Interactions of natural hazards and society in Austral-Asia: evidence in past and recent records

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Abstract

Interactions of some of the principal historical natural hazards with human populations in the Austral-Asian region are discussed both from the perspective of the impact of the hazard on humans as well as the effects of human activities and climate change on hazard magnitude and frequency. Basically, the former type of interaction is evident for most hazards, while the latter interaction is primarily confined to terrestrial and coastal flooding, erosion, landslides, sea level rise, drought, and fire. Social vulnerability to natural hazards is related to the resources available to cope with the hazard, level of economic development, the ability to predict the occurrence of a hazard and to adjust and adapt to conditions posed by the hazard, and planning measures embraced by societies. Historical chronologies are presented for a range of hazards. Problems in reconstructing historical records of natural hazards include: interpretations of oral records; lack of supporting artifacts; obliteration of evidence of chronic hazards by higher magnitude events; and the inability to distinguish between the effects of different hazards in sediment records. Nevertheless, useful examples illustrate the effects and awareness of volcanic activity and associated hazards, such as tsunami, by early Maori and subsequent development of avoidance strategies; the effects of widespread land use changes and increases in population on the occurrence of floods, landslides and gullies in China and New Zealand; and the effects of forest conversion and drought on fire hazards in Indonesia.

1. Introduction

Austral-Asia is characterized by the highest global levels of tectonic, seismic, and volcanic activity, which manifest a host of hazards such as earthquakes, tsunami, landslides, lahars, and pyroclastic flows. Additionally, the extent of low-lying coastal areas and numerous islands coupled with seasonal rains, pose severe issues of vulnerability related to landfall typhoons and flooding. In other areas, droughts, famines, wildfires and extreme erosion are well documented in historical records. Given the early and dense settlement in many parts of this region, it is perhaps not surprising to learn that the ability to live with, adapt to, and even benefit from many natural hazards has become incorporated within local cultures. Nevertheless, in the past century, human activities have increasingly interacted with and increased the severity of natural hazards. Changing demographics due to economic, political, and social pressures have concentrated many poor and disadvantaged people in vulnerable areas and dwellings. Examples include migration to coastal areas and the practice of shifting cultivation in steeper terrain (Adger, 1999; Templeton and Scherr, 1999). Additionally, government organizations in many of these developing countries are poorly prepared to respond to natural disasters, further increasing vulnerability. At the regional scale, climate change may exacerbate many types of hazards, the most obvious of which are associated with sea level rise (e.g., Woodroffe, 1993; Watson et al., 1998). However, climate change may in some areas also increase the
potential for landslides, severe surface erosion, riverine flooding, wildfires and glacial hazards (e.g., Yim, 1996; Lo and Cai, 2002; Sidle and Dhakal, 2002). Thus, in the Austral-Asian region it is apparent that the three major components of hazard risk—exposure to the hazard over time, vulnerability, and the probability that a hazard will occur—are all very high and, in combination, pose risks unprecedented in other parts of the world.

The most important anthropogenic interaction with hazards in the past two centuries has undoubtedly been caused by widespread changes in land cover, and in particular the conversion of forests to agriculture or grazing land (Sidle et al., 1985; Froehlich et al., 1990; Garrity and Agustin, 1995; Harwood, 1996; Thapa, 2001). More localized exposure to hazards is a result of the movement of people from rural to urban areas and the resulting industrialization during the past 250 years, a trend that has been realized only in the past 50 years in developing nations (Chester et al., 2001). Furthermore, technological advances in both agricultural and disaster control pose complicating challenges and even problems, especially if these are not fully integrated with prevailing socio-economic conditions (Yim, 1996; Islam, 2001; Thapa, 2001). Land cover changes and control measures have escalated at historically unprecedented levels during the past century, spurred on by over-population, internal politics, transmigration, the drug trade, and economic investments from industrialized nations whose resources have already been depleted or protected from such exploitation (e.g., Fox et al., 1995; Templeton and Scherr, 1999; Verburg et al., 1999; Islam, 2001).

Natural hazards can be categorized as episodic or chronic. Generally episodic hazards such as large earthquakes, volcanic eruptions, tsunami, floods, and debris flows attract more attention because of their magnitude and short-term temporal impact. Chronic hazards, however, pose considerable risk of environmental damage, especially in the long term. Examples of chronic hazards include persistent surface erosion, rises in sea level, the melting of permafrost and certain types of mass wasting. Such chronic hazards may exacerbate desertification, land degradation, coastal flooding, wildfires, and sedimentation processes, and may lead to the incidence of much more catastrophic events.

Typically episodic hazards are better preserved in past records compared to evidence of chronic hazards; thus, here we emphasize the occurrence of episodic hazards in Austral-Asia (the region bisected by the PEP II transect) using historical examples. Additionally, the importance of a range of chronic hazards and processes are discussed. Chronic hazards are often masked and overlooked when examining only historical records (Froehlich et al., 1990), although their overall impact may be great. A comprehensive coverage of all types of natural hazards within the entire the Austral-Asian region is beyond the scope of this paper; instead, the objective is to highlight examples of certain types of hazards that cover a range of time scales with an emphasis on societal interaction. A conspicuous omission is earthquake hazards per se, although these are indirectly addressed via landslides and tsunami, as well as discussed in relation to social vulnerability.

2. Physical and social aspects of vulnerability to hazards

Hazards infest our cultures, stories, and economic life, and coping with variability in the physical environment is not exceptional to the processes of human experience, but rather is a central characteristic of resource use. Middleton (1995) explains why societies apparently tend to cluster at the most risky locations by pointing out that the physical phenomenon responsible for a hazard may also offer some of its advantages—a river prone to flooding is a hazard, but also provides both water and important sediments and nutrients. Thus, ‘a hazard should be seen as an occasionally disadvantageous aspect of a phenomenon which is often beneficial to human activity over a different timescale’ (Middleton, 1995, p. 265). There are also cases of societies geographically far removed from the site of hazard being the beneficiaries. For example, Davis (2001) suggests that the major famines and attendant diseases that swept through large parts of Austral-Asia towards the dawn of the 20th century, killing tens of millions of people in China and India, were caused largely by a combination of socio-economic and climate changes related to, respectively, rapid colonial expansion and El Niño-associated anomalies. By causing the depopulation of vast tracts of land and severely weakening local populations and systems of governance, agriculture, and trade in the process, Davies (2001) argues that the repeated incidence of disastrous famines may have contributed to the speed and extent of the spread of both colonialism and capitalism.

Furthermore, human transformation of the environment throughout history has in many cases irrevocably changed the nature of hazard and risk. Environmental change has been both a driver and consequence of major social upheaval and change. Climate and weather variability, for example, are significant constraining factors in the development of agriculture (Diamond, 1999). There is a history of fruitful analysis of the adaptation of human societies to different climates and to changes in climates in terms of food production (e.g., Lamb, 1995). The scale of alterations of human transformation of climate, in particular, is now truly global. Land use change in the past few centuries and industrialization since the 19th century have altered the composition of the atmosphere and hence the global
climate (Houghton and Skole, 1990). No part of the world is immune to these changes in the global climate system. Both observed climate change of the past century and the projected future change in climate result in significantly altered patterns of climate risk. These changes are manifested in various forms, including coastal and river flooding, coastal erosion as a result of sea level change, drought, and increased variability in the driving climatic factors (Hulme and Viner, 1998; IPCC, 2001a; Milly et al., 2002; Adger and Brooks, 2003).

Vulnerability can be defined as the exposure of groups or individuals to stress and comprises several components (see Table 1). One of these is adaptive capacity, which is determined by the resources available to cope with exposure, the distribution of resources across the landscape and among groups within a population, and the institutions that mediate both resources and coping with hazard. Change in social vulnerability from its baseline level incorporates notions of economic development, as well as adjustments to livelihoods based on adaptation to hazard, and changes in institutional and political structures. If institutions fail to plan for hazards or for changing environmental conditions and risks, social vulnerability increases (Adger, 1999, 2000a; Comfort et al., 1999).

