SUSTAINABILITY ASSESSMENT OF NATURAL RESOURCE MANAGEMENT IN THE YUNGAÑAN RIVER MICRO-BASIN IN THE ECUADORIAN ANDES †

[EVALUACIÓN DE LA SUSTENTABILIDAD DEL MANEJO DE RECURSOS NATURALES EN LA MICROCUENCA DEL RÍO YUNGAÑÁN, EN LOS ANDES ECUATORIANOS]

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SUMMARY

Background. As a strategy to design actions aimed at sustainable development at the local level, it is necessary to carry out a thorough diagnosis of the social, economic and environmental dimensions that affect the sustainability of a community. **Objective.** With that in mind, this research evaluated the sustainability of the natural resource management of the productive units in the Yungañan River micro-basin in the Ecuadorian Andes in order to identify the strengths and weaknesses of their actions as well as the possible internal differences between the different management systems. **Methodology.** For the execution of this work, 25 indicators were developed in a participatory manner, organized into 8 attributes that respond to the social, economic and environmental dimensions, following the methodology proposed by Sarandón (2002). These indicators were evaluated in the field through interviews and the results were weighted on a scale of 0 to 4 for analysis. In order to verify similarities and differences between the different productive units, a cluster analysis was carried out and a t-test was performed to verify significant differences between the indicators evaluated. **Results.** If we consider each dimension analyzed, the economic dimension reached an average value of 2.14, the social dimension 1.65 and the environmental dimension 1.80. Consequently, the average of all the indicators measured through the General Sustainability Index (GSI) was 1.86, which indicates deficient sustainability in the sector, with critical values for the social and environmental dimensions. With respect to internal differences, two groups were identified that were mainly conditioned by differences in the economic dimension. **Implications.** The main aspects to be addressed in the sector to improve its sustainability were identified and the usefulness of the methodology employed for studies of similar characteristics was highlighted. **Conclusions.** In order to design an effective strategy for the community's development, the strengths detected in this study must be taken into account, such as the relatively efficient management of the community's crops, and weaknesses, such as the lack of technical training, the lack of association and the difficulties of access to the sector, as well as the internal differences detected between the different productive units.

Keywords: Ecuadorian Andes, Natural Resource Management, Sustainability Indicators.

RESUMEN

Antecedentes. Como estrategia para diseñar acciones encaminadas al desarrollo sostenible a nivel local, es necesario realizar un diagnóstico preciso de las dimensiones sociales, económicas y ambientales que afectan a la sostenibilidad de una comunidad. **Objetivo.** Con éste propósito, en esta investigación se evaluó la sostenibilidad del manejo de recursos naturales en la microcuenca del rio Yungañán, en los andes Ecuatorianos, conformada por 15 unidades productivas, para identificar sus fortalezas y las debilidades de sus acciones así como las posibles diferencias internas entre los distintos sistemas de manejo. **Metodología.** Para la ejecución de este trabajo se desarrollaron, de manera participativa, varios indicadores (25), organizados en 8 atributos que responden en su conjunto a las dimensiones sociales, económicas y ambientales, siguiendo la metodología propuesta por Sarandón (2002). Estos indicadores fueron evaluados en el campo mediante entrevistas y los resultados fueron ponderados en una escala de 0 a 4 para su análisis. Para comprobar similitudes y diferencias entre las distintas unidades productivas se realizó un análisis cluster y una prueba t para comprobar diferencias significativas entre los indicadores evaluados. **Resultados.** Si consideramos cada dimensión analizada, la dimensión económica alcanzó un valor promedio de 2,14, la social, 1,65 y la ambiental, 1,80.

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En consecuencia, el promedio de todos los indicadores medidos a través del Índice General de Sostenibilidad (ISG) arrojó un valor d 1,86, lo que indica una sostenibilidad deficiente en el sector, con valores críticos en las dimensiones social y ambiental. Respecto a las diferencias internas se identificaron dos grupos condicionados principalmente por diferencias en la dimensión económica. **Implicaciones**. Se identificaron los principales aspectos a trabajar en el sector para mejorar su sostenibilidad y se evidenció, a su vez, la utilidad de la metodología empleada para estudios de similares características. **Conclusiones.** Con el fin de diseñar una estrategia efectiva para el desarrollo de la comunidad se deben tener en cuenta las fortalezas detectadas en este estudio como es el manejo relativamente eficiente de los cultivos en la comunidad y, debilidades como la falta de capacitación técnica, la falta de asociatividad y las dificultades de acceso al sector, así como las diferencias internas detectadas entre las distintas unidades productivas.
Palabras clave: Andes Ecuatorianos, Manejo de Recursos Naturales, Indicadores de Sustentabilidad

INTRODUCTION

According to the National Institute of Statistics and the 2019 census (INEC, 2019), the poverty index in Ecuador according to unsatisfied basic needs is around 34%. These increase to 47% in the province of Cotopaxi, where this study was carried out. One of the main causes that generates these results is the lack of access to innovation in many rural sectors of Ecuador due to issues including the lack of appropriate road networks, a low educational level and low levels of associativism (INEC, 2016). As a consequence, many rural inhabitants are engaged only in subsistence agriculture.

In order to deal with the challenge of reducing poverty in these communities and to fulfil the sustainable development goals (UN, 2015), several local development projects are being implemented to improve the economic, social and environmental conditions of the communities that are most vulnerable, according to the diagnosis established by INEC in 2019.

To achieve this purpose, first it was necessary to carry out an effective diagnosis of the sustainability of the communities, as proposed by Astier (2008), Hart (1985), Masera *et al.*, (1999), and Sarandón and Flores (2009).

