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Runoff from tropical alpine grasslands increases with areal extent of wetlands

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ABSTRACT

Tropical alpine grasslands of the northern Andes, commonly known as the páramo, provide abundant high-quality water for downstream populations as well as a variety of other environmental services. Yet, very little is known about the role that landscape characteristics play in the hydrologic functioning of these ecosystems. To help fill this knowledge gap, we investigated the relationships between various landscape attributes and hydrology in a wet páramo ecosystem of southern Ecuador. Using linear regression analysis, we examined the influence of soil type, vegetation cover, catchment area, geology, and topography on runoff coefficient, streamflow rates, and evapotranspiration. Our study site is located at the Zhurucay River experimental catchment, which is composed of seven nested microcatchments ranging in size from 0.20 to 7.53 km^2 and in elevation from 3200 to 3900 m a.s.l. We found that (1) water yield accounts for a high percentage of the water budget; (2) runoff coefficient and specific discharge are strongly correlated with the extent of Andean páramo wetlands (Histosol soils and cushion plants), and also increase with catchment size; (3) conversely, inferred evapotranspiration is the highest in catchments having the greatest percentages of upland terrain (Andosol soils and tussock grasses); and (4) low flows are highly positively correlated with steep slopes. These results suggest that in the high-elevation tropical grasslands of the Andes, runoff coefficient and specific discharge increase with catchment size because as catchment size increases, so does the relative area of permanently near-saturation zones (Andean páramo wetlands); likely because of reduced available storage capacity of the Andean páramo wetlands, and their hydrologic connectivity to the stream network.

1. Introduction

The wet, high-elevation grasslands known as the páramo occupy the upper portion of the northern Andes, at elevations ranging from 3000 to 4500 m (Sarmiento et al., 2003), and provide critical ecosystem services for the Andean region (Buytaert et al., 2006a, 2011; Crespo et al., 2011, 2012). These services include not only carbon sequestration and water regulation capacities, but also the support of a wide variety of flora and fauna that make the tropical Andes one of the most richly biodiverse regions in the world (Myers et al., 2000). A significant proportion – approximately 60% of the total – are endemic species that have adapted over time to the difficult climate conditions (Luteyn, 1992).

Water supplied from the wet páramo ecosystems plays a key role in the socio-economic development of several major cities in the Andean region, such as Bogotá, Quito, Mérida, and Cuenca (Buytaert and De Bievre, 2012; Buytaert et al., 2010; Célleri and Feyen, 2009; Postel and Thompson, 2005). Well over half of the water needs of many downstream regions are met by water from the mountainous areas (Viviroli et al., 2007). However, despite the importance of these water sources, very little is currently known about the processes that govern their hydrological behavior, providing them with a remarkable capacity for providing a sustained flow of water throughout the year (Buytaert and Beven, 2011; Célleri and Feyen, 2009).

But these ecosystems are also highly susceptible to local and global stressors, including the growing human presence in the region, changes in land use, unsustainable exploitation of mineral resources, and climate change and variability (Buytaert et al., 2006a; Célleri and Feyen, 2009). For these reasons, the protection, conservation, and management of the páramo have become a priority in the northern Andes. Clearly, the task of developing and implementing effective conservation and management policies depends critically on an improved scientific understanding of páramo landscapes, particularly with respect to water (Farley et al., 2011). Further, the knowledge gained will provide the foundation for a beneficial and sustainable collaboration between the scientific community and local and regional stakeholders and decision-makers (Crespo et al., 2012). This task is increasingly urgent given the rapid pace of land cover change in the region (Buytaert et al., 2010).

One key aspect of understanding the hydrology of a given region is knowing how different landscape characteristics affect different

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hydrologic variables (Buttle et al., 2004; Jencso and McGlynn, 2011). As noted by Post and Jakeman (1996), establishing relationships between the bio-physical characteristics and hydrological response of a catchment is “a fundamental, but largely unresolved, problem in hydrology.” These relationships have now been investigated in several regions, and these studies have yielded a number of new insights. In this way, the hydrological controls of poorly monitored catchments can be predicted through the use of landscape and climate data from other catchments located in similar regions (Post and Jakeman, 1999).

This study, then, seeks to advance our understanding of the hydrologic functioning of páramo ecosystems by examining the influence of various landscape characteristics on hydrological behavior. The research questions to be answered are: (i) Do the landscape characteristics of the catchment influence the hydrologic functioning of the páramo ecosystem? (ii) If they do, which landscape characteristics affect runoff and evapotranspiration (ET) within the study area? (iii) Which landscape characteristics control hydrological behavior at different rates of flow? Answering these questions is a first step toward understanding the connectivity between hillslopes, riparian areas, and stream zones in the páramo (Jencso et al., 2009).

