

Typology of livestock farms and its relationship with the environmental offer in high Andean dairy systems

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Method Article

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Abstract

The knowledge of the existing environmental offer in a certain area allows to generate awareness about the current environmental condition, to evaluate the positive and negative aspects regarding the relationship of the human being with its natural environment, the determination of conflicts, actions and prioritization for its good exploitation; For this, there are different ways to evaluate natural resources, for example, satellite models are one of the reliable and low-cost ways to describe natural characteristics and anthropocentric actions in nature, which is an important input to provide information for local and territorial decision-making. From a pre-existing database of the *Corredor Tecnológico Agroindustrial de Bogotá y Cundinamarca* with the Project called "Mejoramiento de la competitividad de pequeños y medianos productores de leche de la asociación de cooperativas lecheras de Guatavita ASOLEGA", data were obtained from the farms of which resulted in 4 clusters that typify the dairy production of the area; In addition, from satellite data such as DEM, precipitation, NDVI, slope, and temperature, a map was obtained that categorizes the environmental offer of the study area. 61.5% of the farms are located in an area of medium environmental offer and only 8.3% of the farms are in an area of very high environmental offer. The areas where most of the farms are located have agrological factors that are not suitable for production, which generates pressure on the land, and is expressed in decision-making by the producer on the technology to make it viable and efficient (adopting external energy such as chemical fertilizers, machinery, supplements for animals) to supply the deficiencies of the environment.

Introduction

Societies have been important in the use of the land surface, initially transforming the natural vegetation, generating changes around their subsistence such as the expansion of agricultural frontiers, the cultivation of food and animal husbandry, up to agriculture and intensive and extensive livestock and the delimitation of protected natural areas. Transformations in land cover, for example, aspects related to vegetation that are caused by the same climatic variation and anthropic activities, affect the climate because they generate alterations in temperature, humidity, wind speed and precipitation (Carvajal & Pabón, 2016); Therefore, it is necessary to study the relationship between climatic factors and technology use in farms, in order to understand environmental context and productivity in the study area.

The extent of human intervention in agroecosystems is directly proportional to the energy flows that enter it. The external energy flow is minimal when human intervention is also minimal and therefore respects the internal dynamics of the ecosystem; on the other hand, external energy flows increase significantly when an ecosystem is simplified (for example a monoculture), which, in order to optimize biomass productivity, reduces diversity and limits interference (Guzmán & González de Molina, 2017). In this case, it can be deduced that the decision of management of the systems by the producers is mediated by the environmental offer of the area, the economic purpose and environmental appropriation and the sense of belonging they have for the territory and with it, the understanding of its sustainability.

In Colombia, the National Agricultural Census carried out in 2014 reports that in the country, the total of the dispersed rural area surveyed corresponds to 111.5 million hectares and regarding the percentage of use, 38.6% was dedicated to agricultural activity, 2.2% to non-agricultural and natural forest area participated with 56.7% of the total registered. The total hectares corresponding to agricultural use are 43.0 million ha, of which 80.0% were used for pasture and stubble, 19.7% for agricultural activity and 0.3% for agricultural infrastructure (DANE, 2014).

The department of Cundinamarca has approximately 67% of the agricultural land used for pastures and stubble. Guatavita's economic activities are mainly agriculture, in which crops of potatoes, corn, peas, barley, broad beans, legumes and livestock stand out (Pinzón Carvajal, 2019).

It is essential to know the carrying capacity (CC) in grazing livestock production systems, that is, to determine the maximum livestock load that would allow the producer to obtain high levels of production in a given area on their farms, without deteriorating the resource.

Net primary productivity (NPP) is the amount of energy incorporated into plant tissues and can be expressed in terms of energy accumulated (joules/hectare/year), and it is of high interest in agrarian metabolism because represent the construction of the food chain (Ruiz & González de Molina, 2014). The estimation of the NPP comprises two levels: the above and the underground. The low availability and high variability of data on the Net aerial primary productivity (NAPP) are one of the main factors that have the greatest influence on the efficiency of livestock establishments, since the high variability can trigger an underutilization of forage, or also overexploitation causing deterioration of forage and edaphic resources (Golluscio et al., 1998). Net aerial primary productivity (NAPP) is one of the most relevant items to estimate the livestock unit because it represents the main energy source for animals; there are different methods by the NAPP can be estimated, among these, existing the successive biomass cuts and empirical models based on data provided by remote sensing (Pezzani et al., 2017) (Altesor et al., 2011), and the spectral indices such as the Normalized Difference Vegetation Index – NDVI – that is one of the most used. The agronomic parameters responsible for the development and productivity of the plants are highly correlated with the NDVI (Guzmán & González de Molina, 2015).

Considering that the environmental offer is an important factor to determine the territorial productive offer, it was considered in the present study to evaluate the slope, temperature, precipitation and altitude together with the NDVI and their correspondence with the agrological classification reported by the Agustín Codazzi Geographical Institute - IGAC (in Spanish) in the study area. The characterization of the territory involves initially identifying the environmental offer of the area as one of the predominant factors that influence the energy process involved in the agricultural activities. Thus, this article aimed to do a contextualization of the target area and relate the typology of dairy farms with said context.

Satellite maps have become a fundamental tool in obtaining, analyzing and processing the different effects and phenomena that occur on the surface of the earth, which is efficient in terms of costs and results (Felegari et al., 2022).

This information constitutes an important input to achieve healthy agroecosystems, under participatory and people-centered approaches and management structures, which will also improve their ways of life. To greatly reduce the pressure on the natural environment, production systems must be incorporated into landscapes, in ways that take advantage of natural biological processes, recycle waste and residues, and create integrated and diversified agricultural systems (FAO, 2013).

Materials and methods

The study area is located in Guatavita municipality in Colombia (Fig. 1), being part of the Province of Guavio, 53 km northeast from Bogotá. It presents an average altitude of 2668 meters above sea level, with an average annual temperature of 11.4°C and average annual precipitation of 1227 mm (Climate Data, 2021).

Guatavita is located on two main basins conformed by the Bogotá and Guavio rivers, with 60.8% and 39.2%, respectively, of the total area of the municipality; it is a territory with great importance for agricultural and livestock development. Guatavita weather is characterized by low rainfall between December, January, February, and mid-March, followed by high rainfall from mid-March, April, May, June, July, and August. Also, it presents a transition period from September to December, which causes water shortages in some regions (Moreno Vásquez, Grisales Camargo, & Polo Carrera, 2018).

Geographical context characterization

✓ Area identification

The target area previously selected in Guatavita Municipality was visited during the year 2019, doing of farms georeferencing, and agricultural technology characterization through structured questionnaire; thus, variables of productivity and physic information was obtained.

✓ Obtaining the information

The target area was delimited considering the geopolitical division of Guatavita. In this methodological phase, ArcGIS software was used with Magna SIRGAS coordinate system (EPGS 3116). After the target area was defined, the search for satellite information was carried out using Geo-spatial datasets from the page of United States Geological Survey-USGS, acquiring multispectral images of Sentinel 2 (year 2019). As an image selection criterion, the quality of the image was evaluated (null or with little cloudiness for the study area and compatibility with the ArcGIS software), resulting in a total of ninety-one images between January and December 2019, of which, according to quality, 1 was chosen (Fig. 3).

The Data Base of project named “Corredor Tecnológico Agroindustrial de Bogotá y Cundinamarca”, was used for spatial analysis of this study. The precipitation data were obtained from the meteorological stations of the Regional Autonomous Corporation (Corporación Autónoma Regional - CAR in Spanish) Cundinamarca, and the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM in Spanish); Thus, a daily and monthly basis to calculate the multiannual average precipitation, with a temporality of analysis of the last 10 years were used (Moreno Vásquez & Grisales Camargo, 2018).

The land uses, and geographical factors, were evaluated along the year 2019; extracting vegetation cover, the precipitation, as a factor closely related to vegetation development, and the land use classification, conservation of protected areas, and the advancement of areas dedicated to pastures and crops, being part of the forms of economy of the inhabitants of the area.

