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# Geospatial Inventory of Springs and Agroecological Zoning in a Semi-Arid Rural Community: A Case Study of Puñun, Peru

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**Abstract:** The study carried out in the Puñun Peasant Community had as its main objective the inventory of springs and the planning of agroecological zones, assessing water availability in a semi-arid environment. The methodology included the georeferencing of 139 springs and flow measurement using the volumetric method in Sector II. Measurements were taken quarterly on three key dates during the 2024 dry season: April, June, and December. Agroecological zones were delimited considering soil and climate factors and morphological factors, using Arc GIS 10.8 GIS software. A mixed approach was also applied to collect quantitative and qualitative data, including interviews with experts. The results showed that springs contribute significantly to the available flow in the agroecological zones, with a total water volume of 631.56 $m^3$ in Sector II, distributed among four identified zones. According to experts, the spring inventory had a strong influence on agroecological planning, reaching an index of 0.89. Likewise, the Pearson correlation test between the area of the agroecological zones and the volume of water available in the springs showed a nearly perfect positive relationship ($r = 0.99$). The conclusions highlighted the importance of springs for agricultural sustainability and the urgent need to implement efficient water management strategies, promoting responsible water use and environmental conservation. It is estimated that the total available volume can support agricultural irrigation of approximately 29.19 hectares.

**Keywords:** Manantiales; Georreferenciación; Caudales; Zonas agroecológicas; Planificación sostenible

## 1 Introduction

The inventory of springs is a technical-cartographic procedure that consists of identifying and georeferencing water sources, also known as puquiales [1], while agroecological planning in a rural community is related to the physical planning of the territory, as a territorial development strategy supported by agriculture and high environmental resilience [2]. According to Altieri [3], agroecological zones are defined as territorial units delimited based on their edaphoclimatic, topographic and morphological characteristics, which condition agricultural use and sustainable management of resources; likewise, Villanueva et al. [4] explains the importance of inventorying springs to plan and implement agricultural ecosystems in arid and semi-arid regions, as a strategy not only for environmental conservation but also to improve the quality of life of rural inhabitants [5]. Springs are sources of water that emerge from the groundwater by gravitational processes and hydrostatic and isostatic pressure differences. As a natural resource, they have great environmental impact on the improvement of the rural landscape, mainly in semi-arid areas such as the high floors [6] Andean regions of Peru. Furthermore, agroecology in a rural community result in an economic activity with great environmental, social, and economic sustainability. Agroecological systems not only concentrate the processes of biomass production and biodiversity but also incorporate biogeoclimatic and soil mechanisms that enhance landscape and environmental quality by generating multiple environmental services, including the emission of sufficient amounts of atmospheric oxygen through photosynthetic processes [7].

Peru has more than 5,000 rural communities located between arid and semi-arid regions, which experience water shortages for eight months of the year. Therefore, it is important to channel the use of springs, as many of them remain year-round. Therefore, it is important to quantify their water volume and spatial distribution through geospatial inventory.

In this regard, Denim et al. [8] managed to inventory springs in the Catamarca province of Argentina through direct georeferencing and then calculated the magnitude of their flows in volumetric terms, generating strategic information for land-use planning.

Along the same lines, Thapa et al. [9] promoted multidisciplinary studies to record springs located above 2,500 meters above sea level, which were used to design hydraulic structures with a local impact.

In Peru, Moreno-Herrera et al. [10] of the Metallurgical Institute has conducted an inventory of springs in the basins of the main coastal rivers to obtain a national hydrogeological map. In the Ica River basin, they inventoried 75 water sources, including springs and surface sources; in the Colca River basin, they recorded more than 80 springs, including cold thermal waters and seeps.

Alfaro [11] also worked on the spatial location of water sources, in order to establish a baseline in “Water Resources” and have a database that allows the evaluation of surface water resources and know the availability of this resource for the optimization of its use and rationalization of the water resource in various uses. The realization of this research allowed to know the spatial location of water sources, in order to establish a baseline in "Water Resources" and have a database that allows to evaluate surface water resources that in turn allow to know the availability of this resource for the optimization of its use and rationalization of the water resource in various uses. Although there are studies oriented to the location and evaluation of surface water sources, such as that of Alfaro [11], there is still a lack of comparative research in high Andean communities with a semi-arid climate, subsistence agriculture and strong dependence on springs. This absence limits the regional analysis, but at the same time highlights the exploratory and pioneering value of the present study.

The study of springs for agroecological purposes is definitely of great importance to the development of rural communities in the high Andes of Peru. For these communities, springs, wells, and sources constitute a valuable cultural and environmental heritage that must be understood and protected for future generations. Aware of the importance of springs and their high vulnerability, this research project aims to identify, conserve, and enhance the value of springs, wells, and sources in communities like the Puñun Rural Community and contribute to their social, economic, and environmental development. Therefore, the objectives of this research are to inventory the springs in the Puñun Community, delimit the agroecological zones, and establish the degree of correlation between the spring inventory and agroecological planning in a rural community. However, for a more comprehensive approach, we propose to evaluate the spatial correlation between spring water reserves and agroecological zones in the Puñun Rural Community.

