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THE ROLE OF MAN AND EXTREME EVENTS IN THE TRANSFORMATION OF ENVIRONMENT AT THE MARGIN OF THE EASTERN HIMALAYA AND THEIR PIEDMONT

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Between 2013 and 2016, the Institute of Geography and Spatial Organization of the Polish Academy of Sciences pursued a research project entitled "The role of man and extreme events in the transformation of environment at the margin of the Eastern Himalaya and their piedmont", as financed by the National Science Centre of Poland (NN 2012/05/B/ST10/00309). This was under the supervision of Paweł Prokop, and also involved Roman Soja (IGSO PAS) and Adam Walanus (AGH University of Science and Technology) as contractors.

The Himalaya are recognised as among the world's most tectonically active mountain regions, with high-intensity monsoon precipitation incurring some of the highest-known rates of water and sediment transfer to the foreland. The human activity present in so dynamic a natural environment causes further acceleration of the circulation of energy and matter. However, recent studies have hypothesised that, while there is no doubt that the Himalaya and their forelands have undergone a dynamic change of environment, the effects of human interventions, especially in the context of connections between mountains and their forelands, are dependent on both scale (catchment size) and time (a lag in sediment transfer). This would leave the effects of human impact eclipsed by the magnitude of natural processes, and frequently beyond the scope of any direct documentation.

The Sikkimese-Bhutanese Himalaya, as part of the Eastern Himalaya, were used as a testing area in which to verify the above hypothesis, by determining the relative importance of human impact as compared with natural processes involved in transforming the environment of the Sikkimese-Bhutanese Himalayan region over the last 150 years. The impact of extreme events and human activity were therefore evaluated through analyses

of rainfall, land-use changes and soil properties, in the context of mountain-piedmont linkages.

Detailed study was carried out in both India and Bhutan, over an area of 2000 km^2, at the margin of the Sikkim (Darjeeling) and Bhutan Himalaya, and their piedmont (Fig. 1). Here, the southern front of the mountains forms the first orographic barrier encountered by humid south-westerly monsoon winds, on their way from the Bay of Bengal to the Himalaya. The area therefore experiences some of the highest annual rainfall totals (of 4,000–6,000 mm) anywhere along the Himalayan front. The mountain front in the study area is very distinct, and usually rises abruptly from the piedmont zone. The southernmost frontal zone of the Darjeeling-Bhutan Himalaya is composed of unconsolidated sandstones and conglomerates of the Siwaliks. This discontinuous belt, up to 5 km wide, is bounded to the north by deep weathered gneisses, shales and phyllites. The terrain is intensively dissected with closely-spaced and incised river valleys. Among the rivers only the Tista and the Torsa originate in the glaciated High Himalaya, while the Jaldhaka starts in the Lesser Himalaya. The other rivers are small and drain mountain catchments of stream order 5–6 and areas of just 10–150 km^2. In these small catchments, heavy falls of rain give rise to specific runoff several times greater than in large river catchments. This facilitates very high rates of denudation, and the formation of alluvial fans at the outlets of rivers on to the Himalayan piedmont.

The piedmont area represents a system of fans and tectonic blocks decreasing in elevation from 200–500 m a.s.l. at the base of the mountain to just 100 m a.s.l. over a distance of 15 km. The surface here is dissected by the braided channels of the rivers draining the Himalaya. At a distance of 15–20 km southward from the Himalayan foothills, the fans coalesce into an extensive alluvial plain, gradually lowering from 100 to 50 m a.s.l.

Moreover, the region exhibits great variability of human impact on the environment. This is especially visible between the part of the Sikkimese Himalayas in India that is densely-populated and much-deforested for agriculture,

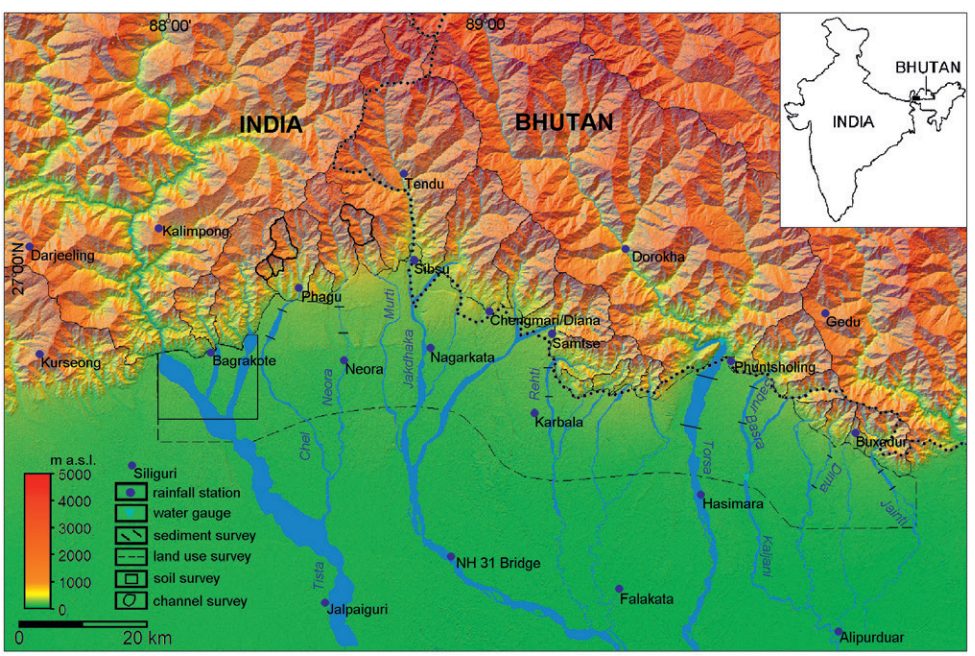

Figure 1. Study area

road construction and mineral extraction, and the low- population part of the Bhutanese Himalayas with its still-preserved natural forest cover. This is also an area in which relationships between the activity of natural and anthropogenic processes have changed over time, with a distinct dominance by human impact since the turn of the 19th and 20th centuries, and increasing effects of high rainfall and flooding through to the present day.

