



WATER BALANCE COMPONENTS IN THE PARAMO OF JATUNSACHA, ECUADOR

COMPONENTES DEL BALANCE HÍDRICO EN LOS PÁRAMOS DE JATUNSACHA, ECUADOR

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Abstract

The neotropical paramo is a high mountain biome distributed from the upper side of the andean forest to the permanent snow line of such ecosystems. From a hydrological point of view, this kind of ecosystem is characterized by maintaining a constant amount of base flow, as a result of the interaction of several of its water balance components such as: precipitation; soil moisture and evapotranspiration. Therefore, Andean communities and population located downstream of the catchment are able to count with enough water most of the year. The main objective of this research work is to perform an assessment of the influence of such water balance in the zone of Jatunsacha paramos. This research work is carried out based on the collection, evaluation and processing of hydrologic data from stages located in the zone of the Antisana. Such information will be used as a decision making support tool for the conservation and management of recharge zones in the northern part of Ecuador. In accordance with the obtained results, the dynamics of the hydrologic regime depends on: the frequent occurrence of low intensity, low volume and short duration rainfall events; soil moisture variability at both field capacity and the point of saturation; a relatively low evapotranspiration; a highly variable flow discharge that generates a low discharge coefficient; and, a high rate of percolation which is typical from porous zones such as the volcanic paramo zones.

Keywords: Precipitation, discharge, evapotranspiration, soil moisture dynamics, hydrology.

Resumen

El páramo es una zona biogeográfica de alta montaña que comúnmente se extiende entre el límite superior del bosque andino hasta por debajo de las nieves perpetuas. Hidrológicamente este ecosistema presenta una buena regulación de los caudales bases, como resultado de la interacción de los componentes precipitación, humedad del suelo y evapotranspiración, lo que permite el abastecimiento continuo del recurso hídrico para las poblaciones ubicadas en las cuencas medias y bajas de la región Andina. La presente investigación tiene como objetivo evaluar el comportamiento de los principales parámetros que caracterizan el balance hídrico en los páramos de Jatunsacha, con base en la recolección, análisis y procesamiento de la información hidroclimatológica de estaciones ubicadas en los páramos de Antisana, como mecanismo de apoyo en la toma de decisiones para el manejo y conservación de zonas de recarga hídrica de la parte norte del Ecuador. De acuerdo con los resultados, la dinámica del régimen hidrológico en la zona de estudio está determinada por eventos de lluvia de baja intensidad, volumen y duración pero muy frecuentes, por un contenido de humedad del suelo entre capacidad de campo y punto de saturación, por una evapotranspiración relativamente baja, por un caudal muy variable que genera un coeficiente de escorrentía bajo y por una percolación alta típico en zonas con geología porosa.

Palabras claves: Precipitación, Caudal, Evapotranspiración real, dinámica de la humedad del suelo, hidrología.

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1 Introduction

Moorlands are natural ecosystems distributed throughout the tropical zone, specifically at 8° north latitude and 11° south latitude (Hofstede *et al.*, 2003). In the Andean part they form a corridor between the Cordillera of Mérida, in Venezuela, until the depreciation of Huancabamba in the north of Peru; but there are also more separate complexes such as the Moors in Costa Rica and the Sierra Nevada of Santa Marta (Hofstede *et al.*, 2003; Buytaert, Cuesta-Camacho y Tobón, 2011; Luteyn *et al.*, 1999).

More than 100 million people in the Andes and in the mountainous parts of Africa and New Guinea are indirectly dependent on the vital fluid supply of this ecosystem (Hofstede *et al.*, 2003), which is affected by a gradual degradation caused by the change in land use and increased demand for water resources for consumption, irrigation and hydropower generation (Buytaert *et al.*, 2005; Buytaert, Célleri, De Bièvre, Cisneros, Wyseure, Deckers y Hofstede, 2006; Buytaert, Iniguez y De Bievre, 2007; Crespo *et al.*, 2011; Harden *et al.*, 2013).

Despite the importance mentioned by its constant water supply, at the scientific level the information from hydrological and climatological databases are scarce and information processing procedures (pre-processing) are almost non-existent; this situation generates that the interpretation of results are erroneous, so it is necessary to standardize protocols for data extraction, pre-processing, maintenance of equipment with different types of sensors and base storing that can be accessible for scientific studies and that would allow the decision makers a proper use and management of the moorland ecosystem.

Research in the moorland ecosystem on hydrological functioning mention that precipitation for the Andean region varies between 700 mm to 3 000 mm, with a variability at local scale influenced by the irregular topography, altitude, slope and orientation (Buytaert, Iniguez y De Bievre, 2007; Buytaert, Célleri, De Bièvre, Cisneros, Wyseure, Deckers y Hofstede, 2006; Celleri *et al.*, 2007). On the other hand, studies at microwatershed level in the south of Ecuador determined evapotranspiration variations between 0.6 to 2.51 mm day⁻¹ (Buytaert, 2004; Célleri y Feyen, 2009; Hofstede, 1995; Buytaert, Célleri, De Bièvre, Cisneros, Wyseure, Deckers y Hofstede, 2006; Favier *et al.*, 2008). Similarly, Ochoa-Tocachi *et al.* (2016) assessed the runoff coef-

ficient in moorland basins located in the Antisana and Pichincha volcanoes, obtaining values between 8 and 13% that differ from the results in the studies of Tobón y Arroyave (2007); Buytaert, Iniguez y De Bievre (2007); Crespo *et al.* (2011); Guzmán *et al.* (2015) with values published between 53% and 73% for the moorlands in Colombia and southern Ecuador.