## 2 Materials and Methods

This study is of an applied nature and has a mixed approach, combining quantitative methodologies (such as the analysis of geospatial and soil data) and qualitative ones (such as participatory validation and local knowledge). It is framed within a non-experimental, descriptive and exploratory design, since phenomena are observed and analyzed in their natural context. The Global Positioning System (GPS) was used for spatial georeferencing and determining the location and distribution of springs. For this purpose, the GPS Glonass Carmin ±3 m was used. For flow measurement, the volumetric method was applied. which relates time and volume, using a 1000 $\mathrm{cm}^3$ Pyrex container (HSTI 1000 ml) calibrated with a 500 ml measuring cylinder (KLASS). Five tests were performed, obtaining an average record of 1004.58 ml, with a margin of error within what is tolerable. Likewise, an EXTECH model 365515 digital stopwatch was used.

ArcGIS 10.8 was used to delimit the agroecological zones, complemented by fieldwork that included direct observation and measurement of environmental units based on soil and climate criteria and terrain morphology [12]. For spatial analysis and the generation of continuous surfaces from the georeferenced points of the springs, the Inverse Distance Weighting (IDW) interpolation method was applied in ArcGIS 10.8, with a search radius of 1000 meters and considering the 12 nearest neighbors [13]. This method was selected for its simplicity and for giving greater weight to the closest points, which is appropriate in a territory with significant altitudinal variations. In Sector II, where ten nearby springs draining into a lagoon were identified, the IDW interpolation revealed an area of high-water density, highlighting the hydrological linkage essential for agroecological planning.

To size the agroecological zones, three indicators were selected: land slope (0.40), flow rate (0.35), and distance to springs (0.20). The weights were assigned using the Analytic Hierarchy Process (AHP), which allowed the relative importance of each factor to be assessed. These weights were used to construct a composite index that facilitated the precise delimitation and characterization of the agroecological zones, supporting territorial planning based on hydrological and morphological criteria [14].

Finally, expert interviews were conducted using a structured guide and a double-entry assessment table [15]. The data were processed in IBM SPSS Statistics 25, applying correlational analysis to demonstrate the relationship between the spring inventory and agroecological zone planning, validating the consistency between the criteria applied and the zoning obtained.

The Puñun Peasant Community, located in the Checras District, Huaura Province, and Lima Department, was chosen as the study area. The Puñun Peasant Community covers an area of 3,260 hectares and is home to 492 permanent residents. The geographic area of the Puñun Peasant Community within its territorial boundaries presents a rugged morphology, marked by an altitudinal sequence of stepped hills and certain plains with isolated distributions, such as the Palcaura, Puchactama, Huagarachin, Arcatama, and Ñawiscocha areas. The study area extends from 2,310 meters above sea level in the Checras River basin, in the Piedra Blanca area, to 4,932 meters above sea level, corresponding to the summit of Santiagorumi Mountain. As such, it encompasses the following altitudinal zones: Yunga, Quechua, Suni, and Puna [16].

The Puñun CC presents a semi-arid and sub-humid landscape with dry winters and rainy summers, giving rise to seasonal ecosystems dominated by thorny trees in the lower levels, shrubs and bushes in the middle levels, and herbaceous vegetation widely distributed in the middle and upper levels. These are typical cover crops of the steppe and puna mountain ranges [17].

## 3 Results

### 3.1 Inventory of Springs

The inventory process of the springs in the Puñun Community consisted first of spatial georeferencing, then coding each spring, measuring the flow rate, calculating the monthly water volume in $\mathrm{cm}^3$, liters, and $\mathrm{m}^3/\mathrm{s}$, and calculating the storage volume using the mass curve. The inventory of the springs began with the delimitation of the study area, which corresponds to the boundaries of the Puñun Peasant Community, which covers an area of 3.26 km$^2$.

#### 3.1.1 Georreferenciación espacial y codificación

The main objective of spatial georeferencing was to locate each spring on the ground. The following tools were used: GPS Glonass Carmin (with a minimum error of 3 m and a maximum of 10 m), Google Earth, mobile applications such as QField, and modeling programs such as ArcGIS 10.8 to correct and adjust the coordinates.

**Table 1.** Number of springs coded and georeferenced

| N° | Spring Code | East (E) | North (N) | Altitude (masl) | Sector |
|---|---|---|---|---|---|
| 1 | M1 | 229500 | 8795550 | 2725 | I |
| 2 | M2 | 298700 | 8795800 | 2370 | |
| 3 | M3 | 299050 | 8795280 | 2860 | |
| 4 | M4 | 298870 | 8796050 | 2740 | |
| 5 | M5 | 298650 | 8796150 | 2500 | |
| 6 | M6 | 229250 | 8794875 | 2915 | II |
| 7 | M7 | 298600 | 8794425 | 3030 | |
| 8 | M8 | 299050 | 8794190 | 2960 | |
| ... | ... | ... | ... | ... | ... |
| 136 | M136 | 296710 | 8790200 | 4250 | XIV |
| 137 | M137 | 297150 | 8790200 | 4155 | |
| 138 | M138 | 296450 | 8790300 | 4190 | |
| 139 | M139 | 297600 | 8790500 | 4300 | |

Note: The table presents information on 139 springs, with their respective code, East (E) and North (N) coordinates, as well as the altimetric elevation (in meters above sea level).

