I. INTRODUCTION

Global environmental change is a major issue today. However, due to rather skewed perspectives relating to the work and debate on the subject (a result of overemphasis on "systemic" types of change as against "cumulative" changes), the totality of the global environmental change - its processes, consequences, and possible remedial measures - are inadequately understood and addressed. Annex Table 1 summarises some of the relevant details in this respect. In view of the greater certainty of issues involved and their regional disaggregation, a discussion focussed on "cumulative" types of global change can prove very useful. Furthermore, to fully capture the cumulative types of change, regions can be identified with ecosystems (e.g., mountain ecosystem) in the context of which man nature interactions and their consequences can be understood more easily.

The preceding issues form the background to the discussion on environmental risks in mountain areas in the context of global environmental changes. The emphasis is on understanding and handling environmental risks in the mountains, which are affected both by specific features of mountain habitats and the way the imperatives of these features are ignored or considered by human interventions in mountain areas. The discussion draws upon earlier works related to the subject (Jodha 1990a, 1990b. and 1990c).

The paper focusses on the aspects discussed below.

a) Of the two types of global environmental change, namely, (i) "systemic" change and (ii) "cumulative" change (Turner et al. 1990), the latter forms the broad context for present discussion. The former is covered only in a limited way because of the lack of sufficient information and uncertainties associated with the predicted changes.

b) Environmental risks are perceived in terms of circumstances that disrupt the basic biophysical processes and natural flows which, in the ultimate analysis, determine the health, productivity, and stability of environmental resources - land, water, vegetation, etc - and their interaction, in a given ecosystem.

c) The paper discusses environmental risk in the context of mountain areas where interactions between imperatives of specific mountain conditions such as inaccessibility, fragility, diversity, etc, on the one hand, and varying degrees of human interference on the other, constitute the circumstances that influence the biophysical processes and natural flows.

d) The geographical context of the discussion is the mountain region of the Hindu Kush-Himalayas. The paper does refer to other mountain systems, such as the Andes, to a limited extent. Within the mountain regions, agriculture (including all land-based activities such as cropping, livestock, forestry, and horticulture) is used as a focal point. This is because of both the predominance of this activity in the mountains, and to the recognition of the fact that the important environmental degradation/rehabilitation issues in most cases relate to agricultural resource use.

'Systemic' and 'Cumulative' Changes

In order to get an idea of these two types of change, we can take the lead from some recent conceptual work on the subject. Turner et al. (1990) discuss two dimensions of global environmental changes: (i) 'systemic' change and (ii) 'cumulative' change. Broadly speaking, systemic change is one which, while taking place in one locale, can affect change in the system elsewhere. The underlying activity need not be widespread or global in scale, but its potential impact is global in the sense that it influences the operation and functioning of the whole system as manifested through the subsequent adjustments in the system; CO_2 emissions from limited activities that have impacts on the great geosphere - biosphere system of the earth and cause global warming is a prime example. The cumulative types of change refer to localised but widely replicated activities where a change in one place does not effect changes in other places. When accumulated, they may acquire the scale and potential to influence the global situation in specific ways. Widespread deforestation and extractive land use practices and their potential impacts on the global environment serve as examples. Both types of change are the products of nature-man interactions and are linked to each other in several ways.

This brief introduction to the important concepts may appear sketchy but are sufficient for our purpose. Emphasis on one or the other type of change (along with the relative focus on geocentric perspectives or anthropocentric perspectives) in the work on global changes will have very different implications. These are briefly summarised under Annex Table 1 and the paper directly or indirectly illustrates some of them.

Environmental Parameters

Environment, unless expressed in terms of its vectors (or contributing factors or resources), is a product of several interactive processes of different components of a system (e.g., a mountain ecosystem). The interactive processes between living and non-living things (such as soil, water, vegetation, and animals) generate products and services that act both as inputs into the continuity and performance of the system and its output. Hence, for practical purposes, it is often difficult to separate "environment as services and products" from "environment as manifested by the status of the resources" that generate the services and products. In other words, separating the conditions generated by interactions of soil, water, vegetation, etc from the status of these resources themselves is quite difficult. However, the overall dynamics or pace and pattern of interactive processes of the resources is affected by specific attributes of the latter and the way these attributes are manipulated while using the resources. This provides evidence to say that human intervention is one of the crucial components in the environmental matrix of an ecosystem.