As a response to the analysis carried out and in order to generate knowledge about hydrological functionality, the present research was carried out in the Jatunsacha River basin, in the Antisana moorland, as part of a national initiative of hydrometeorological monitoring of the FONAG Water Protection Fund, in order to evaluate the behavior of the main parameters that characterize the water balance in the Jatunsacha moorland.

2 Materials and methods

2.1 Area under study

The basin under study is located in the Antisana moorland and belongs to the hydrographic unit of the Jatunhuaycu River, source of drinking water for Quito, Ecuador; it is geographically located at 0° 28' 15" south latitude and 78° 14' 34" west longitude. Jatunsacha drains its water towards the Amazon River basin and covers an area of 2.1 km², with an average slope of 20% distributed in an altitudinal gradient varying between 4 036 masl and 4520 masl (Figura 1); with relatively low intervention by cattle and without contribution by flow of the Antisana glacial (Alvarado, 2009; Torres, 2016).

The geology of the basin is formed by units containing metamorphic rocks of the Loja land, located in volcanic rocks of the Pisayambo formation (Barberi *et al.*, 1988), covered by a series of superficial deposits that include materials plastic, glaciers and colluvial (Coltorti y Ollier, 2000; Lavenu *et al.*, 1992; Alvarado, 2009; Bourdon *et al.*, 2002). The soils are usually of volcanic origin and belong to the order of Andisols, with the presence of black slime (Torres, 2016; Alvarado, 2009; Ochoa-Tocachi *et al.*, 2016).

The vegetation cover in Jatunsacha is part of the dry super-moorland (Cleef, 1981; Sklenár y Balslev, 2005) dominated by plant species as: *Festuca vaginalis*, *Plantago nubigena*, *Astragalus geminiflorus*, *Biden sandicola*, *Conyza cardaminifolia*, *Calamagrostis mollis*, *Cerastium imbricatum* y *Silene thysanodes* (Sklenár y Balslev, 2005).