A key lesson from social science approaches is that vulnerability is socially differentiated. In other words, virtually all hazards impact differently on different groups in society depending on their ability to cope. Many comparative studies have noted that the poor and marginalized have historically been most at risk from natural hazards. Poorer households are forced to live in higher risk urban areas, exposing them to both river and coastal flooding (Utio, 1998; Takahashi, 1998). Fordham (2001) argues that domestic space is particularly at risk in earthquakes since this part of the constructed environment tends to be less regulated or of older stock than public buildings. And in a number of significant earthquakes, women and other household dependants have suffered much greater mortality.

A society experiences a natural disaster when it is subject to an environmental perturbation of such a magnitude that its ability to cope is exceeded. It is thus important to examine both the social and physical elements in hazard and societal interactions and the impacts of human transformations on the environment that make it more hazardous. In the historical records, these interactions are also important. Examples of natural disasters arising from continuous large-scale environmental change are found throughout the study of historical climate change. Humans have adapted to long-term changes in climate and other environmental parameters and there is increasing evidence from archaeological records and other sources that large-scale, systematic changes in global climate have had profoundly negative consequences for many societies in the past (De Menocal, 2001; Adger and Brooks, 2003). Societies dependent on climate-sensitive resources are themselves heterogeneous and will have variable experience and success in coping with similar amounts of stress brought on through climatic changes. This is clearly shown by historical insights into coping with decadal-scale climate changes. Haberle and Lusty (2000) argue that observed climatic changes, although not modifying cultures directly, may have stimulated changes in resource management and use. Vulnerability to these climatic changes led to very different strategies of coping among societies, from migration to changes in patterns of agriculture (see Bird et al., 2003).

Levels of vulnerability are important considerations when projecting impacts of future changes in climate, but in most cases are difficult to determine. This is mainly because of shortages of appropriate, detailed information on both the drivers of change and their impacts. Climate conditions in Austral-Asia are strongly influenced by monsoons, westerlies, cyclones and ENSO, although to date none of these have been adequately incorporated into coupled atmosphere-ocean GCMs, which are the basis for the most widely accepted projections of future climate changes. Given the high level of uncertainty that characterizes the nature and rate of transition to future climate states (Hulme and Viner, 1998; Watson et al., 1998), responses to climatic changes are virtually impossible to project to a satisfactory level of certainty. Moreover, generalizations

| Hazard | The probability of occurrence of an extreme event whose influence extends over a defined area with particular characteristics. These characteristics of hazards include magnitude, frequency, duration, areal extent, speed of onset, spatial dispersion, and temporal spacing (Burton et al., 1993). |
| Sensitivity | The extent to which a human or natural system can absorb the impacts without suffering long-term harm or some significant state change. This concept of sensitivity, closely related to resilience, can be observed in physical systems with impact-response models, but requires greater interpretation in ecological and social systems, where harm and state change are more contested (Adger, 2000b). |
| Adaptive capacity | The ability of a system to evolve in order to accommodate environmental hazards or to expand the range of variability with which it can cope (e.g., Jones, 2001). |
for the Austral-Asia region are not worthwhile, because of massive differences in environmental and socio-economic conditions, the sensitivity of environmental systems to shocks, and the adaptive capabilities of human societies.

3. Volcanic and tsunami hazards

Volcanic eruptions and tsunami are frequent occurrences in the Austral-Asia region owing to the active convergence of several tectonic plates. In addition to earthquakes, volcanic eruptions can also trigger tsunamis, as witnessed by the 1883 Krakatau eruption that generated a devastating tsunami that killed more than 30,000 people in coastal Java and Sumatra.

The PEP II transect passes through one of the most volcanically active regions in the world. Active volcanoes are a hazard in many parts of the region, from New Zealand in the south to northeastern Russia, although activity is concentrated in an almost continuous tectonic arc-trench system that runs from Okinawa in the northeast, through the Philippines, Indonesian, Nicobar and Andaman islands to Myanmar in the northwest. This system is highly active; for example, more than 80 volcanic eruptions have taken place in Indonesia during the historical period, of which the Tambora eruption, on Sumbawa Island in 1815, is the largest documented anywhere in the world (Hutchison, 1989; Pyle, 2000). Within a 2-week period in early June 1991, two violent eruptions occurred in the region about 2400 km apart: Mount Unzen, Japan and Mount Pinatubo, The Philippines.

Globally, the highest concentration of tsunami occurs around the rim of the Pacific Ocean in the Austral-Asia region. Japan and New Guinea are particularly susceptible to tsunami because of their proximity to triple junctions among tectonic plates. Historic records indicate that Japan has the greatest tsunami hazard (Fig. 1); however tsunami are under-represented in historic records of Southeast Asia and Oceania and the hazard in these areas (particularly New Zealand, Indonesia, and New Guinea) may be higher than indicated in Fig. 1. To illustrate the interactions between humans and both volcanic and tsunami hazards in the region, chronological examples are presented for New Zealand in the following two sections (3.1 and 3.2).

3.1. Volcanoes and prehistorical human interaction in New Zealand

Volcanism in New Zealand, originating from its position astride an obliquely converging and active boundary between the Australian and Pacific lithospheric plates (Fig. 2, inset), provides a good example of the fine balance between a hazard, and thus a potential source of danger to humans, and a provider of resources. The North Island’s main locus of current volcanic and geothermal activity is the Taupo Volcanic Zone (TVZ), which is a unique type of rifted arc dating back to ca. 2 Ma (Wilson et al., 1995; Newnham et al., 1999; Rowland and Sibson, 2001). The highly-productive rhyolite caldera volcanoes of the Taupo and Okataina volcanic centres occupy central TVZ, whereas andesitic stratovolcanoes, including those of Tongariro Volcanic Centre and Whakaari (White Island), occur at its southwest and northeast ends. In addition to TVZ centres, Taranaki volcano (also called Mt. Egmont), the Auckland Volcanic Field, and the Tuhua Volcanic Centre, are also regarded as recently active.

Archaeological and palaeoenvironmental evidence indicates that the initial settlement of New Zealand by Eastern Polynesians occurred between ca. 1250 and 1300 AD (Higham and Hogg, 1997; Newnham et al., 1998; Higham et al., 1999; McGlone and Wilmshurst, 1999; Lowe et al., in press), although Holdaway (1996) suggested there may have been earlier transient contact. Since ca. 1250–1300 AD, five of the volcanic centres in North Island have erupted. It is likely that early Maori (descendants of the original Polynesian settlers) witnessed only one rhyolitic eruption (Kaharoa, 1314 ± 12 AD, from Mt. Tarawera) (Hogg et al., 2003), two basaltic eruptions (Rangitoto Island, ca. 1400 AD; Mt. Tarawera, 1886 AD), and numerous andesitic eruptions (dozens to possibly hundreds) from the frequently active volcanoes of Tongariro Volcanic Centre, Whakaari, and Taranaki.

The extent of impacts is uncertain because written records in New Zealand began only after European settlement from ca. 1800 AD. Direct prehistoric linkages are sparse: (i) human footprints are recorded in the ash erupted ca. 1400 AD from Rangitoto Island, (ii) three earth ovens (“umu”), buried by tephras erupted ca. 1450–1500 AD, occur on the upper slopes of Taranaki, and (iii) cultural remains overlie (i.e. post-date) the Kaharoa Tephra at numerous sites in eastern North Island (Lowe et al., 2000). The historical Tarawera eruption of 10 June, 1886 (Thomas, 1888), had traumatic and long-lasting effects, including at least 108 fatalities (mostly Maori), total ruination of villages and other possessions, loss of the main livelihood (tourism), dispossession of land, and subsequent need for resettlement (Lowe et al., 2002).