One of the tools available for generating such a diagnosis is the evaluation of the sustainability of natural resource management systems. The concept of sustainability is complex because of its different philosophical, ideological and technical dimensions (Sarandón 2002; Sarandón *et al.,* 2006) and the need for a holistic approach that enables the analysis of different dimensions simultaneously in a given management system (Sarandón and Flores, 2009). However, in recent years, several methodological proposals have been developed to assess sustainability based on designing indicators (Kessler, 1997, Masera *et al* 1999, Mitchell *et al* 1995, Pean *et al* 2015). The advantage of this approach is that indicators can be adjusted to the reality of the locality studied, are able to integrate different aspects of the system to be evaluated and moreover are measurable (Masera *et al.,* 1999, Sarandón *et al.* 2006).

In the context of Latin America, there are more than 100 case studies on sustainability assessment based on indicators (Arnés and Astier, 2018). In Ecuador, the most recent case studies on assessing sustainability on smallholder farms were developed by Bravo-Medina *et al.*, (2017), Rodríguez *et al.*, (2018) and Viteri Salazar *et al.,* (2018) in the eastern Amazon region, while Mendez et al. (2016) studied the western coastal region, and Cruz *et al.*, (2016) and Hernández Maqueda *et al.,* (2018) studied Andean communities. These research projects have served mainly to identify which activities should be strengthened and which should be improved to ensure the sustainability of the smallholders' communities and thus achieve the sustainable development goals.

In the Yungañan River micro-basin, located in the western Andean mountain range of Ecuador, a local development project was carried out which, aligned with the sustainable development goals set by the UN, (2015), aims to seek alternatives for the sustenance of the 15 households that inhabit the basin, taking advantage of the available resources. This project, of a mutltidisciplinary nature, involves fields as broad as the evaluation of biodiversity and its possible role in community development, identifying the resources available to the community, and establishing possible entrepreneurial alternatives that can satisfy the needs of the inhabitants.

To achieve this and to establish effective actions, it was necessary to generate a clear diagnosis of the situation of the micro-basin inhabitants. Therefore, the objective of this article is to evaluate the sustainability of the Yungañan River micro-basin from a social, economic and environmental point of view in order to identify both the strengths to be reinforced and the weaknesses to be worked on in order to design effective actions aimed at sustainable local development.

MATERIAL AND METHODS

Description of the Study Area

The micro-basin of the Yungañan river is located in the parish of El Tingo-La Esperanza in the province of Cotopaxi. From a geographical point of view, it is situated in the western cordillera of the Ecuadorian Andes, in the upper part of the Guayas River basin under the coordinates 0º 42' 56.4" and 0º 42' 55.08", latitude S; and 98º 56' 49.52" 98 56' 53.98" longitude E, and has an altitude range of 684 m to 2227 m. It is a transition region to the tropical rainforest, with pronounced slopes and shallow soils of low organic matter content. Annual rainfall is 536 mm, distributed in the rainy and dry seasons, with average temperatures of 19°C (Figure 1). There are 15 farms in the sector dedicated mainly to a subsistence agriculture and/or livestock production. Although livestock is the priority activity, there are other activities that contribute to a greater or lesser extent to family income, such as the production of sugar cane for *panela* and *aguardiente* (a strong liquor) and blackberry production.

Methodology for Sustainability Assessment

Sustainability of the management of natural resources (soil, water, biodiversity) was therefore evaluated according to the main productive activity on each farm, using the criteria outlined by Sarandón (2002) and Sarandón *et al.* (2006), which establish the following main stages: a) the selection of participants, b) the dimensions and attributes to be evaluated, c) the construction of indicators, d) the measurement and interpretation of the indicators, and e) definition of the aspects around which the subsequent action plans should be designed to strengthen or improve the different activities.

(a) Selection of participants. This study is based on the evaluation of the sustainability of natural resource management in the entire micro-basin of the Yungañan River, therefore the participants were all the productive units present in the basin (15 in total).

b) Description of the dimensions and attributes of sustainability. Three main dimensions were analyzed: economic, environmental and socio-cultural. To evaluate the economic dimension, two main attributes were selected: A. Food self-sufficiency and B. Economic risk. The environmental dimension was evaluated using 3 attributes: A. Conservation of soil life; B. Erosion risk; and C. Biodiversity Management. Finally, for the social dimension, the degree of satisfaction of the socio-cultural aspects was measured using the following attributes: A. Satisfaction of basic needs; B. Contributions in the production system; and C. Integration in organizations.

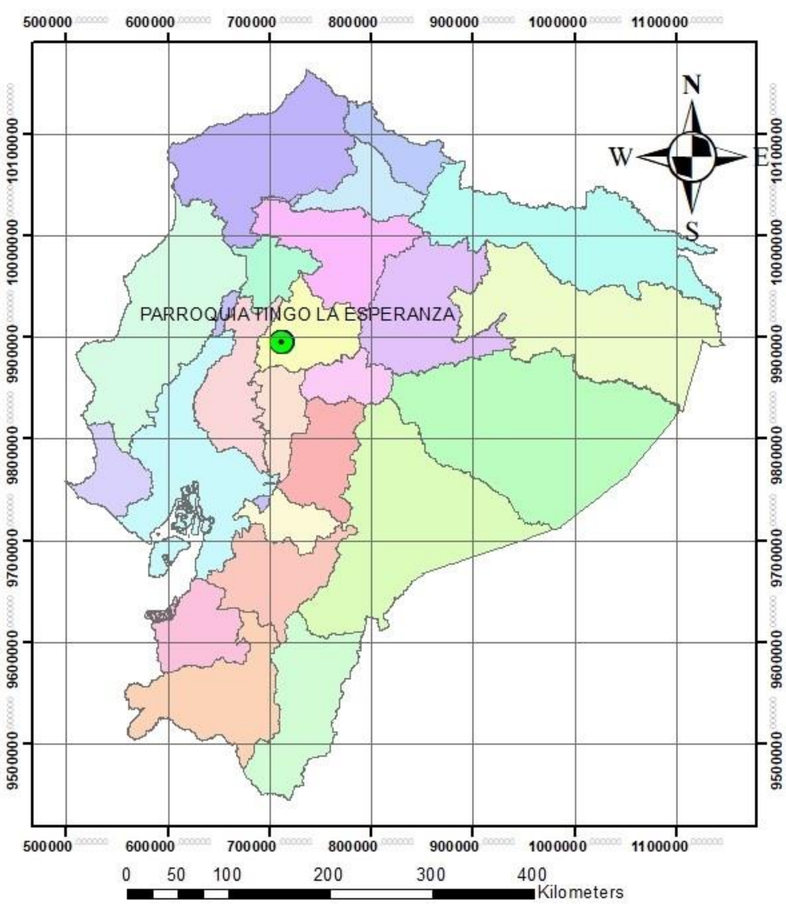


Figure 1. Geographical location of the study area.

