TYPES OF LAND DEGRADATION IN BHUTAN

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Introduction

There is a growing global awareness that land degradation is as much a threat to environmental well–being as more obvious forms of damage, such as air and water pollution (e.g. Greenland & Szalbocs, 1994; Conacher, 2001). Although the source of land degradation is usually local, its effects often stretch for considerable distances from the source site. It can impact large areas and many people. Governments, NGO's and community groups therefore have the right and duty to be concerned, and to intervene and assist where needed.

Because of its topography and altitude, Bhutan has inherently limited resources of productive land. Moreover, the predominantly steep slopes put these resources at particular risk from some forms of degradation. Land degradation is therefore an even more serious threat in Bhutan than in most places. This is recognised in policy, vision, and review documents, such as the Biodiversity Action Plan (MOA, 1998), the National Environment Strategy (NEC, 1998), and Bhutan 2020.

Practical action has also begun on the ground. Khangma RNR Research Centre undertook a multi–village land degradation assessment in the six eastern dzongkhags (Turkelboom *et al.* 2001). This was a participatory survey for extension agents and farmer, and it did not get deeply involved in technical aspects of land degradation. The National Environment Commission has also conducted participatory non-technical surveys of land degradation, and

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has assisted communities to plan local remedial action plans (NEC, 2000).

Sustainable and successful intervention requires clear understanding of the nature of the problem. In order to clarify what is meant by land degradation and to quantify its global extent, the Food and Agriculture Organisation and the International Soils Reference and Information Centre initiated the Global Assessment of Soil Degradation (GLASOD) in the early 1990's (Oldeman, 1994). Young (1994) applied the GLASOD classification and criteria in a survey of land degradation in South Asia. Unfortunately it was compiled without data from Bhutan. Initially he tried to extrapolate to the situation in Bhutan from neighbouring parts of the Himalayas, but felt that this gave an exaggerated picture of degradation in the country. In the end he assumed that 10% of Bhutan's cropland is subject to some degradation, but only one tenth of that is assumed to be more than slight.

Planning, practical intervention on the ground, and discussion of the Bhutan situation in the regional and global contexts (e.g. Bhutan – Bangladesh Joint Team, 1990) all require clarification of the types and extent of degradation in the country. As a contribution towards this, the National Soil Service Centre and the Wang Watershed Management Project held a technical workshop at Semtokha in October 2001. The aim was to frame a comprehensive inventory and technical descriptions of the land degradation processes, effects and indicators that are important in Bhutan. This paper summarises the main findings.

Definition of Land Degradation and its Interactions with Natural Hazards

We started from GLASOD's functional definition of land degradation (Oldeman, 1994), but extended it to include diversity as well as productivity, i.e.'Land degradation is thedecline of land's capacity to sustain agroforestal and other biotic production and diversity due to human activity.'

This definition has significant implications:

The definition excludes decline in productivity that is due wholly to natural causes, and land degradation is restricted to anthropogenic effects. The definition in the South Asian survey (Young, 1994) did not restrict degradation in this way, nor did Stocking (2001). However stocking and Murnghan (2001) indicate that land degradation includes all productivity-reducing effects that are due to 'inappropriate use', implying that degradation is a result of human activities. The definition excludes changes, no matter how visible, that do not detract from the land's productivity.

The exclusion of natural processes is particularly problematic in Bhutan. Because of its high relief, steep slopes, and location in a zone of orogenic (mountain building) activity, the landscape of Bhutan is naturally dynamic. Ultimately, much of the Eastern Himalayas are destined to end up adding to the huge fan of sediments that floors the Bay of Bengal. There are many very powerful natural processes such as river down cutting, erosion of slopes, and landslips, that are working vigorously towards this. Much of the landscape of Bhutan is only quasi–stable, and needs only a small trigger to destabilize it and for its surface materials to slip down slope and eventually be washed downstream. Several kinds of human activity can provide the trigger and carry some potential risk. When this kind of change occurs, it is difficult to distinguish between the small anthropogenic trigger, i.e. land degradation as defined above, and the large natural event that was poised and waiting to happen. For example, a substantial landslip at Radhi has been attributed to a single leaking standpipe (Sharma *et al.*, 1998). If this diagnosis was correct, it is clear that the surface material was delicately balanced and was ready for almost any event, no matter how small, to start it sliding.