NDVI processing

Satellite image processing was carried out in three phases: in the first, a contrast adjustment was made with the natural color composition (Fig. 3a), which turned out from the combination of bands 4, 3, 2 in Sentinel 2. A visual interpretation of the images was made, based on pictorial-morphological characteristics (such as tone-color, shape, and location) using the land cover maps obtained through the use of the CORINE Land Cover methodology with scale 1:100000, period 2010–2012, published on the IDEAM website. With this map, the types of coverage present in the study area were determined. The second step, was the infrared image (Fig. 3b). This was processed to observe the soil layers that, according to the combination of the bands, offer a wavelength that allows observing with more detail the land cover, which complemented the pictorial-morphological characteristics mentioned with the Natural Color. The third step, it was calculated the NDVI index (Fig. 4) as input for the spatial analysis. This index was calculated from the reflectance in the portion of the electromagnetic spectrum corresponding to red and infrared bands according to the following equation (Tucker, 1979), $NDVI = ((NIR - VIS) / (NIR + VIS))$, which has a tight relationship with the Fraction of Absorbed Photosynthetically Active Radiation (fAPAR) and NAPP by green vegetation (Cristiano P et al., 2010) (Rui et al., 2002).

Reclassification

A reclassification of land areas was done. In satellite image processing, reclassification is useful when the researchers want to replace the values in the input raster with new values that are of interest to the investigation. The 4 chosen aspects of the environmental offer were reclassified in the software according to the best parameters chosen in the classification of the maps that correspond to an adequate environmental offer for dairy production in the Guatavita's area (Table 1).

Table 1
reclassification ranges for each chosen parameter.

Category	DEM (m.a.s.l)	Temperature (°C)	Slope (%)	NDVI (-1 + 1)	Precipitation (mm)
1	3100–3519	7.2–8	25–94	-0.404–0.1	708.55–850
2	2800–3100	8–10	12–25	0.1–0.3	850–1100
3	2600–2800	10–12	1–12	0.3–0.6	1100–1400
4	2499–2600	12–14.1	0–1	0.6–0.87	1400–1819.04

Finally, thematic maps were generated in raster format (grid), using the program ArcGIS 10.1, which allows them to be superimposed to generate a map built for the characterization of the biophysical context, using the following equation: $EO = DEM + T + NDVI + PP + S$ where, EO is the environmental offer; DEM, is the Digital Elevation Model; T, is the ambient temperature; NDVI is the normalized difference vegetation index; S is the slope, and PP is the regional pluviosity.

Typology: an agricultural technology characterization of dairy farms

Based on a wide pre-existent DataBase from *Corredor Tecnológico Agroindustrial de Bogotá y Cundinamarca* with the Project called "Mejoramiento de la competitividad de pequeños y medianos productores de leche de la asociación de cooperativas lecheras de Guatavita ASOLEGA", this study used the data of 391 ASOLEGA farmers associates (Guatavita Milk Producers Association in Spanish), of which they were taken variables which corresponding with the main objective of the investigation (Table 2).

Table 2
Variables are taken from the pre-existent DataBase from *Corredor Tecnológico Agroindustrial de Bogotá y Cundinamarca*.

Variables
1. Modern Technology Index – MTI*
2. TransitionTechnology Index – TTI*
3. Milk/cow/day*
4. Pasture area
5. Livestock units
6. Topography
7. Precipitation
*Variables calculate for the author

The construction of the two first variables of Table 1 was set up considering an index based on countable criteria which were established on different factors existing in the primary database. The index is a statistic data whose purpose is to synthesize the information provided by the various parameters that affect the situation to be analyzed. MTI refers to the use of conventional technology in dairy farms, for example, milking equipment, chemical fertilizer, among others); TTI is based on the management of endogenous farm resources. It's important to clarify that the predominance of some characteristics does not mean the other factors are absent. These variables were chosen accordingly to the aims of the project and the dimensional reduction of the variable through principal component analysis. In order to normalize the data, each variable was evaluated by binary assignment 0–1 which mean absence and presence, respectively, according to the pre-existing survey and with this the present total sum was made; After obtaining this total, and in order to maintain the general distribution with the relationship in the source data, a normalization of minimums and maximums was developed. The index was assigned with the following equation: $((X_v - L_v) / (H_v - L_v)) * 100$ where L_v is the lowest value among all data and H_v is the highest value among all data.

The liters of milk/cow/day, the area corresponding to pastures, livestock units and topography, were pre-existing numerical values in the database, which served as input to define the clusters for the productive characterization of the farms.

Typology of dairy farms

Correspondingly, the sample selection and information processing was taking into account the diagram of the methodology of characterization and typification of livestock systems developed by Cabrera et al. (2004) and the flow was modified according to the main steps of the project (Fig. 5):

A statistic software was used for clusters' characterization. in this case, cluster analysis was performed obtaining four (4) representative types according to the production systems.

For each cluster, centromere farms were identified. The extraction of the centromere farms was carried out using the K-means classification algorithm, which made the respective groupings, minimizing the sum of distances between each object and the centroid, based on their characteristics. 10 farms were

chosen from each characterized group and the first 4 farms closest to the centromere were interviewed, for a total n of 16 farms. Finally, an analysis of localization of centromere farms on the geographical context was done.

Generate supervised classification Land Cover

Para la determinación de diferentes coberturas y usos principales de la tierra en la zona, se clasificó en las siguientes cinco categorías: pastos, agua, páramo, bosque y cultivos, a partir de puntos de control de cada uno de ellos mediante GPS. A partir de herramientas algorítmicas y usos de nuevas tecnologías, se realizó una clasificación supervisada utilizando códigos de procesamiento de imágenes satelitales con los algoritmos smilleCart SVM, RF y BRT, mediante la herramienta de análisis Google Earth Engine. Los RF constituyen un método de aprendizaje propuesto por (Tien Bui et al., 2016), que utiliza varios árboles clasificatorios para solucionar problemas de clasificación, regresión y aprendizaje no supervisado. La herramienta CART es una técnica con enfoque estadístico que utiliza datos históricos para construir árboles de clasificación o de regresión y, de esta manera, cumplir con el objetivo de clasificar o predecir nuevos valores (Goetz et al., 2015). El clasificador SVM suponen una generalización de un clasificador simple denominado *maximal margin classifier*, el cual necesita menos muestras y no requiere que éstas estén distribuidas normalmente. El modelo Boosted Regression Tree BRT resultan de la combinación de dos técnicas: algoritmos de árboles de decisión y métodos de boosting, en éste, los datos de entrada se ponderan en árboles posteriores de manera sucesiva, de manera que el modelo intenta mejorar continuamente su precisión.

Dentro del desarrollo de la clasificación se destaca la selección y uso de las bandas visibles, infrarrojas cercanas, e infrarrojas de ondas cortas B4', 'B5', B6', B7', dentro de las rutinas de cada uno de los clasificadores; a partir de la selección de los puntos recopilados en campo e interpretación de coberturas a partir de la combinación de bandas para cada uno de los usos de la tierra evaluados, se aplicó una matriz de confusión la cual evalúa la precisión respecto a cada uno de los algoritmos de clasificación del conjunto de datos.

La selección de los puntos y la evaluación de los clasificadores con sus respectivos usos del suelo se realizó con una cantidad reducida de puntos, intentando en principio reducir la incertidumbre, ya que es la introducción al desarrollo de una nueva investigación donde se evaluarán los resultados a partir del levantamiento de una mayor cantidad puntos de control en campo permitiendo evaluar la eficiencia y precisión de las interpretaciones así como también, corregir y robustecer la clasificación con nueva información geoespacial y cambios de uso del suelo.

El objetivo de este proceso es hacer un contraste con los resultados del análisis y clasificación y categorización de la oferta ambiental de la zona de estudio, generando un análisis a una escala temporal determinada, una asociación porcentual y geoespacial de los diferentes resultados, siendo una primera aproximación para corroborar los usos del suelo de la zona de estudio.

Results

Resulting images of reclassification processes are show in the Fig. 5. These layers constitute the main input to determine a sectorization of target area biophysical contextualization (Fig. 6).

The maximum precipitation values occur in the upper part of the target territory, on the border with the municipality of Guasca, to the southeast of the basin; they are extremely cold, very humid areas; with values that vary between 1,400 mm and 1,800 mm and decrease towards the west of the basin, where the lowest values are recorded, with rainfall of less than 850 mm. Although, a significant proportion of the target territory (31.2%) presents a high precipitation, especially in the southeastern area, it is notorious that this is the area where there is less presence of dairy farms, possibly due to the fact that the altitudes exceed the protection level, rough conditions for dairy production and the absence of tertiary roads. In contrast, under categories 3 and 4 of less rainfall (708–850; 850–1100 mm) is where the highest concentration of farms occurs; in fact, these are the areas with the greatest agricultural activity, where the precipitation regime is dry cold.