**Table 2.** Extreme points of Sector XIV

| Point | North Coordinate (N) | East Coordinate (E) | Altitude (masl) |
|---|---|---|---|
| Point 1 | 8790709N | 297960E | 3163 |
| Point 2 | 8789218N | 296301E | 4359 |
| Point 3 | 8788724N | 296737E | 4336 |
| Point 4 | 8790453N | 297416E | 3946 |

Note: The extreme points of each sector provide the coordinates and dimensions that delimit the area where the springs are distributed.

A total of 139 springs were counted with M1, M2, M3, and M139 codes, which were grouped into 14 sectors. In this way, information related to each spring's spatial position, defined by its UTM coordinates and elevation, was obtained (Table 1).

Each of the 14 sectors are defined by four georeferenced points, according to the cardinal points, North East, West, and South. Thus, Sector XIV presents the following spatial reference points (Table 2).

The coordinates and dimensions of Sector XIV range between the following intervals:
•North (N) coordinates vary from 8788724N to 8790709N.
•Easting (E) coordinates vary from 296301E to 297960E.
•Altimetric heights (ml) vary between 3163 msnm and 4359 msnm.
The distribution and degree of spatial concentration of the springs can be seen in the following plan (Figure 1).

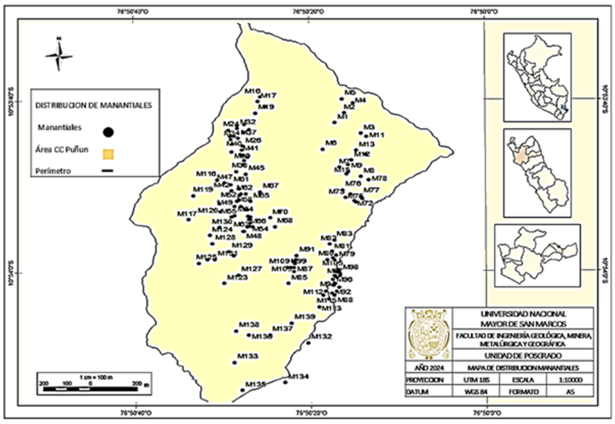

**Figure 1.** Spring distribution map

Note: The distribution and degree of concentration of springs in the Puñun CC is determined by geology, which favors the accumulation of water in aquifers, and by the morphology of the terrain, which facilitates its flow and degree of underground infiltration.

According to the National Geological Map (Carta Oyon) of the Geological, Mining, and Metallurgical Institute (INGEMEMET), the articulated distribution and concentration of springs in the Puñun CC is determined not only by the general geology that favors accumulation in aquifers, but also by the presence of geological structures, such as faults and fissures, which act as preferential pathways for groundwater flow.

In several sectors of the Puñun rural community, an aligned arrangement of springs is observed, which explains their correspondence with the structural lines of the terrain [18].

These geodynamic conditions, along with the morphology of stepped hills and local depressions, facilitate both the infiltration and emergence of water at specific points, explaining the recorded water concentration.

3.1.2 Estimation of flow rates

Spring flow measurements were carried out in Sector II. Ten springs were selected from Sector II, known as the Ñawiscocha Sector, due to their scenic importance as a lagoon and the presence of surrounding springs with year-round water. They are also directly accessible and have high cultural value for the inhabitants of the rural community (Figure 2).

**Figure 2.** Frontal landscape of Sector II Ñawiscocha

Note: The image shows the landscape of the Ñawiscocha area, corresponding to two moments of the year: The first is the dry season period (August) and the second image corresponds to the beginning of the rainy season (January), which clearly contrast with the water availability.

Over the course of 9 months in 2024, between April and December, a total of 9 measurements were taken on three consecutive dates. For each of the 10 springs, three measurements were taken at three times: At the beginning of the dry season (April, at the height of the dry season (June) and at the end of the dry season (December), according to the following table (Table 3).

In the following table, there are records of monthly water flow and volume in $\mathrm{cm}^3$, Liters and $\mathrm{m}^3$, which correspond to the records of the first scheduled date (Table 4).

The same procedure was followed for the other two scheduled dates, obtaining flow rates in $\mathrm{cm}^3/\mathrm{s}$ and water volume in $\mathrm{cm}^3$, liters, and $\mathrm{m}^3$.