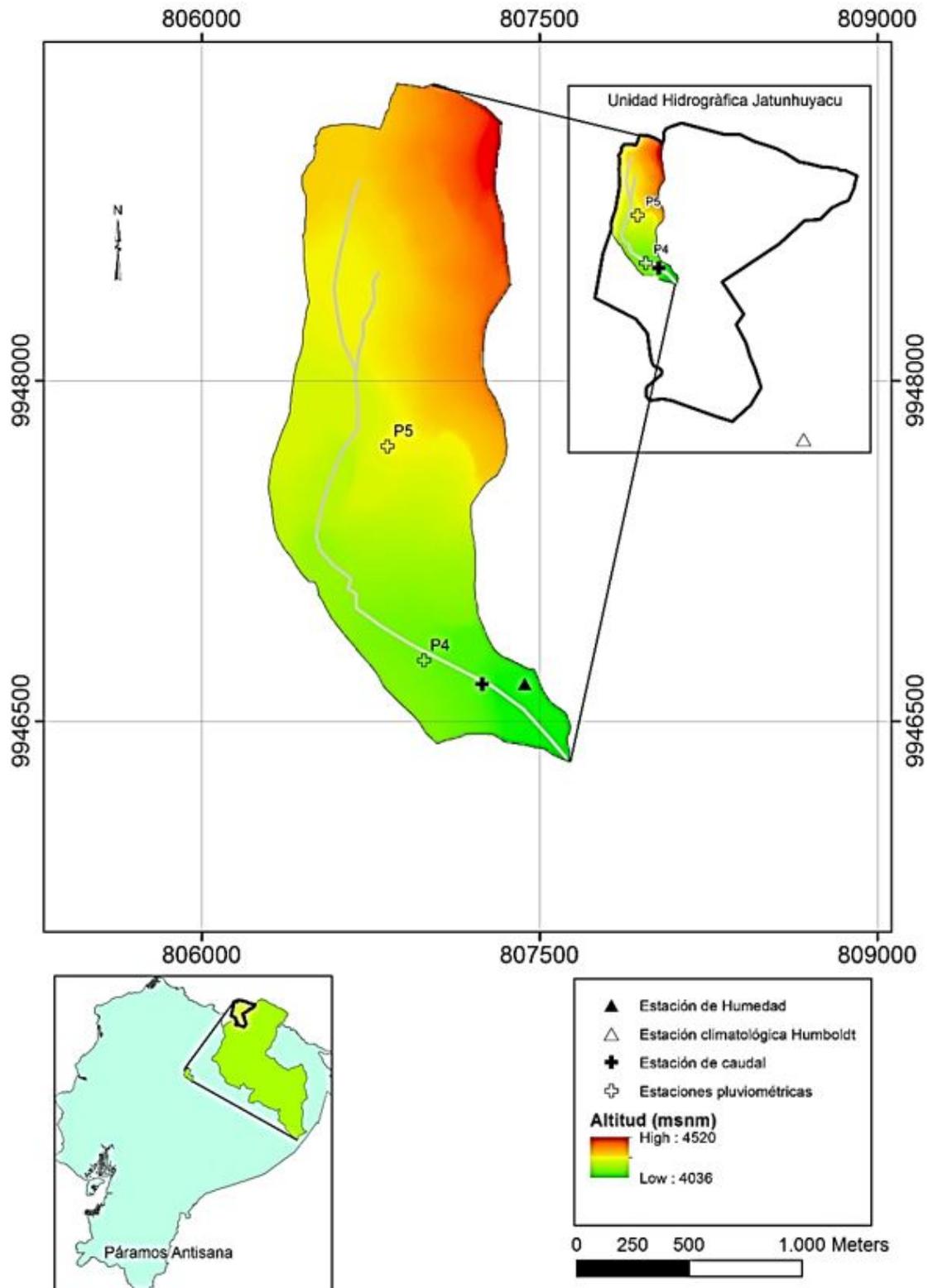


Figure 1. Geographic location of the watershed and detailed location of the pluviometric stations, flow, soil moisture and climatological installed for the hydrometeorological monitoring.

2.2 Data and methods

2.2.1 Precipitation

To determine the entries by precipitation and its temporal variability a pluviometer TEXAS TE525MM was installed, of electronic tipping bucket, with 0.1 mm resolution associated to a datalogger Campbell Scientific Cr-200X, placed both in the lower and upper part of the basin (Figure 1), which recorded information from January 1st 2014 to April 30 2015. In this part of the methodology the aim was to analyze the rainfall at intra-annual scale to know how much rain in the moorland and how it is distributed monthly.

For the characterization of precipitation events, the information of the fourth pluviometer (P4) was

used, which was located in the lower part of the basin (Figure 1), by presenting a more complete set of records. With the rain database added every five minutes and with the results of the annual rainfall cycle (Figure 2), rainfall events were characterized in four periods: dry period comprising the months of December, January, July and August; rainy season March, April, May and October; transition from dry to humid February and September and transition from wet to dry June and November. Although there is no standardized criterion for defining an event of a time series (Tokay *et al.*, 2003), for the study area the separation was established in a maximum time of one hour between two consecutive tips; this in reference to some studies (Tokay *et al.*, 2003; Holwerda *et al.*, 2006; Nystuen, 1999) which set the maximum times between 15 minutes and two hours.

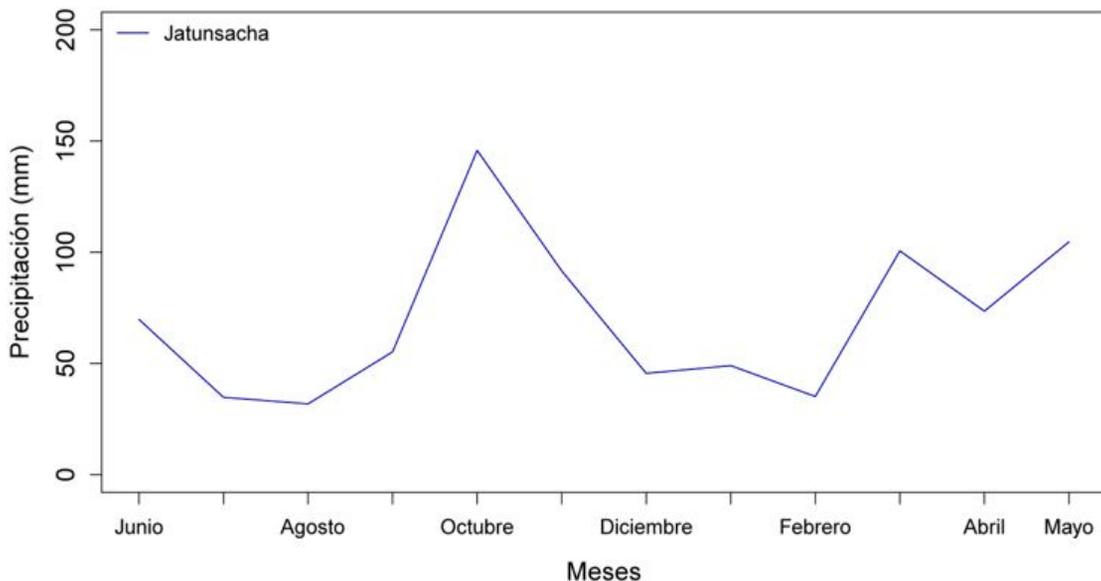


Figure 2. Seasonality of the annual rainfall cycle for the study area.

With the database in the R Studio program we calculated the magnitude, duration, intensity and number of events, which is a direct measure of the frequency. The magnitude was established by adding the amounts recorded in each event, the duration corresponds to the time elapsed in each event, the intensity was determined dividing the magnitude between the effective time where the entry by precipitation was recorded during the event, and the frequency was calculated by adding the number of events in each period analyzed. For each va-

riable, a characterization of its probability distribution function was carried out, which allows to extract confidence limits to 95% for the dimensioning of its intrinsic behavior.