An important proportion of the dairy farms studied (30%) is under precipitation range 3 (1100–1400 m), in the thermal floor between 2600 and 2800 m.a.s.l. The previous attributes of the different categories are in line with the different areas of the territory based on the NDVI, thus, it is evident that the areas with the highest index are associated with lands under forest vegetation, above 2500 m.a.s.l., which, in turn, time, they are areas of high precipitation. However, it is notorious that most of the territory has a low NDVI (64.9%), which suggests its high intervention with agricultural land uses; the location of most of the dairy farms is on surfaces with low NDVI.

The topography is one of the most limiting factors of agricultural activities in a territory; In the study area, steep slopes (> 25%) predominate in the eastern part of the territory, which corresponds to the eastern slope (Fig. 6c); this topography covers 25.8% of the territory. In their order, they follow the lands with an undulating and inclined slope (12–25%), presenting a significant proportion (45.7%) of the territory; Flat lands (< 12%) represent 27.3% where the urban area of Guatavita is located.

As a result of the superposition of the different layers and indices, a map of land distribution, which gives an idea of the environmental offer (EO) of the territory (Fig. 7). The extension of each of these EO classes suggests that most of the area has a medium-level EO (13.442,7 ha), representing 57.1% of the area; Only 23.6% of the territory presents an EO between high (4788,1 ha) and very high (772.3 ha), the latter being located in the mountainous part of the southeast of the territory. The land with low EO is located in the higher lands, with paramo vegetation; they are generally class VII and VIII lands, and they represent 19.2% of the territory.

Most of the dairy farms are located under medium EO. Only 8.3% of the farms are located in a space with a very high EO (Table 3, Fig. 8).

Table 3
Farms localization and their respective correspondence to the classification of environmental offer.

Environment offer category - OA	Farms (#)	Proportion (%)
Low	18	4.7
Medium	241	61.5
High	99	25.4
Very High	33	8.3

Tipology of dary farms

Once the homogeneity was determined according to the types described in Table 2 and selecting the number of clusters, the K-means cluster analysis was carried out (Fig. 9).

Cluster analysis was performed obtaining four (4) representative group's types which by the specific characteristics are described in Table 2.

Cluster 1 is characterized by being production systems with modern technology (MTPS); They present the highest MTIs, which is reflected in a high milk productivity index, although with a low high carrying capacity, since they are the farms with the largest extension, with an average of 25.8 ha/farm, which present a greater average area in pastures, some of them with improved pastures; they rotate pastures; generally demand the use of chemical fertilization. They are located on medium fertility soils, under a flat topography; high primary productivity, and high soil mechanization; They use mechanical milking.

Cluster 2, are medium productivity production systems (MPPS); They also present high rates of use of modern technology and Transitional technology (MTIs and TTIs); which is reflected in a high load capacity and medium milk productivity; They are medium-sized farms (average 7.6 ha) that have an average pasture area of 6.52 ± 4.65 ha, some of them with improved pastures; they rotate pastures; generally the use of chemical fertilization is low. They are located on medium fertility soils, under an undulating and sloping topography; They are in areas of low primary productivity, little mechanization of the soil and do manual milking.

Cluster 3, are systems of Traditional Production Systems (TPS); they present the lowest rates of use of modern technology and Transitional technology (MTIs and TTIs); which is reflected in the lowest milk productivity; They are the smallest farms (average of 5.3 ha), they present the lowest average area in pastures land use, for which the stocking rate is the highest; generally with naturalized pastures, with little pasture rotation; generally demand the use of chemical fertilization. They are located on medium to low fertility soils, under an undulating and sloping topography; they are in areas of low primary productivity, do little soil mechanization, and they practice manual milking.

Cluster 4, are eco-friendly production systems (EFPS); they have lower rates of use of modern technology and Transitional technology (MTIs and TTIs); however, milk productivity is acceptable; they present an average farm size area of 8.3 ha and a low pasture area of 6.43 ± 3.84 ha, generally with naturalized pastures; good rotation of pastures, although the stocking rate is low. They generally use little chemical fertilization, and recycle nutrients with organic fertilization. They are located on medium to low fertility soils, under an undulating and sloping topography; they are in areas of low primary productivity, do little mechanization of the soil, and use mechanical milking.

Table 4
Description of the typification according to the production systems found in the groups.

Cluster (group)	n	ITMs	ITEs	Productividad (l/C/D)	Área pastos (ha)	Carga animal (AU/ha)
1	131	$0,53 \pm 0,15$	$0,48 \pm 0,17$	$11,69 \pm 14,60$	$11,93 \pm 17,44$	$1,58 \pm 0,88$
2	87	$0,46 \pm 0,21$	$0,47 \pm 0,17$	$8,81 \pm 4,47$	$6,52 \pm 4,65$	$2,01 \pm 1,18$
3	90	$0,28 \pm 0,16$	$0,23 \pm 0,13$	$7,62 \pm 3,34$	$3,72 \pm 3,02$	$2,96 \pm 2,42$
4	83	$0,30 \pm 0,12$	$0,30 \pm 0,13$	$8,53 \pm 4,01$	$6,43 \pm 3,84$	$1,45 \pm 0,57$

Finally, a group of four farms close to the centromere farm were selected to carry out the energy productivity analysis, which will be the subject of another chapter of this thesis.

Generate supervised classification Land Cover

Classifiers	Land Use Types	Environment offer category - OA -hectares								Total x Land Use Type		Confusion Matrix A.	Kappa
		Very High	%	Medium	%	Low	%	High	%				
CART	Pasture	216.30	28%	1067.28	8%	91.77	2%	588.29	11%	1963.63	8%	0.93	0.92
	Water	1.15	0%	710.48	5%	4.60	0%	745.71	13%	1472.86	6%		
	Moorland	119.50	16%	2001.67	14%	948.08	21%	62.17	1%	3739.42	15%		
	Forest	247.77	32%	2829.16	20%	1331.65	29%	2219.25	40%	5710.33	23%		
	Crops	181.26	24%	7409.10	53%	2140.72	47%	1839.75	33%	11946.81	48%		
RF	Pasture	302.70	40%	2298.08	16%	308.60	7%	1056.93	19%	3966.31	16%	0.99	0.98
	Water	1.16	0%	714.69	5%	6.74	0%	758.54	14%	1481.12	6%		
	Moorland	143.93	19%	2142.41	15%	1011.34	22%	722.92	13%	4020.60	16%		
	Forest	239.89	31%	2770.39	20%	1374.41	30%	1228.27	22%	5612.96	23%		
	Crops	78.30	10%	6092.12	43%	1815.73	40%	1765.91	32%	9752.06	39%		
BRT	Pasture	334.98	44%	2228.07	16%	245.67	5%	1074.53	19%	3883.24	16%	0.91	0.88
	Water	1.19	0%	712.15	5%	4.77	0%	757.82	14%	1475.93	6%		
	Moorland	104.27	14%	1972.41	14%	987.70	22%	643.02	12%	3707.39	15%		
	Forest	264.73	35%	2937.36	21%	1391.12	31%	1287.28	23%	5880.48	24%		
	Crops	60.81	8%	6167.71	44%	1887.56	42%	1769.93	32%	9886.00	40%		
SVM	Pasture	283.07	37%	1397.81	10%	116.72	3%	768.77	14%	2566.37	10%	0.96	0.95
	Water	1.15	0%	706.92	5%	1.52	0%	755.96	14%	1465.55	6%		
	Moorland	140.89	18%	1749.17	12%	1136.88	25%	600.24	11%	3627.18	15%		
	Forest	276.93	36%	3560.66	25%	1047.69	23%	1631.81	29%	6517.09	26%		
	Crops	63.95	8%	6603.12	47%	2214.00	49%	1775.79	32%	10656.86	43%		
Total OA		765.98	100%	14017.68	100%	4516.81	100%	5532.57	100%	24833.05	100%		

Discussion

The environmental offer can be defined as those “riches” that are characteristic of a certain territory such as services, environmental potentialities and all the development processes and opportunities that derive from this; Knowledge of the existing natural resources in a certain area allows generating awareness about the current environmental condition, evaluating the positive and negative aspects regarding the relationship of the human being with its natural environment, the determination of conflicts, actions and prioritization for proper use. In Colombia, the Agustín Codazzi Geographical Institute – IGAC (for its acronym in Spanish) designed a methodology to define agrological classes, which are evaluation systems that seek the suitability of soils and the capacity of land use for agricultural activities to make (IGAC, 2014).