**Table 3.** Number of flow measurement records

| Spring Code | Record (R) | Instant Flow Qi $(cm^3/s)$ | Registration Dates |
|---|---|---|---|
| M001 | R1 | Qi1 | |
| M001 | R2 | Qi2 | 26–27/04/2024 |
| M001 | R3 | Qi3 | |
| M001 | R4 | Qi4 | |
| M001 | R5 | Qi5 | 29–30/06/2024 |
| M001 | R6 | Qi6 | |
| M001 | R7 | Qi7 | |
| M001 | R8 | Qi8 | 14–15/12/2024 |
| M001 | R9 | Qi9 | |

Note: The flow record was made to track the amount of water flowing through the spring at different times throughout the 9 months of the dry season.

**Table 4.** Record of flow rates and water volume for the month of April 2024

| Spring Code | Container Volume $(cm^3)$ | Registration Date 04/26- 27/2024 | | | Average Time (s) | Caudal $(cm^3/s)$ | Monthly Volume $(cm^3)$ | Monthly Volume (L) | Monthly Volume $(m^3)$ | Total Volume $(cm^3)$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | R1 | R2 | R3 | | | | | | |
| M1 | 1000 | 04/26-27/2024 | 71 | 72 | 71 | 71 | 14.02 | 36336449 | 36336.45 | 36.34 |
| M2 | 1000 | 04/26-27/2024 | 60 | 59 | 60 | 60 | 16.76 | 43441341 | 43441.34 | 43.44 |
| M3 | 1000 | 04/26-27/2024 | 53 | 54 | 52 | 53 | 18.87 | 48905660 | 48905.66 | 48.91 |
| M4 | 1000 | 04/26-27/2024 | 47 | 48 | 48 | 48 | 20.98 | 54377622 | 54377.62 | 54.38 |
| M5 | 1000 | 04/26-27/2024 | 42 | 41 | 41 | 41 | 24.19 | 62709677 | 62709.68 | 62.71 |
| M6 | 1000 | 04/26-27/2024 | 38 | 37 | 37 | 37 | 26.79 | 69428571 | 69428.57 | 69.43 |
| M7 | 1000 | 04/26-27/2024 | 35 | 34 | 34 | 34 | 29.13 | 75495146 | 75495.15 | 75.50 |
| M8 | 1000 | 04/26-27/2024 | 33 | 32 | 32 | 32 | 30.93 | 80164948 | 80164.95 | 80.16 |
| M9 | 1000 | 04/26-27/2024 | 30 | 29 | 29 | 29 | 34.09 | 88363636 | 88363.64 | 88.36 |
| M10 | 1000 | 04/26-27/2024 | 28 | 27 | 27 | 27 | 36.59 | 94829268 | 94829.27 | 94.83 |
| | | | | | | | | | VT= Months | 654.05 Abr, May |

Note: The monthly volume in $cm^3$ was obtained by multiplying the flow rate in $cm^3/s$ by 2,592,000 seconds, which corresponds to a 30-day month. Thus, in April, spring M1 generated 36.34 $m^3$ of water.

**Table 5.** Recording times (s) and obtaining the average flow rate in $cm^3/s$ and L/s

| Spring Code | Container Volume $(cm^3)$ | Filling Time Record (s) | | | | | | | | | Average Time (s) | Caudal $(cm^3/s)$ | Caudal $L/seg$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | R1 | R2 | R3 | R4 | R5 | R6 | R7 | R8 | R9 | | | |
| M1 | 1000 | 71 | 72 | 71 | 72 | 72 | 73 | 71 | 72 | 71 | 72 | 14 | 0.014 |
| M2 | 1000 | 60 | 59 | 60 | 61 | 61 | 60 | 59 | 59 | 60 | 60 | 17 | 0.017 |
| M3 | 1000 | 53 | 54 | 52 | 53 | 54 | 54 | 53 | 52 | 52 | 53 | 19 | 0.019 |
| M4 | 1000 | 47 | 48 | 48 | 48 | 47 | 49 | 47 | 46 | 46 | 47 | 21 | 0.021 |
| M5 | 1000 | 42 | 41 | 41 | 42 | 43 | 43 | 42 | 41 | 40 | 42 | 24 | 0.024 |
| M6 | 1000 | 38 | 37 | 37 | 38 | 39 | 39 | 38 | 37 | 38 | 38 | 26 | 0.026 |
| M7 | 1000 | 35 | 34 | 34 | 35 | 36 | 36 | 35 | 34 | 34 | 35 | 29 | 0.029 |
| M8 | 1000 | 33 | 32 | 32 | 32 | 33 | 33 | 33 | 32 | 32 | 32 | 31 | 0.031 |
| M9 | 1000 | 30 | 29 | 29 | 30 | 31 | 30 | 30 | 31 | 31 | 30 | 33 | 0.033 |
| M10 | 1000 | 28 | 27 | 27 | 28 | 29 | 29 | 28 | 27 | 27 | 28 | 36 | 0.036 |
| | | | | | Total | | | | | | | 250 | 0.250 |

Note: The instantaneous flow rate of the 10 springs was calculated by dividing the measured volume (1000 $cm^3/s$) by the time recorded for each measurement. This process was repeated for each of the 90 times to obtain the corresponding 90 flow rates.