2.2.2 Behavior of the soil humidity

To characterize the soil moisture behavior, automatic instruments were installed, based on the measurements of the dielectric permittiveness of the soil, called TDR Time Domain Reflectometer (Jo-

nes, Wraith y Or, 2002), which are bimetal sensors placed horizontally on the surface horizon (a) at a depth of 10 cm and on the horizon 2Ab at 70 cm, inside a trial pit dug in a hillside of the basin (Figure 1), associated with dataloggers brand Campbell Scientific 200X that registered data of the water content in the soil, with a 5-minute resolution.

As a result of the unique characteristics of volcanic ash soils such as high porosity, low density, presence of volcanic glass and high moisture retention (Buytaert, 2004; Buytaert, Iniguez y De Bievre, 2007; Nanzyo, Shoji y Dahlgren, 1993) and on the basis of the recommendations of Blume, Zehe y Bronstert (2007) of calibrating the internal equations of the dataloggers, the equation proposed by Guarderas (2015) was used to transform the transit time series recorded in the sensor to volumetric content values; specific relationship based on field sampling in both horizons.

With the average soil moisture data series aggregated daily from April 30, 2014 to March 13, 2015, the dynamic moisture curve was graphic and analyzed in order to characterize the behavior of the soil water content in the Jatunsacha basin. Additionally, the apparent density was sampled by triplicate in each horizon, based on the mass ratio of the dried sample for 24 hours at 105 °C and the volume of the cylinders (Grossman, 2002); organic matter through the Walkey and Black method (Black, 1965), total porosity that was established from the relationship of apparent density and current density (Klute, 1986a); saturated hydraulic conductivity by using the constant hydraulic charge method (Klute y Dirksen, 1996), hydrogen potential, pH through the ratio 1:1 between water and soil and the moisture retention curve considering the characteristic points: field capacity, saturation point and permanent wilt point, which were determined in the Soil Physics Laboratory of Universidad Nacional de Colombia, Medellín campus, from undisturbed samples taken with stainless steel rings with 5 cm in diameter and 1 cm in height, subjected to saturation by capillarity and subsequently transferred to the plates with membranes, calibrated at different pressures inside the "Richard pressure cooker" and dried in constant temperature range (Klute, 1986b).

2.2.3 Real evapotranspiration

For the calculation of real evapotranspiration (ET_r), the relationship that integrates the climatic beha-

avior, the particular characteristics of vegetation and the limitations due to the water availability at the basin level in the Antisana moorland were used (Allen *et al.*, 1998; Buytaert, Iñiguez, Celleri, De Bièvre, Wyseure y Deckers, 2006; Guzmán *et al.*, 2015), which is expressed as (Equation 1):

$$ET_r = ET_a \times K_c \times K_s \quad (1)$$

Where: ET_r is the current evapotranspiration (mm day⁻¹), ET_a is the reference evapotranspiration (mm day⁻¹), K_c is the crop coefficient (dimensionless) and K_s the water Stress factor (dimensionless).

For the determination of ET_a, Penman-Monteith equation was applied (Allen *et al.*, 1998) (Equation 2), with data from the Humboldt climatological station (Figure 1), which accumulated and recorded information every 30 minutes of the main climatic variables from January 1, 2014 to April 30, 2015, provided by the National Institute of Meteorology and Hydrology of Ecuador (INAMHI). The processing was done at a time-level (mm hour⁻¹), but for the analysis of the behavior it was done by daily scale (mm day⁻¹).

Researches in the moorland (Buytaert, Iñiguez, Celleri, De Bièvre, Wyseure y Deckers, 2006; Guzmán *et al.*, 2015) determined K_c values of 0.42 for natural conditions of the ecosystem, with homogeneous vegetation and with relatively low intervention by agriculture and livestock; and records of K_s of 1 indicating soil moisture content on field capacity close to saturation point; peculiarity found in the moors of the region.

2.2.4 Flow

For the flow measurement a thin-walled, triangular and rectangular, combined section was built and an automatic level instrument Northwest (INW) PT2X mark was installed, which accumulated data every five minutes (Torres, 2016) from January 1st 2014 to April 30, 2015. The data was transformed to flow by applying the relation Sotelo Avila (1974) for the triangular section and the Kindsvater y Carter (1957) for the rectangular section with the information of the height measurements of the water level that relates the pressure of the water column above the zero point of the landfill and the atmospheric pressure, and considering the dimensions of the hydraulic infrastructure.

With the information processed, the base stream of the storm flow was separated, based on the numerical algorithm of the two parameters proposed by Chapman (Chapman, 1999); with a two-day recession and elaborated on the basis of a digital filter at daily level (Ochoa-Tocachi *et al.*, 2016).

