Environmental Change and Sustainability

Rosemary Charles

Environmental Change and Sustainability

Edited by **Rosemary Charles**

Callisto Reference
New York

Published by Callisto Reference,
106 Park Avenue, Suite 200,
New York, NY 10016, USA
www.callistoreference.com

Environmental Change and Sustainability
Edited by Rosemary Charles

International Standard Book Number: 978-1-63239-311-1 (Hardback)

Printed in the United States of America.

Environmental Change and Sustainability

Preface

Various issues related to the diverse challenges faced for sustainable change have been dealt in this elucidative book. Across the globe, climate, ecology and environment are facing rapid changes brought about by human interference. This has been further accelerated by growing population, industrialization and a globally expanding economy. Also, increasing consumer demands have only served to aggravate the challenges. Sustainability is a term used to describe policy principals that attempt to even the odds of economic development and environmental issues that arise from it. This book is a valuable addition towards the studies for sustainable ways to tackle global environmental change. The authors of this text have delved into the finer details of environmental changes that are being witnessed in various parts of the world. Various topics discussed throughout this book explain the need for location specific sustainable development. The authors have recommended taking into account; the sustainable counteractions to climatic change as a negotiated outcome between various socio-economic parameters of relevance. This book presents a timely overview on the relationship between environmental change and sustainability, approaches mentioned in natural science and importance of the understanding of environmental change interpreted by human beings. The emerging role of external events in shaping up befitting responses pertaining to environmental changes and role of sustainable development for reduction in risks and challenges as a way of reducing vulnerability have been examined closely. Global processes for a sustainable development model that synthesizes local, traditional knowledge of the environment and environmental management with the techniques and understandings generated by modern environmental science have also been elucidated in this expansive book on environmental change.

Various studies have approached the subject by analyzing it with a single perspective, but the present book provides diverse methodologies and techniques to address this field. This book contains theories and applications needed for understanding the subject from different perspectives. The aim is to keep the readers informed about the progresses in the field; therefore, the contributions were carefully examined to compile novel researches by specialists from across the globe.

Indeed, the job of the editor is the most crucial and challenging in compiling all chapters into a single book. In the end, I would extend my sincere thanks to the chapter authors for their profound work. I am also thankful for the support provided by my family and colleagues during the compilation of this book.

Editor

Contents

Section 1

Physical Dimension

Chapter 1

Environmental Change and Geomorphic Response in Humid Tropical Mountains

Wolfgang Römer

Additional information is available at the end of the chapter

1. Introduction

The tropics encompass a wide variety of environmental conditions sharing high radiation and high temperatures, whilst the timing and annual amount of the rainfall and the seasonal moisture pattern enable the distinction between humid tropical, seasonal wet tropical and arid tropical zones and of the savannah and rain forest environments [40]. As a result of its great areal extent, the tropical zone encompasses a wide range of tectonic regimes, structural and lithological settings and landscapes [38].

The understanding of environmental changes in the tropics appears to be of particular importance as this zone encompasses 35 to 40 per cent of the land surface of the earth and includes about 50 per cent of the world's population [67]. Tropical countries are characterized by a rapid growth in the population and a rapid development of urban areas [6, 45]. This has resulted in increasing demands on fresh water, food, arable land and energy and mineral resources, leading to an increase in per capita consumption and severe environmental degradation.

Tropical ecosystems have been subjected to human interference for thousands of years in the form of traditional land use of many and varied kinds [87, 38]. However, rapid growth in the population and the technical advances of the last 100 years have increased the human impact on physical environments to a much higher degree than the thousands of years of human activity before that. Human interference and environmental change have been rapidly increasing since the mid-twentieth century. Gupta quotes a mean annual loss of rain forest of 174,000 km^2 during the decade 1980 to 1990 [38]. Agriculture and urbanization have modified and transformed large parts of the physical environment and have altered the operation of the geomorphic process-response systems [36]. According to [2], the annual deforestation rate of rain forests ranges from 0.38 to 0.91 per cent in Latin America, Africa and

Southeast Asia with extraordinary high rates of 5.9 per cent in Sumatra and 4.9 per cent in Madagascar. More recent estimates of gross forest-cover loss in the first decade of the 21st century indicate no reversal of these trends [39]. Recent studies indicate an increase in hazards in many regions in the tropics. These appear to be linked to changes in global climate, an accelerated and disorderly process of urbanization, deforestation and the associated loss of hydrological storage capacity, particularly in mountainous domains and to the concentration of settlement activity in potential high-risk areas [44].