Finally, 9 records were obtained for each spring, yielding a total of 90-time records expressed in in seconds and therefore the record of 90 instantaneous flows, as shown in the following table (Table 5).

#### 3.1.3 The flow duration table

In Sector II, the 10 springs show a significant increase in flow during the rainy season (January, February, and March), reaching up to three times the flow of the dry season, with February being the month of highest flow. The flow duration curve reflects this seasonal variability, being concave and decreasing, indicating that high flows are less frequent and brief, while low flows predominate for most of the year. This behavior is typical of areas with a seasonal climate, where water availability directly depends on rainfall. The following table shows the flow data or records for Sector II of the 10 springs, including the flow, volume, and exceedance probability values for each month of the year (Table 6).

**Table 6.** Flow duration table

| Order Number | Month | Caudal $(\mathrm{L/s})$ | Probability of Exceedance (%) |
|---|---|---|---|
| 1 | FEBRUARY | 0.7535 | 16.07 |
| 2 | JANUARY | 0.7176 | 32.99 |
| 3 | MARCH | 0.7176 | 49.92 |
| 4 | APRIL | 0.2529 | 55.70 |
| 5 | JUNE | 0.2455 | 61.31 |
| 6 | DECEMBER | 0.2448 | 67.09 |
| 7 | MAY | 0.2418 | 72.81 |
| 8 | SEPTEMBER | 0.2382 | 78.26 |
| 9 | JULY | 0.2353 | 83.81 |
| 10 | NOVEMBER | 0.2335 | 89.10 |
| 11 | AUGUST | 0.2329 | 94.65 |
| 12 | OCTOBER | 0.2283 | 100.00 |

Note: Flow rates are in liters per second (L/s). The probability of exceedance is calculated using the annual cumulative volume. In January, February, and March, flow rates are almost three times greater than in the dry season, with February being the month with the highest flow. Source: Own data (2025).

#### 3.1.4 The mass and storage volume curve

The mass curve calculation corresponds to the accumulated water from the 10 springs in Sector II. The accumulated water for the nine months between April and December 2024 is recorded.

To complete the missing data record (May, July, August, September, October, and November), the correction factor Fr = 0.99 was applied. Thus, the accumulated water volume for the month of April was multiplied by 0.99.

obtaining a volume of 647.51 $\mathrm{m}^3$, corresponding to the month of May. The procedure with this calculation by 0.99 was applied for the months of July, August, September, October, and November.

In Table 7, the adjustments to the accumulated monthly water volume record are shown, which allows obtaining the total annual volume, equal to 5684.00 $\mathrm{m}^3$.

**Table 7.** Monthly water volume record

| Month | Volume $(\mathrm{m}^3)$ | Accumulated Volume $(\mathrm{m}^3)$ |
|---|---|---|
| APRIL | 655.76 | 655.76 |
| MAY | 647.51 | 655.76 + 647.51 = 1303.27 |
| JUNE | 636.53 | 1303.27 + 636.53 = 1939.80 |
| JULY | 630.17 | 1939.80 + 630.17 = 2569.97 |
| AUGUST | 623.86 | 2569.97 + 623.86 = 3193.83 |
| SEPTEMBER | 617.63 | 3193.83 + 617.63 = 3811.46 |
| OCTOBER | 611.45 | 3811.46 + 611.45 = 4422.91 |
| NOVEMBER | 605.33 | 4422.91 + 605.33 = 5028.24 |
| DECEMBER | 655.76 | 5028.24 + 655.76 = 5684.00 |

Note: As the water volume accumulates in each interval, the total accumulated volumes (for all 10 springs) are recorded over time.

$$V_{\text{Total}} = \sum_{j=1}^{10} Vij$$

where, $V_{\text{Total}}$ is the total accumulated volume in interval $i$, and $Vij$ is the accumulated volume of each spring $j$ in interval $i$. Then, by performing the entire process in a table, the following mass curve (Figure 3) of the accumulated volume was obtained.

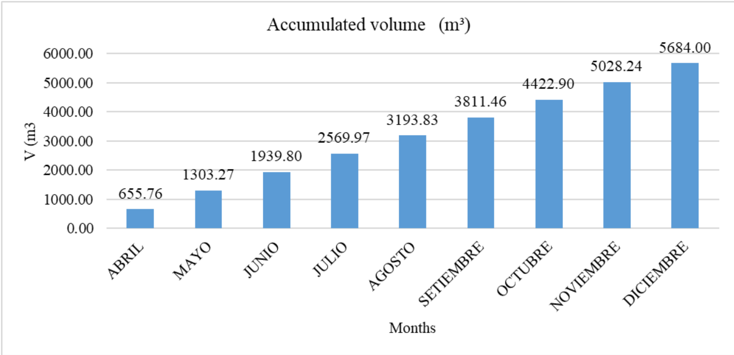


**Figure 3.** Mass flow curve of the 10 springs

Note: The mass curve is useful to visualize the behavior of the accumulated flow over time and how each of the 10 springs contributes to the total flow.