The contributions of interactive processes to the stability and sustainability of the environment (both as inputs and products of an ecosystem) take place through the crucial biophysical functions and flows which are quite interrelated and often invisible. They could be categoried as **"regeneration"**, **"variability-flexibility"**, **"resilience"**, **"natural cycles"**, or **"energy and material flows"**. These biophysical functions and flows (to be elaborated later) are the basic mechanisms through which the level and performance of environmental services (e.g., productivity), as well as the health and status of environmental resources of a system, are ultimately determined. These scientifically well-recognised processes are often not readily visible but their operation can be perceived through an understanding of more easily visible, measurable or verifiable circumstances.

In light of the above, the environmental risks of a system (e.g., a mountain ecosystem) can be understood in terms of instability or destruction of (i) natural resources, (ii) their productivity potential, and (iii) the processes represented by the biophysical functions and flows stated above. The environmental risks can be characterised and identified with reference to a negative change in any of the three categories of variables mentioned above. However, because of the ultimate analysis, the extent and nature of environmental risk will relate to the disruption of the last category of the above variables and the biophysical functions and flows. This is elaborated with reference to mountain areas in the present paper. However, because of the complexity and direct invisibility of most of these functions and flows, the focus of the discussion will be on more easily understood and visible circumstances that influence them.

Accordingly, first, we describe the objective circumstances, i.e., specific conditions of mountains and their likely impacts on the above functions and flows in a relatively undisturbed situation. This is followed by a discussion of changes through human interventions, under relatively low pressure on resources as manifested by traditional resource use systems in mountain areas. The next stage is characterised by increased resource use intensification, following the high pressure on mountain resources generated by increased population, accentuated market demands, and State interventions. The processes at this stage represent some dimensions of the cumulative types of global environmental change mentioned above. The discussion reveals the degree of mismatch between the imperatives of mountain characteristics and certain attributes of resource-intensification strategies as the key source of environmental risks in mountain areas. These risks are quite severe even without considering the systemic types of environmental change. They tend to make mountain areas and people more vulnerable to the potential risks of systemic changes induced by global warming.

Biophysical Functions and Flows

Since environmental risks in the mountains are discussed primarily with reference to the biophysical functions and flows stated above, an explaination of this choice is essential. Taking the lead from the understanding provided by ecological sciences and the descriptive and operational categories or terms used by them (NRC 1986, Conway 1985, Monasterio et al. 1985, Lowrance et al. 1984, Shutain and Chunru 1988, and Krutilla 1979), we try to understand the stability of mountain environments (i.e., absence of environmental risk) in terms of normal functioning of the interrelated processes such as regeneration, the system's internal variability and flexibility, resilience, natural flows, etc. Regeneration, involving processes of germination, growth, decay, decomposition, re-emergence, etc, using photosynthetic and other mechanisms supported by nature's energy and material flows, is one important condition associated with the environmental health of a system. The process of regeneration and the ability of a system to withstand stress are facilitated by the internal variability of the system where input needs and output flows of different components (e.g., annual and perennial plants) are organically interlinked. The system's internal variability, involving organisms and mechanisms with temporally and spatially non-covariate input demand and output performance, offers a degree of flexibility to the system to adjust to different perturbations. Quite related to the above are the visible or non-visible flows and cycles involving energy, moisture, and nutrients of different types and sources. Nature's pattern of energy and material flows and their balancing in the context of a system, links the components from geosphere, biosphere, etc, and helps in sustaining the health and productivity of a system. The operation of the above basic functions and flows, as mentioned earlier, is affected by the state of the natural resources, i.e., its status structure and usage pattern. For instance, a system based on diversified vegetation would be more conducive to regeneration processes and smooth functioning of natural flows. A similar case may be the practice of zero tillage on fragile mountain slopes or systematic crop rotations and the indigenous agro-forestry practices followed in mountain areas. Any practice disturbing the above arrangements may disrupt the underlying biophysical functions and flows and initiate the process of environmental instability and risk.

