Effects of land-use changes on soil properties: volcano watershed in Quito, Ecuador

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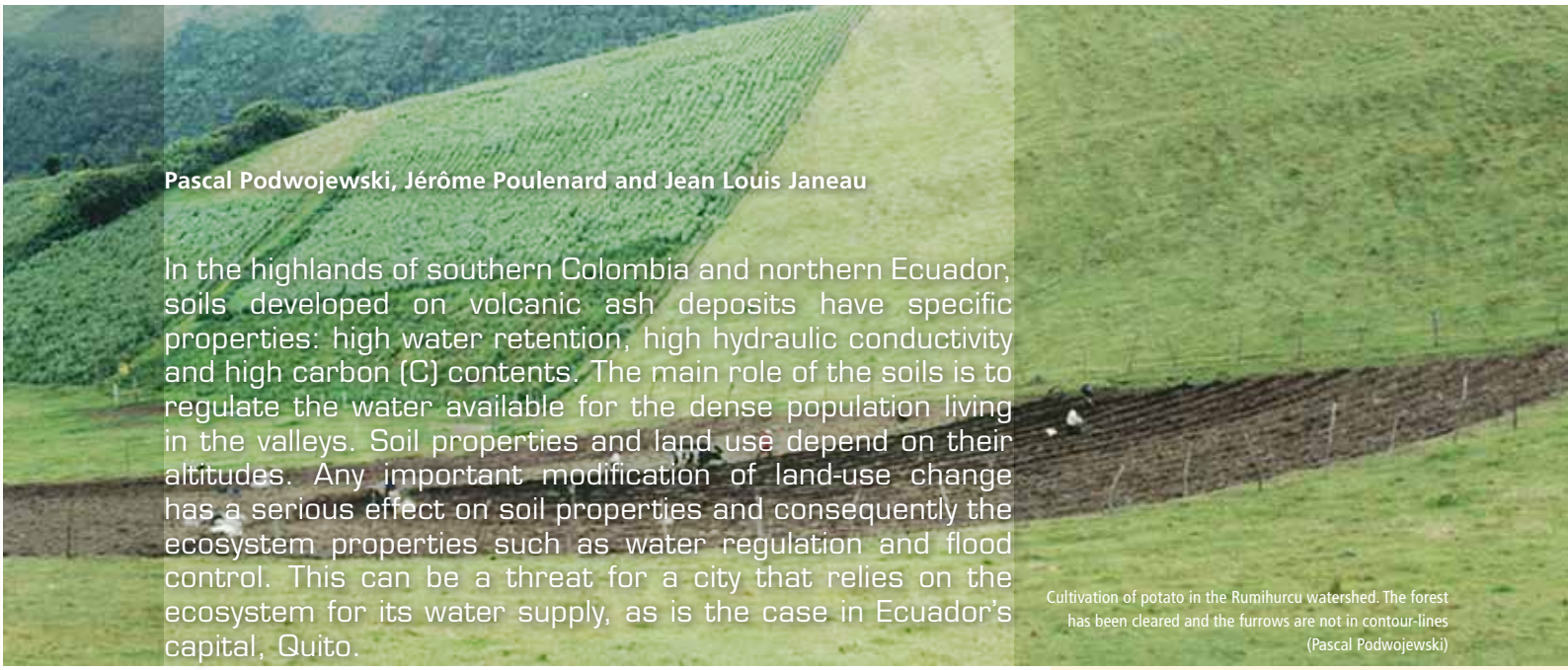
In the highlands of southern Colombia and northern Ecuador, soils developed on volcanic ash deposits have specific properties: high water retention, high hydraulic conductivity and high carbon (C) contents. The main role of the soils is to regulate the water available for the dense population living in the valleys. Soil properties and land use depend on their altitudes. Any important modification of land-use change has a serious effect on soil properties and consequently the ecosystem properties such as water regulation and flood control. This can be a threat for a city that relies on the ecosystem for its water supply, as is the case in Ecuador's capital, Quito.



Cultivation of potato in the Rumihurcu watershed. The forest has been cleared and the furrows are not in contour-lines (Pascal Podwojewski)

The Pichincha volcano dominates the city of Quito, Ecuador. A study conducted by Poulenard *et al.* of the soil types and hydrostructural properties in the watershed of Rumihurcu on the steep slopes of the Pichincha between 4 200 and 2 800 masl. found degradation of their physical properties due to changes in soil chemical properties and land use.

