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# Regional variability of volcanic ash soils in south Ecuador: The relation with parent material, climate and land use

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**Abstract**

The high Andes region of south Ecuador is characterised by intense land use changes. These changes affect particularly the páramo, which is a collection of high altitudinal grassland ecosystems. In this region, the interaction between airborne volcanic ashes and the cold and wet climate results in very typical soils, with an elevated organic C contents. The physical soil properties are closely related to the high and reliable base flow in rivers descending from the páramo, which makes them important for the socio-economic development of the region. In this study, we analyse the regional variability of the soils in the south Ecuadorian rio Paute basin. In a first part of the study, data from soil profiles along north–south transects are used to determine the soil properties, and to relate the spatial variability of these properties to the major trends in parent material, volcanic ash deposits and climate. The profiles are Histic Andosols and Dystric Histosols devoid of allophane, with very high amounts of organic matter. Significant differences between the western and central mountain range are observed, as well as a general decrease in Andic properties from north to south, coinciding with the decrease in volcanic influence. Finally, the impact of human activities on the soil properties is assessed in a case study in the Machangara valley. Data from 5 profiles, located in an area with natural grass vegetation and a low degree of human impact are compared with 4 profiles in a heavily disturbed, intensively drained cultivated area. Despite the intensity of the land use, very few significant differences are found.


*Keywords:* Andosols; Land use; Ecuador; Páramo; Organic matter; Cultivation

## 1. Introduction

### *1.1. Soils of the Ecuadorian páramo*

The páramo is a neotropical alpine ecosystem covering the upper mountain region of the Andes of Venezuela, Colombia, Ecuador and northern Peru. It consists of vast grasslands, extending from the continuous forest border (about 3500 m altitude) up to the perennial snow limit (about 5000 m altitude). The total area covered by páramo is estimated between 35,000 (Hofstede et al., 2003) and 77,000 km$^2$ (Dinerstein et al., 1995). This discrepancy is primarily due to uncertainties in the lower limit of the páramo. The vegetation is dominated by tussock grass species and xeromorphic herbs, with a high number of endemic species (Luteyn et al., 1992). In valley bottoms and near streams, scattered shrubs occur, consisting mainly of *Polylepis* sp. (Vargas and Zuluaga, 1986).

The major factors affecting soil formation in the páramo are the occurrence of Holocenic ash deposits and the cold and wet climate (FAO/ISRIC/ISSS, 1998). In locations with high volcanic ash deposits and a relatively dry climate, Vitric Andosols develop. For example, these soils occur around Quito and Latacunga in northern Ecuador, where they developed on fairly young, rhyolitic volcanic ashes from Pichincha, Cotopaxi and other volcanoes. As a result, these soils contain significant amounts of volcanic ash, have a rather high pH (5.7 to 6.5), a low organic carbon content (between 2.6% and 8%) and a marked concentration of basic cations and volcanic

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minerals such as allophane (FAO, 1964; Wright, 1968; Colmet-Daage et al., 1969; Poulenard, 2000). On the other end of the spectrum, highly weathered Hydric Andosols, almost devoid of allophane, occur in locations with a wet climate and limited ash deposits (Buytaert et al., 2002; Poulenard et al., 2003). These soils are found for instance, in the Austro Ecuatoriano, the Ecuadorian Andes region between 2°15′ and 3°30′ south (Dercon et al., 1998).

The rio Paute basin (Fig. 1) is the largest hydrological basin in the Austro Ecuatoriano. It is located about 100 km south of the southernmost volcanoes of the Northern Volcanic Zone (i.e., the Sangay and Tungurahua volcanoes, Fig. 1), belonging to the Carnegie ridge (Barberi et al., 1988; Monzier et al., 1999). As a result of this distance, volcanic ash deposits are thin and highly weathered (Buytaert et al., 2005a). Although Andosols have been observed as far south as Loja (PRONAREG, 1983), it is more probable that they gradually evolve into Histosols and Umbrisols in the south of the basin. The exact limit, however, is unknown.