The important reasons for focussing on these biophysical-chemical processes and flows, rather than on simple categories of resources, such as forest, water, soil, and their product or service flows, to understand the environmental risks in the mountains are as discussed below.

In the overall context of environmental stability, sustainability, and productivity, it is the understanding of the dynamics of underlying processes and flows rather than the structure of environmental resources (represented by composition and types of resource) that can help evolve strategies to minimise environmental risks in mountain regions. An understanding of the above processes and their associated conditions can help to identify alternative resource structures, usage patterns, and their alterations to meet changing demands. For instance, in view of the unavoidable intensification of resource use in the mountains to meet the growing demands, restoration of the traditional resource-extensive management practices as well as the structure and pattern of natural resources (such as the extent and composition of forests) may not be feasible. However, by using the rationale behind traditional systems, it may be possible to evolve new resource-intensive systems that are compatible with new demands and conducive to resource conservation and the uninterrupted operation of underlying biophysical functions and flows. For instance, balancing intensive and extensive land uses by putting some proportions of an area under crops and retaining large parts under forests may not be possible. However, for the smooth operation of certain biophysical functions and flows, the key factor is the complementarity of annuals and perennials rather than the rigid proportions of specific land use categories. The aforesaid complementarity facilitated through specific proportions of intensive and extensive land use categories can be partly ensured by interplanting annuals and woody perennials, as under agro-forestry systems. Similarly, reforestation using traditional species involving a felling cycle of, say, 100 years may not be feasible today, but reforestation using early maturing trees, especially those with multiple functions, can be promoted. Thus, in the micro-level context of a degraded watershed, the focus of interventions need not be on re-creation of its past, but on its rehabilitation using the rationale behind its past status. This, in turn, implies emphasis on the dynamic biophysical processes and flows (regeneration, system's internal variability, etc) using the new leads and understanding offered by modern science and technology blended with the rationale of traditional resource management systems (Jodha 1991).

Another reason for emphasising the basic biophysical functions and flows as the focal point for understanding environmental risks is because the environment (whatever way it is defined) is an integrated product of several processes. Such processes cannot be properly addressed by focussing on individual environmental resources or their productivity. Any approach addressed to them usually acquires sectoral character and misses the required integrated focus. For instance, any strategy directed towards the stability of the hydrological cycle in a mountain region or vegetative regeneration of a mountain slope, will require the integrated use of multiple components affecting the biophysical processes and flows, rather than the application of a single component (such as reforestation) directed to achieve the same goal. Finally, for an integrated understanding of mountain characteristics, human interventions, and their risk implications, the biophysical functions and flows (rather than environmental resources) offer a more useful and effective context. This will become clear later (Tables 1 to 3).

Mountain Specificities

Since smooth operation or disruption of the above-stated biophysical processes is largely a product of specific attributes of a system (i.e., mountains), and the way in which they are treated while using their the natural resources, it is essential to briefly disgress into a discussion of relevant mountain characteristics and their risk imperatives in terms of the above-mentioned biophysical processes.

The important conditions characterising mountain areas which, for operational purposes, separate mountain habitats from other areas, are called here 'mountain specificities'. Six important mountain specificities (some of which might be shared by other areas such as deserts) are considered here. The first four, namely, inaccessibility, fragility, marginality, and diversity or heterogeneity, are called first order specificities. Natural suitabilities or 'niche' (i.e., activities/products in which mountains have comparative advantages over the plains) and 'human adaptation mechanisms' in mountain habitats are second order specificities. The latter are different from the former in the sense that they are responses or adaptations to first order specificities. But nevertheless, they are specific to mountains (Jodha 1990a).