Table 1. Dimensions, attributes and strategic indicators used for sustainability assessment in the Yungañan River micro-basin.

Attribute	Indicator	Scale (0-4)
		Economic Dimension
Food self-sufficiency	A1. Productive crops	The producer: **0.** does not carry out agricultural activity, **1.** single crop**, 2.** two crops, **3.** three crops, **4.** four or more crops.
	A2. Surface area for self-consumption	**0.** < 1000 m^2; **1.** 1000 m^2; **2.** >1000 m^2 to < 2000 m^2; **3.** > 2000 to < 3000 m2; **4.** > 3000 m$^{2.}$
	A3. Incidence of pests and diseases	**0.** More than 30% loss, **1.** >20 % to 30 % loss, **2.** >15 % ≤ 20%, **3.** ≥ 10 % to 15%¸ **4.** < 10% loss.
	A4. Diversification of production	**0.** does not diversify, **1.** prevalence of monoculture, **2.** two agricultural products, **3.** combines agriculture and livestock, **4.** agriculture, livestock and other products.
	A5. Yield (t/ha)	**0.** no production; **1.** <5 t/ha sugar cane, < 2.8 t/ha blackberry or < 2.5 t/ha corn; **2.** ≥ 5 t/ha sugar cane, ≥ 2.8 t/ha blackberry or ≥ 2.5 t/ha corn; **3.** > 5 to 10 t/ha sugar cane, ≤ 4 t/ha blackberry or ≤ 4 t/ha corn; **4.** > 10 t/ha sugar cane, > 4 t/ha blackberry or > 4 t/ha corn.
	A6. Monthly net income	**0.** $0 – 30 per month; **1.** < $150 per month **2.** >$150 < 385 per month; **3.** >$386 <600 per month; **4.** > $600 per month
Economic Risk	B1. Sales diversification	**0.** does not commercialize, **1.** commercializes one product only, **2.** commercializes two products, **3.** commercializes three products, **4.** commercializes four or more products.
	B2. Distribution of products	**0.** no exchange of products, **1.** local exchange or via intermediaries, **2.** local market, **3.** association of producers, **4.** own marketing channels.
		Environmental Dimension
Conservation of soil life	A1. Crop management	**0.** no management practices, **1.** only for soil preparation, **2.** application of nutrients without technical criteria, **3.** use of organic techniques, **4.** adequate fertility management.
	A2. Crop residue management	**0.** no management, **1**. burns the residues, **2.** uses the crop residues for fodder, **3.** incorporates the residues into the soil, **4.** composting with crop residues.
	A3. Appropriate management of irrigation water	**0.** no management, **1.** irrigates with rainwater only, **2.** has regulated irrigation water without technical management, **3.** has constant irrigation water with technical management, **4.** has constant irrigation water with technical management and also has water reservoir.
Risk of erosion	B1. Slope	**0.** Slope > 60%, **1.** Slopes < 60 % and > 45%, **2.** Slopes > 30 % < 45%, **3.** Slopes > 15 % < 30%, **4.** Slopes > 0 <15%.
	B2. Soil conservation	**0.** no management, **1.** use of deep grooves, **2.** diversion trenches and use of gradient curves, **3.** use of terraces, **4.** proper soil management.
	B3. Soil typology	**0.** rocky bed, **1.** stony, reddish soil with little water retention, **2.** sandy, yellowish soil with little vegetation, **3.** light brown, argillaceous soil with little diversity, **4.** dark brown or black soil with abundant organic matter
Biodiversity management	C1. Functional biodiversity	**0.** no agricultural activity, **1.** abandonment or monoculture, **2.** little diversity, no associations, **3.** association between crops, **4.** presence of fruit trees, live fences and crops.

Attribute	Indicator	Scale (0-4)
	C2. Use of agroforestry	**0.** uncontrolled felling, **1.** crops without tree cover **2.** trees as fences, **3.** associations between fences and crops, **4.** live fences with fruit trees, native plants and crops.
	C3. Ecological Awareness	**0.** has no knowledge, **1.** has poor knowledge, **2.** has no knowledge, but eventually, carries out management similar to ecological principles, **3.** consciously applies some of the knowledge based on ecology, **4.** knows the fundamentals and applies them.
Socio-cultural Dimension		
Satisfaction of basic needs	A1. Housing	**0.** no minimum conditions, **1.** very basic house, **2.** 1-storey dwelling, **3.** provides basic conditions, **4.** finished, provides adequate comfort.
	A2. Access to education	**0.** illiteracy, **1.** has attended some literacy campaign workshops, **2.** access to primary education, **3.** access to secondary education centers with difficulty, **4.** access to primary and secondary education centers without difficulty.
	A3. Access to health	**0.** health center very distant (180 or more minutes away), **1.** health center poorly equipped, very distant (around 120 minutes away), **2.** health center poorly equipped, distant (around 60 minutes away), **3.** health center nearby and easily accessible, **4.** health center well equipped and easily accessible.
	A4. Services	**0.** no minimum conditions, **1.** no basic services, **2.** no electricity and water from a well, **3.** electricity and untreated water for human consumption, **4.** electricity, treated water and a variety of communication channels.
Contributions in the production system	B1. Participation in productive work	**0.** no cooperation, **1.** temporary workers, **2.** close relatives, **3.** unified family system, **4.** unified family system and neighbors.
	B2. Acceptance of the production system	**0.** disappointed, **1.** plans to change activity, **2.** not very satisfied, **3.** happy, but thinks about improvement, **4.** very happy with the production system.
	B3. Collaborating parties	**0.** none, **1.** the Church, **2.** support from public institutions, **3.** support from public institutions or local governments, **4.** support from public institutions, NGOs and local governments.
Social Integration	C. Participation in organizations	**0.** none, **1.** occasionally at *mingas**, **2.** sometimes at neighborhood meetings, **3.** membership of a public or private association, **4.** membership of a corporate group.