Examination of the spatial distribution of annual rainfall and rainfall hazard indices in the Darjeeling (southern Sikkim) and Bhutan Himalaya indicates that the area put most at risk by the effects of these processes extends from the Himalayan foothills up to 1000 m a.s.l., with a width of about 8–10 km towards the mountain interior. This zone of mountain front compares with the adjacent foreland and the mountain interior in having the highest rainfall, accompanied by the lowest concentration of precipitation, the highest probability of runoff occurrence, as well as the presence of 2-, 3- and 4-day falls of rain that initiate landslides..

In comparison with the Bhutan Himalaya, the Darjeeling Himalaya reveals lower indices for daily rainfall concentration, predisposition to overland flow and probability of landslides being triggered where the duration of rainfall equals or exceeds 2 days. Thus, the catastrophic effects of erosion, landslides and floods in the Darjeeling Himalaya, as described frequently in the literature, are more related to intensive human activity (such as the development of settlements, agriculture, roads and reservoirs), than to rainfall hazards alone.

The role of natural and anthropogenic factors in transforming land-use and soil properties has varied over time, and with the landform being utilised. Natural forces related to the tectonically-active Himalayas, with their deep-weathered mantle and high monsoon rainfall, are the most powerful factors in water and sediment flux into the piedmont zone. The land reforms related to the location of tea gardens caused rapid deforestation of more-elevated terraces with soils suitable for commercial tea production in the period 1874-1930. The period 1930-2010 was then characterised by relative stabiliation of land-use structure within terraces, as well as deforestation of floodplains. Continuous population growth did not cause significant extension of built-up areas, thanks to the concentration of population within tea plantations, and the social-economic support extended to plantation labourers. A gradual extension of tea plantation and forestry development additionally helped in stabilising land-use structure. In the period 1930-2010, the aforementioned floodplain deforestation caused an increase in fluvial activity.

The replacement of natural forest by monocultural tea and rice cultivation influenced physical and chemical soil features of the piedmont of the Eastern Himalaya. However, the soil remains suitable for sustaining long-term tea cultivation and production. The experience of other tea-based agricultural systems dictates that the plantation system has probably reached a state of equilibrium, with little or no net change in soil carbon and nitrogen levels. In turn, the reduced soil fertility ensuing under a rice-based cropping system can be compensated for in part by the deposition of new soil eroded from the mountains.

Population growth and duration of activity are not the most important factors leading to human-induced transformation of the natural environment in the area with high rainfall. The most essential factor proves to be the adaptation of human activity to local conditions present in the natural environment. An erosion and mass-movement hazard arises on the margin of the Darjeeling Himalaya, where there is uncontrolled deforestation, chaotic building-up of slopes and undercutting arising through the construction of roads and reservoirs. In the piedmont of the Eastern Himalaya, the introduction of suitable legal solutions as early as at the first stage of development of agriculture, led to appropriate farming and forestry on terraces over the period of the last 150 years. Only the parallel process of the deforestation of mountain catchments and floodplains disturbed the dynamic equilibrium between forest vegetation and fluvial

activity. The extension of river channels had the paradoxical effect of excluding large areas of floodplain from cultivation, as well as increasing the risk of soil degradation.

The results of the project contribute to a better understanding of the relationships between natural and anthropogenic processes at a time of growing variability of climate on the global scale. Elaborated land-use stability maps of the Eastern Himalayan piedmont will be of help in spatial planning, given their delimitation of stable (i.e. potentially safe) areas, as well as those experiencing dynamic land-use change that should not be deemed suitable for the development of settlement, cultivation and infrastructure, given that they may be affected by inundation, river-bank erosion or mass movements. The investigation into the monocultural cultivation of tea and paddy and its effects on soil physical and chemical properties in turn has application when it comes to future detailed analysis of long-term human impacts on soil productivity.

The results in question have been presented at several conferences and already published in part (Prokop 2013, Prokop & Płoskonka 2014). Further results will be submitted for publication gradually. The land-use mapping, and morphometric and soil surveys, carried out in the course of the project should all serve as valuable source material for future us in evaluating human impact on the environment.

Editors' note:
Unless otherwise stated, the sources of tables and figures are the authors', on the basis of their own research.

References

Prokop P., 2013. *Wpływ człowieka na środowisko przyrodnicze w klimacie monsunowym północno-wschodnich Indii.* Prace Geograficzne, 237, Warszawa: Instytut Geografii i Przestrzennego Zagospodarowania PAN.

Prokop P., Płoskonka D., 2014. *Natural and human impact on the land use and soil properties of the Sikkim Himalayas piedmont in India*. Journal of Environmental Management, vol. 138, pp. 15-23.

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