2.2.5 Water balance

The general equation (Equation 2) applied to the moorland ecosystem was used to calculate the annual water balance. (Buytaert, Iñiguez, Celleri, De Bièvre, Wyseure y Deckers, 2006; Guzmán *et al.*, 2015), and adapted to the characteristics of the area.

$$P = E + ETr + Q + \frac{ds}{dt} + L \quad (2)$$

Where P is the precipitation in mm, E represents the amount of water intercepted by vegetation and evaporated directly from the canopy in mm, which for the moors areas is relatively low (Tobón y Gil Morales, 2007) and according to (Buytaert, Célleri, De Bièvre, Cisneros, Wyseure, Deckers y Hofstede, 2006) this term can be excluded in the equation. ETr is the current evapotranspiration (mm), Q represents the basin flow in mm, L refers to the deep percolation in mm and ds/dt describes the change in soil moisture content in mm and according to Torres (2016) for Jatunsacha is equal to or near zero, affirmation corroborated by Buytaert, Célleri, De Bièvre, Cisneros, Wyseure, Deckers y Hofstede (2006) in a study carried out in a moorland microwatershed in the southern Ecuador.

3 Results and discussion

3.1 Temporal variability of rain

The annual rainfall for the study basin was 840.2 mm, with October being the wettest month with 145.8 mm and February the driest with 17.5 mm. The results in this study are consistent with the information reviewed in the bibliography, referring to rainfall records varying between 700 mm and 3

000 mm for the South American moors (Buytaert, Iñiguez y De Bievre, 2007; Buytaert, Iñiguez, Celleri, De Bièvre, Wyseure y Deckers, 2006; Celleri *et al.*, 2007; Crespo *et al.*, 2011; Tobón y Morales, 2007).

The annual cycle presented a bimodal distribution (Figure 2) with four marked periods: 1) Two rainy seasons that began from March to May and a second concentrated in the month of October; 2) Two dry periods that presented in the months of December, January, July and August; 3) The transition from dry to humid comprising the months of February and September and 4) the transition from wet to dry which includes the registers of June and November.

Several authors (Villacís, 2008; Vuille, Bradley y Keimig, 2000) explain that the behavior of precipitation at intra-annual scale in the basin under study is influenced by moist air masses from the Amazon basin, by the movement of the Intertropical Convergence Zone ITCZ, and by the Influence of El Niño-oscillation of the South (ENSO) in its two phases (El Niño and La Niña). Additionally, (Villacís, 2008) mentions in the research that the rainfall values, especially of the watersheds located in the west of the Antisana, suffer a decrease due to the "screen effect" of the volcano, which acts as a natural barrier for the masses of humid air originating in the Amazon.

3.2 Characterization of the precipitation events

During the study period, 819 events were recorded with rainfall amounts ranging from 0.1 mm to 8.9 mm, with durations from 5 min to 452.75 min and intensities between 0.21 mm h⁻¹ to 3.6 mm h⁻¹. The rainy season presented the largest number of events with 362 and the broadest range in the amount of rainfall. The transition from dry to humid recorded the least number of events (112), and ranges with low length in the variables duration and intensity. In the dry period were recorded 221 events with the shortest range in amount of rainfall; finally the transition from wet to dry defined by 124 events presented the highest range in duration (Table ⁻¹).

Table 1. Characteristics of rainfall event for dry, rainy periods, dry to wet transition and wet to dry transition.

Period	Event frequency	Quantity (mm)*	Duration (min)*	Intensity (mm h ⁻¹)*
Dry	221	0.1 – 6.5	5 – 332.5	0.2 – 2.76
Rainy	362	0.1 – 10.69	5 – 499.75	0.22 – 3.6
Transition Dry - Wet	112	0.1 – 8.9	5 – 323.6	0.32 – 3.4
Transition Wet - dry	124	0.1 – 8.3	5 – 543.5	0.2 – 4.5
Complete period	819	0.1 – 8.9	5 – 452.75	0.21 – 3.6

* The range formed by the 2.5 percentile and the 97.5 percentile were used as upper and lower limits taken from the probability distribution function of each variable.

Analyzing the proposed periods (Table reftabla1) a seasonal precipitation trend is not observed, these statements are consistent with what was expressed by (Celleri *et al.*, 2007), referring that the rain on the moors in southern Ecuador does not concentrate in the humid season. On the other hand, the results show an increase in the number of events and the variable quantity for the rainy season, and although the process cannot be explained with certainty, it may be related to the existence of two rainfall patterns different in the year, which generate the bimodality suggested by the entry of humid air from the Amazon basin and the Pacific coastal region (Villacís, 2008; Vuille, Bradley y Keimig, 2000).

Based on the results and the revised bibliographic (Buytaert, Céleri, De Bièvre, Cisneros, Wyseure, Deckers y Hofstede, 2006; Celleri *et al.*, 2007; Tobón y Arroyave, 2007) The rainfall of the investigated basin is characterized by presenting 819 events, short duration (5 minutes - 7.5 hours), low volume (0.1 mm - 8.9 mm) and low intensity (0.21 mm h⁻¹

- 3.6 mm h⁻¹), typical of the rainfall distribution in the Neotropical moors.

