ANALYSIS OF THE WATER BALANCE OF SMALL PÁRAMO CATCHMENTS IN SOUTH ECUADOR

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KEYWORDS / ABSTRACT: páramo / water balance / hydrological monitoring / evapotranspiration / seasonality / human impacts.

The páramo is a high altitudinal wetland ecosystem in the upper Andes of Venezuela, Colombia, Ecuador and northern Peru. It is a reliable and constant source of high quality water and as such, the major water provider for the Andean highlands and part of the coastal plains. Water is used for consumption as well as electricity production. However, scientific evidence suggests that the quality and quantity of this water source may be at risk, due to increasing human interference in the wetland ecosystem. The current study analyses the water balance of two microcatchments near Cuenca, Ecuador. One is covered by the typical natural grass vegetation, while the other catchment is heavily interfered and intensive cultivation, cattle grazing and drainage are taking place. Three rain gauges and a V-notch were installed in each catchment, and one meteorological station in a nearby location. Analysis of the precipitation data reveals that seasonal variability in the páramo is extremely low. This property is a major reason for the sustained base flow, which characterises the páramo. However, evapotranspiration, represented by the crop coefficient, is more than twice as high in the cultivated areas (0.95), compared to the natural vegetation (0.42). The increased evapotranspiration may seriously affect the water production of interfered páramo catchments. Finally, based on water balance analysis, the variation in water storage in the páramo is very low, with a yearly variation of about 25 mm. In the interfered catchment, the storage in variation is even lower, about 15 mm, suggesting a deterioration of the regulation capacity.

J. Krecek and M. Haigh (eds.),
Environmental Role of Wetlands in Headwaters, 271–281.
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1. Introduction

The páramo is a neotropical ecosystem located in the upper Andean mountain region, between the tree border and the eternal snow line (Medina and Vasconez, 2001). Depending on the local geographical and climatic conditions, these limits correspond roughly to an altitude of respectively 3500 and 5000 m altitude. The ecosystem is characterised by a tundra-like vegetation consisting of tussock-forming grasses, small herbs and xerophytic shrubs, with scarce patches of *Polylepis sp.* bushes [9, 8, 14]. The climate is cold and wet. Precipitation ranges between 1000 and 3000 mm year^{-1} and the average daily temperature is about 8°C at 3500 m altitude [5].

The páramo is known for its large water supply and good water regulation. Precipitation is moderate, but the real water input in the hydrological system is probably significantly higher. Rainfall events in the páramo are typically of high frequency and low intensity. In combination with strong winds and a very irregular topography (rain shading) this may result in a high spatial rainfall variability and large errors in precipitation registration. Additionally, "horizontal rain", i.e. precipitation due to fog and dew, may add an unknown quantity of water to the hydrological system, especially where patches of arbustive species such as Polylepis are present. This mechanism is similar to occult precipitation in the lower montane cloud forest, where it typically adds 5 to 20% of ordinary rainfall [4, 2]. On the other hand, natural water consumption in the páramo is very low, because of the predominance of tussock grasses and xerophytic herbs with low evaporation characteristics, despite the high evaporative force of UV-radiation at this altitude and latitude. As a result, there is a large water surplus, feeding the rivers descending to both the coastal regions and the Amazon basin.

Due to the cold and wet climate and the lack of seasonal variation in precipitation, the páramo is a constant and reliable source of high quality water for the Andean regions of Ecuador, Colombia and Venezuela. Water is used for urban, industrial and agricultural purposes. Besides direct water consumption, the water supply function is of economic importance as it feeds many hydropower plants, located both in the páramo itself as well as in the dryer, lower Andean regions. In Ecuador, hydropower accounts for more than 50% of the total electricity production [12]. All together, it is estimated that the high Andean wetlands, of which the páramo forms a major part, provide environmental services to more than 100 million people [10]

For ages, the páramo has remained a natural ecosystem with only minor human activity. However, recently, human interference has increased drastically, because of population growth and expansion of urban areas, as well as soil degradation in the lower regions. Grassland is converted for the cultivation of potatoes and beans, and natural vegetation is replaced by more nutritive grass species. These changes are suspected to alter significantly the hydrological cycle of the páramo, thus endangering its water supply function. The current study aims at a detailed analysis and uncertainty estimation of the water balance of two microcatchments in the páramo of the rio Paute basin (south Ecuador) in order to determine the impact of agriculture on the water production of the páramo ecosystem.

