The dilemma of mountain roads

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Mountain roads and trails are proliferating throughout developing southeast Asia. The long-term consequences of associated landslides and surface erosion on downstream aquatic environments could be severe, but are largely unrecognized.

The rapid expansion of mountain road and trail systems in rural southeast Asia is a mixed blessing. Growing transportation networks support agricultural development as well as local travel, trade and tourism. But they also create problems associated with sediment production and landslide hazards. Organizations such as the Asian Development Bank, the Food and Agricultural Organization of the United Nations and the World Bank support aggressive programmes of rural road expansion in the hilly terrains of southeast Asia. They justify these efforts by socioeconomic benefits and a perceived interrelationship between mountain road networks and sustainable livelihoods of rural residents[1–3]. However, increases in road density are also directly linked to drastic transformation, or even elimination, of traditional shifting cultivation methods (as practiced in rural uplands)[4], and have been implicated in deforestation and land exploitation in remote regions[5,6].

Loss of soil and sediments by landslides and surface erosion from roads and trails can be substantial in southeast Asia[7,8]. But much of the contemporary increase in sediments transported and then deposited in the local rivers has instead been attributed to widespread deforestation or the effects of shifting cultivation. It is now becoming obvious that many mountain roads are poorly planned and constructed without well-designed drainage systems, leading to destabilizing hillslopes and soil erosion. Furthermore, these roads provide pathways for sediment transport into streams and rivers. As a result, water quality and aquatic habitat degrade, agricultural productivity declines due to loss of topsoil, and, where landslides occur, casualties and property damage have been reported[7–9].

We argue that land management is not sustainable without fully accounting for the impacts of road and trail networks on soil erosion and landslide hazards. Particularly in the developing region of southeast Asia, there is an urgent need to alleviate both local and downstream sediment problems associated with mountain transport networks.

An example from Bukit Tarek Experimental Watershed in Malaysia illustrates the importance of road and trail connectivity as a facilitator of sediment delivery to streams. Here, logging of a small catchment in the Selangor River basin was supported by a network of roads, skid trails and landings (Fig. 1). Soil erosion from the disturbed road and trail surfaces (230–275 Mg ha^{-1} yr^{-1})[10], together with a smaller amount of landslide erosion along the logging road, exceeded the highest rates reported from any agricultural practices in the region[8]. Because of its connection with skid trails, proximity to the stream and interception of subsurface flow, 78% of the soil loss from the logging road was delivered directly to the stream[10]. As a result, roads and trails in this catchment increased sediment export nearly 6-fold compared with a nearby previously harvested catchment with no active roads or trails[11]. The roads and trails occupied only about 11% of the catchment area, but efficiently shunted storm runoff and sediment to the headwater stream through a system of discharge nodes[10]. Such erosion and sedimentation problems are proliferating in southeast Asia. Another example can be found in the Mae Sa catchment of northern Thailand, where more subtle networks of trails connect with unimproved roads associated with expanding agriculture, tourism and residential development in the mountains.

Sediment is produced from unpaved roads and trails in a number of ways. First, the compacted and exposed travel surfaces, cut-slopes and fill-slopes impede infiltration and therefore cause sediment-laden overland flow, which in turn creates rills and gullies when runoff energy increases during heavy rainfall[8]. Second, subsurface stormflow is intercepted along road cuts and enhances surface erosion[11]. And third, when such sediment-laden drainage discharges from roads, it causes channel headcutting and erosion, and can even initiate landslides[7,10]. In the tropics, where monsoon rains meet exposed, highly weathered soils, such erosion can be significant. Because the developing road and trail systems are all connected, they are particularly efficient in delivering sediment to streams[8,10] (Fig. 1).

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Figure 1 | Extensive surface erosion and small-scale landslides in a system of logging roads and skid trails in the Bukit Tarek catchment, Peninsular Malaysia. The connectivity of these roads and trails exacerbates sediment delivery to the stream.

Figure 2 | Large-scale landslides along a newly constructed mountain road near Weixi (Yunnan Province), China, which killed six people and transported most of the sediment directly into a tributary of the Mekong River.

Landslides are not widespread in undisturbed terrain in southeast Asia. But when poorly designed roads have been excavated into steep hillsides, landslide rates have exceeded the highest road-related landslide erosion ever reported[9]. To put this into perspective, landslide erosion from both paved and unpaved roads in steep terrain of Yunnan, China (Fig. 2) was 46 to 800 times higher[9] than landslide erosion from forest roads in the mountainous Pacific Northwest, USA during the 1970s and 1980s[7]. The impact of these latter rates (60 Mg ha^{-1} yr^{-1}) on sedimentation of streams and fish habitat heightened environmental awareness to a degree that led to curtailment of forest logging on government lands in the Pacific Northwest.

Where landslide erosion is significant, the extent of sediment delivery to streams is governed by the slope gradient below the road, the size and position of the landslide and the complexity of the downslope topography. Along the Salween River and upper tributaries of the Mekong River in Yunnan, China, the steep gradients below many of the newly constructed roads facilitate transport of most of the landslide sediment directly into the river (Fig. 2). By contrast, in the Malaysian and Thai catchments at Bukit Tarek and Mae Sa, respectively, smaller landslides were largely trapped on road surfaces or below the road to be later entrained as surface eroded sediment[8]. Thus, the steeper and more linear slopes in Yunnan promote episodic delivery of large amounts of sediment to streams, whereas in Bukit Tarek and Mae Sa, sediment is delivered more slowly and steadily.

Accreting sediments in headwater rivers throughout southeast Asia affect downstream water quality, flood risk, aquatic habitat and navigation. These long-term effects are directly associated with the proliferation of unpaved roads and trails, but this link has been largely ignored in deference to economic development in this region. International donor organizations, non-governmental organizations and local governments need to face up to the long-term problems that are being created by many of the economic development projects that they currently support. These transportation networks need to be better planned and constructed, with due attention to minimizing erosion and landslides, so that downstream communities and river systems are adequately protected. ❐

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Additional information

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