Although there are many Maori oral legends about the supposed origins of volcanic landscape features in North Island, very few relate to disasters associated with volcanic activity (Lowe et al., 2002). Aside from the numerous beneficial and spiritual aspects of volcanism to early Maori, ranging from preferential occupation of volcanic cones as fortified villages (“pa”) to the use of volcanogenic iron oxides as pigments for functional and
ceremonial purposes, the dearth of legends concerning disasters associated with volcanic activity (cf. Cronin and Neall, 2000; Grattan and Torrence, 2002) probably relates in part to the lateness of New Zealand’s settlement and its sparse population, which meant there were few opportunities for substantial populations to witness very destructive eruptions. It seems that early Maori had a strong awareness of volcanism generally and may have developed a spiritual disaster culture to reduce the impacts of eruptions in proximal locations by making certain volcanoes sacred and thus inaccessible (Lowe et al., 2002). After an eruption, such volcanoes initially were possibly declared out-of-bounds ("rahui"). Later, a more religious or superstitious restriction was applied to them. Any violation of this sacred status ("tapu") was considered likely to bring upon a calamity (Lowe et al., 2002).

The application of tephrochronology to the issue of New Zealand’s Polynesian settlement history is now well established, and the Kaharoa Tephra in particular provides a key chronographic marker, enabling archaeological and palaeoenvironmental sites to be both linked and dated (Anderson, 1991; Lowe et al., 1998, 2000). No Maori artefacts are recorded beneath it and the earliest inferred environmental impacts (forest clearance for settlement) are dated to ca. 1280 AD, just prior to its deposition (Wilmshurst, 1997; Newnham et al., 1998; Lowe et al., 2000, in press). That the extremely powerful and devastating Taupo eruption of ca. 200 AD (Wilmshurst and McGlone, 1996; Lowe and de Lange,
(2000) is unregistered in Maori legends is consistent with the model of late 13th century settlement of New Zealand.

3.2. Interactions of tsunami and humans in New Zealand

The history of tsunami events in New Zealand, where two centuries of written records are preceded by rare Maori oral accounts from prehistoric times (i.e., since ca. 1300 AD: Lowe et al., 2000, 2002), is relatively well documented. The historical record indicates that locally generated tsunami represent a greater hazard than those that cross the Pacific Ocean (Downes and Stirling, 2001; de Lange, in press). However, the historical local tsunami have only affected limited regions along the coastline, whereas the largest distant-source tsunami have affected all of the New Zealand coast (de Lange and Healy, 1986a; de Lange, 1998; Fraser, 1998). It is also evident from the historical record (de Lange, in press) and numerical simulation (Walters, 2002) that...
some coastal regions are subjected to greater hazard because of local amplification of tsunami. The highest level of amplification occurs between Canterbury Bight and Pegasus Bay, including the whole of Banks Peninsula, with localized increases up to 800% (Fig. 3). Significant amplification also occurs around Chatham Island and within Hawke Bay, Hauraki Gulf, and Cook Strait (Walters, 2002).

Tsunami damage in New Zealand includes loss of life, damage to structures and inundation by saltwater (Fig. 4). However, until the 1950s, the population and infrastructure exposed to potential tsunami hazard was relatively small (de Lange and Healy, 1986b). Damaging distant-source tsunami have originated mostly along the coasts of Peru and Chile, with the 1868, 1877 and 1960 tsunami producing maximum crest-to-trough heights of ~7 m. Fortunately, the crests during these events did not reach far above high tide level (~3 m), so the withdrawal of water associated with the trough generally caused the most damage. It is not known whether this behavior was a fortuitous interaction with low tide or a fundamental characteristic of tsunami resonance. Only one distant-source tsunami is known to have inflicted fatalities. Amplification of the 1868 Chilean tsunami in the lee of Chatham Island generated large waves that destroyed the Maori settlement of Tupunga with an unknown number of casualties (Dennison, 1975). The same waves drowned one European in Waitangi (de Lange and Healy, 1986a).

Occurrences of large, local-source tsunami are documented in 1820s, 1830s, 1855 and 1947 (two events). Only the first of these was particularly damaging because the other four affected areas were sparsely populated at the time of the tsunami. The 1820s tsunami may have been associated with a major earthquake on the Alpine Fault in 1826–27. The tsunami affected the southern coast of the South Island and is reported to have killed a large number of Maori travelling along the beach near Orepuki (Macintosh, 1985; de Lange, in press). Deposits containing artifacts dating to this event have been reported but not studied in detail. Although most of these events were associated with earthquakes, there is ongoing debate whether the largest waves were of seismic or landslide origin.

Although the 1855 tsunami did not cause much damage, it did contribute to considerable unease in the
fledging settlement of Wellington that bore the brunt of the earthquake that generated the tsunami. A large earthquake also affected Wellington in 1848, causing some settlers to leave. A few more departed after the 1855 earthquake and tsunami, but those who remained found that coseismic uplift had increased the amount of flat land available for development. It was also realized that wooden structures survived earthquakes, while brick structures did not. Consequently, when the general government removed to Wellington in 1865 all major government buildings were erected of wood (Grapes and Downes, 1997).

Maori oral accounts that may represent tsunami events are rare, and those that exist have been subjected to some imaginative interpretation (Bryant, 2001). Consequently, sedimentary and archaeological evidence is the primary tool used to characterize prehistoric tsunami (Goff and McFadgen, 2001a). Due to the size of storm waves around the New Zealand coast, it is likely that only the largest tsunami events are preserved. However, these represent the greatest hazard.

Palaeotsunami studies indicate that a major tsunami struck at many locations around the New Zealand coast during the 15th century (Goff and McFadgen, 2001a, b). These tsunami events are associated with archaeological evidence of widespread abandonment of early Maori settlements located on low-lying coastal land such as spits and coastal terraces. A growing number of these abandoned sites have been found and provide evidence of tsunami damage to structures. It has been noted that tsunami inundation coincides with a cultural change from the Archaic to the Classic period, and the onset of “pa” construction (Schmidt, 1996) and inter-tribal warfare (Goff and McFadgen, 2001a, b).

The 15th century tsunami events coincide with a cluster of large earthquakes along the Alpine Fault, and major faults in Cook Strait and within Hawke Bay, suggesting a seismic origin for the tsunami. However, recent data indicate that Healy volcano, a large submarine caldera located on the southern Kermadec frontal arc (Wright and Gamble, 1999), also erupted during the 15th century, contributing to the sea-rafted Loisels Pumice deposit (Shane et al., 1998) found around eastern New Zealand’s coastline (B.G. McFadgen, pers. comm., 2002). This eruption may have been the cause of tsunami deposits in northeastern New Zealand that occur up to 32 m above present sea level (S.L. Nicol, pers. comm., 2002). It is also possible that the eruption of Rangitoto Island in the Hauraki Gulf ca. 1400 AD (Lowe et al., 2000) generated a tsunami (de Lange and Prasetya, 1999; Goff and McFadgen, 2001b) that impacted on Maori coastal settlements in the adjacent Auckland region. Other volcanic events since ca. 1300 AD (see Lowe et al., 2002) are unlikely to have generated tsunami of any consequence, although some eruptions or eruptive-related landsliding from White Island in eastern Bay of Plenty may have been locally significant (de Lange and Healy, 1986b). Further, the most powerful eruption in Maori prehistory, the rhyolitic Kaharoa event in 1314 ± 12 AD (Nairn et al., 2001; Hogg et al., 2003), may have generated a small meteorological tsunami through atmospheric coupling as described for the extreme (pre-Maori) Taupo event of ca. 200 AD (Lowe and de Lange, 2000).