We therefore do not attempt to distinguish rigorously between anthropogenic degradation and natural processes. Instead we indicate how processes that detract from land's productive capacity can be initiated and/or intensified by human activities.

Land degradation processes are interactive, sequential and cumulative. For instance, quite small depletions of some nutrients may lead to a decrease in soil organic matter. This in turn may weaken the physical structure of the topsoil, making it easier for rainfall and surface runoff to remove it. In this way a relatively minor change in soil chemistry can lead to erosion. Similarly, minor forms of erosion can intensify rapidly, and small rills can grow to large gullies. We indicate the more important of these causative and sequential relationships in Table 1.

Main Types of Land Degradation and Associated Natural Hazards in Bhutan

Table 1 summarises the Semtokha workshop's inventory of the main types of land degradation in Bhutan. Readers requiring more technical detail are referred to WWMP (2002). The following discussion concentrates on the types that are most extensive in rural ares. The other types of degradation in Table 1 do not affect such large areas. However they can be very severe and may be locally important.

Table 1: Types of land degradation in Bhutan (In Situ-Chemical)

1. Soil Type: Depletion of soil Organic Matter			
Effects	**Interactions with other types of degradation and natural hazards**	**Triggering & intensifying human activities**	**Occurrence in Bhutan**
Lighter topsoil colours Reduced soil reserves of moisture & nutrients Reduced crop cover & yields Soil structures weakened Soils harder & more difficult to cultivate Reduced soil biodiversity	Intensifies: - Nutrient depletion - Acidification - Erosion	Some depletion inevitable when forest or grassland converted to arable Offset by organic fertilisers	Most acute on chhushing Also in kamshing or short fallow tseri
2. Soil Type: Depletion of Nutrients			
Deficiency symptoms Reduced crop yields and plant cover Increased susceptibility to pests & diseases (remove)	Intensifies: - Acidification - Erosion	Excess harvest off-takes without fertilizers Burning and wind-blow of ash	Widespread (intensively cultivated areas)

3. Soil Type: Soil Acidification			
Drop in soil pH Possible P, K, Ca & Mg deficiencies Decreased nodulation in legumes	Reduces availability of nutrients & induces deficiencies Possible nitrate contamination of streams	Nutrient depletion (Ca, Mg) Excessive N fertiliser	Less likely in soils with limestone derived from limestone, e.g. Paro Excess urea on some maize and rice No reports so far in Bhutan of nitrate or nitrite toxicity in streams
4. Soil Type: Over-fertilization			
Induced deficiencies of other nutrients	Possible eutrophication or contamination of streams	Excessive P fertiliser (potato and apple crops)	Possible excess P fertiliser applied to apples in W Bhutan Eutrophication unlikely in fast flowing streams. No lakes in Bhutan appear to be vulnerable
5. Soil Type: Industrial & Urban Pollution			

Visible presence of pollutant Land bare & sterile	Pollutant may leach through to streams Bare soil highly vulnerable to surface erosion	Effluents from plants, workshops & urban waste	Not extensive – but some cases around Thimphu & in South

Table 2: Types of Degradation (In Situ Degradation-Physical)

1. Soil Type: Topsoil capping			
Crust forms on surface Reduced infiltration of rain & irrigation water Delayed or reduced seedling emergence	Increases runoff & surface erosion	Insufficient organic fertilisers Exposure of bare soils during heavy rain	Silty & fine sandy soils vulnerable Land freshly cultivated for kamshing vulnerable Chhushing land protected by surface water
2. Soil Type: Subsoil compaction			
Slower drainage Reduced root growth & yields of crops Increased firmness in upper subsoil	Increases runoff & surface erosion Increased risk of waterlogging	Cattle grazing on wet land Continuous use of standard ploughing tools (same level of depth)	Widespread in chhushing
3. Soil Type: Water logging			
Increased wetness Increased gleying (bluish grey colours) & rust mottling	Increases runoff and surface erosion Increases	Over-irrigation Leaking or broken irrigation	More common on logging roads than public highways

