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Research Article

Valoración económica de los servicios ecosistémicos de dos espacios abiertos de la ciudad de Pampas, Huancavelica, Perú

Economic valuation of ecosystem services in two open spaces in *Pampas* city, *Huancavelica*, Peru

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Abstract

Urban vegetation is essential for cities due to its ecosystem services and for contributing to climate change mitigation. In this sense, the objective of this research was to evaluate the urban vegetation of two open spaces in the city of *Pampas*, located in the region of *Huancavelica*, Peru, and to determine the ecosystem services and their economic value. A 100 % forest inventory was carried out in each open space; the data were then processed using the i-Tree® Canopy software. 227 individuals from nine families and nine species in the two open spaces were identified, 920 individuals ha^{-1}, and 22.69 Mg of carbon stored, with a carbon sequestration of 0.90 Mg yr^{-1}. The total avoided runoff was 9.77 m^3 yr^{-1}. A tree cover of 8 966.94 m^2 was calculated, which is reflected in a green area factor of 1.14 m^2 per inhabitant. The authors conclude that *Pampas* city is below the threshold suggested by the UN (9 m^2 of green area per inhabitant). Furthermore, it is important to analyze and maintain the green areas in order to guarantee a better life quality.

Key words: Green city, air pollutants, avoided runoff, carbon sequestration, economic value, urban vegetation.

Resumen

La vegetación urbana cumple un rol esencial en las ciudades por los servicios ecosistémicos que otorga y por contribuir en la mitigación del cambio climático. En ese sentido, la presente investigación tuvo como objetivo evaluar la vegetación urbana de dos espacios abiertos de la ciudad de Pampas, localizada en la región de Huancavelica, Perú, con el propósito de conocer los servicios ecosistémicos y determinar su valoración económica. Se aplicó un inventario forestal al 100 % en cada espacio abierto; posteriormente se realizó el procesamiento de los datos mediante el uso del *software i-Tree® Canopy*. Se identificaron 227 individuos de nueve familias y nueve especies en los dos espacios abiertos, 920 individuos ha^{-1}, 22.69 Mg de carbono almacenado con un secuestro de carbono de 0.90 Mg año^{-1}. La escorrentía total evitada fue 9.77 m^3 año^{-1}. Se calculó una cobertura arbórea de 8 966.94 m^2, que se refleja en 1.14 m^2 de factor de área verde por habitante. Se concluye que la ciudad de Pampas se ubica por debajo del umbral sugerido por la ONU (9 m^2 de área verde por habitante). Asimismo, se evidencia que es importante analizar y dar mantenimiento a las áreas verdes para garantizar una mejor calidad de vida.

Palabras clave: Ciudad verde, contaminantes del aire, escorrentía evitada, secuestro de carbono, valor económico, vegetación urbana.

Introduction

Urbanization and high population densities impose constraints that result in the loss of ecosystem services (Sousa et al., 2025), which are benefits provided by nature for human well-being (water, clean air, recreation and food) and that contribute to economic value (Nulkar, 2024) and quality of life (Avendaño-Leadem et al., 2020); they constitute an essential basis for making decisions regarding sustainable development (Chen et al., 2024; Kirby et al., 2025), including physical, chemical and biological processes, as well as improved productivity and sustainability (González-Hernández et al., 2023; Pardo et al, 2022).

The appraisal of ecosystem services considers current urgent challenges and issues like pollution, climate change, participatory management, and ecosystem management (Zandebasiri et al., 2023). Ecosystem service values are classified into direct use, indirect use, and non-use values (Shahimoridi et al., 2024). In this respect, urban vegetation participates and provides direct and indirect benefits (Pérez et al., 2024; Riondato et al., 2020).

The economic valuation of ecosystem services is essential within a context marked by rapid environmental deterioration associated with the advance of economic development (Arango et al., 2023); therefore, it is important to optimize their management, ensure their efficient use, and promote their conservation (García-Ventura et al., 2020).

The intrinsic value of vegetation makes it difficult to determine the ecosystem services provided by green infrastructure; for this reason, the i-Tree Eco is an open access tool developed by the U. S. Forest Service to analyze the urban forested areas based on specific variables (species composition, leaf area and health), and their relationship with impact on the ecological development, society and economy (Lin et al., 2020; Martínez-Trinidad et al., 2021; Riondato et al., 2020).

