International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2019): 7.583

Ecological Condition and Animal Carrying Capacity of Andean Grassland in Three Micro-Basins of the Quero District, Jauja

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Abstract: ***The Andean grassland ecosystems constitute 32% of the surface of the Peruvian highlands, benefiting 5000 rural communities, integrated by rural families in a situation of poverty and extreme poverty. These ecosystems experience degradation processes in their structure and function, which has motivated the evaluation of the ecological condition and the animal carrying capacity of the grassland ecosystems in three micro-basins in the district of Quero (Yananya, Huajaco and Ijira), province of Jauja. The micro-basins were subdivided into three parts: upper part, meddle part and lower part, for the purposes of the evaluation. The floristic evaluation was carried out using the Parker modified step transection method. A floristic composition was found that included 17 families, 21 genera and 35 species of natural grasses, dominated by Aciachnepulvinata, Calamagrostiscurvula, C. rigida, Stipamucronata and S. brachyphylla. No difference was found between micro-basins, but between their parts for p = 0.05. It was concluded that the grassland ecosystem is very degraded which reduces its ecological condition and animal carrying capacity.***

Keywords: floristic composition, ecological condition, animal carrying capacity, Andean grassland

1. Introductión

The Andean grassland ecosystems in Peru constitute 32% of the surface of the sierra (equivalent to 14.3 million ha) and 84% of them benefit 5,000 peasant communities, integrated by peasant families in extreme poverty (Ventura 2003). On the other hand, more than 60% of these ecosystems are in a process of degradation to the point of observing areas in process of desertification (Pignataro et al., 2017). These processes lead to the loss of grassland areas, caused by different factors such as overgrazing, climate change, fire and land use change (Paredes & Escobar-Mamani, 2018; Ingrisch et al., 2018).

In this context, it has been observed that grasslands in the Quero - Jauja district are being degraded mostly by anthropic action (Scotton, 2019), through the overuse of the natural grassland resource (Plieninger&Huntsinger, 2018) aggravated by the effect of climate change (Estrada, Cárdenas, Ñaupari, &Zapana, 2018). This process of degradation directly affects biodiversity, which in the case of the rural population means a decrease in the species of grass preferred by livestock (Yaranga, 2019) and an increase in temporary invasive species that are not useful for feeding livestock, mainly in dry areas (Wairore, Mureithi, Wasonga, & Nyberg, 2015), as is the case of the micro-basins of the Quero River. These degradation processes affect the decline of the ecological condition in relation to the species of historical climate, therefore, the animal carrying capacity of grassland ecosystems is reduced in an alarming way, to the point of irreversibility (Albert et al., 2019); as an additional effect of soil erosion that, incapacitates the soil to fulfill its function of nutritional support for plants (Wang, Deng, Song, Li, & Chen, 2017).

Thus, several authors have expressed the importance of having a database and monitoring changes in floristic composition, the health of grassland ecosystems and the ecosystem services they provide to humanity (Briske, 2017; Wiesmair, Otte, & Waldhardt, 2017; Bremer et al, 2019); however, studies on Andean grassland ecosystems are still very scarce (Wang et al., 2017), suggesting more studies on floral richness and diversity (Auffret, Kimberley, Plue, &Waldén, 2018) and, considering the spatial-temporal heterogeneity of the various areas, whether regional or local (Jung, Gaviria, Sun, &Engelbrecht, 2020). Within the framework of these considerations, the research aimed to evaluate the ecological condition and the animal carrying capacity of grasslands in three micro-basins in the district of Quero, in the province of Jauja.

2. Material and Methods

Location of the studio

The study area is located at the head of the Quero River micro-basin in the district of Molinos, province of Jauja and department of Junín, between 3850 and 4481 meters of altitude that extends the Andean grassland ecosystem in an area of 5447 ha, between the coordinates, latitude 11°39'25.48" S and longitude 75°22'59.11" W (Figure 1). There are several lakes in the area: Yanacocha, Suerococha, Quiullacocha, Rachacmachay, Machocancha, and Desmiro, which are the tributaries of three micro-basins that flow into the Quero River, with 1153.13 ha, 1546.95 ha, and 2700.08 ha respectively. The climate in the area is characterized by temperatures that vary between 3°C and 17°C, which fluctuate between night and day, and an average annual rainfall of between 970 and 1015 mm.