Reduced yields Increased aquatic & hydrophilic weeds	susceptibility to land slips	channels Blockage of natural drainage lines by roads & other structures	
Degradation involving removal – non-water erosion			
4. Soil Type: Glacial erosion			
Freeze-thaw cracking & rockfalls Glacier scouring & moraines	Provides loose deposits prone to wind and water erosion Moraine or ice dammed lakes burst, cause floods	Natural	Only at altitudes above 5000 m
5. Soil Type: Wind erosion of soil			
Loose bare fine sand deposits Reduced crop & plant yields & cover	Organic matter & nutrients depletion	Cultivation of fine sandy soils in windy conditions	Not extensive – mainly in very windy valleys, e.g. Wangdi
6. Soil Type: Wind erosion of ash			
Surface ash stripped Light coloured bare topsoil exposed Decreased crop yields	Contributes to nutrient depletion May contribute to soil acidification Deposited ash vulnerable to sheet erosion	Panshing and tseri	Not extensive – needs concurrence of fresh ash & strong winds
7. Soil Type: Cultivation erosion (movement of dry soil downslope by repeated cultivation)			

Light coloured subsoil exposed at top of field & deep deposits of dark topsoil deposited at bottom Reduced yields in upper parts of fields	Exposed subsoil & fresh topsoil deposits vulnerable to sheet & rill erosion	Repeated cultivation on steep slopes	Mainly in kamshing, noted in maize in Eastern Bhutan & in potatoes in Phobjika Effects similar to more extensive sheet erosion.
Water (+ gravity) erosion			
8. Soil Type: Splash erosion			
Stone-capped pillars Light coloured subsoil exposed	Increases runoff & sheet & rill erosion Depletion of organic matter (& nutrients) by preferential removal of light organic particles	Bare soil exposed by clearing & cultivation during heavy rainfall.	Fine sandy silty topsoil common in Bhutan are vulnerable Not severe in fields, as premonsoon rainfall is fairly gentle, crop cover substantial by time of heavy rains Moderate severe in spoil heaps
9. Soil Type: Sheet erosion (topsoil particle removal by non-channelled sheet runoff)			
Sheet flow across surface during heavy rain Light coloured subsoil exposed Dark coloured topsoil deposits build up behind obstructions Reduced crop	Light particles moved preferentially - organic matter & nutrient depletion Develops into rills & gullies	Exposure of bare surface during heavy rain Deforestation Forestry & flagpole skidding trails Livestock trails Additional runoff	Sheet runoff not seen often, but reported on some clay-rich soils in Eastern Bhutan Exposure of light subsoil & build up of organic-rich behind obstructions common

yields & plant cover Increased runoff		from leaking irrigation channels	Effects similar to tillage erosion
10. Soil Type: Rill erosion			
Runoff concentrated in small & temporary streamlets Small (< 0,5 m deep, < 1 m wide) channels (removable by cultivation)	Develops from splash & sheet erosion Develops into gully erosion Organic matter & nutrient depletion	Exposure of loose & bare topsoil during heavy rain Unchecked sheet & splash erosion Skid & stock trails Additional runoff from leaking irrigation channels	Widespread when pre-monsoon rains are heavy
11. Soil Type: Piping erosion (Subsoil pipes parallel to ground surface formed by concentrated seepage flow)			
Subsoil pipes & tunnels Depressions in ground surface	Associated with waterlogging & subsoil compaction	Increased by creation of free faces, e.g. road cuttings, irrigation terrace	Much subsoil seepage, especially in chhushing, but piping not

where pipe roofs collapse Irrigation channels disrupted	Collapse depressions can coalesce to form gullies Concentrated seepage facilitates landslips Subsoil removal gives some nutrient depletion (very little organic matter)	risers Leaking irrigation channels Over-irrigation	extensive
12. Soil Type: Gully erosion (Deep & wide erosion channels)			
Channels 0.5 – 30 m deep, 1 – 100m wide Complete removal of productive land Disruption of irrigation channels & other structures Large volumes of sediment downslope & downstream Lowering of local water table	Develops from rills Head & side walls vulnerable to landslips Fresh sediment vulnerable to further surface erosion Severe depletion of organic matter & nutrients	Unchecked rills Skid & stock trails	Gneissic sandy loams not very erodible Some deep red clays, e.g. Lobeysa – Punakha, highly erodible & deeply gullied
13. Soil Type: Mass movements (landslips & landslides)			
Deep scar, with steep head- & sidewalls Floor of exposed bedrock or jumbled debris Complete removal of productive land Destruction or	Risk increased by subsoil compaction waterlogging & piping Secondary slides develop in gully walls	Deforestation Free faces, e.g. road cuttings Over-irrigation & other water logging activities	Prolonged & deep saturation increase mass, reduce cohesion & increase landslide risk - highest in South Phyllites & her clay-rich cks are lnerable