The scale varies from 0 to 4, where **0** = poor level; **1** = very low level, **2** = low level, **3** = medium level and **4** = high level; t/ha = tons per hectare^{-1}; **minga* refers to the collaborative work typical of communities in the Andean region of Ecuador.

c) Construction of the indicators to be evaluated. Firstly, based on the application of the conceptual framework, a series of standardized indicators were proposed for the suggested dimensions in accordance with Sarandón *et al.* (2006). These indicators were socialized with the producers of the sector. Subsequently, participatory workshops were held between producers, researchers, technical specialists in sustainable agriculture and agroecology, a sociologist and authorities from the sector to define, in a consensual manner, the definitive indicators to be used in the study. The minimum requirement for selecting the indicators was based on the guidelines of Sarandón *et al.* (2002), Conceição *et al.* (2005) and Machado Vargas *et al.* (2015), in that they were easy to measure, understandable and capable of detecting the different processes occurring on the farm. To proceed with the evaluation of the indicators, data were standardized by transformation into a scale of 0 to 4, with 0 indicating the lowest value and 4 the highest, following the recommendations of Sarandón and Flores, (2009).

Table 1 shows the final 25 indicators applied in the study, as well as the different scale established in a participatory manner by all the actors involved in the project.

Table 2. Formulae applied for the calculation of the Sustainability Indexes.

Dimensions	Index	Formula
Economical	**IK**	$= \frac{(2((A1+A2+A3+A4+A5+A6)/6))+((B1+B2)/2)}{3}$
Environmental	**IE**	$= \frac{(2((A1+A2+A3)/3))+((B1+B2+B3)/3)+((C1+C2+C3)/3)}{4}$
Socio-cultural	**ISC**	$= \frac{(2((A1+A2+A3+A4)/4))+((B1+B2+B3)/3)+C}{4}$
General Sustainability Index	**ISG**	$= \frac{IK+IA+ISC}{3}$

d) Measurement and interpretation of indicators. For this, visits were made to each of the farms, where, through interviews and the application of structured surveys, the required information was obtained to complete the information regarding each indicator.

Once the information was collected for each of the 15 farms, the results were analyzed and the averages and standard errors were obtained for each indicator. Based on the different values obtained, we calculated the indexes for the economic dimension (IK), environmental dimension (IE) and socio-cultural dimension (ISC), whose average provides us with the general sustainability index (ISG), as shown in Table 2.

According to Sarandón *et al.* (2006), it is possible to assign more weight to one group of indicators than others if the researchers consider that they have a specific relevance or they help to better describe the study. In this research, indicators referring to the following attributes were considered to have double the weight: Food self-sufficiency, Conservation of soil life and Satisfaction of basic needs (Table 2).

For the interpretation of the different indexes, values > 3 are considered sustainable. For a better interpretation of the results, the findings for each dimension are presented in amoeba diagrams and analyzed. And subsequently, the sustainability general index (ISG) is discussed, with special emphasis on the established attributes and dimensions.

Statistical Analysis

A cluster analysis was carried out to analyze the heterogeneity of the results obtained among the different farms analyzed using the PAST v.3 software (Hammer *et al*., 2001). Ward's method (1963) was used for the construction of the distance trees. Internal branch support was estimated by heuristic bootstrap searches with 10,000 replicates. Bootstrap is, according to its author (Efron, 1979), a computer-based algorithm employed to characterize the behavior of almost any statistical estimate. For this study, it was used to estimate the probability of an observed cluster to repeat a *n* number of replications. According to this technique, a value >95 is considered significant.

Finally, we analyzed the differences between the values obtained for indicators, attributes and dimensions among the groups that were detected by the cluster analysis. For this, the comparison of the mean values of the variables was carried out by means of the non-parametric Mann-Whitney U test (Montgomery y Runger, 2003) by considering only those groups identified with a bootstrap support of >95.

RESULTS AND DISCUSSION

The values obtained, on average, for each of the indicators evaluated in each of the 15 productive units in the study area are shown below. The indicators are presented using amoeba diagrams, organized according to the three dimensions contemplated for measuring sustainability (economical, socio-cultural, and environmental).

a) Analysis of the indicators measured to evaluate the economical dimension (IK).

Within the economical dimension, the indicators that achieved the highest values are monthly net income (A6IK) and productive crops (A1IK), with values of 2.40 and 2.20 respectively, indicating that the productivity of the system remains in acceptable ranges that are close to 3 according to the methodology employed (Sarandón *et al*., 2006).