### 3.2 Agroecological Planning

Agroecological planning was developed in Sector II of the springs and covers an area of 66.58 hectares. Areas with agroecological potential were identified according to the distribution and degree of concentration of the springs, resulting in 4 agroecological zones: ZAE1, ZAE2, ZAE3 and ZAE4. To delimit the agroecological zones, the soil, climatic and morphological parameters were taken into account (Table 8).

**Table 8.** Area of agroecological zones

| N° | Agroecological Zones | Area (ha) | Area (%) |
|---|---|---|---|
| 1 | ZAE1 | 12.750 | 19.15% |
| 2 | ZAE2 | 7.900 | 11.86% |
| 3 | ZAE3 | 3.860 | 5.80% |
| 4 | ZAE4 | 4.580 | 6.88% |
| 5 | Lagoon | 3.400 | 5.10% |
| 6 | Irrigated land area | 34.090 | 51.21% |
| **Total** | - | 66.580 | 100.0% |

Note: The area of the agroecological zones was calculated based on the total area of Sector II, which is the environmental unit articulated by the Ñawiscocha lagoon, which has an area of 66.58 ha.

### 3.3 Sizing of Agroecological Zones

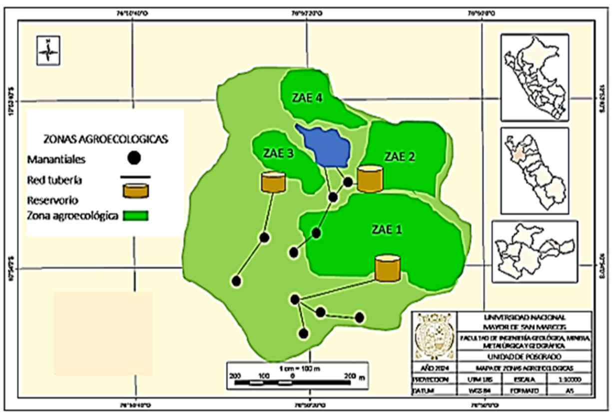


**Figure 4.** Map of agroecological zones

Note: The size of the agroecological zones in Sector II, called Ñawiscocha, is directly related to the size of the flow of the springs.

The size of agroecological zones (ZAE) is closely linked to water availability, especially in a semi-arid climate like that of Puñun. In this context, springs play a key role in the Determination of the effective area for agroecological production (Figure 4).

The size and functional structure of agroecological zone II was determined based on the magnitude of the flow resulting From the sum of the instantaneous flows of each of the 10 springs (Table 9).

**Table 9.** Sizing of agroecological zones

| N° | ZAE | Area de la ZAE ($m^3$) | N° Manantiales | Volumen de Agua ($m^3$) | Litros/$m^3$ |
|---|---|---|---|---|---|
| 1 | ZAE1 | 127,500 | 4 | 252.62 | 1.98 |
| 2 | ZAE2 | 79,000 | 4 | 195.78 | 2.48 |
| 3 | ZAE3 | 38,600 | 2 | 183.16 | 4.70 |
| 4 | ZAE4 | 45,800 | | | 4.00 |
| | Area total | 291,900 | 10 | 631.56 | 2.16 |

Note: ZAE3 and ZAE4 share two high-flow springs, with a monthly accumulation of 183.16 $m^3$ of water. Thus, ZAE 3 receives 4.7 liters of water per $m^2$, while ZAE 4 receives approximately 4. liters.

AE1, having a larger surface area, receives the greatest total volume of water, but less per square meter.

AE2 has greater relative water availability per square meter, which could influence the selection of more water-demanding crops.

AE3 and AE4 receive the highest flow springs, thus having more water per square meter.

Then, based on the design flow, the construction of water reservoirs of 10, 8, and 7 $m^3$ was planned for agroecological zones AE1, AE2, and AE3–AE4, respectively. These are small water reservoirs for daily storage that concentrate flows through integrated piping systems, in addition to a distribution system.

geometrical structure of the same, to feed the crops or agroecological sub-zones, within the agroecological zones.

Regarding water management, the implementation of drip irrigation systems was proposed for 70% of the prioritized plots in the Puñun Peasant Community's four agroecological zones, optimizing the use of spring water and reducing losses due to evaporation and percolation [19]. The selection was based on proximity to water sources, crop type, and community participation. A 40% savings is estimated compared to gravity-fed irrigation. Sprinkler irrigation will complement drip irrigation for crops that require it, depending on microclimatic conditions and soil type. The strategy incorporates a participatory approach for its implementation and local sustainability.