3.3 Variabilidad temporal de la humedad del suelo

Temporal variability of the soil humidity

Soil moisture on the horizon A (Figure 3), at a daily scale for the study period presented two seasons of maximum moisture content on May 12, 2014 and November 11, 2014 with 0.74 cm³ cm⁻³ and 0.73 cm³ cm⁻³, respectively, causing the humidity to be close to saturation point (0.75 cm³ cm⁻³). Its lowest peak was recorded on January 16, 2015 with a value of 0.51 cm³ cm⁻³ which generated the soil moisture curve to decrease below the field capacity (0.6 cm³ cm⁻³). This trend was presented in four additional periods corresponding to September 13, 2014, February 7, 2015, February 23, 2015 and March 13, 2015.

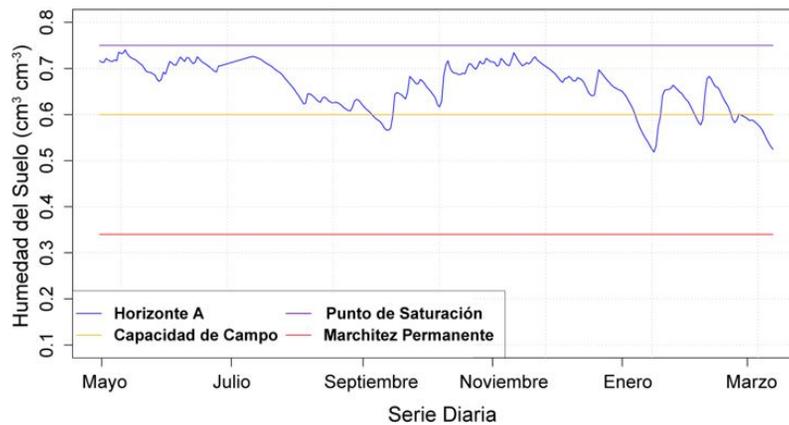


Figure 3. Daily dynamics of soil moisture on the surface Horizon A.

Soil moisture in the superficial horizon showed a very dynamic behavior even higher than the 2Ab horizon, due to the impact of frequent rainfall, evapotranspiration and high root content in the first centimeters of soil that generate preferential flows (Blume, Zehe y Bronstert, 2007; Buytaert, Celleri, Willems, De Bievre y Wyseure, 2006; Hofstede, 1995). Out of the 304 days monitored, it was observed that in most of the period, 85% of daily data, the records were on field capacity (Figure 3). Additionally, if considering the depth of horizon A (21.3 cm), its storage potential would be 108.6 mm to 156.5 mm. According to these results, the surface horizon has great water retention capacity, characterized by its strong structure, high porosity (72.4%), low apparent density (0.64 Mg m^{-3}) and high content of organic matter (11.9%) typical of Andisols (Nanzoyo, Shoji y Dahlgren, 1993; Buytaert, Iniguez

y De Bievre, 2007).

The dynamics of the horizon 2Ab present more stable values between the field capacity ($0.56 \text{ cm}^3 \text{ cm}^{-3}$) and saturation point ($0.68 \text{ cm}^3 \text{ cm}^{-3}$) (Figure 4), with a peak that originated on November 11, 2014 of $0.65 \text{ cm}^3 \text{ cm}^{-3}$. The lowest point of the daily soil moisture curve was presented on March 13, 2015 with a record of $0.58 \text{ cm}^3 \text{ cm}^{-3}$, higher than the one found in the lower peak of the surface horizon ($0.51 \text{ cm}^3 \text{ cm}^{-3}$). The high water content in the 2Ab horizon is mainly due to the low apparent density with 0.70 Mg m^{-3} , high porosity of 68.36% and high organic matter content with 5.8% (Nanzoyo, Shoji y Dahlgren, 1993; Buytaert, Deckers y Wyseure, 2007); that allows a storage capacity between 365.4 mm and 326.43 mm when considering a depth of the 2Ab horizon of 55.8 cm.

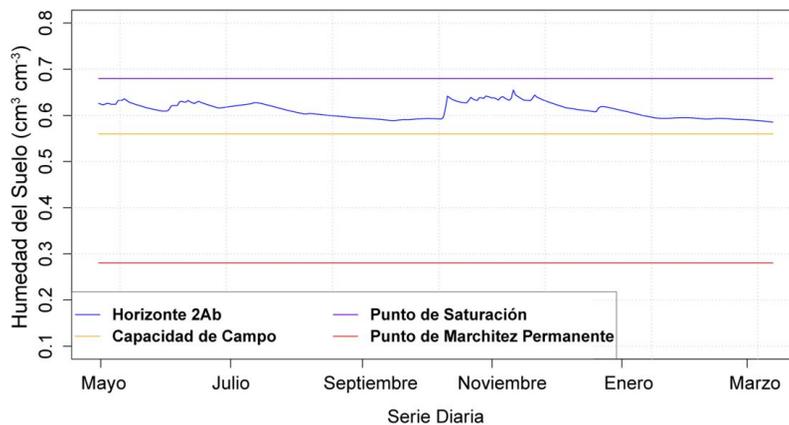


Figure 4. Daily dynamics of soil moisture on the 2Ab horizon.