However, the severity of their impact varies spatially, and the intensity and course of the response to environment changes varies in the different physiographic domains depending on the nature and severity of the change and the sensitivity of the landscape. Landscapes can be viewed as systems consisting of various interconnected components or subsystems [15]. As the subsystems tend to interact on different spatial and temporal scales via different feedbacks, they may dampen or reinforce the effects of environmental changes depending on the coupling strength existing between the system components. The crossing of thresholds, on the other hand, causes a sudden change in the landscape or in the geomorphic processes, and the mutual operation of feedbacks and thresholds within the geomorphic system tends to induce a complex response to changes in environmental conditions. A consequence of these interactions is that the rate of change of landscapes as well as the severity of the geomorphic response to environmental changes is extremely variable.

1.2. Purpose and objectives

The understanding of developmental patterns in respect of the diverse and complex environmental controls and geomorphic responses in the tropics appears to be an essential prerequisite for the assessment and distinction of climatically-driven and humanly-induced environmental changes as well as for the planning of technological, social and political measures and a sustainable development. The objective of this paper is to demonstrate the role of the geomorphic response to environmental changes on a variety of temporal and spatial scales. However, a comprehensive and balanced view of the wide range of geomorphic process responses to environmental change, their causes and functional relationships is beyond the scope of this study. Instead, this study attempts to concentrate on the response of hillslope processes and their specific controls in the humid tropics, and, in particular, on the stability of hillslopes, on the role of surface wash processes in accelerating soil erosion, and on the role of weathering processes from the point of view of the availability of nutrients in the soils and the geotechnical properties of the weathered materials. A further objective of this study is to highlight some aspects of the role of the long-term development paths of the landscapes as this factor may provide some indication of susceptibility and of a potential response to environmental changes on the part of larger-scale landscape units.

The second chapter encompasses a discussion on the various factors which determine rapid mass movements in humid tropical mountains, and provides an overview of the role of extreme rainfall events in triggering landslides. As the responses of hillslopes are often predisposed by virtue of long-term evolutionary processes, the chapter also includes some case studies on the role of long-term hillslope development and of the effects of susceptibility on landslide hazards in rural and urban areas.

The third chapter is focussed on different aspects of soil erosion, land degradation and soil fertility. The fourth chapter highlights some factors which determine the intrinsic complexity of geomorphic response, interaction between human interferences, the role of changes in the frequency and magnitude of external events and the importance of interdisciplinary approaches.

2. Landsliding and environmental change in tropical mountains

2.1. Landslides in humid tropical environments

Rapid mass movements are important processes in mountainous landscapes and include a wide range of types and sizes of landslides and styles of movement (Table 1). Landslides have been documented in nearly all tectonic settings within the tropical area [80, 87]. However, large single landslides and landslide events encompassing hundreds to thousands of landslides tend to occur most frequently in tectonically active mountain belts and, although with a somewhat lower frequency, in highly elevated pericratonic areas, whilst landslide events appear to be relatively rare in cratonic areas. [14, 31, 38]. The frequent occurrence of landslides in tectonically active mountains and pericratonic areas can be attributed to a specific set of conditions, which include high escarpments, long steep hillslopes in ridge and ravine landscapes, copious rainfalls (high annual rainfall totals and high short-term intensity rainfalls), and highly weathered surface materials [59]. Earthquakes, volcanism and rapidly incising streams are further factors acting as trigger mechanisms for rapid mass movements, particularly in tectonically active mountain ranges [55, 80, 87, 12, 56, 38].

Type of movement	**Regolith**		***Rock***
Type of movement	**Fine-grained**	**Coarse grained**	
Falls	Earth fall	Debris fall	Rock fall
Translational slides	Earth slide	Debris slide	Rock slide
Rotational slides	Earth slump	Debris slump	Earth slump
Flows	Earth flow	Debris flow	Rock flow
Avalanche		Debris avalanche	Rock avalanche

Table 1. Modified after [84] and [75]A simplified classification of rapid mass movements