Between 2 800 and 4 400 masl, air temperature on the Pichincha decreases by 0.6 °C per 100 m of elevation, which provides a gradient of land-use constraints (Table 1). All year, the mean daily temperature remains constant, but with very high day/night amplitude. For the same range of altitude, the mean annual rainfall increases starting with 1 000 mm and reaching 1 500 mm on the crest while the rain intensities decrease. At this altitude, frequent fogs, drizzle and hailstorms contribute to the total precipitation amount, and the hydric balance is largely

Upper altitudinal limit (masl)	Land-use	Infiltration rate	Mismanagement	Consequences
4 400	*Páramo* Bunch grasses Grazing	Strong	Overgrazing Burning Pine plantation Pathways	Compaction Irreversible soil drying Local water repellence Linear erosion
3 850	Range land Matorral-shrubs Grazing, Cultivation	Good	Local invasion Local forest clearing Unadapted crops	Irreversible soil drying Local water-repellence Linear erosion
3 750	Cultivation Potatoes, broad-beans	Medium	No contours No soil cover after the harvest	Irreversible drying Slacking of aggregate Sheet erosion
3 500	Buffer forest (eucalyptus)	Weak with burned plots	Clear cut Burning	Severe water repellence
3 200	Semi-urban Small cultivated plots (maize)	Very weak	Uncontrolled building Littering in stream flow Construction of pathways and electric lines	Mudflows channelized in pathways

Table 1: Altitudinal levels, landuse with drainage, mismanagements and their consequences

positive. The ecological function of that ecosystem described by Janeau *et al.* is to collect rainwater, store it in the soils and release it progressively. At lower altitude, soils are much less permeable and more prone to generate runoff, especially with the more intense rainfalls.

Strong volcanic activity occurred from north to central-south Ecuador during the Pleistocene, leaving acidic ash falls that are mainly rhyodacitic to andesitic in composition. On the slopes of the Pichincha volcano, the topsoil developed on young -300 years BCE andesitic ashes over a non-weathered lapilli layer. Soils are very dark, soft with loose aggregates and very porous. The dominant Pichincha soil is classified as a vitric Andisol characterized by low amounts of amorphous constituents (aluminium – Al and iron – Fe), estimated by oxalate extraction (0.7 percent < Al^o percent + ½ Fe^o < 2 percent), a sandy texture with high amount of glass and a relatively high bulk density for an Andosol (0.8 g cm^{-3}). The carbon content is >7percent; the water content at -1 500 kPa matric potential is generally close to 500 g kg^{-1}. All soils have a high hydraulic conductivity (>100 mm h^{-1}).

From 2 500 masl, the soil becomes an andic Cambisol and the carbon (C) content decreases (50-65 g kg^{-1}), as does the water-holding capacity (<300 g kg^{-1}). The water infiltration rate is still high but very variable.

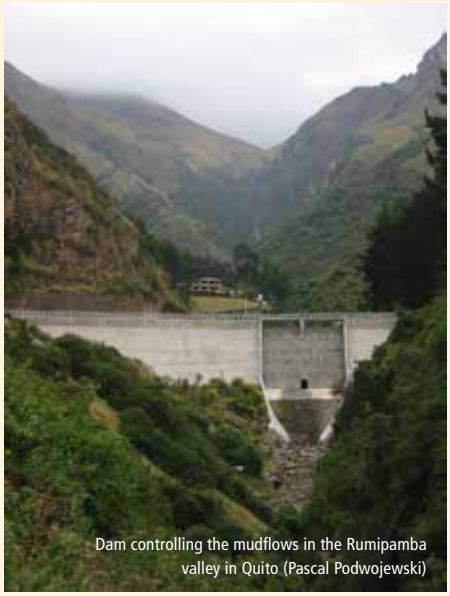
At lower altitudes, the vitric ash layer is often eroded, and the old volcanic ash layer outcrops in a very hard duripan (*cangahua*). The soil is a Leptosol or Durisol with a very low amount of carbon, high bulk density water content and very poor hydrodynamics, which lead to rapid surface water flows.

The slopes of the Pichincha have been increasingly encroached by agricultural land at higher levels and urbanization at lower levels since the 1960s, due to increased population pressure in Quito.