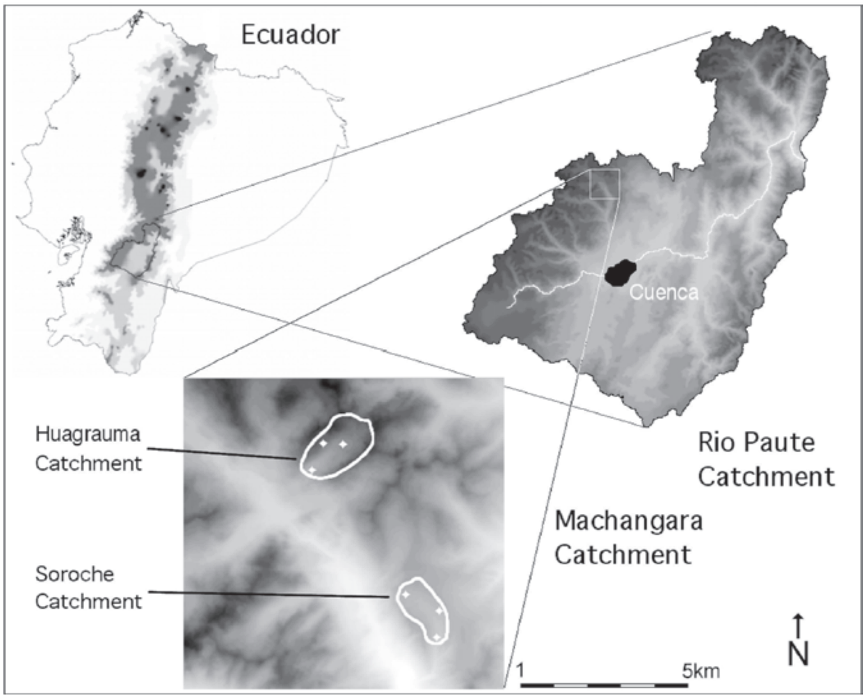

Figure 1: Location of the experimental catchments Huagrauma and Soroche.

2. Materials and Methods

2.1. Location

The experimental catchments *Huagrauma* (2.58 km^2) and *Soroche* (1.59

km^2) form a part of the Rio Machangara basin, located in the NW Rio Paute basin (Fig.1). The Huagrauma catchment is covered by the typical, natural tussock grass vegetation, with scarce, scattered patches of Polylepis trees. The altitude ranges between 3690 and 4100 m. Except for some extensive grazing, human influence is minimal. The borders of the catchment consist of steep slopes, up to 60% and more. At the foot of these slopes, flat areas exist, where bog vegetation develops and regular ponding occurs. Due to the highly dynamic and seasonal nature of the ponds and marshes, it is difficult to estimate their total area in the catchment.

The Soroche catchment is 38% smaller than the Huagrauma basin and ranges between 3520 and 3720 m altitude. This catchment is heavily disturbed by human influence. 30% of the catchment area is used for intensive grazing and cultivation (0.48 km^2). In this area, the original vegetation is cleared and eventually replaced by more nutritive grass species. The soil is drained intensively with an irregular network of open trenches, about 0.7 m deep (up to the subsoil level), with an average distance of about 20 m or less. During the study, the drainage has expanded in additional parts of the catchment, covering an additional estimated 20% of the catchment surface. Compared to the Huagrauma catchment, the slopes of Soroche are gentler and the topography is less accidented. Ephemeral saturation and ponding occurs regularly at the foot of hill slopes.

2.2. Monitoring

Each catchment is equipped with three tipping bucket rain gauges, with a resolution of 0.2 mm. The location of the rain gauges is indicated on Fig. 1. At the outlets, the catchment runoff was measured every 15 min using a V-notch construction and a water level logger. The Kindsvater-Shen relation [13] is used to convert the water level to discharge.

Radiation, temperature, humidity and wind speed were recorded at a 30 min. interval at a meteorological station near the Chanlud dam site. This station is located at a distance of resp. about 2400 and 4600 m from the center of the Huagrauma and Soroche catchment. From these data, the daily reference crop evapotranspiration (ET_o) in the catchment was calculated using the FAO Penman Monteith method [1]. The temperature data were corrected for the difference in altitude. Herefore, a calibration curve was constructed with local mean annual temperatures at different altitudes [3]. Some gaps in the daily minimum temperature, daily maximum temperature and minimum relative humidity were closed using the correlation with the average daily radiation. The Pearson correlation coefficients (r) are respectively -0.56, 0.87 and 0.89. Lacking maximum relative humidity values were set at 100%, as 93.4% of the registered daily maximum relative humidity values reach 100%.