The economic valuation of the ecosystem services of open spaces in *Pampas* is justified by the need to recognize and quantify the benefits these green spaces provide to the population. Despite this city's increasing urbanization, open spaces are crucial for its environmental sustainability, social well-being, and economic development. For this reason, the objective of this research was to evaluate the urban vegetation of two open spaces in *Pampas* city, located in the *Huancavelica* region, Peru, to determine the ecosystem services and their economic valuation.

Materials and Methods

Study area

The study area is located between the geographical coordinates (WGS 84 zone 18 South) of the district center of 12°23′56″ S and 74°52′00″ W, at an altitude of 3 372 m; moderate rainy and temperate climate, with a dry temperate winter during the day and cold at night, whose temperature varies between 12 and 14 °C, dropping to -2 °C (Servicio Nacional de Meteorología e Hidrología del Perú [Senamhi], 2022) (Figure 1). The research was carried out in two urban open spaces (the Ecological Park and the Main Square) of *Pampas* city, *Tayacaja* province, *Huancavelica* region, in the highlands of Peru (Figure 2). The Ecological Park has a surface area of 1 500 m^2 and the Main Square has 965 m^2.

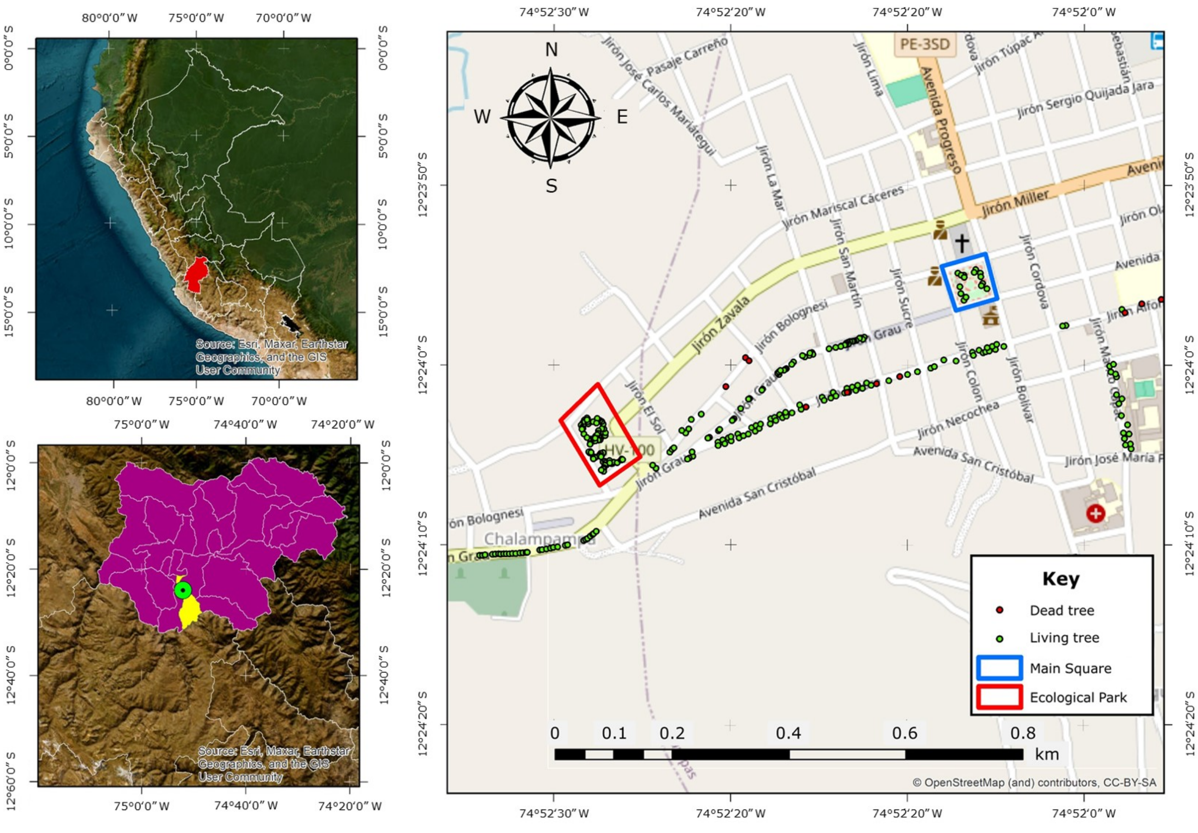


Figure 1. Study area.