The agrological classification reported by the IGAC was used for our analysis. In this classification, there are 8 different categories named agrological classes. The categories (class, subclass and capacity or management group) correspond to a level of generalization of the information referring to the capacity of the land for the production of cultivated plants, the requirement of protection of highly vulnerable areas or the need for conservation and/or recovery of nature (IGAC, 2014).

The IGAC is the entity of the Colombian State whose function is to produce the official map and the basic cartography of the country, it has a Methodology for the classification of lands by its capacity of use, which groups the soils based on the characteristics of the soils that limit their use and generate a risk of their degradation, mainly due to erosion (Instituto Geográfico Agustín Codazzi - IGAC, 2012).

The use of land in its natural state is limited to seasonal agriculture and livestock with low technology, conservation and preservation of natural resources, and ecotourism (IGAC, 2014).

The topography is one of the most limiting factors of agricultural activities in an Andean territory; however, the average slope for the basins of the territory that oscillate between 3 and 18%, suggest that depositional processes occur, which are associated with the flat relief, in this sense, it can be inferred that the speed of the water is low (Betancourth and Garnica, 2017) which reduces the risk of erosive processes (CAR, 2017).

In the areas surrounding the reservoir (2,499-2,600 m.a.s.l), with slopes < 12 and up to 25%, there are slightly undulating and sloping topographies, good drainage, medium to moderately fine textures, and low evolution. They are soils of the order inceptisols (Humic dystrendept), although the precipitation regimes correspond to dry cold, agrologically they are classified as soils II and IV, which indicates that they have moderate limitations for production. In fact,

most of the agricultural activity of the territory is found on these lands due to their proximity to populated centers, better communication routes with appropriate attributes for productive activities (CAR, 2017), which in this study coincide with lands of medium EO.

Generally, the high slopes occur in the first kilometers of the rivers and descents up to 2,700 meters above sea level. The Aves River descends to 2,700 meters above sea level, in just 0.4 km until it joins the Siecha River, which is why steep slopes occur, especially on the eastern slope of this river (Betancourt and Garnica, 2017). They are slopes with some susceptibility to erosion; The main soil orders present in these areas are of the endisol and inceptisol order (Typic melanudands and Humic dystrochets) (CAR, 2017). Some areas are well drained covered by páramo vegetation, others with coarse textures with superficial limitations by fragments of rock classes; A large part of the territory is under agrological classes VII and VIII.

The steep slopes are located mainly in the southeastern part of the territory on the border with the municipality of Guasca. They present high to excessive drainage, they are soils of the Andic dystrochets order; They are deep soils with fine to medium textures, with acid reaction and medium aluminum saturation, their fertility is moderate (CAR, 2017), highly susceptible to erosion, agrologically in a large part of the territory classes VII and VIII predominate. This topographic condition increases the risk of soil loss to erosive processes.

In the municipality of Guatavita there are large extensions of class VIII lands that have ecosystem importance in the generation of water and scientific interest (IGAC, 2014). In the 1990's, of the 24,135 hectares of the municipal area of Guatavita, approximately 51% was covered with pastures, 43% corresponded to forests, and 4,971 head of cattle were registered (CAR, 1995). For the year 2019, the total cattle in Guatavita was 10,434 heads (ICA, 2021), which represents a significant increase in livestock production, with different production systems.

The study by De Mello et al., in 2016, shows that spatial analysis through the use of satellite models constitutes an excellent predictive and planning tool for the use of natural resources, via primary information management in watersheds. The prediction of possible impacts (negative or positive) generated, by the loss of species or changes in soil management, from agricultural to forestry and livestock activities, constitutes an input to understand how to better conserve the environment (De Mello et al., 2016). Satellite tools are also an important resource for simulations and impact studies; however, their use in decision-making is still in its infancy. Although the map of agrological classes of the zones provides information regarding land uses and conflicts, it is not in the public domain. Landscape studies imply moving from actions oriented towards projects to actions oriented towards processes and activities, which requires levels of intervention, starting from the definition of a certain problem, financing and linking interested parties (Sayer et al., 2013).

A study carried out in Costa Rica illustrates the process of building spatial vulnerability indices based on the overlapping of thematic layers with the use of geographic information systems (GIS), which constitute a valuable tool in landscape-scale studies, since facilitate the analysis of the influence of the biophysical context in the configuration of agroecosystems and their associated technology (Mora-Delgado, 2004).

On the other hand, different have been the methods to define types, from the most practical based on the empirical classification carried out by local experts, to the most sophisticated typification systems by multivariate statistical methods (Righi et al 2011). However, the most appropriate could be the definition of the typology based on a combination of the two approaches; this option was chosen in this study. The most usual correspond to a detailed description of the different types that can be obtained through statistical analysis of the available data of farms belonging to the "core" of each type, that is, the farms that are considered similar to the farm type (Landais, 1998); some types scholars call them "centromere farms". Although the type conformation process can be done in the opposite way, first group the individuals based on their similarity of the variables with statistical methods with a subsequent adjustment of the groups under the criteria of the researcher. Thus, a typology could be obtained that represents the reality of the technological practices or socioeconomic characteristics to be studied.

The typification of the production systems provides the bases to simplify the analyzes of the heterogeneous agricultural systems (collier, et al., 2012). The typologies group heterogeneous farms into similar coherent groups that can be used to infer certain characteristics, which is evidenced in this study. In this regard, Amadu et al. (2020) used farm typologies to analyze the adoption of climate-smart agricultural technologies in southern Malawi, while López-Ridaura et al. (2018) assessed animal husbandry technologies and climate impacts on food security in India; In this sense, this study takes up the contributions of studies to the extent that relationships are established between the biophysical context and socioeconomic aspects, such as the adoption of technologies in dairy production systems.

Conclusions

The biophysical contextualization constitutes an important criterion to analyze the typology of production systems, since many characteristics of the types are a function of the context, although others are the result of social decisions that configure the technology of their systems.

For biophysical characterization, satellite models constitute one of the low-cost and reliable ways to describe natural characteristics and anthropocentric actions in nature, which is an important input to provide information for local decision-making, and at the territory scale. Thus, GIS are an excellent tool that has been underestimated by the public administrations of the territories in the sense that a better use of the information can be made for territorial planning plans, since the knowledge on the part of the producers regarding the offers and limitations of your land, you can ensure greater efficiency in the use of resources and a more sustainable management of natural processes and those created and modified by man.

Many of the farms have settled in areas with little environmental offer and agrological factors unsuitable for production, which generates pressure on the land, and is expressed in decision-making by the producer about the technology to make it viable and efficient, that is, the need to include external energy (chemical fertilizers, machinery, supplements for animals) to supply the deficiencies of the environment, constitutes a characteristic in some types of production systems, which possibly makes them inefficient from the point of view of productivity of energy.

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20. Los puntos de selección y de evaluación de los clasificadores con cada uno de sus respectivos usos del suelo se realizaron con una cantidad reducida de puntos, intentando en principio reducir la incertidumbre, ya que es la introducción de al desarrollo de una nueva investigación donde se evaluarán los resultados a partir del levantamiento de una mayor cantidad puntos de control en campo permitiendo evaluar la eficiencia y precisión de las interpretaciones como así también, corregir y robustecer la clasificación, con nueva información geoespacial y cambios de uso del suelo