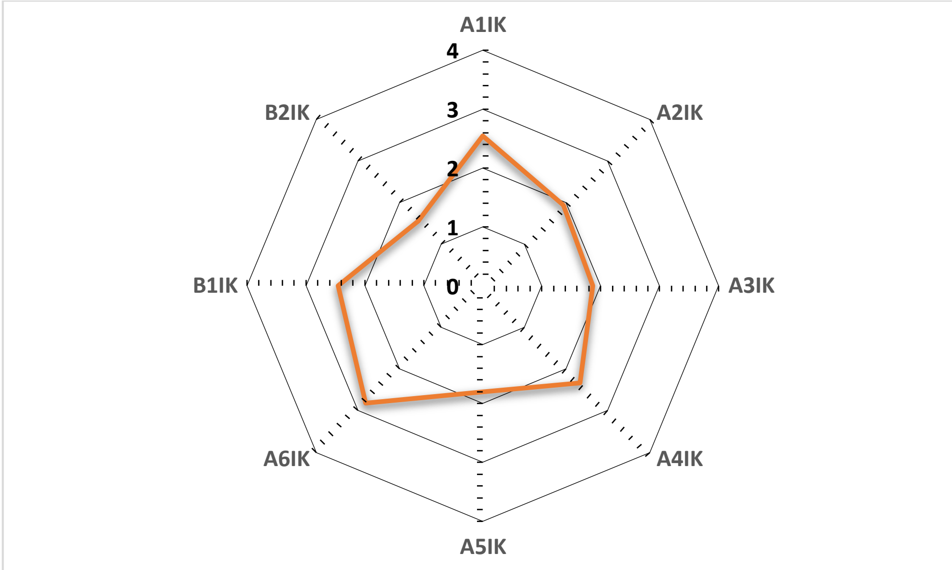


Figure 2. Amoeba diagram showing the averages of 8 indicators evaluated to measure the economic dimension (IK) in the Yungañan river micro-basin. A1IK= Productive crops; A2IK = Surface for self-sustenance production; A3IK = Incidence of pests and diseases; A4IK= Diversification of production; A5IK= Yield; A6IK= Monthly net income; B1IK= Diversification of sales; B2IK= Distribution of products.

On the other hand, the diversification of products and the sales diversification show a medium value (values of 2.33 and 1.87). Although the predominant crop is sugar cane, there is also the sale of milk from livestock, as well as the sale of blackberries and other products, which shows a certain adaptability of the system to respond to possible fluctuations in market prices. This diversification of sales would explain why these producers maintain a monthly net income of around $300 per month, above the level of other producers of the region whose income is below $200 per month (INEC, 2016).

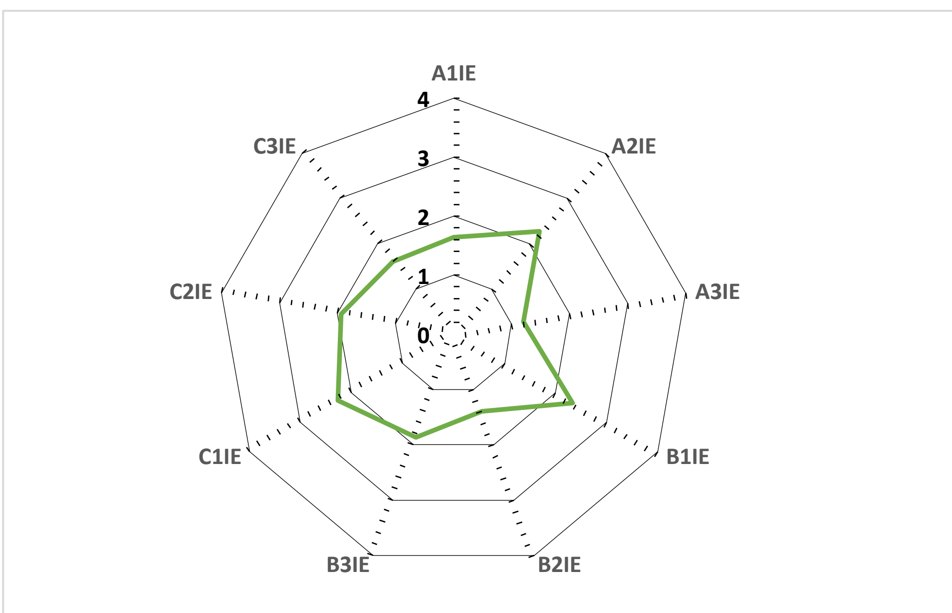


Figure 3. Amoeba diagram showing the average value of 9 indicators evaluated to measure the environmental dimension (IE) in the micro-basin of the Yungañan river. A1IE= Crop management, A2IE=Crop residue management, A3IE= Adequate management of irrigation water, B1IE= Slope, B2IE= Soil conservation, B3IE= Soil typology, C1IE= Functional biodiversity C2IE= Use of agroforestry, C3IE= Ecological awareness.

However, the most critical points that must be highlighted are the incidences of pests and diseases in the crops, which represent losses of about 30%, and this in turn leads to low crop yields. Figure 2 shows the values of both indicators: A3IK with 1.87 and A5IK with 1.80. These aspects demonstrate that producers are not technically qualified to deal with this issue.

In addition, the marketing channels on the farms evaluated are limited to sales in local markets, without any alternative strategy, which limits their sales capacity, therefore the B2IK indicator is very low (1.40).

b) Analysis of the indicators measured to evaluate the environmental dimension (IE).

From Figure 3, it can be seen that most indicators are below the minimum sustainability value (2), with the exception of 3 indicators: crop residue management (A2IE), slope (B1IE) and functional biodiversity (C1IE) with values of 2.27, 2.33 and 2.27 respectively. Crop management obtains an acceptable value, since it is the main source of income in the community. Therefore, certain basic management techniques are observed that involve a supply of nutrients to the crops by means of livestock manure and soil management by means of surface plows.

Regarding the indicator that refers to the slope of the land, an acceptable value is obtained due to its being a sector with a predominant slope of more than 30%. Most producers select flat land areas for agricultural activities, which allows them to retain more nutrients in the soil and therefore improve crop yields.