4. Flooding, mass movements and sedimentation hazards

4.1. Flooding in coastal environments

Coastal areas throughout Austral-Asia are likely to experience increased vulnerability to flooding in the present century, especially in the most densely populated eastern, southern and Southeast Asian parts. Factors leading to increased vulnerability include the realization of projected, global warming-induced environmental changes, such as higher sea levels and changes in the location, number, frequency and intensity of storms, and dramatic expansion of population, particularly in poor urban areas. Hazards posed by sea level will become more severe; estimated current rates of eustatic sea level rise range from 2 to 9 mm yr⁻¹ (IPCC, 2001b), or two to four times higher than for the previous 100 years. Densely populated and heavily industrialized urban areas in Japan, such as Nagoya, Osaka and Tokyo, are already located below mean high water level.
and the anticipated cost to protect against a 1 m increase in sea level is around US$ 80 billion (Lee et al., 1998). The situation appears even more serious for many small island states in the Pacific Ocean, where populations may have to be removed and resettled as a result of sea level changes (Nurse et al., 1998). Even if climate conditions were to remain stable, coastal regions are expected to become more hazardous because of population increases and greater susceptibility to flooding and salinization as a result of compaction and subsidence (Woodroffe, 1995), surface sealing, and loss of buffer zones between the coast and settled areas.

In many cases, levels of regional variations are likely to be greater than globally averaged figures and therefore far more difficult to cope with. Relative rises in sea level can occur locally due to land subsidence caused by tectonic activity or the unsustainable abstraction of ground water, and are already important factors in some of the larger deltaic and coastal urban areas, including Bangkok and Jakarta. Storm activity will also exhibit greater local variation, as global warming alters the frequency, pathways and impact zones of cyclones. One outcome of local variability is that it adds further uncertainty to already uncertain projections. High levels of uncertainty, especially in the context of pressing economic issues, such as poverty alleviation, and political instability, may prove a major disincentive for investments in adaptive strategies in poor countries. In the absence of outside intervention in such nations, it is more likely that formerly productive land will be abandoned as relative sea levels increase and storms become more destructive.

Nicholls et al. (1999) carried out an assessment of changes in vulnerability, based upon a combination of climate change model (HadCM2 and HadCM3) scenarios with data on population increase and changes in gross national product (as a guide to the ability to pay for protection schemes) in a coastal flood model. The model incorporates processes such as sediment accretion and ecosystem migration (Nicholls et al., 1999, p. 576), but assumes a uniform coastal slope and does not include any site-specific information, such as local hydrological conditions and the availability and type of sediments. Additional weaknesses in the model are that no account is taken of either differences in the abilities of people living in affected areas to cope with frequent and at times severe floods, or non-linear responses to increases in sea level such as increased vulnerability to episodic storms. Output from the model indicates that the coastal areas of southern and Southeast Asia are among the most vulnerable to hazards globally (Fig. 5) and together with the southern Mediterranean and equatorial Africa will account for more than 90% of people affected by flooding in the 2080s, irrespective of protection schemes (Nicholls et al., 1999, p. 580). South and Southeast Asia are particularly

![Fig. 5. Coastal areas vulnerable to flood hazards as the result of predicted sea level rise. The most vulnerable coastlines are generally in southern and Southeast Asia (based on Nicholls et al., 1999).](image)
vulnerable, because of high population levels on low-lying deltas and coastal plains, with well over 50% of all people affected globally living in these two regions. The percentage is even greater under a scenario of evolving protection, because the relatively low GNPs in South and Southeast Asia will economically constrain the range of coastal protection possibilities. Impacts are likely to extend inland, due to factors such as saltwater intrusion along drainage networks and displacement of people from inundated areas, and thus conflicts over soil and water resources may expand. The numbers affected in the whole Austral-Asian region could be considerable; Nicholls et al. (1999) estimate that nearly 15 million people in Bangladesh and at least 2 million people in Indonesia could be displaced by a 1 m rise in sea level. In particular, Bangladesh, largely composed of an active delta, experiences frequent extreme flooding (both from the terrestrial and oceanic sides) that will be exacerbated by a gradual rise in sea level (Kubo, 1993; Islam, 2001).

Nicholls et al. (1999, p. 584) propose three precautionary strategies to reduce vulnerability to sea level-induced changes: planned retreat; proofing accommodation against flooding; and armouring coastlines. Planned retreat in parts of the Austral-Asia region is a possibility, but only likely in those areas with relatively low population densities. Proofing accommodation against flooding is already practiced in some parts. For example, the “kampong” houses and bridging walkways of coastal Malay communities are constructed on piles, well above water levels. However, the practice requires additional timber and other natural resources and may contribute to a decline in coastal forests, and hence to the degradation of a natural form of coastal protection. It has been argued that the traditional dig–elevate–dwell principle of settlement practiced in the Bangladesh delta has distinct advantages for sustainability compared to cordoning portions of the Brahmaputra River, which ignores the geomorphic dynamics of this natural system (Islam, 2001). Small-scale flood control projects such as “kasumi-tei” (multiple embankments) and compartmentalization of polders (so-called “waju” system) may be more effective in lowlands of Bangladesh compared to foreign-supported, large-scale structural measures (Kubo, 1993). Armoring of coastlines is an economically viable proposition only where the value of land and infrastructure protected exceeds that of the cost of building and maintaining protective structures. Such high-cost protection schemes are thus only feasible in urbanized and industrialized coastal areas and in the most economically affluent parts of the PEP II transect. Armoring has negative impacts, however, as it may obliterate important coastal ecosystems and, by modifying sediment transfer in the littoral zone, shift the erosive power of the sea to adjacent, unprotected coasts. An additional management strategy is the maintenance of at least a fringing band of coastal forest, especially along the most vulnerable coastlines. Coastal forests have the potential to provide a combination of coastal protection, a source of natural resources, and a habitat for many species of wildlife (Kaly and Jones, 1998). Maintenance of coastal mangrove forests was recommended by Tri et al. (1998) as a cost-effective means of protecting Vietnam’s densely populated coastal zone, including areas presently fronted by engineered protection schemes such as sea dikes.

4.2. Flooding of terrestrial environments

Recent incidences of flood hazards affecting interior parts of the Austral-Asia reflect the increasing habituation and investment in flood prone regions as well as the influence of changes in land cover that impact the magnitude of flooding, extent of surface erosion, stability of slopes, and sedimentation. Examples include riverine floods along the Yangtze River in 1998 and in the lower reaches of the Mekong River in 2000, widespread flooding in central Vietnam in 1999, and post-forest fire flooding in Australia in 2001. During 2002 alone, floods have caused extensive damage and loss of life around Jakarta, Indonesia, along the Cambodia–Laos border, in northern Thailand, in rural Myanmar, and throughout the Philippines, Korea, and China. Based largely on recent historical records, examples are presented to show the changing occurrence of flooding in major river systems in China, including the influence of land cover alterations.

Historical records indicate that flood frequency in China has increased during the last two millennia (Shi et al., 1992; Vorosmarty et al., 1998). For example, major floods in the Yangtze River occurred during the Tang Dynasty on average once every 18 years, during the Song and the Yuan Dynasties once every 6 years, and during the Ming and the Qing Dynasties once every 4 years. Major floods had an even higher frequency during the 20th century. From the 1930s to 1940s, for example, floods occurred once every 2.5 years on average. There have been further increases in the frequency and severity of floods since the 1980s, with major floods in 1980, 1982, 1983, 1989, 1991 and 1998 (Yin and Li, 2001). The economic losses and damage resulting from some of these flood events were enormous: the Yangtze floods in 1998 cost China more than 2 billion U.S.S., damaged about 5 million houses, affected 223 million people, of whom more than 1320 died (Zong and Chen, 2000; Cai et al., 2001), and led to a ban on logging and closure of timber markets in the upper reaches of the river.