Figures

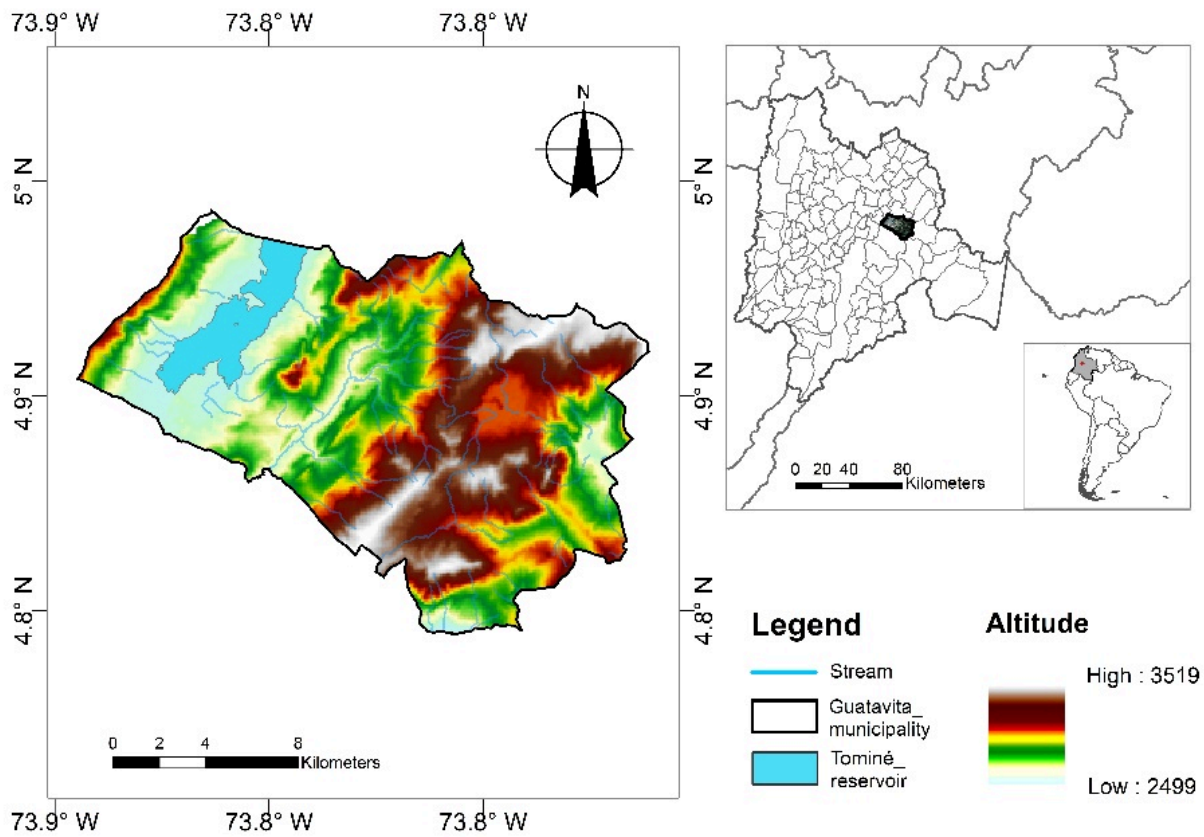


Figure 1

Guatavita, Cundinamarca, Colombia

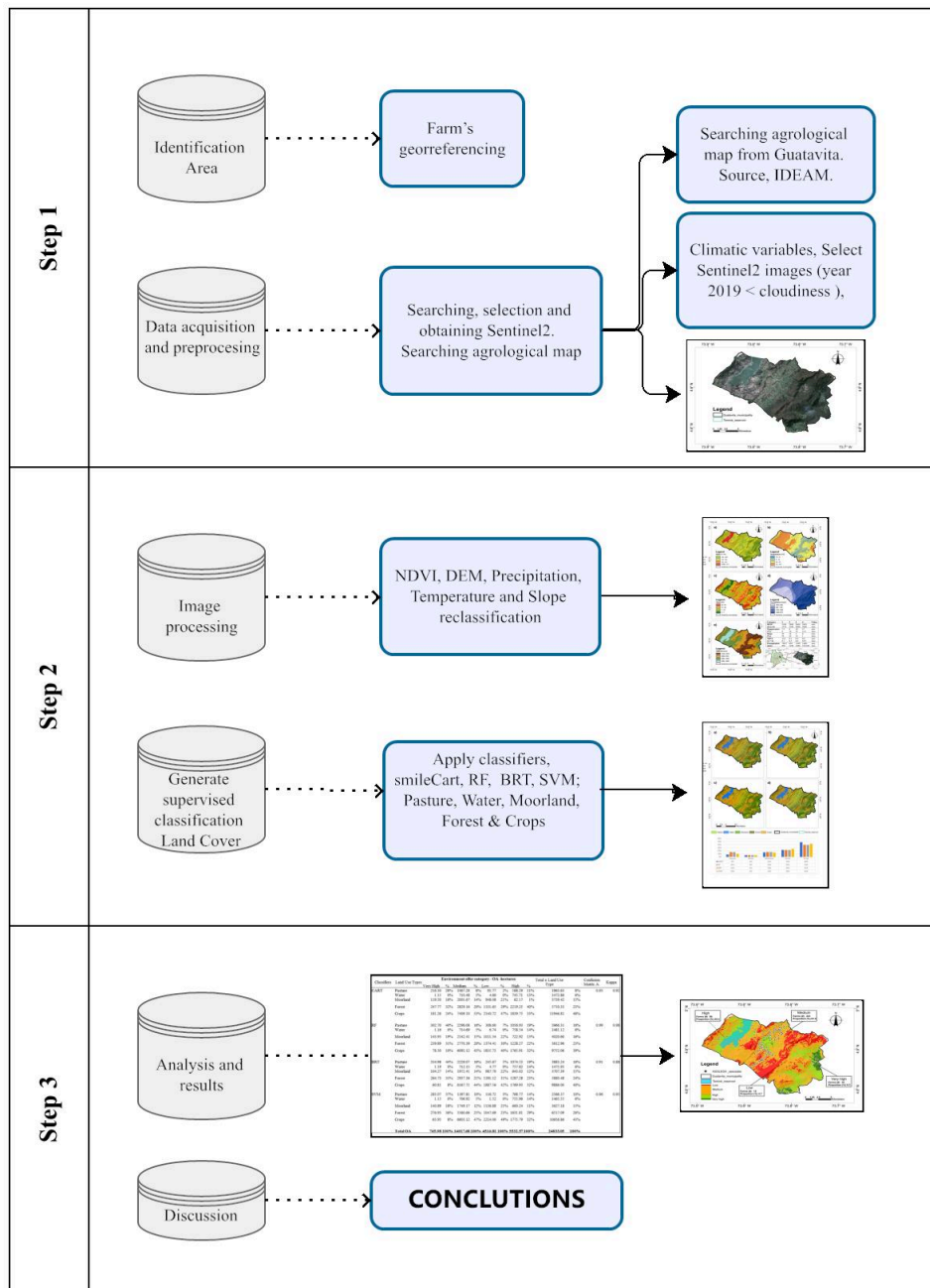


Figure 2
description of data processing to study territory characterization.