disruption of infrastructures Large volumes of sediment downslope & downstream Lowering of local watertable			Gneissic soils & weathered rock fairly stable Some slides triggered by earth tremors, even if very small
14. Soil Type: Ravines (Large long combined gullies & slides)			
Long deep scar, with steep head- & sidewalls Floor of exposed bedrock or jumbled debris Same effects as landslips but on larger scale	Develops by extension of landslip by subsequent gullying and/or Enlargement of gully by secondary landslips	Unchecked gullies & landslides Continuation of land management that caused gully &/or landslip	E.g. Shong Ri at Radhi, many examples on South
River processes			
15. Soil Type: Bank erosion			
Complete loss of productive land Loss or disruption of irrigation other infrastructures Cut-off slip face	Erosion upstream may sharpen hydrograph peaks & make bank erosion more likely Cliff liable to	Often natural Intensified by removal of bank-side vegetation Increased local stream-flow from drainage &	Not widespread in Bhutan But concentrated on productive valley areas

or cliff	gullying & secondary landslips	irrigation runout	
16. Soil Type: Flooding			
Burial of productive topsoil by raw debris Blocks irrigation channels & disrupts other infrastructures	Downstream of severe erosion Deposits easily re-eroded, by further river erosion or by wind	Accentuated by land clearance & erosion upstream	Concentrated in productive valleys, e.g. 1968 flood in Paro (additional information)
Tectonic natural hazards			
17. Soil Type: Earthquakes			
Surface deformation Loss & disruption of structures	Even minor tremors can trigger landslides	Natural Risk possibly marginally increased by heavy loading by e.g. high dams & deep reservoirs	All Himalayas are high risk zones (IV & V) in Indian classification But Bhutan mostly in slightly lower risk zone IV But minor tremors felt moderately frequently Effects possible 100+ km from epicentre
Urban & industrial			

18. Soil Type: Encroachment			
Productive agroforestal land converted to urban, mining or industrial uses	Associated with pollution	Population growth & urbanisation	Mainly Thimphu, Paro, Jakar & in South
19. Soil Type: Pollution			
Productive land degraded by solid, water- or airborne contamination	Special types of chemical or physical degradation	Effluent mismanagement	Mainly Thimphu & South
20. Soil Type: Spoil tipping			
Burial of productive topsoil by raw mining or construction spoil Sediment loading of streams	Bare spoil vulnerable to water & wind erosion Much stream degradation – may be ephemeral Extra loading by spoil can destabilize underlying soil & whole slope liable to landslips	Completely anthropogenic Most acute where spoil tipped 'over the edge'	Not extensive But HEP & road construction generates large volumes of spoil & stream sediments, e.g. Chhukha Dzongkhag

	Some spoils chemically &/or physically unfavorable to plant growth		
21. Soil Type: Riverbed mining for construction sand & gravel			
Local depressions in river bed	May intensify bed erosion downstream	Completely anthropogenic	Not extensive & probably not significant yet (Extensive in the west and south Main area is Punakha – Wangdi stretch of Puna Tsang Chhu Need to scrutinise sediment budgets & off-takes in future

We follow GLASOD (Oldeman, 1994) in differentiating between processes that degrade the soil *in situ*, i.e. without removal, and those that involve the detachment and removal of soil or weathered rock, i.e. 'erosion', in its widest sense.

In situ Degradation

In situ degradation processes and their effects are less spectacular than erosion, and are not always easy to identify. However, they are the most extensive kinds of land degradation in Bhutan. Their effects in reducing agricultural production have not been quantified, but are almost certainly substantial. Although serious, these forms of degradation are mostly reversible, if they are identified before they develop into erosion, and if sufficient remedial measures are undertaken promptly.