3.4 Real evapotranspiration at the basin level

The annual ETr calculated for the Jatunsacha basin was 237.66 mm, with a daily average of 0.65 mm day⁻¹ and with records between 0.28 mm day⁻¹ to 1.04 mm day⁻¹, which correspond to the lower and upper limits of the probability distribution of the data. Its behavior was stationary for the analysis period, showing extreme values of 1.68 mm day⁻¹ in the first days of January 2014 and minimum 0.07 mm day⁻¹ in June 2014 (Figure 5).

The relatively low values found in the real evapotranspiration parameter (Figure 5) for the basin under study, which is part of the Antisana moorland, agrees with the reports for the moorlands of the region, with variations between 0.6 mm day⁻¹ to 2.2 mm day⁻¹ (?Buytaert, Céleri, De Bièvre, Cisneros, Wyseure, Deckers y Hofstede, 2006; Favier *et al.*, 2008); and its behavior depends on

the meteorological conditions (Allen *et al.*, 1998), morpho-physiological characteristics of the vegetation (Cleef, 1981; Hofstede, 1995; Buytaert, Céleri, De Bièvre, Cisneros, Wyseure, Deckers y Hofstede, 2006) and the water content in the soil (Figure 3 and Figure 4).

Los valores relativamente bajos encontrados en el parámetro evapotranspiración real (Figura 5) para la cuenca en estudio que forma parte de los páramos del Antisana concuerda con los reportes para los páramos de la región con variaciones entre 0,6 mm día⁻¹ a 2,2 mm día⁻¹ (?Buytaert, Céleri, De Bièvre, Cisneros, Wyseure, Deckers y Hofstede, 2006; Favier *et al.*, 2008); y su comportamiento depende de las condiciones meteorológicas (Allen *et al.*, 1998), características morfofisiológicas de la vegetación (Cleef, 1981; Hofstede, 1995; Buytaert, Céleri, De Bièvre, Cisneros, Wyseure, Deckers y Hofstede, 2006) y al contenido de agua en el suelo (Figura 3 y Figura 4).

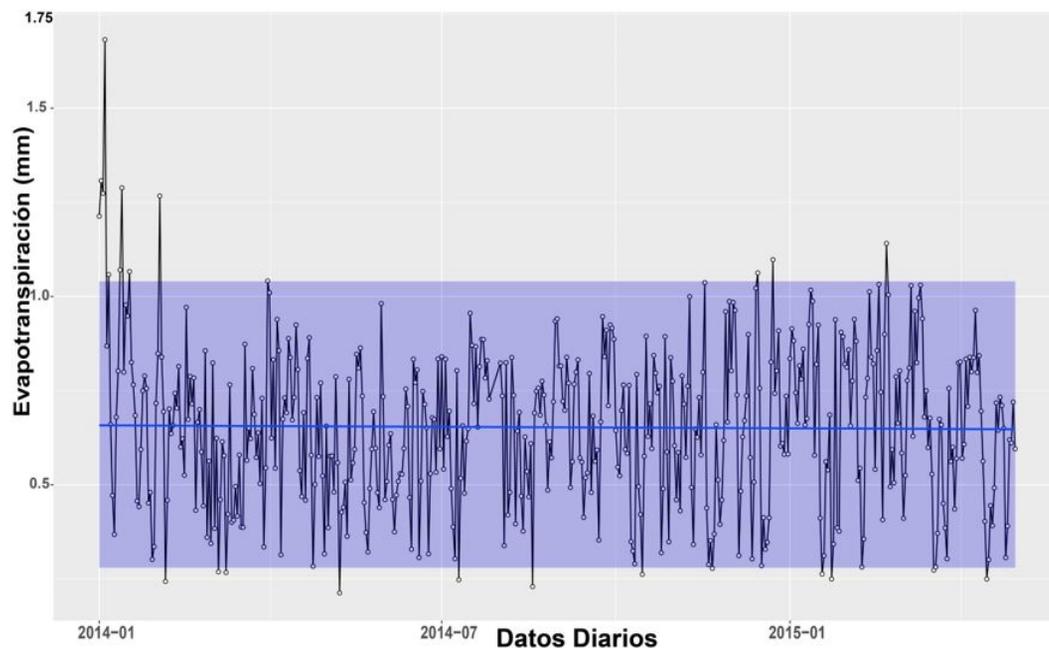


Figure 5. Temporal behavior of real evapotranspiration.

3.5 Temporal behavior of the flow and its components

The results of the flow time series show an annual value of 89.20 mm, i.e. an average daily flow of 5.6 L s⁻¹, formed by two components the base flows

and runoff. The hydrological response in Jatunsacha moorland describes a dynamic behavior, with a maximum peak of 88.13 L s⁻¹ on October 11, 2014 and with a low record of 0.39 L s⁻¹ on February 21, 2016 (Figure 6); which depends on the presence of constant rainfall (Table 1); high water storage soil

capacity with registers (>80%) between the field capacity and the saturation point (Figure 3 and Figure 4), Low evapotranspiration (Figure 5) and high infiltration capacity (Buytaert, 2004; Buytaert, Iñiguez,

Celleri, De Bièvre, Wyseure y Deckers, 2006; Buytaert, Celleri, Willems, De Bievre y Wyseure, 2006; Sarmiento, 2000).