3.3.1 Spatial discretization of Sector II

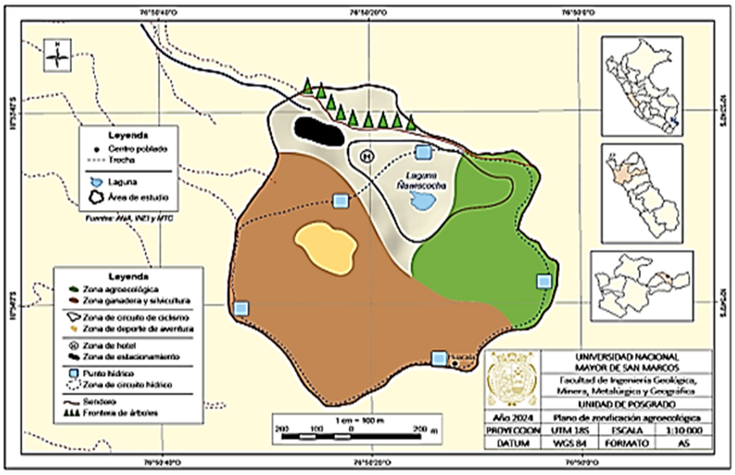


**Figure 5.** Spatial discretization of the Ñawiscocha Sector and the definition of its major use capacity

Note: The process of dividing the total area of Sector II of 66.58 ha into smaller, more manageable units is important for its analysis, such as environmental, geographic or hydrological models, which are used to project highly environmentally sustainable works.

The spatial discretization of Sector II, which includes 10 springs, a lagoon, and several environmental units, including the 4 agroecological zones, was carried out considering the following parameters: morphological differentiation of the terrain according to its slope, microclimatic zoning, type of crop, in addition to criteria of greater soil use capacity that ensure sustainability and environmental harmony [20]. This greater soil use capacity is classified as Medium Agrological Quality (symbol A2), according to the Land Classification Regulations, in a temperate subhumid climate with temperatures between 12 and 17°C, covering 66 ha between 2,900 and 3,081 meters above sea level, according to data from the IGN, SENAMHI, and the classification of Pulgar Vidal and Antonio Brack.

Although actual yield data were not available, the zoning prioritizes areas suitable for horticulture, floriculture, and environmental conservation. It is recommended that these areas be validated with production data in future studies.

85% of the flat land is designated for agroecology (horticulture and floriculture), and 15% for sustainable infrastructure (lodging, administrative control centers, weather stations, and parking). The undulating and sloping land is reserved for tree planting, multifunctional road infrastructure, hydraulic works, and environmental conservation, according to the following plan (Figure 5).

### 3.4 Degree of Correlation Between the Inventory of Springs and Agroecological Planning

As expected, the inventory of springs allows us to measure the productive capacity of agroecological zones, establishing a positive correlation between these two variables.

To this end, a double-entry scoring table was created, indicating the corresponding variables and dimensions, with the following scoring levels: Less than 0.40 correlation low, greater than 0.40 and less than 0.60 medium correlation and greater than 0.60 high correlation.

For the variable "spring inventory", the following dimensions were identified: spring location, degree of spring dispersion/concentration, volumetric flow size, and average flow duration. For the variable "agroecological planning", the following dimensions were considered: location of the agroecological zone, size of the agroecological zone, photosynthetic efficiency, biomass, biodiversity, and landscape quality. Three specialists were then consulted, the results of which are shown in the following tables (Table 10).

**Table 10.** Correlation of variables and dimensions according to expert opinion

| Inventory of Springs | Planning of Agroecological Zones | | | | | | | Punctuation | Degree of Correlation |
|---|---|---|---|---|---|---|---|---|---|
| | Location of the Zone | Size of the Zone | Photosynthetic Efficiency | Biomass | Biodiversity | Environmental Quality | Landscape Quality | | |
| Location of springs | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.40 | 0.60 | 4/4.2 | 0.95 |
| Degree of dispersion/concentration of the springs | 0.40 | 0.40 | 0.40 | 0.40 | 0.60 | 0.40 | 0.60 | 3.2/4.2 | 0.76 |
| Volumetric flow rate of the springs | 0.40 | 0.60 | 0.60 | 0.60 | 0.60 | 0.40 | 0.60 | 3.8/4.2 | 0.90 |
| Degree of duration of average flows | 0.40 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 4/4.2 | 0.95 |

Note: The degree of correlation in the context of descriptive statistics reaches high values. This is a correlation of the influence of variable 1 (spring inventory) on variable 2 (agroecological zone planning). Source: expert opinion.

The table shows the assessment of the correlation between variables in the spring inventory and agroecological planning, based on scores assigned by experts on a scale of 0 to 1. These scores reflect the degree of influence of each spring indicator (such as location, flow, or duration) on different attributes of agroecological zones (such as biomass, biodiversity, or environmental quality). The average score obtained was 0.89, demonstrating a strong influence of flow on the extent of the agroecological area.