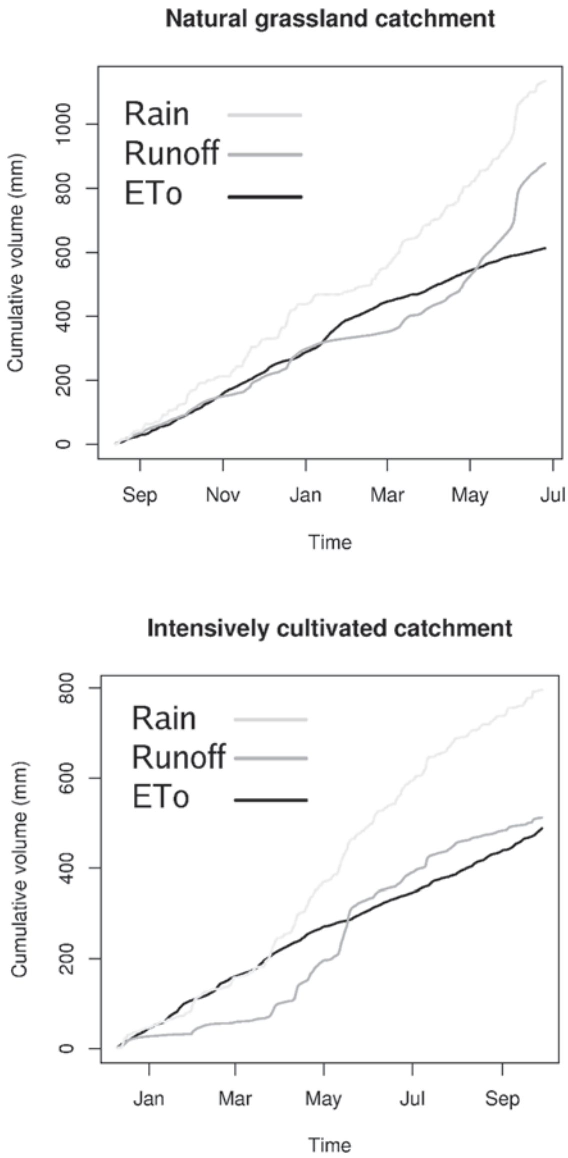

Figure 2: Cumulative rainfall, runoff and reference crop evapotranspiration over the monitored periods for the studied catchments.