In many tropical mountains, landslides are part of a highly dynamic hillslope system, which is characterized by high temporal variability, cyclic changes in stability thresholds and temporal tendencies of recovery. This system is superimposed by climatic conditions, the effects exerted by the tectonic regime, lithology and structure, weathering processes and the rate of river incision. Where landsliding is the dominant formative process, changes in the environmental conditions are likely to influence the response of hillslopes by causing changes in the frequency, size and style of landsliding [58, 13, 56]. The off-site effects of large landslide events are the blocking of streams and valleys with landslide debris, and rapid sedimentation in the river channels promotes flooding in the downstream parts of the drainage basins. In a study on the impact of the hurricane Hugo in Puerto Rico it has been estimated that about 81per cent of the material transported out of the drainage basin had been supplied by landslides [47]. As events of a similar magnitude tend to occur once in 10 year the total rate of denudation due to landsliding has been suggested to range to about 164 mm/ka [47]. In Papua New Guinea, earthquakes provide an additional trigger mechanism, and estimates of denudation by landsliding indicate rates of 1000mm/ka [72, 34]. However, our understanding of the long-term contribution of landslides to the total denudation is fragmentary and the extrapolation of denudation rates to larger areas is subject to serious constraints.

Even in the case of shorter time scales, the triggering of slope failures depends on several interconnected and interacting factors. Site-specific factors such as slope, the relative relief, the degree of dissection of the landscape, the density of the vegetation cover, the geotechnical properties, the thickness of the material on the hillslopes and the intensity of land use determine the susceptibility of hillslopes to landsliding. Earthquakes and rainfall amounts are commonly the decisive triggers of landslides [76, 72, 38]. The incidence of landslides is closely associated with the timing, intensity and duration of the rainfall and the antecedent rainfall amounts [78, 1, 33]. These factors control the accumulation of moisture in the regolith and, hence, are associated with the likelihood of high pore water pressures. Hillslope steepness, on the other hand, controls the downslope directed forces and the rate of downslope subsurface water flow whilst the planform of the hillslopes determines the convergence and divergence of the surface and subsurface water flow lines and controls the size of the moisture-supplying area. The thickness of the weathering cover, its weathering degree, layering and textural characteristics, on the other hand, controls the hydrologic behaviour of the slopes and the type of movement. The accumulation of water by subsurface flow and infiltration in the regolith may also control the position of landslides on the hillslopes. In Puerto Rico most hillslopes failed at an elevation range of 600 to 800m because of the supply of water from higher elevated hillslope units [71]. Similar inferences concerning the position of landslides are indicated in studies of [48]. These indicate that slope failures resulting from extreme rainstorms are triggered on the middle or lower slope units of the hillslopes whilst landslides triggered by earthquakes tend to occur on the upper slopes.

Although landslide events are closely associated with high intensity rainfall events or periods of prolonged rainfall, there is no direct link between rainfall amount, rainfall intensity and the number and volume of landslides. Several studies have shown that rainfall events of similar order are capable of triggering different landslide volumes and of producing different landslide occurrences and landslide types [49, 37, 24]. This indicates that different thresholds are involved in the occurrence of landslide episodes. These thresholds are often interconnected by various feedbacks, resulting in complex relationships between the threshold of slope failure and the accumulation of moisture during the rainfall season and antecedent seasons, and the intensity of the rainfall event triggering the landslide [33, 62].

Instability thresholds of this type often depend on a number of site-specific factors. These may be associated with the impact of previous landslides on hillslope form, hillslope hydrology, regolith thickness, and with materials which are inherited from former landslide events.

However, even in tropical mountains with a high relief, steep hillslopes, high rainfalls and a high likelihood of high-pore water pressure, high-intensity landslide events may be rare [27]. Several factors have to work synergistically in order to trigger large-scale landslide events. Apart from bioclimatic conditions and specific structural and tectonic settings, the state of the landscape controls the response of hillslopes to environmental changes as the magnitude-frequency relationship of landslide events depends on the long-term association between overall denudation rates and the renewal of regolith by weathering. Studies on shallow landsliding in Borneo have demonstrated that under a given set of climatic, geological/structural conditions, landsliding is only possible where weathering processes are able to maintain a regolith thickness that is equal to or thicker than the threshold of critical sliding depth [27]. This indicates that on hillslopes where the regolith remains below the thickness necessary to trigger landslides, as the rate of regolith renewal is unable to keep pace with the gross denudation rate and the rate of river incision is too slow to steepen hillslopes towards a new threshold angle for landsliding, at a lower regolith thickness, large landslide events will be rare. However, this type of "regolith-supply limited" or "weathering limited" conditions appears to occur more often in tectonically active mountain belts or in terrains underlain by highly resistant rocks. As high weathering rates are characteristic features in many hot and humid tropical regions, the weathering processes and the geotechnical properties of the weathering mantles are of prime importance for an understanding of the landslide dynamics in tropical mountains.