The Yangtze floods of 1998 have been blamed on heavier than usual monsoon rains, possibly relating to La Nina climate anomalies, with impacts accentuated by...
human activities (Zong and Chen, 2000; Yin and Li, 2001). Forest removal since 1949 has reduced natural water storage capacity and increased runoff; forest cover in Sichuan Province in the Upper Yangtze was reduced from 20% in the 1950s to 12% in the early 1980s, and from 23% to 13% in neighboring Guizhou Province between the 1960s and the 1980s (Yu et al., 1991). Historical trends in monthly minimum and maximum water discharge for two locations along the main Yangtze channel (Yichang, close to the Three Gorges Dam and Hankou, in Wuhan City, Hubei Province) are shown in Fig. 6. Monthly minimum water discharge at Yichang decreased markedly since the 1880s. Moreover, although soil erosion increased throughout the Upper Yangtze basin, sediment yield at Yichang did not appreciably increase (Gu and Douglas, 1989; Qian et al., 1993; Zhuo and Xiang, 1994; Dai and Tan, 1996).

A probable reason for the lack of a rising trend in sediment yield is that tributary basins in the Yangtze may act as sources and sinks of eroded sediment. Recent investigations have identified major tributaries within the upper basin, including the Yalong, Dadu-Min, Jianlin, and Wu, that either increased or decreased in importance as suppliers of water and sediment during the last 50 years (Lu and Higgitt, 1998) (Fig. 7). Increases in both seasonal discharge and sediment transport has occurred in two tributaries of the Dadu-Min and the Jialin (Chen et al., 2001b) resulting from a 50% reduction in forest cover (Winkler, 1996). The well-known Dujangyan Irrigation System, with a history of more than 2000 years and a vital component of agricultural irrigation in the Sichuan Basin, is threatened by these changes. Conversely, significant decreases in sediment loads have been recorded in some tributaries of the Yangtze due to sedimentation behind recently constructed dams (Lu and Higgitt, 1998). Sedimentation rates of major lakes along the middle and lower reaches of the Yangtze River have increased during the last 100 years (Fig. 8). Sedimentation in water bodies and flood plains significantly reduces the water storage capacity in the Yangtze River basin (Chen et al., 2001b; Du et al., 2001). For example, the riverbed near Jinjiang in the middle reach of the Yangtze River is a few meters above ground level. The surface area of Dongting Lake has declined from 4300 km² in 1954 to 2600 km² in 1990, and the water storage capacity from 29.3 billion m³ in the 1950s to 17.8 billion m³ in the 1990s, while the surface area of Poyang Lake declined from 5000 km² in 1954 to 3900 km² in the 1990s. Even with reduced discharge, the hazard of flooding is increased as a result of sedimentation and reduced water storage capacity. During the 1998 Yangtze flood, higher water levels were measured at most hydrological stations compared with some periods of flooding during the historical record, however, actual discharges were lower (Zong and Chen, 2000).

The Yellow River has experienced even greater changes in water discharge and sediment load during the last 50 years or so (Yang et al., 1998), in part due to forest removal and grassland desertification in headwater areas and the highly erodible nature of substrates forming the Loess Plateau (see Section 4.4). The river ran dry for the first time in history in 1972, and subsequently such dry spells increased in length and became almost annual events, with the river failing to reach the sea for 226 days in 1997 (Chen et al., 2001a). Repeated water shortages threaten food production and power generation as rivers are drained dry and aquifers are depleted: in 2000 alone, an economic loss of US$16 billion was attributed to drought on the North China plains.
The severe droughts forced the closure of the Xiaolangdi power station, the largest hydroelectric scheme on the Yellow River. Apart from the sharp declines in natural storage features, such as forests and lakes, and the increased silting of rivers and reservoirs, urbanization, industrialization and a steady encroachment onto floodplains by land-poor farmers (Du et al., 2001) have all contributed to increased flooding. The interaction of land development and water diversion projects further complicates flooding. For example, previously designated flood-diversion areas in Jinjiang (middle reach of the Yangtze River) are now occupied by farms and factories.

4.3. Landslides

Landslides are endemic geomorphic phenomena in steep terrain of the Austral-Asian region, shaping landforms and delivering sediment to rivers. Earthquakes and high rainfall are the dominant trigger mechanisms in the region (O’Loughlin and Pearce, 1976; Brunsden and Jones, 1984; Shroder and Bishop, 1998; Derbyshire, 2001; Lu et al., 2001). Human intervention affects terrain stability, primarily through changes in land cover (Tsukamoto and Minematsu, 1987; Kuruppuarachchi and Wyrwoll, 1992; Froehlich and Starkel, 1993; Luckman et al., 1999) and, more locally, via road construction (Haigh, 1984; Coker and Fahey, 1993). As a result, sediment transport in streams and rivers is increased, channel forms are altered, and debris flows are more frequent.

Historical records of landslide activity in the Austral-Asian region are scattered and often biased. The only accurate and direct records of landslide disasters are from areas where extensive loss of life has been chronicled (e.g., Sangawa, 1987; Japanese Landslide Society, 1996; Cheng et al., 1997) or landslide deposits
have been dated (e.g., Innes, 1985; Sukhija et al., 1999; Barnard et al., 2001). As such, these recorded landslide disasters are typically very large. Historical records are biased in favor of earthquake-induced events because of their magnitude. In fact, many of the ancient landslides and rock avalanches in tectonically active regions of China have been dated based on records of earthquakes (Weidinger et al., 2002). While such events are known to be catastrophic in terms of loss of life due to their unpredictability, it is generally recognized that the frequency and volume of individually smaller, rainfall-induced landslides are cumulatively much larger (Bishop and Stevens, 1964; O'Loughlin et al., 1982; Sidle et al., 1985). Despite their smaller mass, shallow debris avalanches and debris flows triggered by rainfall or snowmelt can generate devastating consequences because of their high velocities (Wasson, 1978; Pierson, 1980; Sidle et al., 1985; VanDine, 1985). Widespread debris avalanches and debris flows occurred in the Kagoshima Bay area, Kyushu, Japan, in 1993, killing more than 120 people and destroying many homes and farms (Fig. 9). Numerous debris flows near Hualien, Taiwan, in 1990 killed more than 29 people and destroyed 24 houses and a road (Lu et al., 2001). Evidence of these smaller, more numerous landslides is obscured within decades to a century even with careful field reconnaissance, especially in the tropics and subtropics where disturbed sites regenerate rapidly. Contemporary geomorphic processes on hillslopes can destroy evidence of earlier landslide events (DeRose et al., 1993). In the tropics, extensive and frequent landslides may actually prevent forests from reaching equilibrium with climate, as in Papua New Guinea (Garwood et al., 1979).

Large, ancient rainfall-triggered landslides have been documented in some areas (e.g., Japan and New Zealand); however, slower moving, deep-seated mass movement complexes are more commonly identified, as these landforms are better preserved in the geomorphic record (Japanese Landslide Society, 1996). Such slow moving landslide complexes may include combinations of rotational slumps, earthflows, and soil creep (Sidle et al., 1985). Deep-seated mass movements are typically activated during episodically wet periods following cumulative groundwater accretion (Wasson and Hall, 1982; Japan Landslide Society, 1996). Documentation of large historical landslides and rockfalls in the Himalaya and throughout China is patchier (Wiezorek et al., 1987; Billard et al., 1993; Hewitt, 1998; Shroder and Bishop, 1998). Throughout the formerly glaciated terrain of Austral-Asia, accelerated tectonic uplift following the early to mid-Pleistocene exacerbated mass movement (Page and Trustrum, 1997; Gupta and Virdi, 2000; Tamrakar et al., 2002). Fossil vertebrates entombed in sand deposits provide evidence of ancient translational slides in aeolian dunes in Mongolia (Loope et al., 1999). These otherwise dry geomorphic landforms were believed to have failed during rare rainfall events when pore water pressure accreted at shallow hydrologic discontinuities created by a calcite layer within the sand deposits.