Before describing the major mountain 'specificities', it should be noted that these characteristics are not only interrelated in several ways but, within the mountains, they show considerable variability. For instance, all locations in mountain areas are not equally inaccessible, fragile, or marginal. Neither do human adaptation mechanisms have uniform patterns in all mountain habitats. With full recognition of such realities we can briefly introduce the mountain specificities.

Inaccessibility

Owing to slope, altitude, overall terrain conditions, and periodic seasonal hazards (e.g., landslides, snow, storms, etc), inaccessibility is the best known feature of mountain areas (Price 1981, Allan 1986, and Hewitt 1988). Its concrete manifestations are isolation, distance, poor communications, and limited mobility. Besides being the dominant physical dimension, it has sociocultural and economic dimensions (Jodha 1990a). The implications of inaccessibility as objective circumstances, influencing the operation of biophysical functions and flows can be justified as follows. Firstly, it restricts the mobility and external linkage-related disturbance to the ecosystem. Secondly, the relative closedness of the mountain habitat imposes a number of compulsions for linking survival strategies to the local availability of resources, and their protection and regeneration. Thirdly, meeting diversified human needs in a closed or isolated situation induces diversification in production and resource use patterns, both in temporal and spatial contexts. Fourthly, the limited scope for dependable external linkages and supplies induces adjusting demands to supplies (rather than the other way round) through various forms of demand rationing and periodical syphoning of pressure through transhumance and outmigration. The coping strategies stated above are potentially more conducive to biophysical processes essential for environmental stability.

However, a disregard of the above imperatives, for any reason, can make mountain areas and mountain people vulnerable to serious environmental risks. For instance, increased internal pressure on resources through population growth within a relatively closed system may lead to over-exploitation of resources and reduced diversification and flexibility of resource use patterns. Similarly, the establishment of external linkages within the overall context of the general inaccessibility problem may accentuate selective resource extraction and external exchange on unequal terms. Such developments may generate circumstances that are less conducive to environmental stability of the mountain regions. Tables 1 to 4 indicate some of the relevant issues mentioned above.

Fragility

Because of altitude and steep slopes in association with geological, edaphic, and biotic factors that limit the former's capacity to withstand even a small degree of disturbance, mountain areas are known for their fragility (DESFIL 1988). Vulnerability to irreversible damages, caused by overuse or rapid changes, characterising the land, vegetative resources, and even the delicate economic life-support systems of mountain communities, is manifested by limited options. Consequently, mountain resources and environment deteriorate rapidly and sometimes irreversibly due to disturbances (Eckholm 1975 and Hewitt 1988). Environmental risks related to fragility will be commented on shortly.

Marginality

A 'marginal' entity (in any context) is one that counts the least in the context of a 'mainstream' situation. This may apply to physical and biological resources or conditions as well as to people and their sustenance systems. The basic factors contributing to such a status of any area or community are remoteness and physical isolation, fragile and low-productivity resources, and several man-made handicaps which prevent one's participation in the 'mainstream' pattern of activities (Blaikie and Brookfield 1987 and Chambers 1987). The mountain regions, being marginal areas in most cases, share the above attributes of marginal entities and suffer the consequences of such a status in different ways (Jodha 1990b). To this may also be added that 'marginality' implies a comparative context (i.e., a situation, an option, a resource, an area, or a community) and has a marginal status in comparison to other entities of the same genre. Accordingly, an entity acquires marginal status when compared or linked with other entities. There are several examples of mountain areas, their production systems, and people's adaptation strategies, becoming marginalised and, therefore, unequal, through their integration with dominant, mainstream situations in the plains.

Although products of broadly different factors and processes, marginality and fragility characteristics share a number of common risk implications. Accordingly, unless the resources are upgraded or strengthened, the existing use capacity and input absorption capacity of fragile and marginal resources remain low. They are suited for less intensive uses with low productivity and low pay-off. These features, in turn, restrict the scope for diversification and flexibility, and reduce the system's (physical and economic) abilities to absorb shocks, making it vulnerable to different sources of risk. The risks become a reality when increased pressure on resources (caused by population growth, etc) or the side effects of external linkages and interventions, push their usage level far beyond their use capabilities.