### 1.2. Land use impacts

Despite the remoteness, the difficult access and the cold and wet climate, human activity in the páramo is not uncommon. Human presence in the upper Andes dates from prehistorical times (Chepstow-Lusty et al., 1996), but until recently, these activities were limited to extensive cattle grazing, which did not pose a significant pressure on the ecosystem. However, because of population growth, increased urbanisation and soil degradation in the lower valleys, human activities have increased drastically during the last decade. In the densely populated area around Quito in the northern part of the country, these activities started more than 20 years ago, and have resulted in severe soil degradation. Physical soil properties are irreversibly damaged, resulting in a decrease in soil stability, water retention capacity and soil structure, and an increase in water repellency and erosion susceptibility (White and Maldonado, 1991; Basile and De Mascellis, 1999; Poulenard et al., 2001; Podwojewski et al., 2002). Chemical changes include a decrease in oxalate extractable Al ($Al_o$) and Fe ($Fe_o$) content, as well as organic carbon, all of which have an impact on the hydrophysical soil properties (Buytaert et al., 2005a).

These changes strongly affect the hydrological behaviour, in particular the water storage and regulation capacity of the páramo soils. The base flow in rivers descending from the páramo is very large, with a peak over base flow ratio as low as 5 (Buytaert et al., 2004). Although the exact mechanism is not completely understood, studies suggest that the high porosity, combined with a high saturated conductivity, allows for high infiltration rates. The hydraulic conductivity, however, drops fast in only slightly unsaturated conditions and results in a slow subsurface drainage, which is sustained by the elevated water storage capacity of the soils (over 30 vol.%) (Buytaert et al., 2005a).

Because of this high and reliable base flow, and because groundwater extraction is complicated and expensive, surface

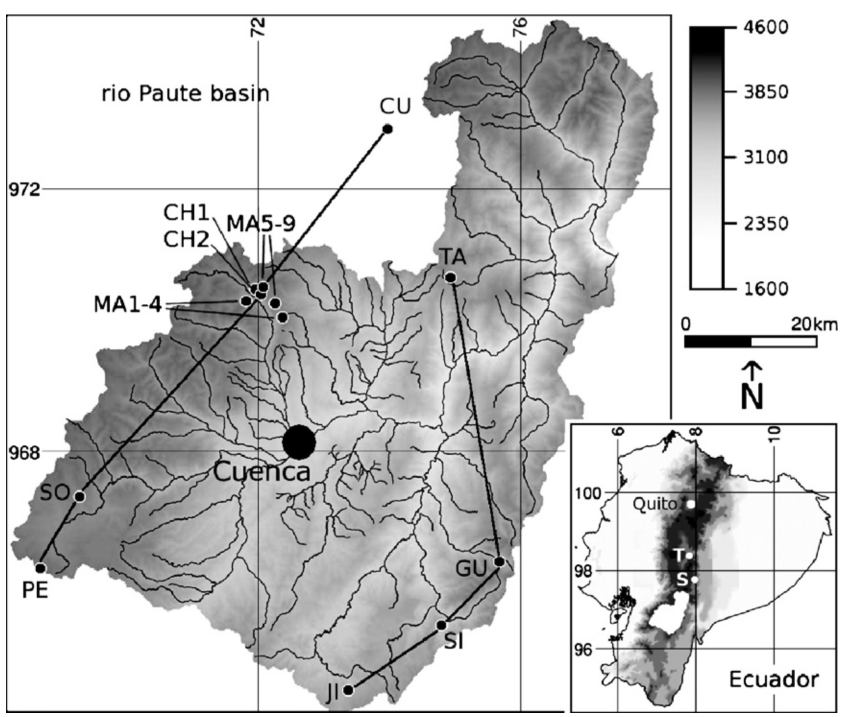


Fig. 1. Geographical location of the rio Paute basin and the location of individual sampled pedons. North–South transects used to study soil properties on natural páramo ecosystems were located on the western mountain range (pedons, CU, CH1, CH2, SO, PD) and on the central mountain range (pedons, TA, GU, SI, JI). An additional 9 pedons were located in the Machangara catchment (pedons MA1–4 and MA5–9) to study the effect of land use on soil properties. S = Sangay volcano, T = Tungurahua volcano.