The list starts with *in situ* chemical degradation, which includes decreases in soil organic matter, depletion of nutrients, soil acidification, and pollution (Logan, 1990). The most widespread in Bhutan is the depletion of soil organic matter. Organic matter levels are naturally moderate - high in forest and grassland soils in Bhutan. They are usually substantially reduced when the vegetation is cleared for cropping, and by the repeated disturbance of topsoils when land is cultivated (Francis *et al.*, 2001). The decline is more marked in the intensive soil cultivation associated with basin-irrigated rice (chhushing), than in soils under rainfed cropping (kamshing), orchard or bush fallowing (tseri). As the organic matter is an important soil store for available water and nutrients, the decreases tend to reduce chemical fertility. In addition, because the large and complex soil ecosystems of animals and microbes depend on organic matter, soil biomass and biodiversity decline. The soil organic matter and the various gums produced by the soil inhabitants are important for cementing particles together to form porous and fertile crumbs and other soil structures. Loss of organic matter reduces the strength of these structures, so that the soil's physical fertility and stability are also diminished(remove this line), and the soil becomes more vulnerable to erosion.

The degree of darkening of moist topsoil colours gives an indication of organic matter status. However, care is needed, as small quantities of organic matter can have a disproportionate effect in sandy soils and give quite dark colours, whereas clays may not look particularly dark, even with moderate or high contents of organic matter.

Bhutan has an enviable and still vigourous tradition in the use of organic fertilisers (Norbu, 1997). Multiple benefits derive from sustaining soil organic matter at moderate or high levels, and organic fertilisers should therefore not be seen only as sources of plant nutrients. Chemical fertilisers can supply nutrients (FAO, 1990), but cannot provide the physical and ecological benefits of organic matter. They should therefore not be used as substitutes for organic fertilisers, and shogshing and related practices need to be kept up.

Nutrient depletion occurs when the nutrients removed by crop harvesting, fire and erosion exceed the inputs from fertilisers, rock weathering, and deposition from the atmosphere. It is sometimes associated with soil acidification. Balanced fertilisation (organic as well as inorganic), mixed cropping, crop rotation, and effective soil conservation can counter nutrient depletion, and soil nutrient fertility can be sustained as long as the soil remains physically stable.

Soil acidification is a particular type of nutrient depletion (Schreier *et al.,* 1995). It occurs when the cationic nutrients (mainly potassium, calcium and magnesium) are depleted, and are replaced by the acidic cations hydrogen and aluminium, which are released from the soil particles. The process occurs naturally, due to leaching by rainfall and is intensified by the natural acids generated during the decomposition of organic matter. Human activities intensify the process by heavy and unreplaced off-takes of the nutrient cations through harvesting and burning. An additional type of agricultural acidification occurs when inorganic nitrogenous fertilisers are applied in excess of the needs and uptake capacity of the crop. The excess nitrogen forms acids in the soils and accelerates the natural leaching of cationic nutrients (Tang *et al.,*2000). Acidification by nitrogenous fertilisers is not uniformly distributed. It is much affected by the soil's parent rocks, and is absent or negligible in soils derived from limestone. For instance, it is a greater hazard in the gneissic hill soils around Thimphu than in the more calcareous hill soils around Paro (Stoessel, 2001). Over-fertilisation with urea, the most widely used N-fertiliser has been noted in maize in eastern Bhutan, and in rice in other parts of the country.

Other types of chemical degradation occur when different chemical fertilisers are applied in excess of crop needs. The only other instance of chemical degradation of this type so far observed in Bhutan has been attributed to the over-application of P fertilisers in some apple orchards in western Bhutan. The excess P locks up other nutrients in forms that are not available to crops, and induces deficiencies of zinc and iron.

Very severe types of chemical degradation are caused by pollution with industrial wastes. They are of very limited extent so far in Bhutan, affecting only small areas downslope and downstream of a few industrial plants and workshops. However, they are not easily reversed, and can have far–reaching effects off–site, particularly where the pollutants are spread by contaminated irrigation water.