The ages of many of the ancient landslides and rock avalanches are dated from deposits that dammed rivers (Adams, 1981; Wiezorek et al., 1987; Hewitt, 1998). As fluvial incision accompanies tectonic uplift, such geomorphic features are predictable. However, as with other historic landslides, only the largest of these deposits remain for dating. Lakebed sediments provide a better integrated, albeit undifferentiated, archive of past erosion processes. When applied to a region where landslide processes dominate, lake sediment records can be useful in reconstructing past episodes of landsliding. Page and Trustrum (1997) analysed the pollen and diatom contents of cores of lake sediments of Holocene age from a landslide-prone region of North Island, New Zealand, and used the results in combination with tephra chronology and historical evidence to assess erosion response due to land use changes during the past.

Fig. 9. Widespread landslides in Shirasu deposits (an unwelded ignimbrite; age 25,000 BP) in the Kagoshima Bay region of Japan. The resulting debris flows during a typhoon in 1993 killed more than 120 people in this region.
2000 years. Erosion losses were low prior to Polynesian settlement when native forests covered the catchments. Fire-induced clearing by the Polynesians beginning in the early 15th century converted indigenous forest to fern/shrub cover resulting in a 5–6-fold increase in erosion. The arrival of Europeans in 1873 prompted a shift in land cover to pasture with a corresponding 8–17-fold increase in erosion compared to indigenous forest cover (Page and Trustrum, 1997). In spite of this well documented chronology, it was not possible to separate periodic landslides from extensive gully erosion that occurred during this period.

The most devastating (albeit imperfectly and belatedly documented) landslide disaster in the past 100 years was a huge dry loess flow in 1920 that occurred in Gansu Province, China, triggered by a large ($M \approx 8.6$) earthquake and killed an estimated 180,000 to 200,000 people (Close and McCormick, 1922). A large ($M \approx 8$) earthquake in Hua County, Shaanxi Province, China, claimed some 830,000 lives; however, the extent of loss of life attributed to landslides was not documented (Weidinger et al., in press). Four large ($M > 8.0$) Himalayan earthquakes have struck northern India in the past ca. 100 years, all of which caused extensive landsliding primarily by liquefaction (Sukhija et al., 1999): (1) the 1897 Assam earthquake in the Shillong Plateau; (2) the 1905 Kangra earthquake; (3) the 1934 Bihar–Nepal earthquake; and (4) the 1950 upper Assam earthquake. Radiocarbon dates of organic material in paleosediments in the Shillong Plateau suggest that return periods for these large earthquakes and associated mass failures are 400–600 years. In recent years, among the industrialized nations in the region, Japan has undoubtedly suffered the most sustained loss of life and property damage due to landslides (Swanston and Schuster, 1989). Large regions with steep hillslopes and unstable geologic materials, coupled with heavy rainfall during the typhoon season and numerous high-magnitude earthquakes, predispose many of the populated mountainous regions in Japan to landslide hazards (Swanston and Schuster, 1989; Okunishi et al., 1999). A major difference in Japan compared to other Austral-Asian nations is the high level of government investment in structural landslide control measures (Sabo works). While such countermeasures undoubtedly prevent and mitigate certain landslide hazards, they are often implemented after a major disaster has occurred and at great cost.

Studies on the recovery of landslide sites in the Austral-Asian region are few, but high rates of rainfall, weathering, and tectonic uplift should promote more rapid recovery (Shimokawa et al., 1989; Froehlich et al., 1990; Chigira, 2002). Studies in Japan have shown that increases in frequency and intensity of rainstorms from late Pleistocene to early Holocene increased the frequency of landslides (Yoshinaga and Koiwa, 1996). Moreover, work in New Zealand has documented increased frequency of landslides as a result of the clearance of mixed evergreen forests and other vegetation during the development of extensive pasture lands by European settlers (1860–1920) (Selby, 1976; Sidle et al., 1985; DeRose et al., 1993; Trustrum et al., 1990; Fransen and Brownlie, 1995; Page and Trustrum, 1997; Luckman et al., 1999). Similar influences of historical vegetation conversion have occurred, but have been less comprehensively documented, throughout interior China. In northeastern Yunnan Province, forest removal began during the Tang Dynasty (618–907 AD), followed by more aggressive cutting in the last 300–400 years to produce charcoal for the expanding copper industry (Chen et al., 1981; Wieczorek et al., 1987). Most of all the forests in the region had been cleared by the late 1940s. Both gully erosion and shallow landslides ensued and, as the gullies deepened, further mass movements occurred from the unstable gully side-walls. Ravines loaded with sediment experienced episodic debris flows, several of which caused extensive damage, killing many people and mandating the relocation of several villages (Wieczorek et al., 1987). Other similar and widespread scenarios of forest removal effects on landslide erosion exist throughout China. The Darjeeling Himalaya may represent an area where rapid tectonic uplift, frequent high intensity storms, unstable regoliths, and extensive forest clearance have precluded a steady-state adjustment in hillslope evolution (Selby, 1974; Froehlich et al., 1990). The Himalaya in general represents the region with arguably the highest levels of landslide erosion (Starkel, 1972; Selby, 1974).

4.4. Surface erosion

Surface erosion is not generally considered a hazard unless it reaches devastating levels. The inter-tropical and subtropical portions of the PEP II transect have been particularly susceptible to surface erosion because mineral soils are easily exposed to the forces of raindrop impact and overland flow during intense storms due to high rates of decomposition of organic matter (Brown et al., 1994; Hairiah, 1999) and extensive and rapid changes in land cover. Additionally, drier regions of central China and Australia have been historically susceptible to severe erosion owing to sparse vegetation cover and erodible soils (Fang and Xie, 1994; Prosser et al., 1994). However, it is typically the advent of widespread land disturbance or the occurrence of a climate anomaly (or both) that converts chronic erosion to episodic gullying (Prosser and Soufi, 1998; Shi and Shao, 2000).

Recent changes in land cover in the region have been driven by incentives from government and international donor that promote high cash value crop production together with poorly coordinated conservation
programs, transmigration schemes, rising market prices for certain crops, and the apparent needs of subsistence farmers to generate additional sources of income from the land (e.g., Byron and Arnold, 1999; Elmihirst, 1999; Cramb et al., 2000; Lu et al., 2001; Thapa, 2001). Sustainable forest management is difficult to accomplish in this region because steep hillslopes, high rainfall intensities, seasonally dry periods and naturally erodible soils exacerbate surface erosion when sites are disturbed (e.g., Lu et al., 2001). Agroforestry is increasingly practiced in mountainous terrain and offers some erosion benefits compared to conversion of forest land to strictly cultivated agriculture (Craswell et al., 1998).

Historical conversion of native and secondary forests and shrublands to pasture and other agricultural land in the temperate and dry zones of Australia and New Zealand has significantly affected water pathways and erosion. Numerous accounts exist of extensive gully erosion in eastern Australia following agricultural expansion in the 1800s, partly as the result of fire (e.g., Eyles, 1977; Prosser and Winchester, 1996). Additionally, Prosser and Winchester (1996) note that much of the gully erosion developed after European settlement, although chronologies are difficult to document due in part to problems with radiocarbon dating. Widespread clearing of natural forests and shrublands in New Zealand between 1880 and 1920 resulted in extensive gully erosion (Page and Trustrum 1997; Kasai et al., 2001).