2. Study area

The Zhurucay experimental catchment is situated in the southern Andean region of Ecuador, approximately 85 km southeast of Cuenca (Fig. 1a) and in the headwaters of the Jubones River, which discharges into the Pacific Ocean. The Zhurucay catchment has an area of 7.53 km^2 and elevations ranging from 3200 to 3900 m a.s.l. Annual precipitation recorded in the region from 1964 to 2008 ranges between 900 and 1600 mm (Ecuadorian National Institute of Meteorology and Hydrology) with weak seasonality (Padrón, 2013). The climate is affected by the Pacific coastal regime from the west and the continental and tropical Atlantic air masses from the east (Vuille et al., 2000), producing a generally cold and frequently cloudy and foggy climate, with rainfall occurring almost daily. The average air temperature at 3500 m a.s.l. is approximately 7 °C and decreases at a rate of

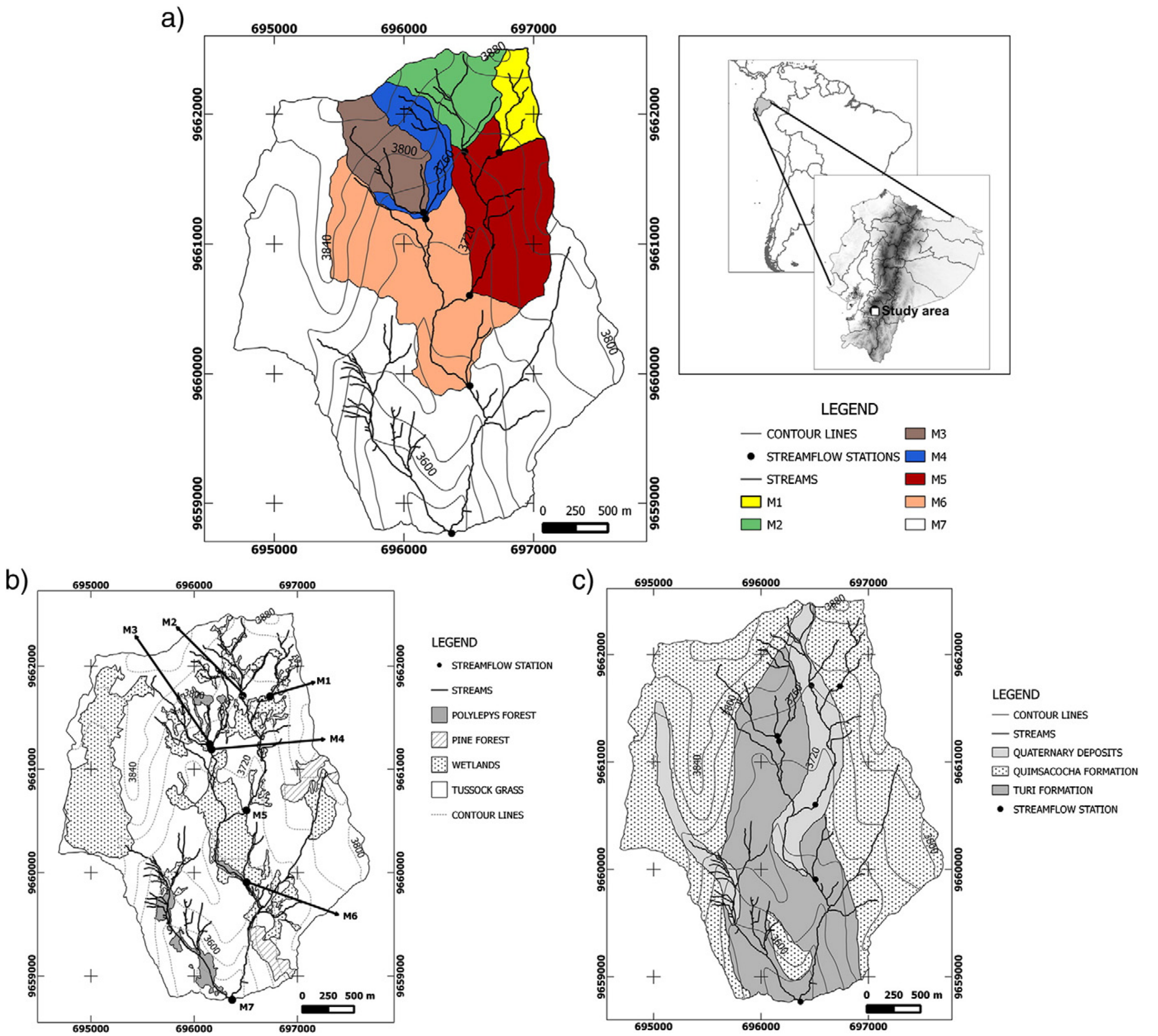

Fig. 1. The Zhurucay experimental catchment located in southern Ecuador highlighting (a) the seven nested microcatchments within the study area, (b) the underlying geology and (c) the coverage of major vegetation types.