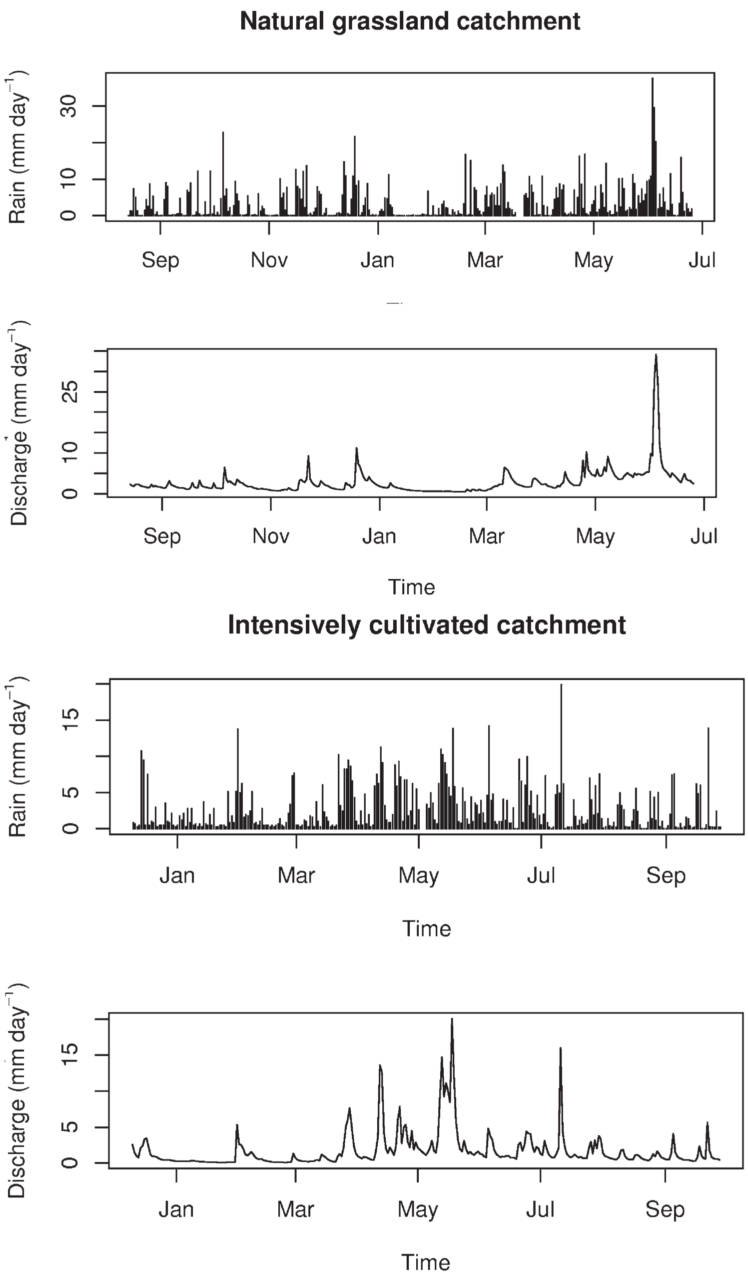

Figure 3: Rainfall- runoff in the natural Huagrauma and the cultivated Soroche catchment

The periods in which the two catchments are compared do not match due to failures in the discharge measurements. For Huagrauma, data from 09/2003 to 07/2004 were used, and for Soroche from 01/2003 to 09/2003. This is not seen as a major problem, due to the lack of seasonality in the páramo and the large homogeneity in rainfall and weather (Fig. 2). Further advantages of this lack of seasonality are:

- The crop coefficient K_c for both the natural vegetation and cultivated crops does not change during the year. The natural vegetation is perennial without seasonal growth stages.
- The water storage in the catchment, both in the soil and in the vegetation, is rather constant. This allows for water balance calculations over short time periods.

3. Results and Discussion

Precipitation and discharge over the monitored periods are given in Fig. 2 for both catchments. In the lower Andean highlands, a bimodal climate exists, with two dry periods, from July to August and from Januari to March. This seasonal fluctuation is visible in the rainfall pattern in the páramo, but it is very low, compared to the other regions. In general, the linearity of the graphs approves the lack of clear seasonality in the páramo.

Fig. 3 shows the cumulative precipitation, discharge and reference crop evapotranspiration in the Huagrauma and Soroche catchments. From these data, the water balance of the catchments can be calculated. The water balance of the catchment can be written as:

$$\text{Rain} + \text{Interception} = \text{Evapotranspiration} + \text{Runoff} + \text{Infiltration}$$

In the Penman Monteith calculation method, evapotranspiration is expressed as follows:

$$ET = K_s * K_c * ET_o$$

with ET_o the reference crop evapotranspiration, K_c a crop coefficient and K_s a water stress factor.

The shallow soils and compacted bedrock, as a result of glacial compaction during the Tertiary (Buytaert et al., 2005), allow no deep infiltration, thus this term can be neglected. It is also unlikely that horizontal precipitation and interception of fog and mist, often found in cloud forests, add a significant quantity of water to the hydrological cycle. Fog and mist are very common in the region, but the interception is generally attributed to arbustive vegetation, which is lacking in both catchments. Finally, K_s can be set at 1, because water stress is non-existing. Former studies (Buytaert, 2004) showed that in the páramo, the soil water content seldomly decreases beneath field capacity.

When these simplifications are taken into account, the only unknown factor in the water balance is the crop coefficient. The water balance was solved for the monitored periods, in which it was assumed that the difference in water storage in the catchment can be neglected. In view of the lack of seasonality in the páramo, a one year monitoring period is likely sufficiently long to make such an assumption. The resulting K_c for Huagrauma is 0.42, while for Soroche it is 0.58. For the natural Huagrauma catchment, where the natural vegetation is homogeneous, the calculated value is likely to correspond to the crop coefficient of the natural graminaceous vegetation. A value of 0.42 is realistic.

Contrary to most grass species, the páramo grass tussocks consist of up to 90% of dead leaves, thus greatly reducing evapotranspiration (Hedberg, 1992). For the interfered cathcment Soroche, the physical representativity of the calculated crop coefficient is less clear. It integrates evapotranspiration from the natural vegetation, the increased transpiration of exotic grasses and crops, as well as evaporation from fallow fields, drainage canals and degraded areas. The interfered area in the Soroche catchment is about 30% of the total area. The remaining 70% is covered with the same natural grass vegetation as Huagrauma, and thus probably has a similar K_c of about 0.42. If this is taken into account, the interfered area in Soroche has an overall K_c of about 0.95, which is twice the K_c of natural grassland. A higher evapotranspiration is directly correlated with a lower water yield, which may greatly affect the many water collecting activities in the páramo and trigger a competition in water use between the lower urban areas and the local agricultural practices.