The Loess Plateau in China has a long history of human encroachment that has undoubtedly influenced gully development. Prior to the Sui Dynasty (581–618 AD), the Loess Plateau apparently had few gullies and was largely covered by forests and lush grasslands (Shi and Shao, 2000). Thereafter, progressive destruction of natural vegetation induced by such human activities as gathering of fuelwood, production of charcoal, reclamation of land, construction of housing, and the potential affects of climate change perpetuated gully development (Fang and Xie, 1994). Erosion rates have reached epic levels ($\approx 10,000 – 60,000$ t/km$^2$/yr) in certain regions (Zheng et al., 1993; Shi and Shao, 2000), initiating hyperconcentrated sediment discharges in the middle Yellow River Basin (Xu, 1999) in which concentrations of suspended sediments have reached $1100$ kg/m$^3$. Gullies underwent headcutting at an average rate of about $5.3$ m/yr from 1957 to 1979 in Shaanxi Province, corresponding to an increase in population of about $65\%$ during approximately that same period (Shi and Shao, 2000). Similar population increases throughout the Loess Plateau in the past half-century have brought added pressures of agricultural production and resultant destruction of the scant remaining natural vegetation. At the turn of this past century, forest cover throughout the Loess Plateau was only about $6.5\%$ and as low as $3\%$ in some regions (Shi and Shao, 2000). Recently, development of coal, coking, natural gas, and oil industries has exacerbated erosion problems in the Loess Plateau (Shi and Shao, 2000).

The extensive terracing in the Loess Plateau, implemented to both increase agricultural production and reduce sediment losses, is a mixed blessing in terms of surface erosion (Fig. 10). Concentration of water on terraces may actually increase pipe erosion, a process that is common in loess soils (Billard et al., 1993). Additionally, intensive cultivation of loess soils promotes the formation of a surface crust, which reduces infiltration capacity and enhances overland flow. Field observations during rainstorms in Lanzhou, north-central China, note that surface runoff occurred from upper to lower terraces with concomitant silt loads (Billard et al., 1993). In other cases, gullies have incised across newly constructed terraces. Thus, the terraces may alter the timing of sediment delivery to downstream (Shi and Shao, 2000), but do not necessarily represent a panacea for either chronic or episodic erosion control. Furthermore, incision of gullies in the Loess Plateau

![Fig. 10. Extensive gully development and erosion in terraced hillslopes of the Loess Plateau, Shaanxi Province, China. Note the pipe erosion (possibly stimulated by agricultural practices) that initiated the gully in the upper middle of the photograph.](image)
increases the potential for deep-seated landslides along gully walls (Wieczorek et al., 1987). As gullies deepen it appears that mass erosion dominates over surface erosion (Xu, 1999), thus minimizing any further benefits of surface erosion control practices, such as terraces.

Slash and burn practices in inter-tropical parts of the region have been poorly studied but are widely (and probably unfairly) blamed for increased soil erosion (Harwood, 1996; Laurance, 2000). Tropical forests converted to more permanent forms of intensive agriculture typically have lower infiltration capacities, promoting greater runoff and surface erosion during storms (e.g., Midmore et al., 1996; Lu et al., 2001). Widespread forest clearance on hillslopes throughout Southeast Asia and subsequent conversion to oil palm, rubber, coffee, vegetable and other types of agricultural plantations typically combine fire with mechanical site clearing during the installation of plantations (see Section 5), thus creating ideal conditions for surface erosion. Increases in surface erosion and related sediment transport are generally experienced from one to several years after a fire; the largest increases occur during the first large storm after the fire with a subsequent decrease in erosion with time as the site revegetates (Heede et al., 1988; Scott and Van Wyk, 1990; Zierholz et al., 1995). Because of the extensive disturbance that occurs during the installation (and sometimes maintenance) of plantations and croplands, similar short-term increases in erosion occur along with loss of soil nutrients. The long-term sustainability of these sites is compromised and productivity typically relies on the sustained inputs of agricultural chemicals and even topsoil depending on the level of continuing disturbance (Midmore et al., 1996; Craswell et al., 1998). Broad platform terraces in steep terrain that require frequent re-working of soils substantially increase surface erosion (Midmore et al., 1996).

5. Biomass fires: the development of a region-wide, chronic hazard

Major biomass fires and the gases and particulates they generate currently threaten global climate systems, levels of biodiversity, human health, and economic activities. At a regional level, they are particularly important hazards on land bisected by the PEP II transect; during the last 20–30 years or so, major biomass fires have been reported along virtually the entire extent of the PEP II transect (e.g., Harris, 1996; Taylor et al., 1999; Tanimoto et al., 2000; Wang et al., 2001, Saha, 2002). These fires are often caused by what Harwell (2000, p. 315) describes, when referring to the conflagration of Indonesian forests during 1997 and 1998, as a ‘convergence’ of environmental and human factors.

The flammability of biomass is dependent upon its susceptibility to ignite, which is a function of inter alia moisture content and the availability of a source of ignition and oxygen, and upon the sustainability of combustion once a burn is underway (e.g., Latham and Rothermel, 1993). Canopy disturbance of the type associated with selective logging operations in many rainforested areas in the region has increased the susceptibility of forest vegetation to fire by facilitating the accumulation and pre-drying of combustible organic matter. Pre-drying is further enhanced during periods of prolonged drought and, according to Stott (2000), is an essential prerequisite of combustion. Moisture is also needed to grow combustible biomass. It is for these reasons that major biomass fires are often associated with strongly seasonal rainfall regimes, with sufficient rainfall to promote the growth and accumulation of biomass and a dry season in which vegetation and litter can be pre-dried.

Fire-adapted vegetation, in which a significant proportion of the component taxa is either able to withstand frequent, relatively low temperature burns or is capable of benefiting from the more open conditions that directly follow a fire, is relatively common in the Austral-Asian region. In fire-adapted ecosystems, long-term functioning may depend upon the sudden fire-induced release of nutrients that would otherwise be sequestered in the litter layers (duff) and in dead vegetation. Thus, rather than a largely destructive force, fire in adapted ecosystems is an important factor contributing to increased diversity, regeneration, and ultimately survival. By comparison, intact rainforests in inter-tropical parts of the region are far less fire-adapted. According to Brown (1998), the vast majority of rainforest taxa in Indonesia are highly fire intolerant, which suggests that damaging fires have not been important over evolutionary time scales.

Biomass fires have a long history of occurrence in more seasonal parts of the PEP II transect. Wang et al. (1999) referred to variations in pollen, charcoal, and elemental carbon abundances in core G6-4, taken from the Lombok Ridge in the eastern Indian Ocean, to reconstruct a history of fires that stretches back about 300,000 years. Interpretation is problematic, owing in part to the large potential source area for carbonized particles in ocean cores. However, the pollen evidence indicates a decline in Eucalyptus woodland from around 185,000 BP and a concomitant increase in grasses and scrubland. These changes follow an increase in charcoal from around 200,000 BP, which could suggest that fire was in some way connected with subsequent changes in vegetation. One drawback is the non-synchronicity of the charcoal and elemental carbon data, which may represent methodological error or that the two curves reflect two different fire histories that were played out in two different source areas. Pollen, charcoal and
elemental carbon data were also recently recovered from core SHI-9014 from the Banda Sea, eastern Indonesia (van der Kaars et al., 2000). Results from the core, relating to the last 180,000 years, indicate that high charcoal levels have been associated with glacial and low levels with interglacials during this period. The timing of onset of high levels of charcoal during a period of relatively stable climate conditions (37,000 BP) could imply that humans were responsible for igniting the fires. However, once again variations in charcoal and elemental carbon levels are frequently out of phase, indicating that much research is needed to elucidate relationships between biomass fires and their sedimentary imprints.