The indicator that refers to functional biodiversity reflects the capacity to benefit from biodiversity managed at the farm level. The role of biodiversity in communities is important because, according to Stupino *et al.*, (2014), it provides different services (such as wood, food or protection from erosion) and management depends largely on the resilience of the communities themselves (Mijatović *et al.*, 2013). In this study, crops are not only used for sale but also for family food, as live fences and in some cases for livestock feed, which shows a certain flexibility in the inhabitant's use of biodiversity.

The most critical environmental indicator was appropriate irrigation water management (A3IE), with a value of 1.20 since no management or technique for this purpose has been implemented. Water for irrigation to satisfy the requirements of crops originates almost exclusively from rainfall and no specific action is undertaken to manage this resource.

Likewise, no producer implements any actions regarding soil conservation, which means that this indicator (B2IE) obtained values close to deficient (1.40). Ecological awareness (C3IE) also obtained a very low average of 1.60, which indicates that most farmers have not acquired this type of knowledge.

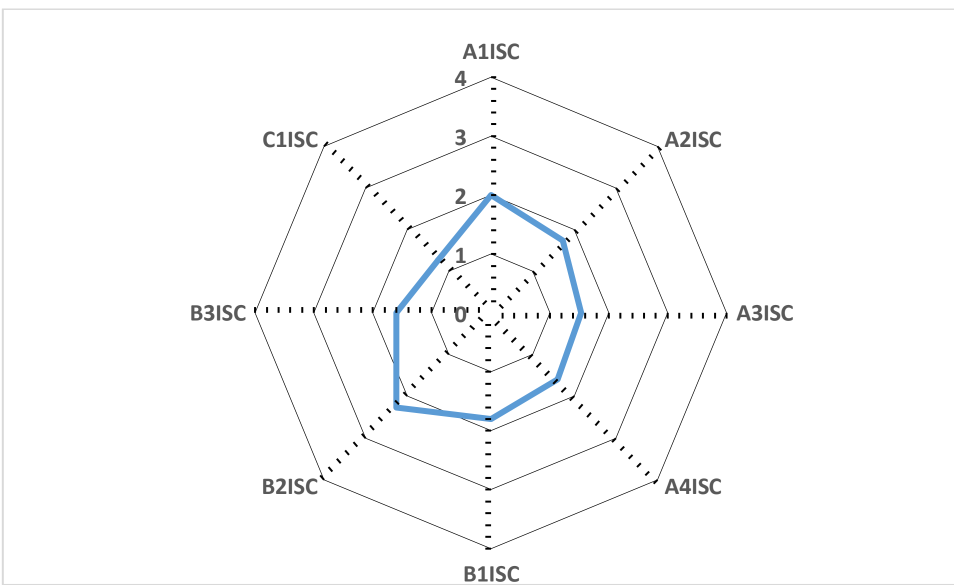


Figure 4. Amoeba diagram showing the average value of 8 indicators evaluated to measure the socio-cultural dimension (ISC) in the Yungañan river micro-basin. A1ISC=Housing, A2ISC=Access to education, A3ISC=Access to health, A4ISC= Services, B1ESC= Participation in the production system, B2ISC= Acceptance of the production system, B3ISC= Collaborating agents, C1IE= Participation in organizations.

Table 3. Average values and standard error obtained for each attribute and dimension analyzed.

Dimensions and attributes	Code	Average	Standard error	Max./Min. value
Economic Dimension (IK)	**IK**	**1.94**	**± 0.178**	**3.06/0.33**
A: Food self-sufficiency	**AIK**	2.09	± 0.176	2.83/0.5
B: Economic risk	**BIK**	1.63	± 0.246	3.5/0
Environmental Dimension (IE)	**IE**	**1.77**	**± 0.098**	**2.42/1.25**
A: Conservation of soil life	**AIE**	1.64	± 0.147	2.67/0.33
B: Risk of erosion	**BIE**	1.87	± 0.101	2.67/1
C:Biodiversity management	**CIE**	1.93	± 0.190	3.3/1
Socio-cultural Dimension(ISC)	**ISC**	**1.65**	**± 0.089**	**2,5/1.21**
A: Satisfaction of basic needs	**AISC**	1.72	± 0.072	2.25/1.25
B: Contributions in the production system	**BISC**	1.89	± 0.115	3/1.33
C: Social Integration	**CISC**	1.27	± 0.266	4/0
Sustainability General Index (ISG)	**ISG**	**1.79**	**± 0.082**	**2.14/1.07**

Dimensions are indicated in bold and attributes in italics. ISG is calculated according the formula presented in Table 2.

c) Analysis of the indicators measured to evaluate the socio-cultural dimension (ISC).

In this dimension, almost all the variables obtained critical values of less than 2, except housing (A1ISC), which was 2.00, since all the houses have minimum comfort levels (untreated water coming from springs and electrical light powered by solar energy). The acceptance of the production system (B2ISC) also obtained an acceptable value of 2.27, demonstrating a certain conformity by producers with their conditions of life and with their production systems.

The most critical values in the socio-cultural dimension were: access to education (A2ISC), with 1.73; access to health (A3ISC), with 1.53; collaborating agents (B3ISC), with 1.60; and participation in social organizations (C1ISC), with 1.27. The low values for the first three indicators (access to education, access to health and collaborating parties) are related to the same problem, which is linked to the lack of appropriate road infrastructure in the area, making it difficult for the sector to connect to the outside world. According to Recalde (2007), this set of circumstances reflects the need to reorient the implementation of current policies in the Ecuadorian context to improve agricultural structures, especially in rural areas, since many of the deficiencies they present cannot be addressed by community management itself.

Meanwhile, the very low value obtained in the indicator that refers to participation in social organizations (1.27) is undoubtedly a limiting factor for the development of the sector, which is reflected, for example, in the lack of alternatives for the sale of its products. As Guerrero Bejarano and Villamar Cobeña (2016) point out, economic and social development depends to a great extent on the capacity of the inhabitants of a given region to face the problems that affect them jointly, and it is within this context that associativity plays a preponderant role.

d) Sustainability General Index (ISG)

Table 3 illustrates the average value obtained for each attribute and dimension after the analysis of the 15 farms studied.