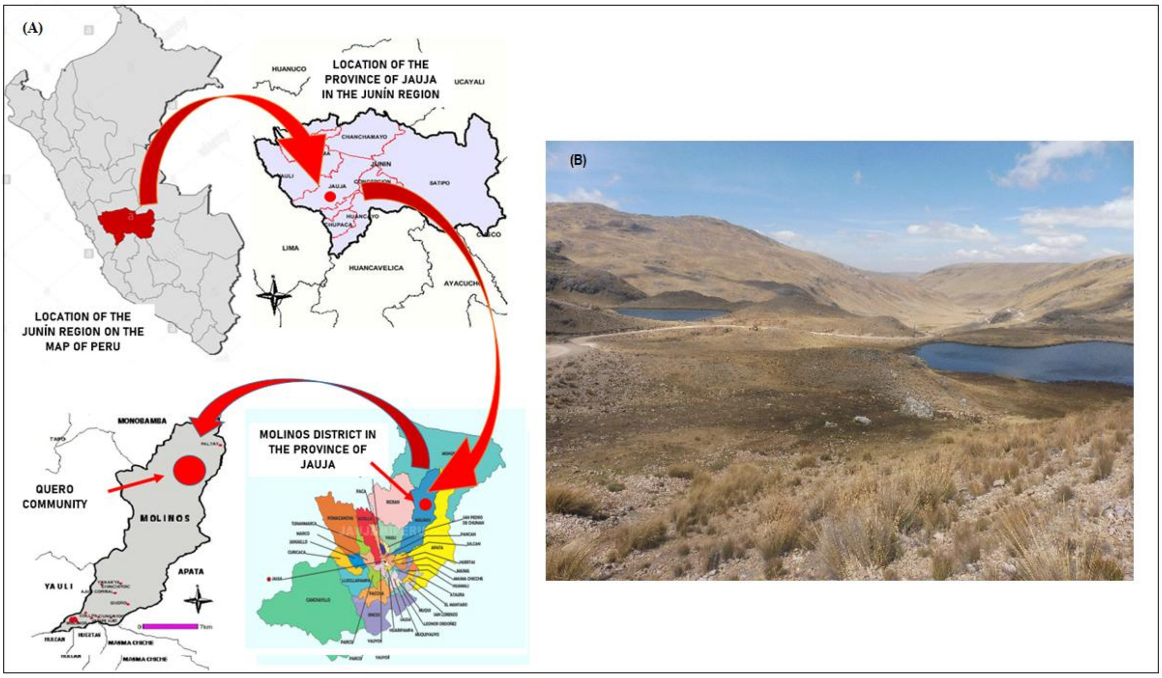

Figure 1: (A) map of the location of the study area in the district of Quero, respect to the region and province of Jauja, (B) photograph of the grassland ecosystem

Data collection

The area occupied by natural grassland between 3900 and 4600 meters above sea level, was segmented according to natural geomorphological formation into three micro-basins and within them three areas of interest considered as high, meddle and low: Huajaco (4510, 4485 and 4450 metres); Ijira (4522, 4515 and 4495 m) and Yananya (4444, 4396 and 4185 m). In a previous tour to the evaluation area, the evaluation points were determined by recording the coordinates using GPSmap Garmin 64s. Samples of natural grass species were also collected and identified by an expert professional in the laboratory of the Centro de Investigaciónen Alta Montaña of the Universidad Nacional del Centro del Perú.

Three species inventories were applied at each evaluation point, using the "transect to pass" method as recommended by Flores and Malpartida (1987). The plant species, mulch, moss, rock and bare soil were recorded and included inside a metal census ring with a 20 mm span attached to a 1-meter long handle. The censorial ring was applied every two steps in a straight line called a transect, until 100 points were recorded on a field card designed for this purpose.

Determining the floristic composition

For this purpose, the table organized in an Excel sheet was used, in which a general table with a double-entry matrix was organized: the species and objects recorded in lines and the transects with the number of records in columns. From this table, the species with the average number of individuals recorded were extracted in another table, according to species by genus and genus by family, with which pie charts and columns were obtained in the same Excel sheet.