Diversity or Heterogeneity

In mountain areas, one finds immense variations among and within ecozones, even within short distances. This extreme degree of heterogeneity in the mountains is a function of interactions of different factors such as elevation, altitude, geological and edaphic conditions, steepness and orientation of slopes, wind and precipitation, mountain mass, relief of terrain, etc (Troll 1988). The biological adaptations (Dahlberg 1987) and socioeconomic responses to the above diversities also acquire a measure of heterogeneity of their own (Price 1981 and Jochim 1981). The diversity or 'heterogeneity' phenomenon applies to all mountain characteristics discussed here. From the view point of environmental risk, internal diversity of mountains is the most important factor that helps in the smooth operation of biophysical processes and flows and thereby ensures environmental stability. This is both a basis for diversified, interlinked activities and a source of resilience for people's survival strategies in the mountains. However, the imperatives of diversity in terms of matching diversification in resource use and production practices can be used as a basis for interventions in the mountains only if the human demands are also diversified. These imperatives may be ignored with reduced diversity of demands on mountain resources. This may happen because of increased population and consequent changes in resource use patterns focussing on staple foods rather than on diversified products. Similarly, market-induced narrow specialisations can reduce diversification. Such changes can prove detrimental to the environmental stability associated with the internal diversity of mountain ecosystems.

'Niche' or Comparative Advantage

Owing to their specific environmental and resource-related features, mountains provide a 'niche' for specific activities or products or services. At the operational level, mountains may have comparative advantages over the plains in these respects. Examples include mountains serving as the habitat for specific medicinal plants, as a sources of unique products (e.g., some fruits, flowers, etc), and as the best known sources of hydropower production. In practice, however, 'niche' or comparative advantages may remain dormant unless circumstances are created to harness them. However, mountains, owing to their heterogeneity, have several specific 'niche', which are used by local communities in the course of their diversified activities (Whiteman 1988 and Brush 1988).

A 'niche' is a product of interactions of various biophysical (and even socioeconomic) factors. Their regulated use and protection are conducive to the environmental health of a region. Since a 'niche' in a way is a part of the diversity characterising mountain habitats, its environmental risk implications are also similar to those of 'diversity' as discussed above. Its role in the circumstances affecting basic determinants of environmental stability (i.e., regeneration, resilience, energy and material flows, etc) is affected by the pace and pattern of extraction of the 'niche'. Over-exploitation of 'niche' (e.g., timber or hydropower potential) and disregard of the side effects of extraction methods can adversely affect the environmental situation. Evidence shows that both State interventions and market forces tend to contribute to over-extraction of 'niche' and thereby affect the environmental stability of mountains.

Human Adaptation Mechanisms

Mountains, through their heterogeneity and diversity, even at the micro level, offer complex constraints and opportunities. Mountain communities, through trial and error over the generations, have evolved their own adaptation mechanisms to manage them (Guillet 1983 and Jochim 1981). Accordingly, either mountain characteristics are modified (e.g., through terracing and irrigation) to suit their needs, or the activities are designed to adjust the requirements to mountain conditions (e.g., by zone-specific combinations of activities, crops, etc). Adaptation mechanisms are reflected through formal and informal arrangements for resource management, diversified and interlinked activities to harness micro-'niche' of specific eco-zones, and effective use of upland-lowland linkages (Allan 1986, Brush 1988, and Whiteman 1988). Adaptation mechanisms helped in the sustainable use of mountain resources and stability of mountain environments in the past. However, with the changes related to population, market, and public interventions, a number of adaptation mechanisms are losing their feasibility and efficacy. It may be noted that understanding their rationale can help in the search for options to reduce emerging environmental risks in the mountains. This will be elaborated upon later.