**Table 11.** Pearson correlation between the volume of spring water and the area of agroecological zones (ZAE)

| Correlations | | | |
|---|---|---|---|
| | | ZAE _area | Spring _water |
| ZAE _area | Pearson correlation | 1 | 0.999** |
| | Sig. (bilateral) | | 0.001 |
| | N | 4 | 4 |
| Spring _water | Pearson correlation | 0.999** | 1 |
| | Sig. (bilateral) | 0.001 | |
| | N | 4 | 4 |

** The correlation is significant at the 0.01 level (two-tailed).

Note: The table shows a near-perfect positive correlation (r = 0.999) between the area of agroecological zones and the volume of spring water.
Source: Prepared by the authors using data from Sector II, Puñun Peasant Community (2024).

Finally, the statistical analysis performed in SPSS 25 shows a very high positive correlation (r = 0.999) between the volume of water in springs and the area of the agroecological zones, indicating an almost perfect relationship between the two factors (Table 11).

In practical terms, the inventory of springs has a direct and very strong influence on agroecological planning, since water availability is a determining factor in defining the size, use, and sustainability of agricultural areas. This high correlation supports the hypothesis that groundwater resources, when quantified and georeferenced, can effectively guide the delimitation and management of agroecological zones, strengthening water security and productivity in semi-arid regions like Puñun.

## 4 Conclusions

Inventorying springs not only provides information on the current availability of water in a given area but also constitutes the basis for sustainable water resource management over time. Accurately determining flows over different time periods—such as instantaneous, average, daily, monthly, and annual—is essential for understanding seasonal fluctuations and how water flows under different climatic conditions. Furthermore, ecological flow is critical for ensuring the survival and health of water-dependent ecosystems, such as wetlands and riparian vegetation. Obtaining flow duration curves and mass curves provides a long-term view of water resource availability, facilitating the planning of hydraulic infrastructure and storage systems and enabling informed decisions regarding agricultural use and watershed management. This type of inventory is crucial not only for direct water use but also for ecosystem preservation and the implementation of public policies for natural resource management.

Agroecological planning goes beyond simple crop design; it is a holistic approach that integrates the efficient use of natural resources with environmental preservation and the socioeconomic development of rural communities. This process involves a detailed analysis of technical factors, such as soil quality, water availability, climatic characteristics, and crop needs, but also considers morphological and microclimatic aspects that influence the behavior of agricultural ecosystems. Through this planning, agricultural practices can be implemented that not only optimize crop yields but also promote biodiversity, improve soil quality, and reduce negative impacts on the environment. Furthermore, it seeks to make agricultural activities resilient to the effects of climate change, ensuring that territories are sustainable in the long term. This planning must be adaptable, allowing for adjustments based on changing climate conditions and community needs, and must involve all local stakeholders in the decision-making process.

Agroecological planning in Sector II of the Puñun Peasant Community has focused on an approach based on precise technical data obtained from spring design flows. This approach ensures that water use is tailored to the hydrological characteristics of the area, maximizing resource efficiency and optimizing its distribution among the various agroecological zones. The sizing of agricultural areas is not only based on available water volumes but also takes into account the soil's water retention capacity and crop needs based on their water consumption. This process is essential in semi-arid regions, such as Puñun, where water is a scarce resource and must be managed strategically. By integrating spring flow into planning, water resource depletion can be prevented and the long-term sustainability of agricultural production can be ensured. This approach allows for the design of efficient irrigation systems, promotes the appropriate use of agricultural land, and improves the community's resilience to climate variations.

The high influence of the inventory of springs with agroecological planning (0.89) on expert opinion, as well as the positive and perfect Pearson correlation test ($r = 0.99$), highlights the effectiveness of integrating detailed water data into land use and agricultural management decisions. This correlation suggests that accurate knowledge of water distribution and availability throughout the year has a direct impact on the selection of crop areas, the allocation of water resources, and agricultural production capacity.

With such a high correlation, it can be concluded that the spring inventory not only provides crucial information on available flows but also influences decisions related to crop type, irrigation planning, and the identification of more efficient agroecological zones. This type of integration between water resources and agroecological planning helps establish a more balanced and sustainable system, ensuring both agricultural productivity and the preservation of natural resources. The implementation of this methodology can serve as a model for other rural communities in similar conditions, promoting efficient water management in agriculture.

In this context, springs constitute a key resource for agroecological planning in high Andean regions. The high correlation found between their distribution and agroecological zones confirms their importance in sustainable territorial management. It is also recommended to strengthen local capacities through training in technologies such as GIS, and to consider the use of unmanned aerial vehicles (UAVs or drones) to improve the efficiency, accuracy, and coverage of studies, as an alternative or complement to traditional land-based methods.

## Data Availability

The data used to support the research findings are available from the corresponding author upon request.

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## Conflicts of Interest

The authors declare no conflict of interest.

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**Nomenclature**

| | |
|---|---|
| M1, M2, M3 ... M139 | Names of springs coded in the inventory, used for their identification and georeferencing on the ground. |
| ZAE1, ZAE2, ZAE3, ZAE4 | Codes for agroecological zones delimited based on water availability and land characteristics. |
| SI, SII, ... SXIV | Codes used to refer to the 14 geographic sectors where the springs are distributed in the Puñun peasant community. |