Determining the ecological condition and the animal carrying capacity

From the general table, the desirable and undesirable vascular species for sheep were extracted, making the sum of individuals of each determined species, together with the sum of the elements the score of ecological condition was automatically calculated by means of the mathematical formula of Flores (1993) below:

$$\text{Score} = 0.5\ (ED) + 0.2\ (IF) + 0.2\ (BOC) + 0.1\ (IV)$$

Where:
ED: Number of desirable species.
IF: Number of desirable species plus undesirable species.
BOC: Number of points covered or the difference between the total points minus the number of bare soil and rock recorded.
IV: Ratio in percent of the height of the dominant species to its optimum growth.

The ecological condition was determined by comparing the score obtained, with the ranges established in a table elaborated by Flores and Malpartida (1987) who considered: 81 to 100 points for excellent condition, 61 to 80 good, 41 to 60 fair, 21 to 40 poor and less than 20 very poor.

The animal carrying capacity was determined by applying the ecological condition to another table that refers to the number of reference livestock units per hectare per year, which varies according to the animal species of interest.

Data analysis

From the table constructed for ecological condition and animal carrying capacity, another CSV table was generated in the same Excel sheet, with which the hypotheses of equal condition and carrying capacity were contrasted, analyzing with the free software Rstudio v 3.5.2, by means of the "Generalized Mixed Linear Model", because the distribution of data with many zeros, as is the characteristic of ecological studies, does not facilitate obtaining normal data distribution. The model used according to Bandera & Pérez, (2018) was:

$$Y = Xb + Zu + e$$

where:
Y represents the response vector (data), X and Z to the design matrices, b as the vector of fixed parameters, u (random effects) and e to the non-observable random vectors (error), considering u and e with a zero value.

3. Results

Floristic composition

The floristic composition of the grassland found in the dry season, for the level of the district was constituted by 17 families 21 genera and 35 species (Figure 2-a) of which, the family Poaceae was the most important due to the greater number of genera and with the contribution of 25% of species mainly *Aciachnepulvinata*, *Calamagrostiscurvula*, *C. vicunarum*, *C. brevifolia*, *Stipamucronata*, followed by the family Asteraceae that contributed with 12% of vascular species mainly with *Hypochoeristaraxacoides*, then the family Cyperaceae. At micro-basin level, the greatest number of families was found in Ijira (37%); however, the greatest number of genus (42%) and species (41%) were observed in the Yananaya micro-basin (Figure 2-b), followed by Ijira, finally the Huajaco micro-basin behaved as the micro-basin with the least wealth (28% of families, 23% of genus and 24% of species.

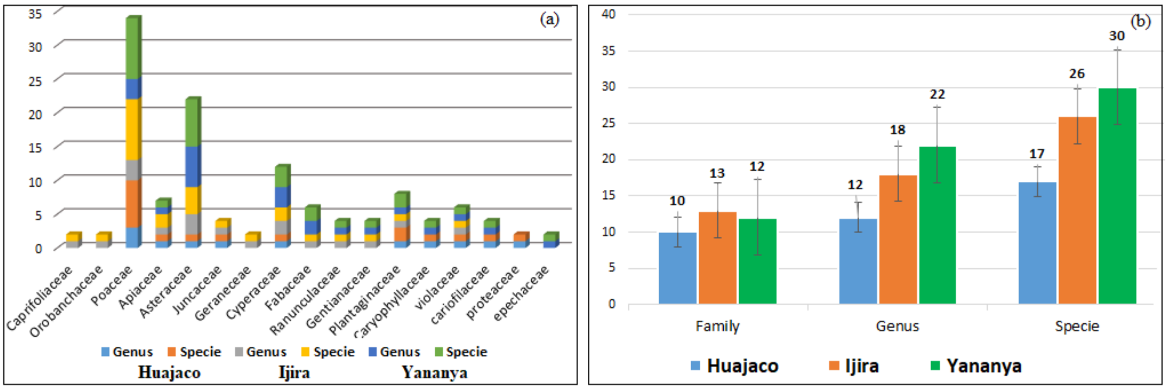

Figure 2: Distribution of the number of species by genus and number of genera by families, in the micro basins: Huajaco, Ijira, Yananya