A = Main Square; B = Ecological Park.

Figure 2. Open spaces.

Inventory

From August 2024 to December 2024, 100 % of the urban vegetation was inventoried using the Visual Tree Assessment methodology proposed by the International Society of Arboriculture (Calaza & Iglesias, 2016). In addition, data such as the health status of the tree, shrub, and palm canopy were recorded according to the i-Tree (i-Tree, 2021); the following data were considered: the district, the species per tree, shrub, or palm in each open space, and its identifier number. The estimation of total height, stem and crown of the trees, shrubs, and palms was obtained with a model PM-5/360PC Suunto® clinometer. The normal diameter of the trees and shrubs was measured with a model 283D/5m Forestry Supliers Inc.® diameter tape measure, while the crown diameter (*k*) was determined using a model TP50ME Truper® 50 m fiberglass measuring tape. The Tropicos® platform was used to corroborate the correct nomenclature of the species (Missouri Botanical Garden, 2022). The botanical material was identified with dendrological keys (Alanís-Rodríguez et al., 2022) and deposited in the Herbarium of the *San Marcos* University (*Universidad Nacional Mayor de San Marcos*).

Population density

The number of people living in the *Pampas* district (7 839 inhabitants) and the urban area they occupy (74.6 km^2) were related to the population concentration per square kilometer within urban areas (Instituto Nacional de Estadística e Informática [INEI], 2025).

Green area per capita factor

The ratio between the area (km^2) of urban tree vegetation of the evaluated open spaces and the area of the city of *Pampas* (km^2) was determined to record the green area per capita factor (Organización de las Naciones Unidas [ONU], 2015).

Analysis of the collected data

The i-Tree® Canopy support (i-Tree, 2021) was used, and then processed in a project for each open space to perform an inventory and analysis of urban vegetation cover, using satellite images or aerial photos, and combine statistical data to estimate the tree cover. Likewise, information from Senamhi (2022) was used for the climate data. Urban vegetation with heights above 2 m and diameters larger than 3 cm at a height of 1.30 m from the ground was considered. Before the analysis in i-Tree® Canopy support, trees, shrubs, and palms whose trunk height (trunk only) exceeded the canopy height were excluded, since i-Tree® Canopy support does not recognize such vegetation.

The ecosystem services carbon content and avoided runoff were selected in i-Tree® Canopy. Additionally, cover classes were identified for trees, shrubs, herbaceous (includes grasses and herbs), weatherproof surfaces (areas where water cannot infiltrate, such as roads, buildings, etc.), bare soil (areas without vegetation cover, such as uncultivated or undeveloped land, exposed to the open air), and water (areas covered by water such as rivers, lakes, or ponds).

According to the i-Tree® Canopy support (i-Tree, 2021), annual carbon sequestration estimates are based on 0.306 kg of carbon or 1.122 kg of CO_2 m^{-2} $year^{-1}$, while the amount of carbon stored is 7.685 kg of carbon, or 28.178 kg of CO_2 m^{-2}. The economic value is expressed in dollars, at the rate of \$0.19 USD kg^{-1} of C or \$0.05 USD kg^{-1} of CO_2 (i-Tree, 2021). The avoided runoff through the hydrological estimates is based on values of kL m^{-2} $year^{-1}$, and the economic value according to the i-Tree® support is expressed in dollars as USD kL^{-1} $year^{-1}$. For the coverage classes in the pollution of the g m^{-2} $year^{-1}$ values are considered, and the economic value according to the i-Tree® support is expressed in USD g^{-1} $year^{-1}$ (carbon monoxide ranges from \$0 to \$0.107 USD; nitrogen dioxide, from \$0 to \$0.423 USD; ozone, from \$0 to \$5.094

USD; sulfur dioxide, from $0 to $0.912 US; PM2.5, from $0.03 to $0.266 USD, and PM10 from $0.01 to $2.043 USD).