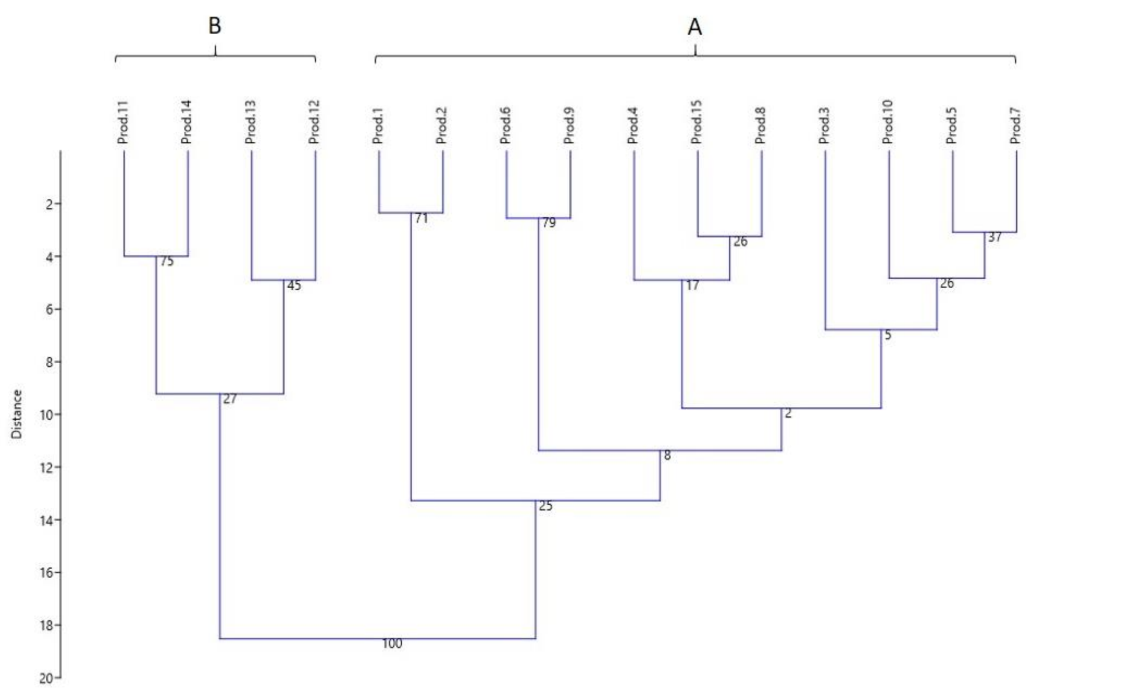
Based on the results obtained for each indicator, as discussed above, it is not surprising that both the attributes and the different dimensions analyzed obtained values quite far from those considered sustainable according to the methodology employed. The social dimension (ISC) has an overall rating of 1.65 (very low to low), the economic dimension (IK) has a rating of 1.94 with a range of low to medium, and the environmental dimension (IE) has a rating of 1.77 with a range of very low to low. Consequently, the Sustainability General Index (ISG) was also low, with 1.79 on average, which indicates that the practices carried out in the area studied are not sufficiently sustainable.

When comparing these results with those obtained by other authors in the Ecuadorian context, it is possible to draw the following conclusions. Firstly, it is difficult to compare the different studies due to the heterogeneity of the methodologies employed for the assessment of sustainability. Only Méndez *et al.*, (2016) and Cruz *et al.*, (2017) used the same methodological framework applied in this study. In addition, the subject matter for each research paper is equally heterogeneous, which adds to the difficulty of establishing comparisons. In this sense, some studies focus on the compared management of different crops, as in Viteri *et al*., (2018) with cocoa and coffee, or Rodríguez *et al*., (2018), who compared different types of cocoa management in the Amazon region. Cruz *et al.*, (2017) compared the management of two agroecological farms, while the studies by Méndez *et al.*, (2016), Bravo-Medina *et al.*, (2017) and Hernández Maqueda *et al.*, (2018) focused on the natural resource management of the different farmers in order to establish the strengths and weaknesses of management at the community level, making them similar to this study.

However, despite the differences found between the different research studies, there are some common aspects that are worth highlighting. On the one hand, most studies (Mendez *et al.*, 2016; Cruz *et al.*, 2017; Bravo-Medina *et al.*, 2017; and Hernández Maqueda *et al.*, 2018) highlight, as in this study, crop diversity as a strength because it implies high levels of food self-sufficiency and a greater degree of resilience. At the same time, they agree on several aspects to be improved, such as the difficulties for associationism, the lack of infrastructure that complicates access to markets and the limited technical knowledge that conditions the adaptability of the different communities (Bravo-Medina *et al.*, 2017; Hernández-Maqueda *et al.*, 2018 and Rodriguez *et al.*, 2018). These ideas coincide with the results obtained in this study through the analysis of the attributes regarding the satisfaction of basic needs and social integration that show very low values of sustainability (1.72 and 1.27, respectively).

e) Internal differences within the community

Figure 5 shows a distance tree based on a cluster analysis showing groupings within the community according to the values obtained for each of the indicators analyzed.



Dimensions	Index	A group	B group
Economical	IK	2.25	1.07
Environmental	IE	1.80	1.69
Socio-cultural	ISC	1.71	1.47
General Sustainability Index	ISG	1.92	1.41

Figure 5. Distance tree based on differences regarding resource management within the community, based on the indicators analyzed. Bootstrap values are indicated above the branches. Bootstrap values higher than 95 indicate high branch support. Axis Y indicates distances based on Ward's algorithm. *Prod.* indicates Productive Unit.