The two most common types of *in situ* physical land degradation in Bhutan is topsoil capping and subsoil compaction. Like chemical degradation, they are not highly visible and tend to overlook. However, they are quite apparent in the feel of the soils, particularly when ploughing and digging. They are widespread and may reduce the productivity of Bhutan's soils more than is realised. Both of them tend to make soils more liable to erosion.

Capping is the formation of a thin but hard crust on the soil surface, which can delay and even prevent seedling emergence. It is mainly due to the beating action of raindrops on bare soil surfaces, especially where topsoil structures are weakened by depletion of organic matter. It is more likely in silty and fine sandy topsoils, which are widespread in the cultivated lands of Bhutan. It is usually a temporary feature, and is less serious that subsoil compaction.

Compaction arises when the structures in the upper subsoil are weakened, the soil particles are compressed together, and the intervening pore space is reduced (Ghildyal, 1978). It is caused by combinations of reduced organic matter, cultivation when the soil is wet, cattle trampling in wet soils after the rice harvest, and high contents of silt and fine sand. In Bhutan it is reported to be associated with chemical fertilisers, especially urea. If the urea is used as a substitute for, rather than as a complement to, organic fertilisers, its association with compaction may be indirect, mainly due to reduced organic matter. However there may also be a direct microbial-physical effect due to the stimulation of soil fungi by flushes of available nitrogen. Profuse growth of fungal hyphae on the surfaces of soil structures may render them hydrophobic, making it difficult for water to infiltrate and soften dry clods.

Waterlogging is an *in situ* physical degradation process, which tends to affect limited but widely scattered areas. Poor drainage fills the soil pores with water and reduces the supply of oxygen to plant roots. This has serious negative effects on the productivity of most crops. In mountainous terrain like Bhutan there is the serious additional danger that gullies and landslides can be initiated by impeded or uncontrolled drainage. The disposal of excess water is a crucial element in management for land stability in Bhutan. Waterlogging and slope destabilisation are major problems for engineers designing structures on steep slopes (Anon, 1997). It is of particular concern in places where roads and channels have to be constructed across areas of chhushing, as the soils are artificially saturated by irrigation for long periods.

Degradation Involving Removal of Soil and Weathered Rock

The degradation processes that involve the erosion of soil and underlying weathered rock are visible and familiar. They have impacted the public consciousness much more than the more subtle effects of *in situ* degradation (e.g. Wangdi, 1998). They are less extensive than *in situ* degradation but their effects on site are more damaging. Because of the sediment and runoff that they generate, their off-site effects are also more serious (Carson, 1985). Furthermore, many of the effects are irreversible within human time scales and without great expense.

Wind and ice erosion do occur and are noted in Table 1, but are less important. Water and gravity are the main agents of erosion in Bhutan. The water-gravity combination works in three main ways in Bhutan – rainsplash, runoff, and mass movements.

Rainsplash erosion occurs where heavy rain falls on bare and loose soil surfaces. The fine particles are splashed up and do not fall back evenly. More land downhill than uphill of the source, and this results in an aggregate downslope transfer of surface material. The best indicators in Bhutan of this type of erosion are pillars of soil, up to 20 cm high in places, under stones, logs and any other object that protect the surface against raindrop impact. Capping exacerbates this type of erosion.

Running water detaches individual soil particles and carries them downhill. Virtually all runoff occurs at the surface, and gives rise to surface erosion. However, running water in subsoil cavities also detaches particles and erodes subsoil tunnels or pipes. These do occur in Bhutan, but their extent and severity have not yet been assessed.

Surface runoff starts as being diffuse, and detaches soil particles from all over the slope. This is sheet erosion, and it is not easy to identify. The best indicators are a lightening of the topsoil colours, as the dark low-density organic particles are preferentially detached. The accumulation of fine, loose, dark topsoils on the upper side of cross-slope obstructions, such as banks, trees, roots and boulders also indicate sheet erosion.

As the sheet runoff flows downhill, surface irregularities tend to concentrate it into small streamlets. These are known as rills, and they erode small channels in the surface. Rills are common in arable land, when it is freshly cultivated and bare. They are often ephemeral features, which can be smoothed out by cultivation. However, their removal is temporary and rills can reappear during succeeding heavy rainstorms, unless the land management is changed.