At the level of the parts of the micro-basin, the floristic composition observed in the highest part: Huajaco at 4510, Ijira at 4522 and Yanango at 4444 meters of altitude respectively, turned out to contain lesser richness (Figure 3) between six and 12 vascular species, with the dominance of the *Aciachepulvinata* in the first micro-basin, due to the high degradation and 64% of plant cover; the domain of *Calamagrostiscurvula* in the second one due to the presence of large humid spaces, and therefore its vegetable cover was 89%; the domain of Calamagrostisvicunarum and a cover of only 53% in the third one, due to its drier characteristic with soils with greater stoniness (23%). In the intermediate part of the micro-basins, the richness of between 12 and 19 species increased, continuing the dominance of *A. pulvinata* domain in the first micro-basin (4485 m) in spite of 95% vegetation cover, due to degradation caused by permanent overgrazing; the *Stipamucronata* domain in the second (4515 m) with 90% vegetation cover and the domain of the same species in the third (4392 m) with 98% coverage, due to the similar geomorphological and dry condition of the previous one; while in the lower part of the micro-basins there were between 13 and 16 vascular species, with the dominance of *Calamagrostisrigida* and a cover of only 43% due to the high animal carrying due to its proximity to the center of the population and the most stony soils (43%); the dominance of C. domain curves due to the softer topography, with 52% coverage caused by overgrazing; and the *Stipabrachyphylla* domain with 96% coverage. On the other hand, it was observed that the greatest wealth was concentrated in the intermediate part of the micro-basin, which has fewer altitude limitations and is characterised by poorer soils and a harsher micro-climate, with a lower animal carrying than in the lower part, which is closer to the population centers.

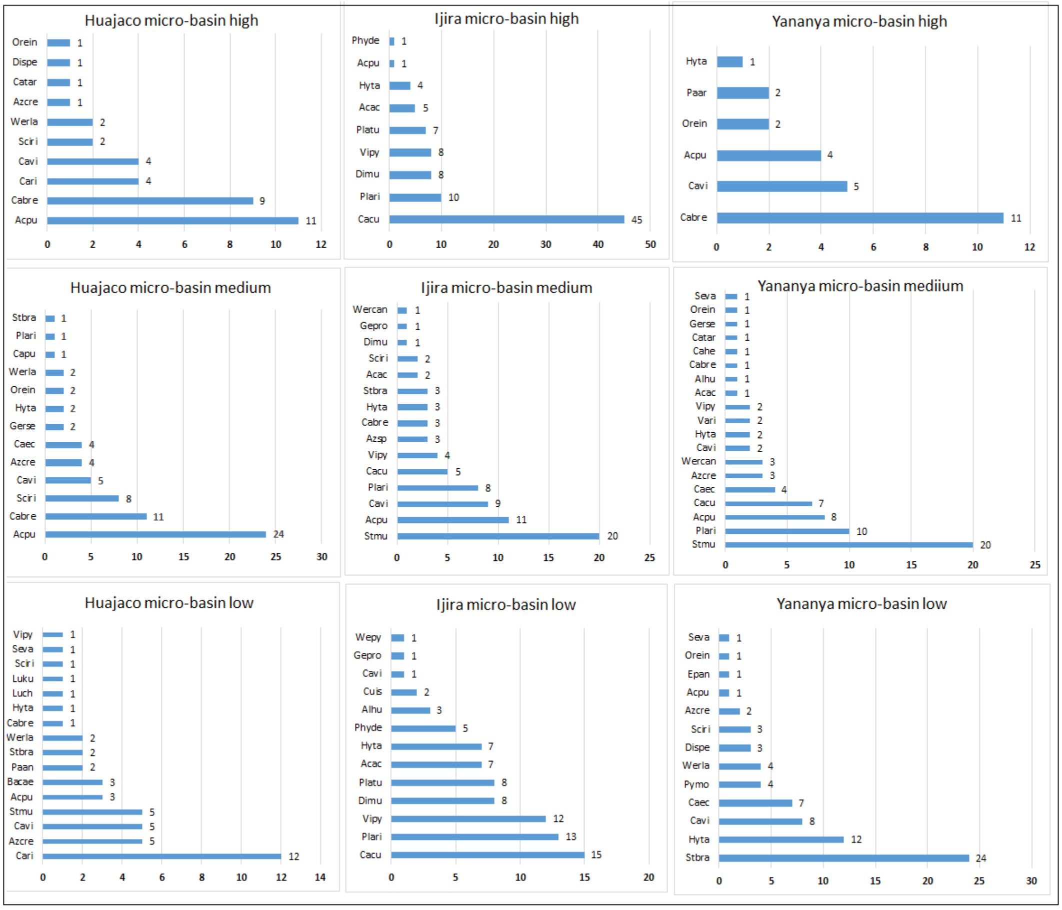

Figure 3: Altitudinal comparison of the floristic composition of the micro-basins: Huajaco, Ijira and Yananya in the district of Quero