Fig. 4 shows the daily variation in water storage in the monitored catchments, using the calculated crop coefficients to close the water balance. As was hypothesised before, the maximum variation in water storage in the natural catchment is very low: less than 25 mm. Nevertheless, the variation in water storage of the interfered catchment is still significantly lower (< 15 mm). This may be an indication of a decrease in water storage and regulation capacity in this catchment. Such a conclusion would be in accordance with other literature (Buytaert et al., 2004). However, at present, the exact mechanism of the loss of water regulation as a result of intensive cultivation is still unknown, and further investigation is therefore recommended.

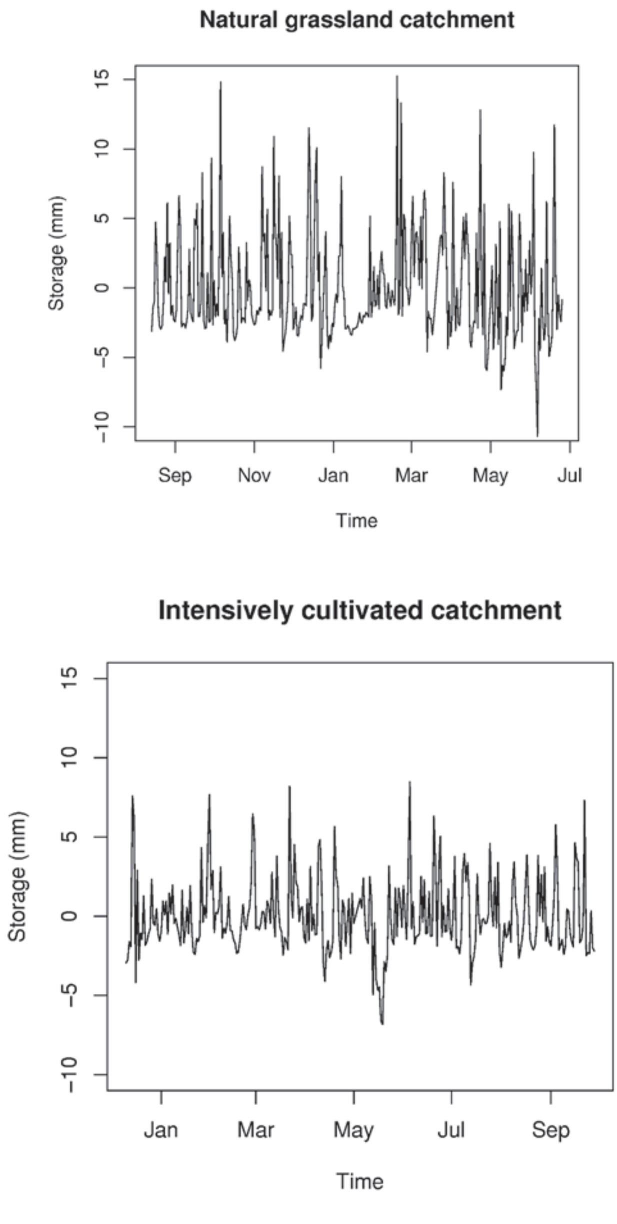

Figure 4: Variation in water storage in the monitored catchments.

4. Conclusions

After studying the water balance of 2 microcatchments in the Ecuadorian páramo ecosystems, the following conclusions can be drawn:

- Precipitation over the year is homogenous and lacks strong seasonal variability.
- The crop coeffient of the natural vegetation is estimated 0.42, which is a realistic value in view of the vegetation characteristics.
- For the cultivated catchment, the overall crop coefficient for the cultivated area is estimated at 0.92. The large difference with the natural vegetation may cause problems in water supply systems using water from these areas.
- The variation in water storage capacity in the catchments is low, with a maximum variation not exceeding 25 mm. The variation in the cultivated catchment is even lower (15 mm), which may indicate a loss in water storage and regulation capacity.

5. Acknowledgements

We thank the Programme for Soil and Water Management. University of Cuenca, Ecuador, and its director, dr. Cisneros, for logistic help during the field work.

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