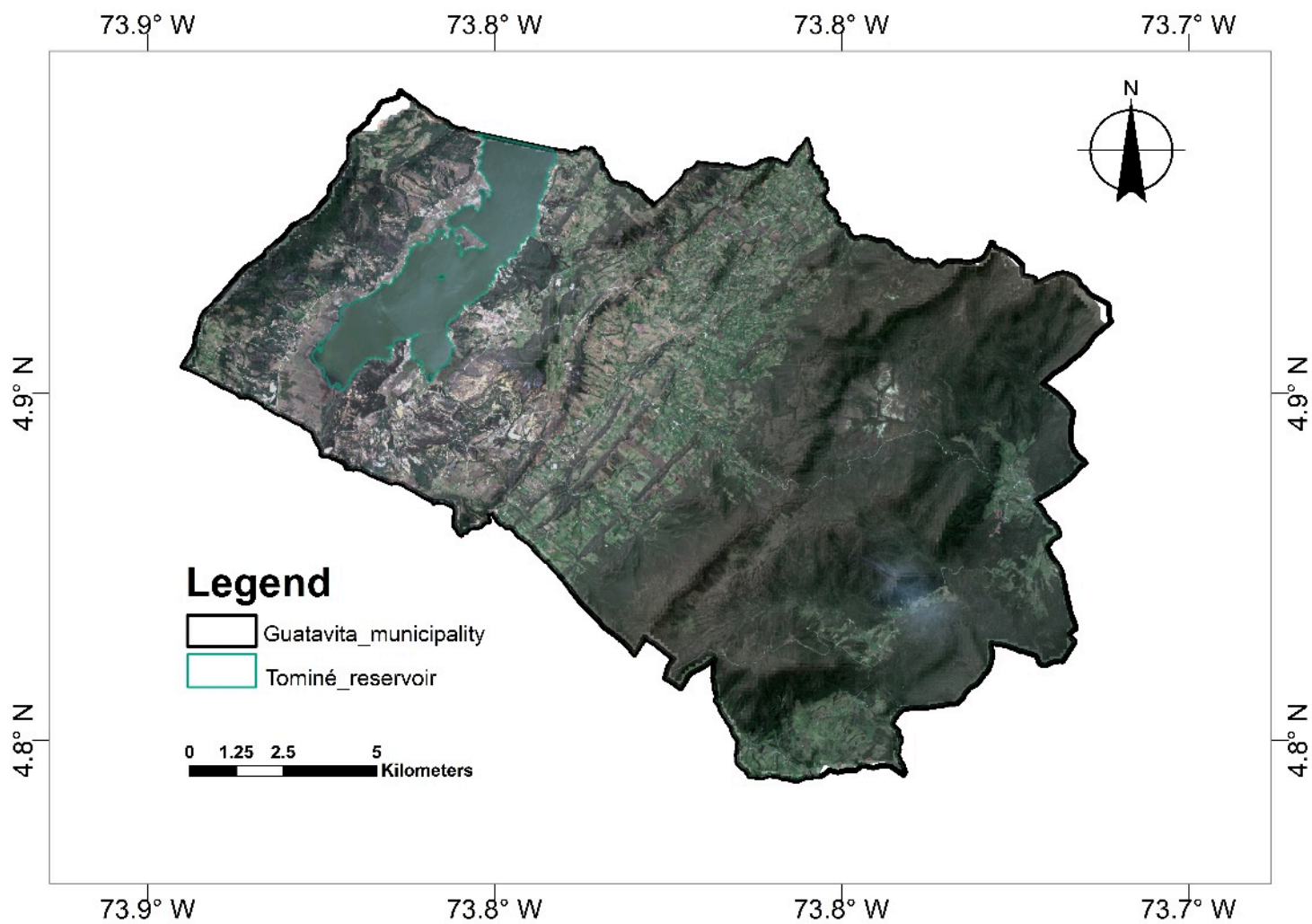


Figure 3

a) Natural Color image of the study area downloaded from the USGS - Source: Image ID: sentinel 2 – 20190203; Source: Processed by authors.

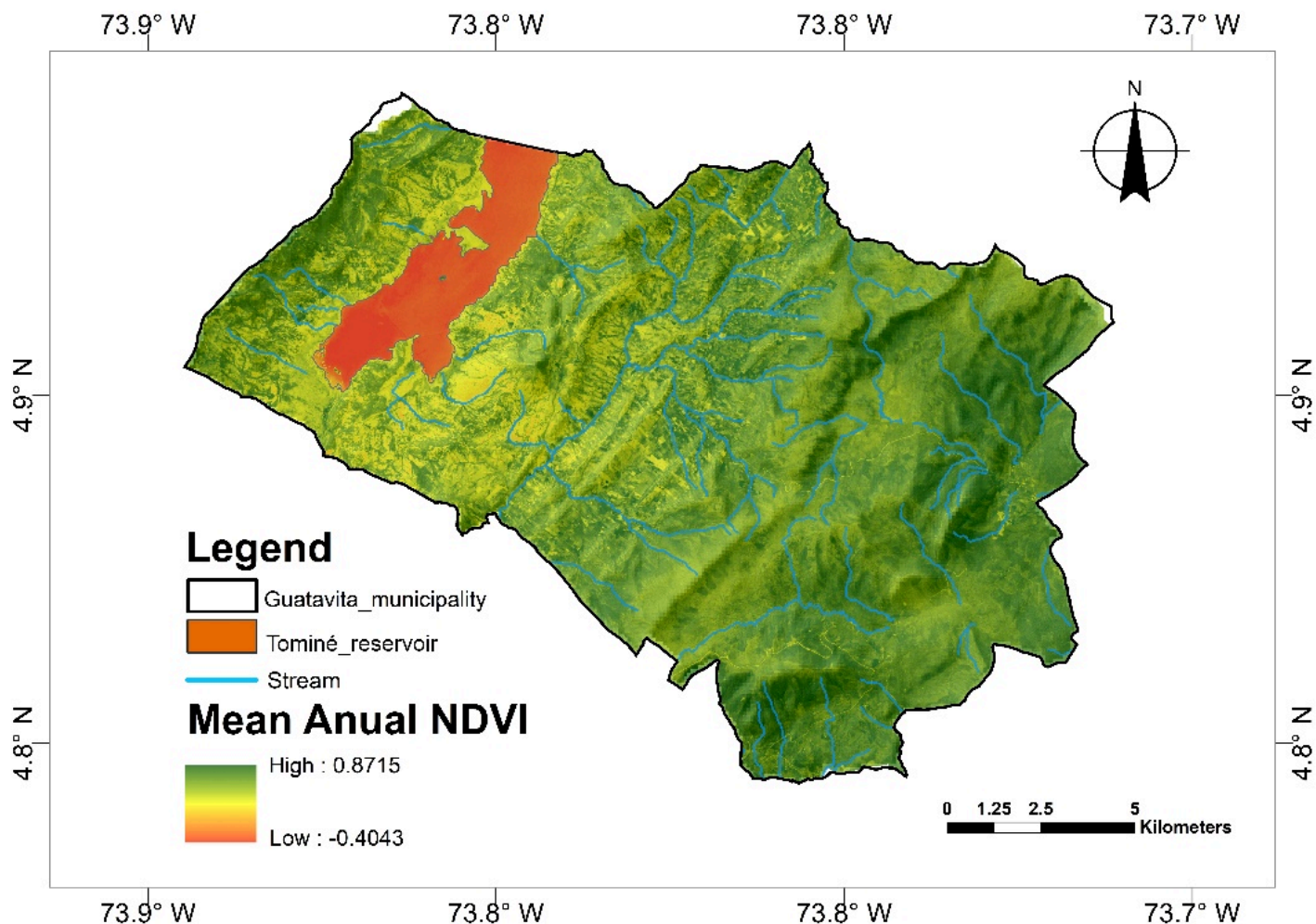


Figure 4

NDVI for the target area in Guatavita, 2019

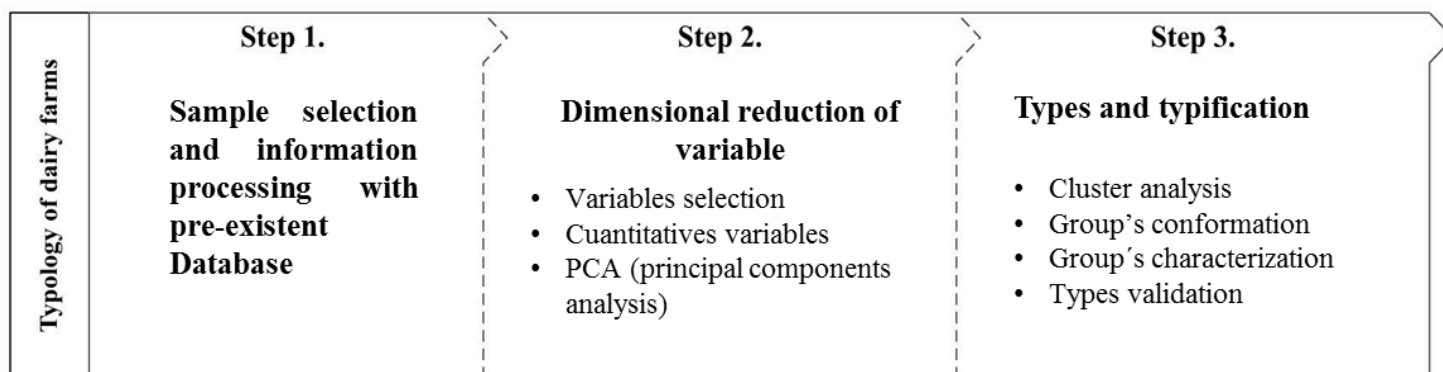


Figure 5

Diagram of the methodology of characterization and typification of livestock systems. Figure adapted from Methodology for the Characterization and Typification of Livestock Systems, (p.3), by Cabrera et al., 2004.