As seen in Figure 5, there are two clearly differentiated main clusters that group on the one hand the productive units 11, 12, 13 and 14 (B group) and on the other hand the remaining productive units (A group), from which the rest of the clusters are derived. Only this grouping shows the maximum bootstrap support (100).

From the remaining associations observed, only the groups 1, 2, 6, 9 and 11, 14 exhibit a moderate bootstrap support of 71, 79 and 75.

Bootstrap support is an effective way to discriminate whether observed clusters contain significant information or, instead, could be due to an artifact derived from the topology construction algorithm. Therefore, only the differences found between the different variables examined for the main cluster (A and B in Figure 5) that obtained a bootstrap support of 100 were analyzed.

Table 4 shows the indicators and attributes selected according to each dimension considered. To facilitate the reading of the table, only those indicators and/or attributes that showed significant differences $p<0.05$ between the two groups (A and B, fig 5) after the application of the t-test are shown.

As shown in Table 4, there are statistically significant differences for the General Sustainability Index between groupings A and B. The sustainability values obtained for the groups according to the scale indicate that group B is more vulnerable than A. Furthermore, the dimensions examined contribute differently to the General Sustainability Index. According to the social dimension, analyzed as a whole, it does not show significant differences. Only the indicator 'Participation in productive work' is statistically significant between both clusters, which contributes also to the differences found upon analyzing the attribute 'Contributions in the production system'. The main differences found between the two groups derives from the fact that the productive units included in group B do not have aid for agricultural work and depend on hiring temporary workers to be able to carry out agricultural tasks. On the other hand, in the rest of the productive units, a certain amount of support is provided by close relatives, which, among other benefits, reduces production costs.

With respect to the environmental dimension, differences are only observed for two indicators: appropriate management of irrigation water and soil topology. In the former, the productive units in group A share certain management techniques, which despite being rudimentary allow for an improved use of water, such as basic canalizations or water reservoirs), however in group B, there is no type of management and the irrigation method is by means of rainwater. In the latter, the soil typology shared by the productive units in group B is reddish soil with little water retention and a low productivity.

Undoubtedly, in view of the results, the dimension that contributes most to the differences found between the two groups is the economic one. As can be seen, statistical differences are found when analyzing the dimension itself, mainly because the two attributes are equally different. Particularly striking is the low crop yield, partly caused by the type of soil, as discussed above, but also by the lack of technical management, which means that the monthly net income indicator is significantly lower. This is aggravated by the fact that the sales diversification of the productive units in group B are much lower in comparison to the rest of the smallholders, because they reside in places farthest from the main road and their sales are reduced to a single product (sugar cane) in local markets.

Table 4. Differences between groups A and B according the indicators and attributes evaluated.

	Code	Average GROUP A	Average GROUP B	p-value
Economical Dimension	**IK**	2.25(±0.11)	1.07(±0.30)	0.007*
Food supply sufficiency	*Attribute*	2.37(±0.13	1.29(±0.30)	0.01*
Yield	A5IK	2.45 (±0.28)	0.25 (±0.25)	0.004*
Monthly net income	A6IK	3(±0.35)	0.75(±0.75)	0.02*
Economic Risk	*Attribute*	2(±0.23)	0.6(±0.31)	0.01*
Sales diversification	B1IK	2.54(±0.34)	0.25(±0.25)	0.007*
Environmental Dimension	**IE**	1.8(±0.11)	1.69(±0.21)	0.63
Appropriate management of irrigation water	A3IE	1.45(±0.15)	0.5(±0.28)	0.02*
Soil typology	B3IE	2.09(±0.21)	1.25(±0.25)	0.045*
Socio-Ecological Dimension	**ISC**	1.71(±0.11)	1.47(±0.11)	0.43
Contribution to the production system	*Attribute*	2.03(±0.13)	1.05(±0.09)	0.03*
Participation in productive work	B1ISC	2.09(±0.25)	1(±0)	0.02*
General Sustainability Index	**ISG**	**1.92(±0.06)**	**1.41(±0.13)**	**0.01***

*indicates significant differences ($p < 0.05$). **Group A** includes Productive Units 1-10 and 15, while **Group B** includes Productive Units 11, 12, 13 and 14, as identified in the cluster analysis (Figure 5).

Consequently, these findings reveal different levels of vulnerability that will certainly have to be taken into account in order to define effective action plans for the sustainable development of the community.

CONCLUSIONS

The research carried out through the analysis of the productive units present in the Yungañan River micro-basin allowed us to obtain a situational diagnosis on the sustainability of their resource management.

The sustainability values obtained by means of the Sustainability General Index show low ranges according to the methodology employed. From the analysis of the different indicators, some strengths can be observed, such as a certain efficiency in crop management, which allows the producers to obtain acceptable incomes in the context of the region. In addition, a number of diversified products for sale can be noticed, which permits a certain adaptability in order for the farmers to cope with external changes.

The most critical issues that require special attention are, on the one hand, the lack of technical knowledge that prevents the producers from optimizing farm management. This is reflected in a high infestation of pests and the absence of techniques for soil, water and biodiversity management, which diminishes their capacity for innovation. On the other hand, the limited associativity should be noted, because it makes it impossible for them to influence decisions at a political level and to find alternatives for marketing their products.

Additionally, given the results, there are smallholders with a greater degree of vulnerability, derived mainly from aspects related to the economic dimension. Consequently, this heterogeneity should be considered in order to design an appropriate strategy for improving the sector's sustainability.
Lastly, beyond the factors mentioned, external factors such as the improvement of access routes, and technical management training should be also considered in order to ensure that the actions needed for sustainable development are implemented effectively and can produce positive results in the medium and long term.

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Compliance with Ethical Standards. The information contained in this document is completely anonymous and all participants were informed through a consent statement according to the ethical guidelines established for this type of study.

Data availability. Data are available from the corresponding author: emerson.jacome@utc.edu.ec

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