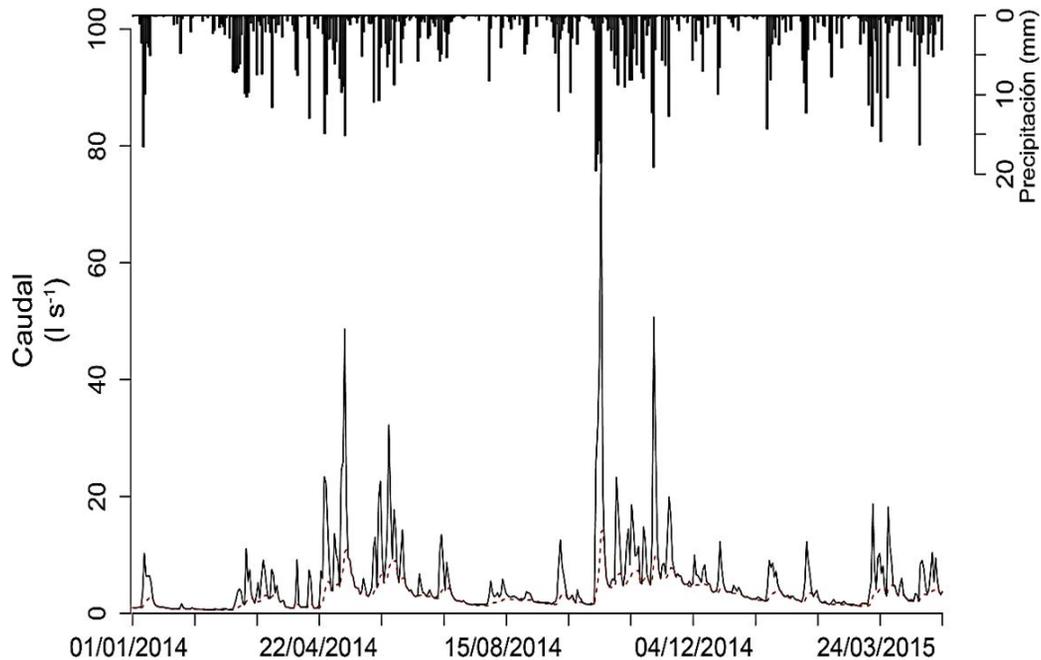


Figure 6. Temporal behavior of the base and storm flows at a basin scale with moor cover.

The base flows, which in the mountain ecosystem represent the capacity of water regulation, for the basin under study is relatively high (60%), with an average value of 3.4 l s^{-1} ; allowing a constant water flow especially during drought periods (Hofstede *et al.*, 2003; Buytaert, Celleri, De Bièvre, Cisneros, Wyseure, Deckers y Hofstede, 2006; Buytaert, Celleri, Willems, De Bievre y Wyseure, 2006). On the other hand, results of the flow time series present an average surface runoff record of 2.2 L s^{-1} , which implies a contribution of 40% to the total flow and is generated by superficial saturation flow (Chow, 1996) that occurs when the subsurface water content saturates the soil from lower layers, contributing significantly to effective precipitation; statement corroborated by investigations carried out in

the southern of Ecuador (Buytaert, Iniguez y De Bievre, 2007; Crespo *et al.*, 2011).

3.6 Water balance

The annual water balance in Jatunsacha presents estimates for precipitation input of 840.24 mm and output flows by evapotranspiration of 237.66 mm (Table 2) and flow rate of 89.20 mm, which implies a runoff coefficient of 10.6%; being this measure the water yield of the basin that for Jatunsacha was relatively low; data that is similar to the rank found in the investigation of Ochoa-Tocachi *et al.* (2016) for moor basins located in the Antisana and Pichincha Volcanoes with percentages from 8% to 13%.

Table 2. Annual water balance in the Jatunsacha basin.

Parameters	Values (mm)	Precipitation percentage (%)
Precipitation	840.24	
Flow	89.20	10.6
Real evapotranspiration	237.66	28.3
Deep percolation	513.38	61.1

With the precision instrumentation installed and with the quality information processed in each of the parameters of the annual water balance analyzed, the loss of water by deep percolation for recharge of aquifers was quantified based on the general equation; projecting a record of 513.38 mm that represents 61.1% of the precipitation (Table 2), being the main parameter that generates output flow of the system, and this is apparently generated by the porous geostructures in the area (Coltorti y Ollier, 2000).

4 Conclusions

The behavior of the parameters that integrate the hydrological dynamics in the Jatunsacha moorland basin are characterized by a) precipitation with a non-stationary annual trend, describing a bimodal behavior with frequent rain events with low intensity and volume; b) by a moisture content in the soil between the field capacity and the saturation point related to the high content of organic matter, high porosity, and low apparent density; c) by a relatively low evapotranspiration with a very stationary dynamic, d) by a constant flow formed by a base flow that contributes to 60% of the flow and by a runoff flow that implies a contribution of 40% to the flow. Similarly, the area under study presents a e) relatively low runoff coefficient and f) high percolation due to the presence of porous geostructures.

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