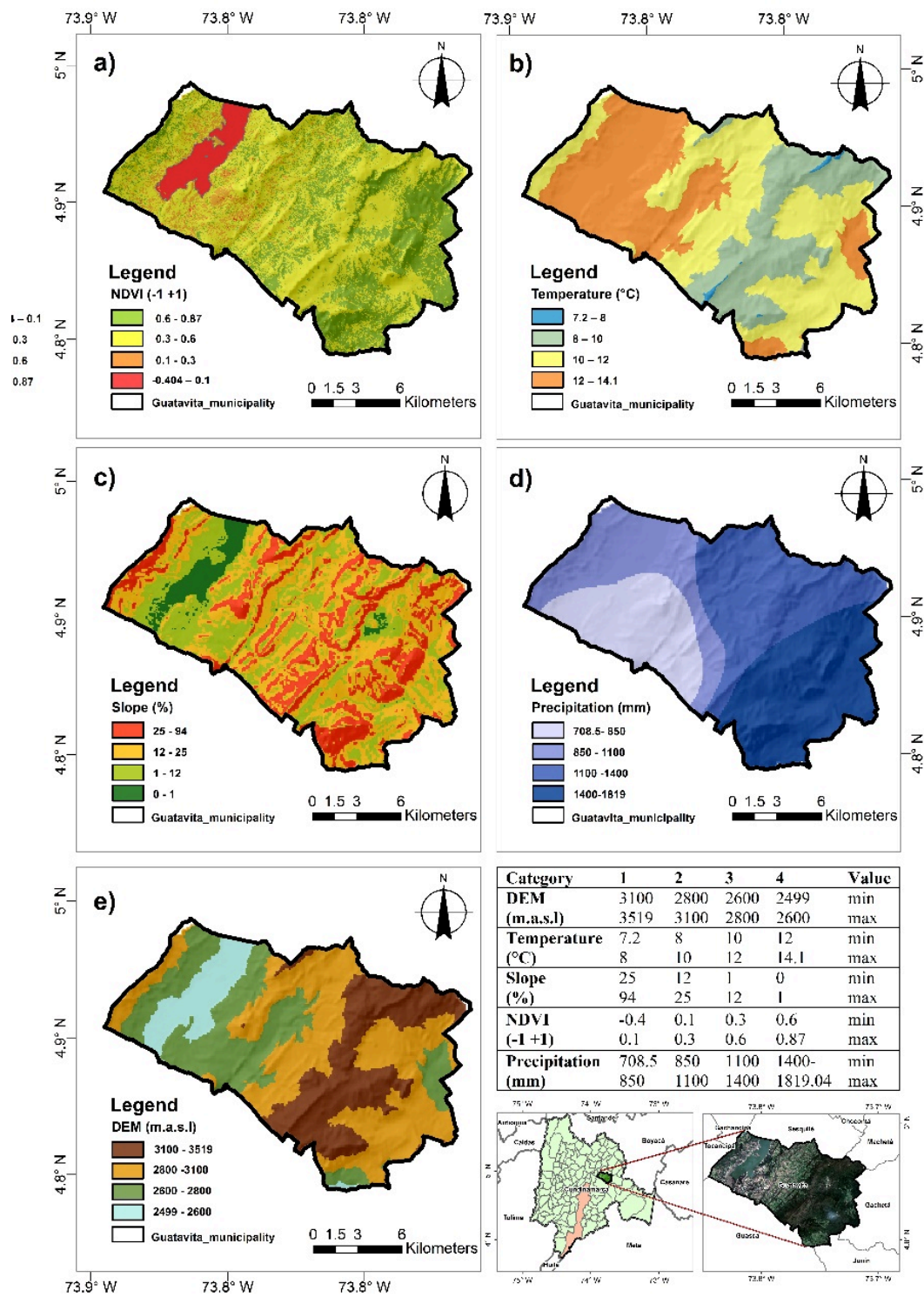


Figure 6

Reclassification A. NDVI; B. Temperature; C. Slope; D. precipitation; E. DEM.

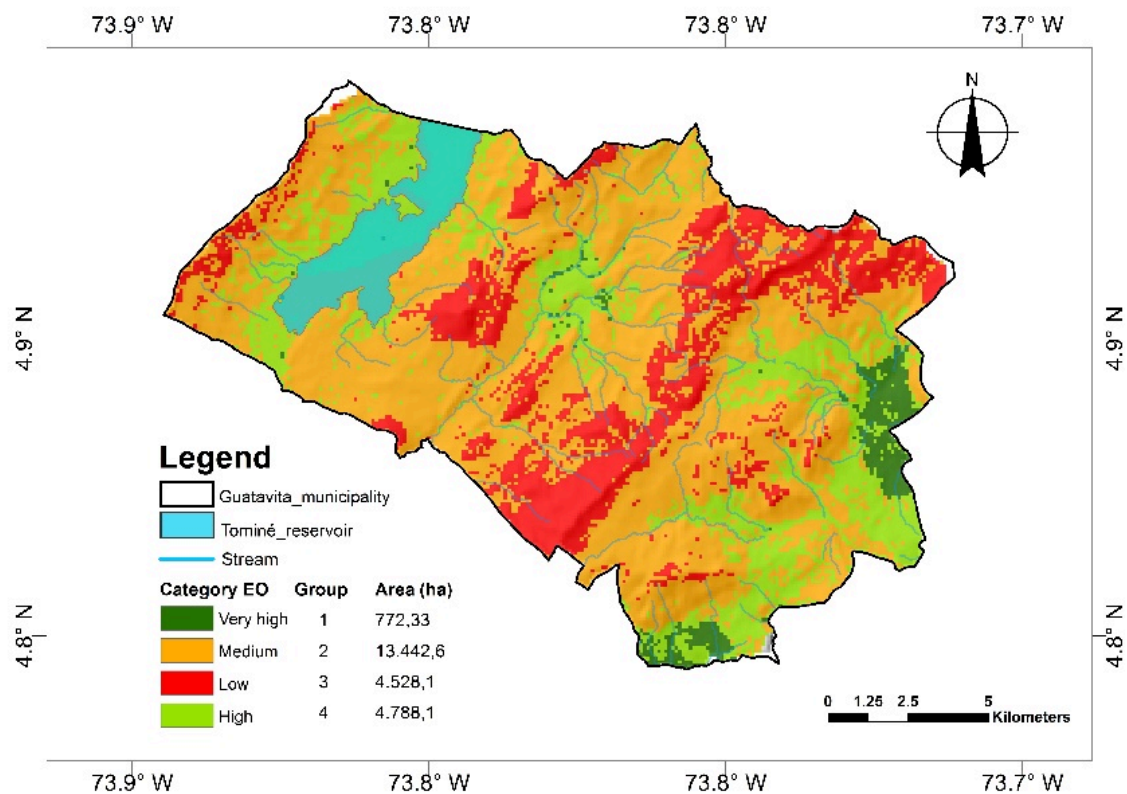


Figure 7

Colorimetric categories for Environmental Offer with the chosen parameters.