The less spectacular types of surface erosion, such as rainsplash, sheet and rills, are extensive and probably cause significant losses of potential agricultural production. They may remove only the top few centimetres of the soil, but this material is disproportionately rich in organic matter, nutrients, and water-storing porosity, and its removal greatly depletes soil fertility. Also the removal of the organic matter weakens structural bonding, and makes the freshly exposed soil more susceptible to further erosion. This is positive feedback, by which the erosion processes intensify their continuation.

Rills merge downslope and deepen with time, and eventually enlarge to gullies and ravines. These represent a massive increase in the severity of degradation. The land is not just reduced in productivity - it may be totally obliterated. Gullied land cannot be cultivated or logged, and is difficult to graze. Gullies disrupt channels and other infrastructures.

Surface runoff occurs when rain falls faster than it can infiltrate the soil surface. It is the intensity, rather than the volume, of the rainfall that triggers runoff and surface erosion. Splash erosion is also mainly controlled by rainfall intensity. In Bhutan rainfall intensity is correlated with quantity (Turkelboom *et al*., 2001), and is highest in the South, which is the zone with the most severe surface erosion.

Soils vary in their vulnerability to surface erosion. Soils derived from gneiss are relatively stable and erode less easily than those from other rocks. Bhutan is fortunate in having a high proportion of gneissic soils. Over much of the country surface erosion is less than expected from the prevailing steep topography. However, the very intense rainfall in the South erodes even gneissic soils. Erosion can be more severe on susceptible soils derived from other rock types. The deep red clays and loam derived from non-gneissic rocks in the

Lobeysa-Punakha area are scarred by many deep gullies. Streams draining from these soils, such as lower Lingmutey Chhu, are coloured bright red after heavy rain, due to their loads of eroded iron-rich clay particles (BSSP, 1999).

Mass movement occurs when soil and weathered rock slip as block, rather than as separate particles. The main factors favouring such slippages are steep slopes and complete saturation by heavy and prolonged rain. Slips may be triggered by earth tremors, even if these are very small (Mitchell *et al.,* 2001). As with surface erosion, rock types vary in their susceptibility to mass movement. Landslips tend to be larger and more frequent on clay-rich rocks, such as phyllite. It has been reported from other parts of the Central and Eastern Himalayas that weathered gneiss and gneissic soils are relatively invulnerable to mass movements (Gupta *et al.*, 1993; Gerrard, 1994). This also appears to be the case in Bhutan The incidence of landslips is lower than expected from the topography, as shown by the relative stability of steep road cuttings in gneisses along much of the East-West highway. The South is tectonically more active, has the heaviest rainfalls and a high proportion of non-gneissic rocks, and it therefore suffers the most frequent and severe landslips.

It is often where that land mismanagement initiates or intensifies *in situ* degradation and the smaller scale forms of erosion such as sheet and rills. However the origins of larger erosion events, such as gullies, landslides and ravines are less obvious, with human activities often appearing to make minor contributions to then natural dynamics of the landscape. The on–going discussion about the origin of the landslide and ravine at Shong Ri in Radhi (e.g. BSS, 2000) is an example of how different observers interpret the balance between natural inevitability and the effects of land management.

Conclusion

It is hoped that this paper will contribute to the typology of degradation in Bhutan. It does not attempt to be exhaustive on the causes, and it gives no estimates of the extent of the areas affected. It intentionally concentrates only the physical processes and effects, and ignores the social dimensions of degradation.

Another aspect not covered is the perception of some erosion and sedimentation sites as opportunities rather than threats (Stocking & Murnaghan, 2001). Himalayan farmers, including those in Bhutan, are adept at creating agricultural land out of gullies and landslips (Carson, 1992; Gerrard & Gardner, 2000). Examples in Bhutan include the small and ephemeral fields created on the floors of the gullies downslope from Bajo Lakhang, and the sustained rice production on land at Radhi that appears to have been subject to multiple landslips (BSS, 2000).

These omissions need to be made good by further field studies and by interaction with other groups. Eventually, we may perhaps see a 'Land Partnership' in Bhutan, to parallel the recently instituted Water Partnership. Its formation would recognise that the well-being of land and its protection from degradation are important, multi–disciplinary, and multi–Ministry concerns. It could help different groups to see how their work fit into the wider context, and to coordinate their activities.

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