FThe important role of chemical weathering in the development of impermeable layers in the regolith, and the importance of the highly variable geotechnical properties of the saprolite, soil and colluvium on hillslopes of the Serra do Mar (Brazil) has been emphasized by several authors [32, 46]. Another set of factors is associated with the coupling strength of hillslopes and rivers, the imprints of formerly different climatic conditions including hillslope deposits with variable geotechnical properties as well as the delayed response of hillslopes to the change from dry to humid conditions in the transitional periods from the Pleistocene to Holocene and their influence on the developmental paths of hillslopes [81, 82, 61]. The interaction of these different factors may result in hillslopes which are highly prone to landsliding, though the trigger mechanisms often depend on a site-specific combination of factors as different landscape components of the mountainous terrain are affected.

Human interference in the form of deforestation and urbanization and increased rural land use coupled with infrastructural measures and construction resulting in an oversteepening or undercutting of hillslopes and changes in hillslope hydrology frequently exacerbate the susceptibility of hillslopes to landsliding. The combined sum of the effects of human modifications and alterations in the mountainous domains has increased the socioeconomic impact of landsliding and also the risks in areas with a much lower natural susceptibility to landsliding [41]. Although the contemporary landscape setting, the geotechnical properties of the material, climate and the impact of human alterations determine to a large degree the incidence of mass movements, the triggering of slope failures may be also associated with processes that occurred in the past. The landscapes in which mass movements occur are often a composite of forms and deposits that are genetically linked with actual process dynamics on the hillslopes. The long-term component in studies of mass movements has often been neglected because of the underlying assumption that the current state of a hillslope or landscape is ascertainable from an analysis of the contemporary process-response system. In many cases, this assumption appears to be justified. However, the knowledge of the long-term developmental paths of landscapes may lead to predictions of the susceptibility or sensitivity to react to environmental changes or may lead to predictions on the consequences and impacts of past events which were caused by environmental change.

2.2. Form-process relationships and geomorphic response in south-eastern Brazil

2.2.1. Landsliding in the Serra do Mar

The Serra do Mar forms the elevated passive margin along the Brazilian Atlantic coast and extends from Rio de Janeiro to Santa Catarina with elevations ranging from 700 to about 2000 m. Most of the area consists of folded and faulted metamorphic and plutonic rocks from the Precambrian age and landscapes range from highly elevated plateaus with steep escarpments to dissected ridge and ravine terrains, and muliconvex hilly terrains [3]. The climate is humid tropical with maximum rainfalls in the summer and without marked dry seasons in the winter. The mean annual rainfall totals range from 1500 to 2500 mm, though annual rainfall may rise locally to 4000mm [68]. About 70 percent of the annual rainfall occurs in the summer, which is also characterized by high intensity rainfalls [68]. The potential vegetation along the Atlantic coast is pluvial rain forest, which formed a highly diverse assemblage of trees, shrubs, lianas, tree ferns and epiphytes [42, 89]. Settlement and forest clearance have destroyed much of the original rain forest and estimates indicate that the remaining forests merely constitute 5 per cent of the original coverage [20]. Some local measures have attempted in recent decades to reverse these trends by the afforestation of pines and other tree species [7]. However, the destruction of forests by increasing rural land use and urbanization remains a major problem [53].

Over the last fifty years, the rapid growth of urban areas has resulted in marked changes in hillslope hydrology and the stability of hillslopes. These changes are also associated with an increasing influence of social and economic factors on risks associated with flooding and landsliding [5, 53]. In several regions, hillslopes, villages and urban areas are affected nearly every year by disastrous landslides, and particularly highly dissected terrains with steep hillslopes and highly weathered, thick regolith mantles are prone to landsliding even under undisturbed conditions [22, 19]. Many important roads cross the Serra do Mar and villages, industrial complexes lying at the foot of mountain slopes and escarpments or in basins and valleys are exposed to serious hazards caused by landsliding [53].

However, in many areas of the Serra do Mar, landslides were presumably the most important formative processes since the Late Quaternary period. Landscape evolution was probably non-uniform because of base level changes and climatic changes in the Quaternary, and the intensity of landsliding is likely to have varied as a function of climatic conditions and periods of river incision [17, 18, 61]. The various controls are often genetically linked with the sensitivity to landsliding and concern several aspects of the long-term development of hillslopes.