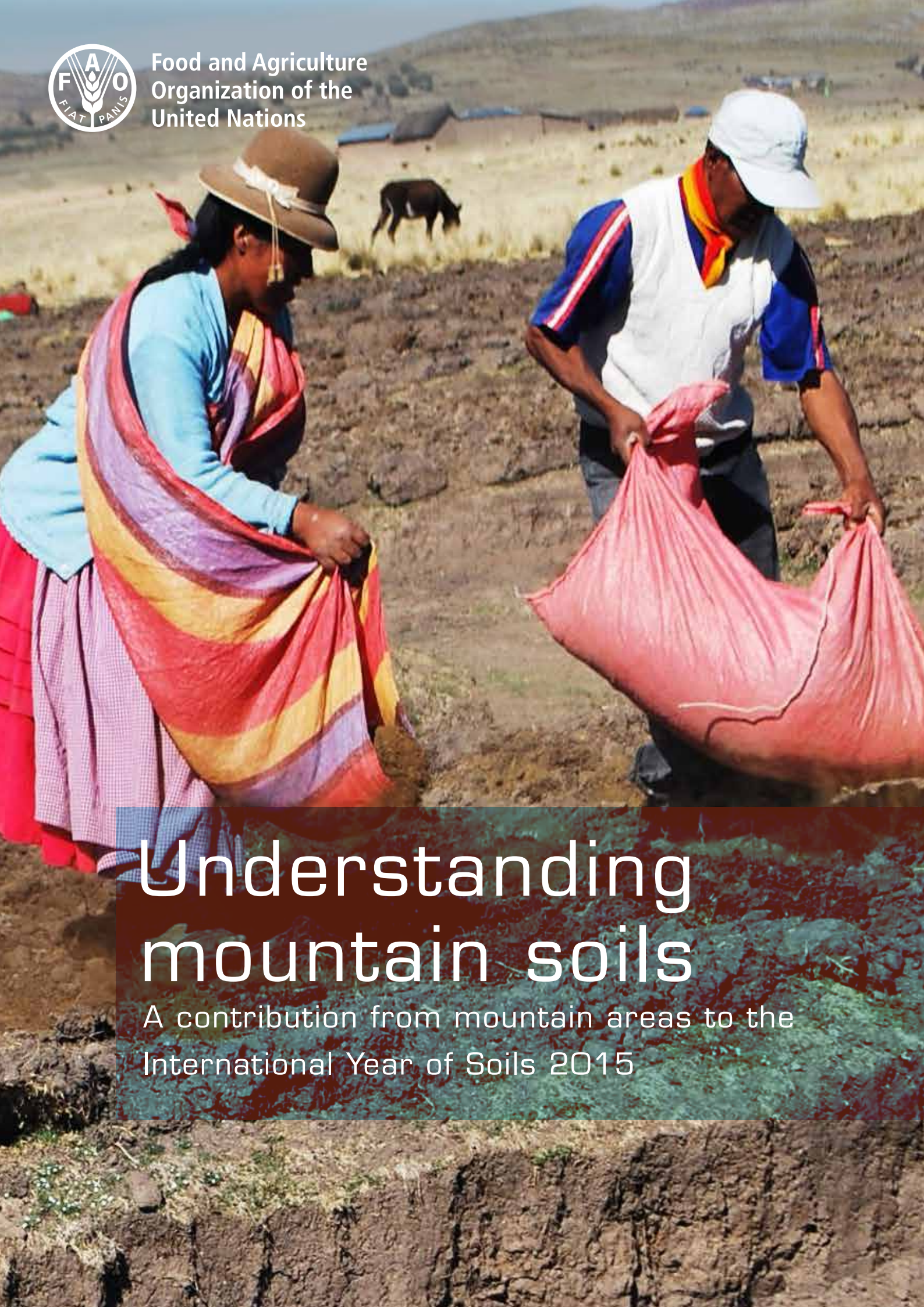
In the *páramo* highlands, repeated fires that generate scattered hydrophobic soil properties are associated with the overgrazing that compacts soil in localized patches and decreases infiltration. The accompanying reduction in vegetation exposes the bare young Andisols' surface to raindrop impact and aggregate slacking which generates surface crusting and runoff, and causes superficial but irreversible drying of bare surfaces. Intense solar radiation and the Andisols' black colour increase soil evaporation. When the soil cover is altered, the surface hydraulic conductivity is reduced by a factor of three, which generates concentrated flows leading to gullies.

At lower altitudes, the planted forest should be protected, never burned to avoid the formation of severe water-repellent soil patches. After tillage, the soils are exposed to rain, hailstorms and rapid irreversible changes in the soil structure by irreversible drying. Dry aggregates develop strong water-repellence, leading to diffuse surface flows and interrill erosion by floating water repellent aggregates. Cultivation should be conducted in contour lines with minimal tillage and maintain a soil cover as long as possible, especially after the harvest. If the topsoil is eroded, the sterile duripan outcrops at low altitude, which is a severe constraint for cultivation and water infiltration, and can lead to mudflows on steep slopes that are catastrophic with risk of loss of life and economic problems.

Due to the modification in land-use change and global climate change, the water-regulation of this ecosystem and its soil fertility could be adversely affected for the future. It is clear that such changes will have a detrimental effect on the city's water supply.



Dam controlling the mudflows in the Rumipamba valley in Quito (Pascal Podwojewski)



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