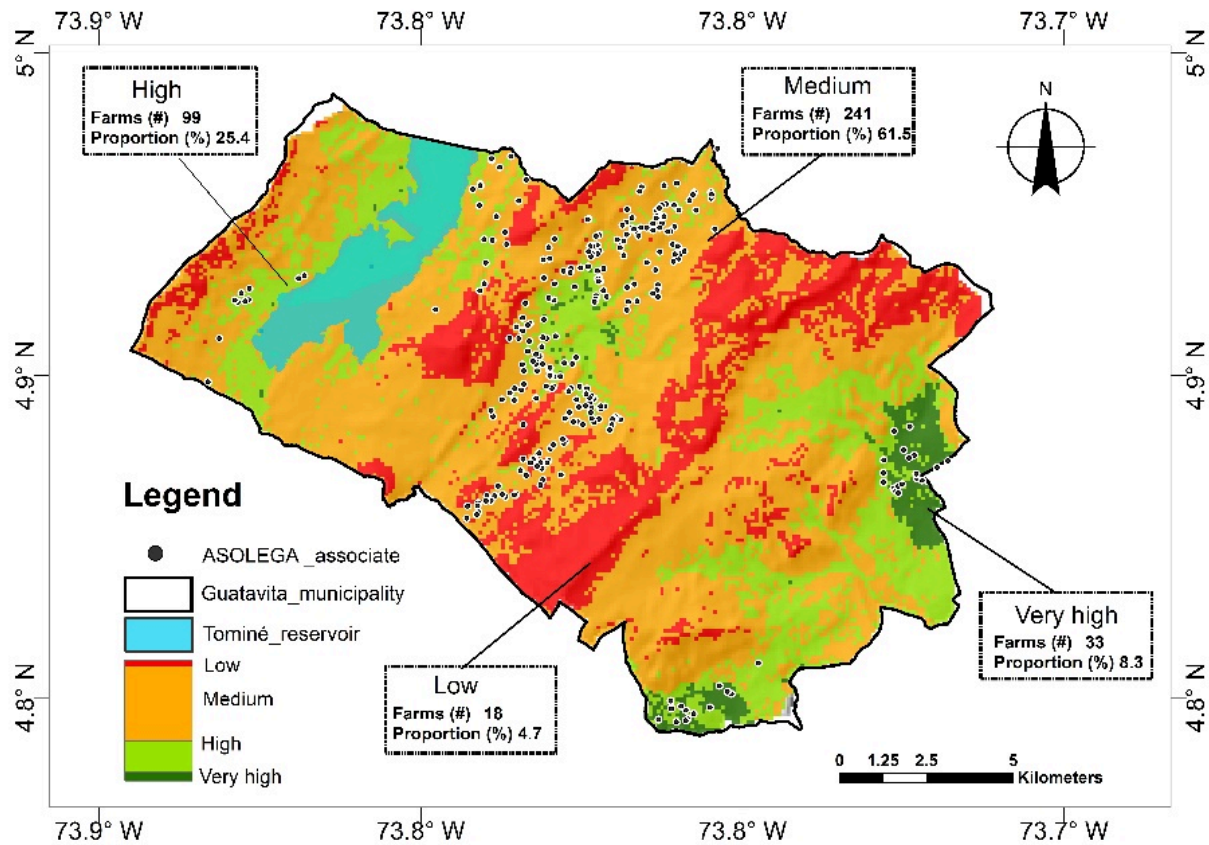


Figure 8

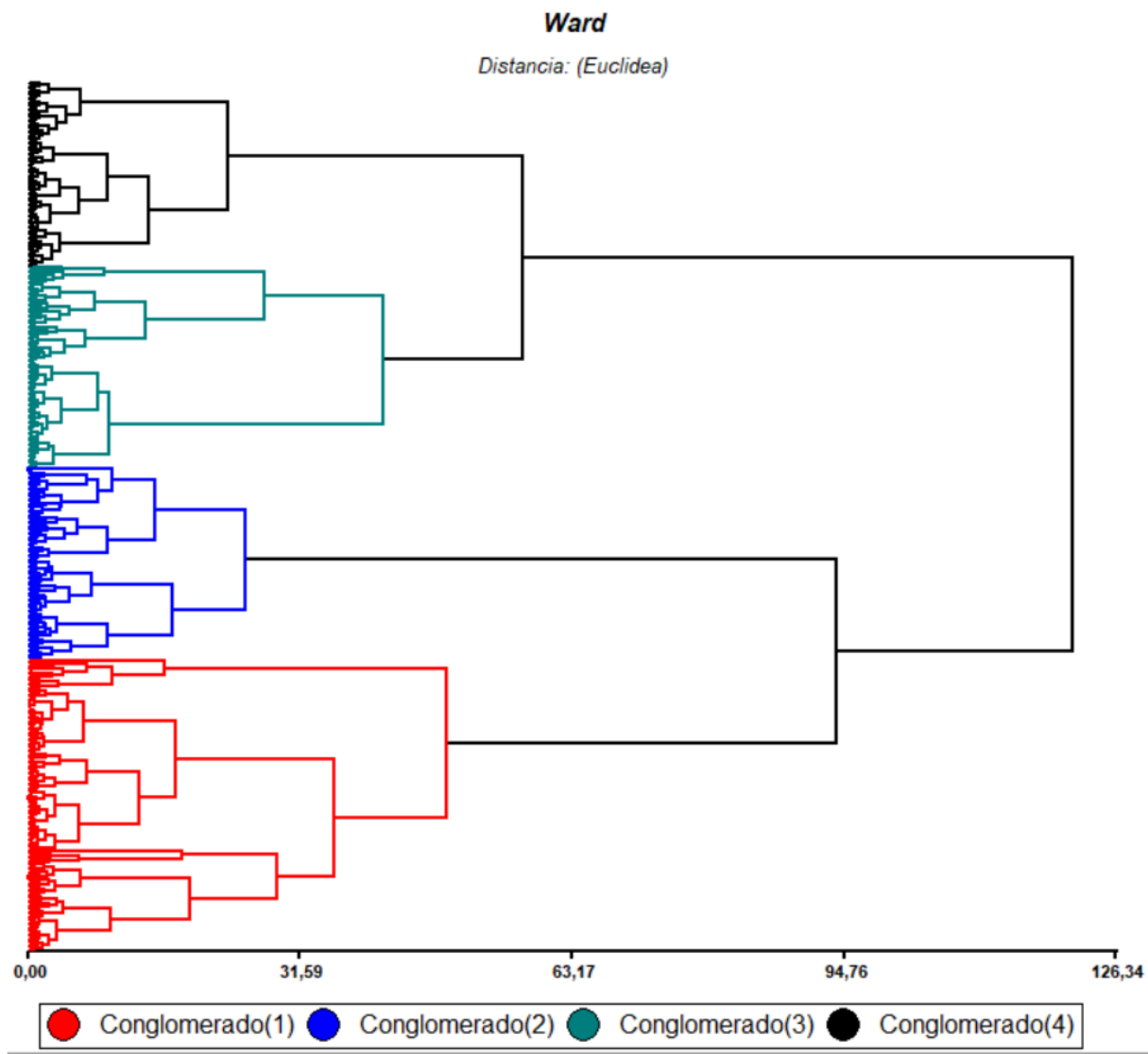


Figure 9
Clustering analysis using Ward distance.

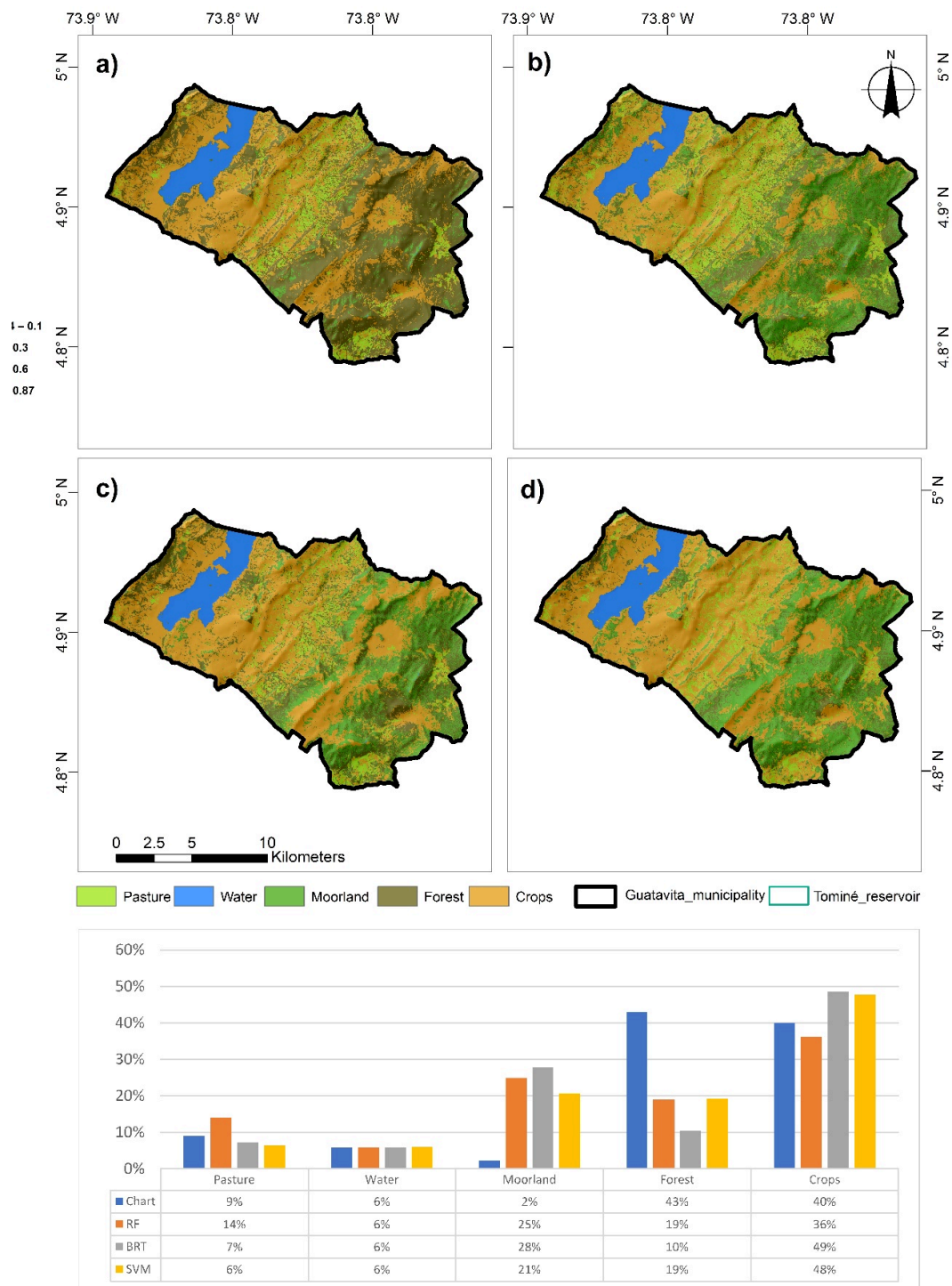


Figure 10

Unnumbered image in the Results section.