2.2.2. Some aspects of the role of long-term process-response systems

Predictions about the way hillslopes tend to respond to changes in environmental conditions may be gained from studies of the long-term development of hillslopes. Of particular importance in this respect are the roles of inherited materials and the effects of a differing hillslope-channel coupling strength. Inherited materials may provide information on the processes that have acted during past environmental changes. This enables predictions on the vulnerability of hillslopes with respect to specific slope processes or supports regional surveys on hazards with respect to the geotechnical properties of soils, weathering layers or colluvial deposits. In the Serra do Mar, several lines of evidence suggest that mass movements have occurred alongside periods of intense colluvial accumulation in the Pleistocene and early Holocene [8, 83, 54].

The accumulation of the colluvium occurred as a result of relatively dry climatic conditions in the Pleistocene and the higher frequency in the magnitude of storm events in the early Holocene. The areal extent of land surfaces currently underlain by colluvial deposits in São Paulo is estimated to be in the range of 50 per cent [30]. Today, the knowledge of the complex stratigraphy, the geotechnical properties and of the distribution pattern of the colluvial deposits is important as these deposits are often associated with debris flow hazards which often occur after vegetation clearance [46, 19].

The tendency of landscapes to react to environmental changes by landsliding may be also indicated in the hillslope development paths. Many ridge and ravine landscapes in the Serra do Mar encompass steep hillslopes, which are covered by a moderately thick weathering mantle. In southern Sao Paulo, this terrain-type is underlain by mica schists and phyllites and often exhibits summit heights, which are dictated by the steepness of the valley-side slopes and by the spacing of the rivers [61]. These terrains are characterized by v-shaped valleys and straight valley side-slope profiles with a relative relief of 120 to 200m. The valley side slopes exhibit a narrow range of slope angles ranging from 26° to 34° for the mean slope angle and the mean maximum segment slope angle. A consequence of the geometric control of summit height by slope angle and valley spacing is that areas with similar drainage density and stream spacings are characterized by accordant summit heights [61, 60]. Such an adjustment is unlikely to result from short-term changes because the incision of the drainage net, the fixation of rivers in valleys and the development of steep valley side slopes with a mean relative relief of 120 to 200m are unlikely to have been accomplished within a period that is shorter than 10^5 years. Conversely, in order to maintain the geometrical expression, the hillslope processes and the hillslope-channel coupling have had to operate throughout the Holocene period.

Horizon	clay	silt	sand	cohesion	friction angle
units		weight- per cent		kPa	degree
B	54.3	26.4	19.3	10.5	31.5
B	47.2	23.8	29.0	6.6	30.2
B	67.8	15.3	16.9	13.7	29.9
T	28.8	19.1	44.9	1.9	30.4
S	20.7	28.5	50.8	0.9	38.0

Table 2. Geotechnical properties of the regolith on mica schistsB- textured B-HorizonT – transitional zone between B-Horizon and SaproliteS – SaproliteShear strength was determined by direct shear tests after consolidation to allow excess of pore pressures

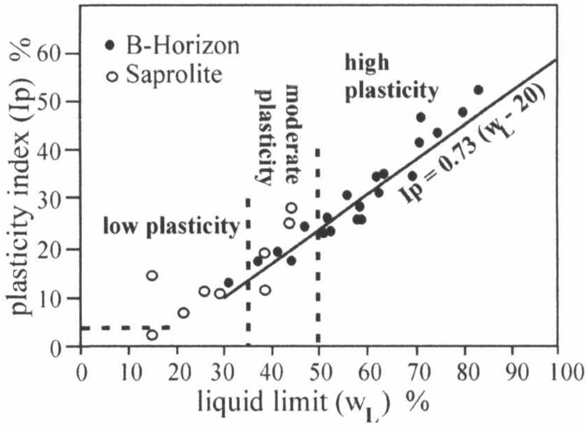

Figure 1. Range of plasticity index and liquid limits of B-Horizons and saprolitic weathering products of mica schists (modified after [61]).

Most valley side slopes in the area are covered by numerous landslide scars and landslide deposits of various ages indicating that the important formative hillslope process is shallow landsliding. The valley side slopes are covered by red-yellow podzolic soils, which show marked differences in the geotechnical properties of the soil horizons (Table 2, Figure 1, Figure 2). Particularly, at the contact of the B-Horizon to the transitional layer the decline of the cohesion tends to facilitate the development of a subsurface plane of failure. This is also indicated in the location of slip surfaces of relatively recent landslides, which occurred at a depth of 0.9 to 1.2m below the surface. This depth coincides roughly with the depth of the transitional layer.