Ecological condition and animal carrying capacity

The comparison between micro-basins was no different for p = 0.05, even though the Huajaco micro-basin showed the very poor condition in its upper and lower parts, which reached a very low score of 18.2±6.56 and 15.1±2.86, as well as the regular condition (48.1±10.34) in the lower part observed in the Yananya micro-basin (Table 1). On the other hand, it was found that the animal carrying capacity varied between 0.19±0.12 Units Sheep per hectare year (US ha^{-1} $year^{-1}$). This variation is explained by the conditions of the place already exposed in the previous item.

However, the comparison between the upper, middle and lower parts of the micro basins, a significant difference was observed for p = 0.05 (Figure 2), in which the lower and middle parts are in better ecological conditions, and therefore also have a higher animal carrying capacity.

Table 1: Ecological condition and animal carrying capacity for sheep, according to parts of the micro basins:

Micro-basin	Micro-basin part	Condition score	Ecological condition	Animal carrying capacity
Huajaco	upper part	18.2±6.56	Very poor	0.23±0.16
	middle part	27.7±4.31	Poor	0.42±0.29
	lower part	15.1±2.86	Very poor	0.19±0.12
Ijira	upper part	37.5±1.48	Poor	0.66±0.03
	middle part	36.6±2.04	Poor	0.64±0.025
	lower part	34.6±1.32	Poor	0.59±0.032
Yananya	upper part	20.8±13.67	Poor	0.28±0.29
	middle part	33±9.78	Poor	0.55±0.33
	lower part	48.1±10.34	Regular	0.86±0.28

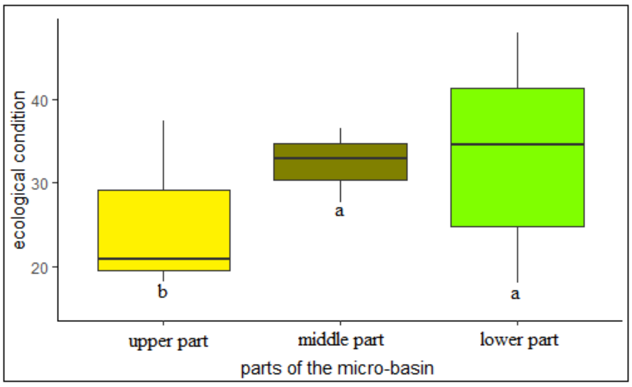

Figure 4: Comparison of the ecological condition between the upper, middle and lower parts of the Huajaco, Ijira and Yananya micro-basins in the district of Quero

4. Discussion

4.1 Floristic composition

The variation in floristic composition between micro-basins was based on the capacity of natural grass species to survive the scarcity of rainfall for long periods (Carlyle, Fraser, & Turkington, 2014), the physical-chemical characteristics of the soil, the slope and orientation of the hillside (Alichaev, Kaziev, &Sultanova, 2020) and the local microclimate conditions (Oijen, Bellocchi, & H glind, 2018), which varied between the Huajaco, Ijira and Yananyamicrobasins; Thus, the presence of lagoons and fogs due to their orientation towards the east of the Yananya micro-basin, which comes into contact with the fogs coming from the tropical forest, favored the humidity of the soil and therefore, the presence of greater richness, contrary to the situation of the Huajaco micro-basin, which presents drier, stony soils with eastern slopes towards the west, which did not allow greater richness or early death of the plants that were considered as mulch at the time of the evaluation. Another very important factor that intervened in the variation of the floristic composition was the way in which the natural grassland resource was used by the cattle families, which carry out the shared grazing (Pignataro et al., 2017; Ingrisch et al., 2018), which generates the overuse or overgrazing that affects the stability of the most vulnerable species to the grazing (Mudongo, Fynn, &Bonyongo, 2016).

