that a comprehensive Disaster Management Strategy is evolved and responsibilities of communities, and state and non-state agencies, drawn out, with respect to risk reduction measures as well as preparedness and response. Various conservation and protection actions, vegetative and structural, may be undertaken. These could include plantations and floodplain development actions, check walls and dams, storage measures of various kinds, such as storage tanks and seed banks. For instance, most of the watersheds that face a severe threat to livelihoods, belong to the second hydrological level. These watersheds are typically at a greater distance from the water source. As a result of Climate Change, the quantity of water available in glaciermelt streams and springs that the population is dependent has reduced, while many streams and/or springs have dried up or function for a shorter period during the year, often drying up during the core summer months. Much agricultural lands have already been laid to waste and crop failures are a recurrent feature in these watersheds. Water diversion and storage systems that ensure water security for the affected populations is crucial.

(d) Community governance and conservation

Communities have shown their capability to govern natural heritage by managing controlled use of larger wild areas through the use of social sanctions; common property resources are relatively well administered by communities through usage norms and rights. A participative management of wild areas, along with a thrust on conservation education and activities, would help revive a sense of community stewardship. Conservation has tended to be a rights-denying intervention, but need not necessarily be so, as has been proved through some best practices. There could well be synergies between conservation and livelihood generation, as well. Conserved spaces, if managed well, can be visited and enjoyed without destruction, and if marketed well, they can provide avenues for generating revenues. Tourism associated revenues from nature parks, is an acknowledged synergistic avenue, when the revenues generated flow to inhabiting communities. Similarly, human-made wetlands may be used for pisciculture, which could in turn provide local incomes, while also performing the normal ecological functions of wetlands.

4.3 Conclusion

The Himalayan cold deserts are among the most critically affected by severe impacts of Climate Change, and the lives and livelihoods of its communities are at risk. These areas have been unfortunate to have received very little development attention, in spite of their increasing vulnerability. Most policies and funds tend to flow to the most visible hotspots, and the extreme remoteness of the region obstructs it from grabbing eyeballs. There is a clear need for first of all, acknowledging the marginal worlds such as the Himalayan cold deserts as urgently requiring attention and ensuring a flow of resources and interventions at global and national levels, and a special place in the Climate Change policy-space. It also requires the delivery of a package of solutions that recognizes the inalienable right of cold desert communities for a secure and equitable life while protecting the ecological integrity of a region that is highly vulnerable.

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