Hope (2001) concludes that natural fires were the source of much of the charcoal recovered from cores of mire sediments in southern Sulawesi and dated to 50,000–75,000 BP, because of an absence of evidence for human activity close to the site of deposition. The generally small particle sizes of the charcoal would not appear to rule out long distance transport from anthropogenic fires elsewhere in the region, however, Haberle et al. (2001) reached a similar conclusion to that of Hope (2001), based on charcoal extracted from sediments that have accumulated since 20,000 BP. The sediments were obtained from 10 sites throughout Indonesia and Papua New Guinea. Haberle et al. (2001) identify two major episodes of burning that appear associated with rapid climate change and high climatic variability. The first of these peaks (dated 17,000–9000 BP) coincides with a period of warming during the last glacial–Holocene transition. The second peak (from 4500 BP) is associated with the middle to late Holocene intensification of ENSO-related phenomena. A broadly similar bimodal distribution of charcoal was also recorded from a swamp in Singapore (Taylor et al., 2001).

Charcoal samples with ages from 50,000 to 3500 BP have also been obtained from soils beneath rainforests in East Kalimantan on the island of Borneo (Shimokawa, 1988; Goldammer and Seibert, 1989, 1990), indicating that rainforests occasionally burn, presumably during prolonged droughts. Periods of prolonged drought in inter-tropical parts of the Austral-Asia region are today associated with low index phases (El Niño) of ENSO cycles; 80% of ENSO events recorded for the period from 1877 to 1982 were associated with drought in the region (Ropelewski and Halpert, 1987), while all major ENSO events post-1982 have been associated with below average rainfall. There is evidence from the 19th century of major biomass fires in association with El Niño climate anomalies. For example, a major El Niño is now thought to have occurred in 1876–77 and to have coincided with major forest fires in what was then the Dutch East Indies (e.g., Forbes, 1945). However, according to documentary evidence, major rainforest fires in association with El Niño-induced droughts were not frequent occurrences until the early 1970s, peaking in 1997–1998 when huge areas of forests, particularly in Indonesia but also in the region as a whole, were devastated (Taylor et al., 1999) creating a severe transboundary hazard in the form of atmospheric pollution (Quah, 2002). The total cost of the fires is probably impossible to determine to a high level of accuracy, with estimates highly politicized and varying greatly according to who was responsible for collecting and publishing the figures. Even reaching a consensus over the area burned proved problematic. For example, according to Harwell (2000, pp. 308–309), in October 1997 estimates for the area of burn in Indonesia ranged from 96,000 ha (Indonesian Ministry of Forestry) to 1.7 million ha (WALHI, an environmental NGO).

A large part of the increased frequency and extent of major biomass fires in countries such as Indonesia can be linked directly to massive expansions in commercial logging and plantation agriculture since the Second World War (Stolle and Tomich, 1999; Harwell, 2000). Fire provides a relatively quick and inexpensive means of clearing large areas of rainforest during the preparation of land for plantations. Drier periods during the year are preferred, because relatively little effort is required to ignite pre-dried biomass. Once ignited, these fires easily burn out of control, directly impacting surrounding areas of selectively logged forest and smallholder agriculture. As a consequence, fires associated with the establishment of plantations can affect huge areas of forested and agricultural land. Lesser factors contributing to more frequent and widespread rainforest fires include more extensive shifting cultivation, as improvements in infrastructure and raised levels of population cause formerly intact areas of forest to be opened-up to small landholder farmers, and an increased frequency of natural fires in vegetation damaged by logging.

Aside from impacting biodiversity and people, biomass fires may have major influences on climatic and geomorphic processes. Burning vegetation contributes directly to levels of atmospheric pollutants, including greenhouse gases (Fearnside, 2000). Land cover changes and associated fires can expose organic-rich soil horizons to rapid decomposition, thus forming a second major source of greenhouse gases (Kasimir-Klemetsdon et al., 1997; Rosenzweig and Hillel, 2000). Given their massive extent, it is likely that transformations of land cover in Austral-Asia contributed substantially to global greenhouse gas emissions during the last two centuries. Such expectations receive support from high resolution biosphere model (HRBM) simulations, which suggest that around 25% of global releases of CO2 during the period 1860–1978 were due to land cover changes in South and Southeast Asia (Esser, 1995). The
interplay between climate, humans and fire is an important but relatively neglected area of research. It is interesting to speculate on the influence on climates of increased atmospheric greenhouse gases as a result of more widespread biomass fires towards the end of the last ice age and during the late Holocene. Climatic warming during these two periods would also have raised rates of decomposition in organic-rich soils (Chapman and Thurlow, 1996) and therefore pushed surface erosion and related desertification. The devas-

tating effects of widespread forest conversion to pastoral and agricultural land in New Zealand, Australia, Southeast Asia, and China have been documented in accelerated rates of surface erosion and landslides, as well as related sedimentation and susceptibility to flooding. In many of these cases, the resultant hazards appear to have inflicted long-term negative consequences on the sustainability of natural resources, which may in turn further exacerbate anthropogenic pressures on regional resources.

Climate change presents an additional complication for assessing natural hazards in the region, partly due to the uncertainty introduced. Although civilizations in Austral-Asia have adapted to past climatic changes, there is evidence that such coping mechanisms altered resource use and allocation, thus potentially increasing occurrence of certain hazards. Current trajectories of land use and demographics in developing nations within the region, present a pessimistic outlook for occurrence of certain hazards, such as coastal and riverine flooding, wildfire, drought, landslides, and surface erosion, as well as vulnerability to most episodic and chronic natural hazards.

An important contemporary issue in Austral-Asia is the development of low-cost hazard prediction and mitigation strategies for poorer nations. Recent flood damage in highly vulnerable and expanding urban areas of Southeast Asia (e.g., Jakarta, central Vietnam) presents a major challenge for governments and institutions dealing with hazard control and mitigation. Underlying themes are the interconnection of various hazards and the difficulties of affecting decision-making processes, because of shortages of information and political will. While feedbacks and interconnections may compound problems in accurately recording the causes of disasters, they can also greatly accentuate the eventual impacts. It is also worth noting that the feedbacks and interconnections are dynamic, and therefore subject to change. Thus, forest removal in the headwaters of the Yangtze has converted a chronic hazard (the relatively slow removal of top soil and its transport to lower altitudes) into one that is episodic and potentially catastrophic (flooding and mass movements). By comparison, conversion of rainforests to plantations and agriculture in inter-tropical parts of the region has transformed episodic biomass fires with relatively long return periods into a chronic hazard with devastating and possibly unquantifiable impacts. Such long-term ecosystem interactions need to be captured in hazard prediction models and techniques.

6. Conclusion

The examples of recent and historical hazards presented, while not comprehensive, clearly demonstrate both the frequency and extent of natural hazard occurrence throughout Austral-Asia. Particularly evident is the role of increased levels of population and extensive and rapid transformations of land cover on the incidence and severity of hazards. Typically it is the more chronic hazards (e.g., surface erosion, sea level rise, coastal flooding, and, in some cases, wildfire and landslides) that are impacted by human activities, while episodic hazards (e.g., volcanic eruptions, earthquakes, tsunami) are controlled strictly by geophysical processes. Both chronic and especially episodic hazards have inflicted large damage on humans and structures in the region, however, the environmental damage caused by chronic hazards is often underestimated.

Early historical accounts document evidence of obliteration of towns, villages and ecosystems impacted directly by volcanic eruptions, tsunami, earthquakes, landslides, fires and floods. However, many examples exist in the region of how societies coped with and even benefited from certain hazards or hazardous situations. For example, it appears that the early Maori in New Zealand were able to develop effective avoidance strategies for both volcanic eruptions and tsunami. As populations have increased and land use activities intensified, particularly during the last two centuries, a strong feedback from human activities on the magnitude and frequency of certain hazards is evident—particularly fire, coastal and terrestrial flooding, landslides, and surface erosion and related desertification. The devas-

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