The greater importance of the Poaceae and Asteraceae families is based on the ecological niche of the species that for their development of historical climax on geographical spaces with cold mountain climates abruptly changing between day and night, prolonged periods of drought, poor soils (Andrade et al., 2015; Hinojosa, Napoléone, Moulery, &Lambin, 2016; Silva Mota et al., 2018). Among some reports on Andean floristic composition in Peru, we have de Alegria (2013) who, in the community of Rancas (Pasco), found a predominance of the Asteraceae family (18.52%) and Poaceae (16.67%) over a plateau morphological space and the presence of wetlands,

4.2 Ecological condition and animal carrying capacity

The variation in the ecological condition of the rangelands is primarily due to local soil characteristics and rainfall (Wang et al., 2017), in fact, the difference in the soil in the lower and middle parts, which differ from the upper part of the micro-basins due to greater stoniness and steep slopes that make the soil very prone to erosion phenomena (Ali et al, 2017; Van Oijen, Bellocchi, & H glind, 2018), were the determining factors in differentiating the vigour and specificity of the species that finally determined a more degraded ecological condition in the upper parts. Likewise, the presence of soils favoured by the presence of lagoons that allow the presence of humid soils as is the case of the Ijira micro-basin where there were soils with greater plant cover, which is also another of the causes for a better vegetative condition.

Another cause of the variation in the ecological condition of the grassland observed was overgrazing, that is, the permanent application of grazing with high animal carrying (Arjumend, 2018) by the livestock families in the area, who share the grazing areas, which does not facilitate planned exploitation or rotational grazing, with a population of 2561 sheep, 286 camelids and 48 cattle, according to the records of the Quero Rural Community for the year 2018 in only 3964.60 ha. While it is true that atropogenic actions are the most important causes of the degradation of the ecological condition, it is also no less important the effect of climate change, due to the variation in temperature and precipitation patterns (Muñoz, 2017), of which the locals feel that precipitation occurs in less and less time and the temperature presents greater extremes in recent times, reasons that would also be affecting the development and persistence of plants during the year (Norton, Malinowski, &Volaire, 2016). Among some authors who reported on the ecological condition of Andean grasslands, they indicate that the ecological condition is decreasing (Estrada et al., 2018), and they coincide in their location with similar characteristics to the study area.

The animal carrying capacity in natural ecosystems is supported only by primary production, which depends on the vigor of plants and the species of grasses (Getabalew&Alemneh, 2019; Yaranga, 2020). These factors are also dependent on the characteristics of the local soil and climate, which have already been addressed; however, the high animal carrying capacity that is applied in the three micro-watersheds studied, reveals that it is decreasing at the same rate as the ecological condition (Getabalew & Alemneh, 2019). This situation of observing a very low carrying capacity means that the degradation of the grasslands is also compromising the sustainability of the livestock activity, whose chain ends in the impoverishment of the rural population, especially the livestock families of Quero. Among the latest reports on animal carrying capacity in Andean grasslands in Peru, we have Estrada et al. (2018) who in the Cusco region found an average carrying capacity of 0. 75 Andean camelid units per ha/year (*Vicugnapacos*) indicating that the regular condition of the grassland was in the process of degradation, which coincides with the degradation, but in better ecological condition than in Quero, another in the Huaraz de Vega region (2016), who found between 0.3 and 1.3 UO ha/year, which partly coincides with the result obtained, depending on the soil moisture of the study areas.

5. Conclusion

The study reveals that the floristic composition of the Andean grassland ecosystem varies according to the altitudinal gradient and the slope orientation as a geomorphological aspect which in turn affects the microclimate variation and the soil characteristics, which together with the way of use applied by the livestock families, are determinant in the ecological condition, the floristic richness and the importance of the species in particular.

6. Recognition

The authors would like to express their gratitude to the communal authorities and livestock families settled in the three micro-watersheds studied, which allowed the entry into their territory and the development of the field assessments carried out.

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Appendix

Table 2: Natural grass species in three micro-basins in the Quero district during the dry season

HUAJACO micro-basin		IJIRA micro-basin		YANANYA micro-basin	
Acac	*Aciachneacicularis*	Acac	*Aciachneacicularis*	Acac	*Aciachneacicularis*
Acpu	*Aciachnepulvinata*	Acpu	*Aciachnepulvinata*	Acpu	*Aciachnepulvinata*
Azcre	*Azorellacrenata*	Haum	*Haleniaumbellata*	Haum	*Haleniaumbellata*
Cabre	*Calamagrostisbrevifolia*	Azcre	*Azorellacrenata*	Azcre	*Azorellacrenata*
Cacu	*Calamagrostiscurvula*	Azsp	*Azorellasp*	Cacu	*Calamagrostiscurvula*
Caec	*Carexecuadorica*	Cabre	*Calamagrostisbrevifolia*	Caec	*Carexecuadorica*
Capu	*Castillejapumila*	Cacu	*Calamagrostiscurvula*	Cavi	*Calamagrostisvicunarum*
Cavi	*Calamagrostisvicunarum*	Caec	*Carexecuadorica*	Cuis	*Cuatrecasasiellaisernii*
Dimu	*Distichiamuscoides*	Cahe	*Calamagrostisheterophylla*	Dimu	*Distichiamuscoides*
Gerse	*Geranium sessiliflorum*	Capu	*Castillejapumila*	Dispe	*Disantheliumperuvianum*
Luch	*Lupines chlorolepis*	Catar	*Calamagrostistarmensis*	Epam	*Ephedra americana*
Luku	*Luciliakutiana*	Cavi	*Calamagrostisvicunarum*	Gepro	*Gentian prostrata*
Hyta	*Hypochoeristaraxacoides*	Dimu	*Distichiamuscoides*	Hyta	*Hypochoeristaraxacoides*
Orein	*Oreithalesintegrifolia*	Gepro	*Gentian prostrata*	Orein	*Oreithalesintegrifolia*
Paar	*Paronychia argentea*	Gerse	*Geranium sessiliflorum*	Phyde	*Phyllocirpusdeserticola*
Phyde	*Phyllocirpusdeserticola*	Hyta	*Hypochoeristaraxacoides*	Paan	*Paronyhiaandina*
Plari	*Plantagorigida*	Orein	*Oreithalesintegrifolia*	Plari	*Plantagorigida*
Platu	*Plantagotubulosa*	Plari	*Plantagorigida*	Platu	*Plantagotubulosa*
Sciri	*Scirpusrigidus*	Sciri	*Scirpusrigidus*	Pymo	*Pycnophyllummolle*
Stbra	*Stipabrachyphylla*	Seva	*Senecioevacoides*	Sciri	*Scirpusrigidus*
Vipy	*Viola pygmaea*	Stbra	*Stipabrachyphylla*	Seva	*Senecioevacoides*
Werla	*Wernerialamprophylla*	Stmu	*Stipamucronata*	Stbra	*Stipabrachyphylla*
		Vari	*Valerianarigida*	Vipy	*Viola pygmaea*
		Vipy	*Viola pygmaea*	Wepy	*Werneriapygmaea*
		Wercan	*Werneriacandamoana*	Werla	*Wernerialamprophylla*
		Werla	*Wernerialamprophylla*		

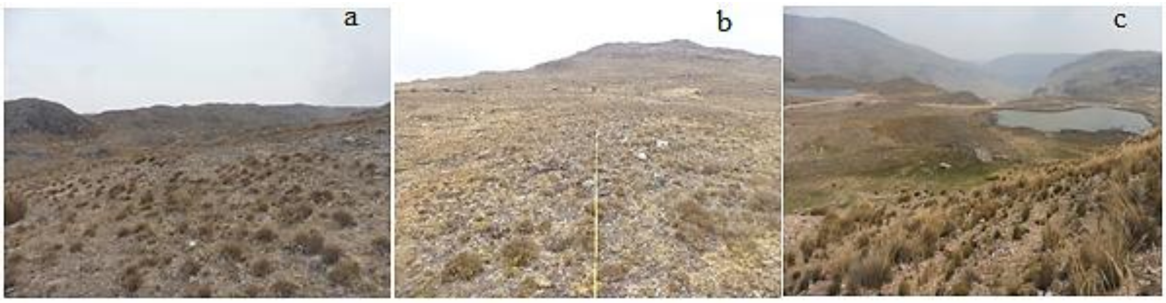

Figure 4: Images of the upper parts of the micro-basins: a) Huajaco, b) Ijira, c) Yananya