Results

In the Ecological Park and the Main Square, 229 individuals of urban vegetation were censused; however, after excluding those that could not be processed by the i-Tree® Canopy (2 trees), only 227 individuals of urban vegetation were analyzed. Eight families, nine genera, and nine species were recorded; among these, *Prunus lusitanica* L. accounted for 0.44 % of the total number of inventoried individuals, which means that there is no equity in abundance (Table 1).

Table 1. Floristic composition in the two open spaces inventoried in *Pampas* city, *Huancavelica*, Peru.

Species	Common name	Origin	Abundance	%
Araucaria columnaris (J. R. Forst.) Hook.	New Caledonia pine	New Caledonia	8	3.5
Fraxinus americana L.	American ash	USA and Canada	30	13.2
Genipa americana L.	Genip tree	America	7	3.1
Ligustrum lucidum W. T. Aiton	Glossy privet	China, Korea, and Japan	120	52.9
Phoenix canariensis Wildpret	Canary Island date palm	Canary Islands	9	4.0
Populus nigra L.	Black poplar	Iberian Peninsula	24	10.6
Prunus lusitanica L.	Portuguese laurel	Portugal and Spain	1	0.4
Sambucus nigra L.	Black elder	Germany	22	9.7
Schinus molle L.	Peruvian peppertree	Peru	6	2.6

Source: Prepared by the authors with data from the research.

Figure 3 shows the distribution of cover classes in the two open spaces evaluated.

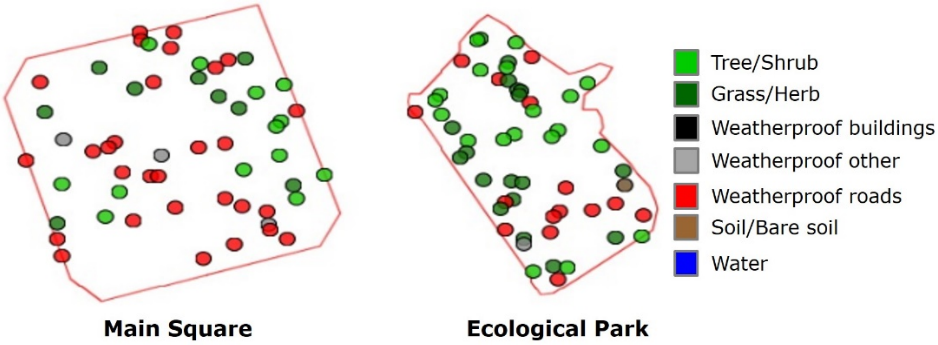


Figure 3. Tree cover in the two assessed open spaces.

Table 2 shows that the Ecological Park had the largest surface area (1 500 m^2), with the highest values for vegetation density (1 380 individuals ha^{-1}), tree cover (6 127.15±1 390.29 m^2), amount of carbon stored (17 439.24±3 094.25 kg, equivalent to 17.44±3.09 t), carbon sequestration (694.41±123.21 kg yr^{-1}, equivalent to 0.694±0.123 t yr^{-1}), and avoided runoff (7.51 kL yr^{-1}, equivalent to 7.51 m^3 yr^{-1}). Conversely, the Main Square, whose records were: a surface area of 965 m^2, 207 individuals ha^{-1}, tree cover of 2 839.8±606.8 m^2, 5 253.7±1 269.7 kg of carbon stored (equivalent to 5.25±1.27 t), a carbon sequestration of 209.2±50.6 kg $year^{-1}$ (equivalent to 0.209±0.051 t $year^{-1}$), and an avoided runoff of 2.32 kL $year^{-1}$ (equivalent to 2.32 m^3 $year^{-1}$).

Table 2. Variables evaluated in the two open spaces of *Pampas* city, *Huancavelica*, Peru.

Location	Area (m^2)	Density (trees ha^{-1})	Number of individuals	Tree cover (m^2)	Stored carbon (kg)	Carbon sequestration (kg $year^{-1}$)	Avoided runoff (kL $year^{-1}$)

Main Square	965	207.3	20	2 839.8 ±606.8	5 253.7 ±1 269.7	209.2 ±50.6	2.3 ±0.6
Ecological Park	1 500	1 380.0	207	6 127.2 ±1 390.3	17 439.2 ±3 094.3	694.4 ±123.2	7.5 ±1.3
Total	2 465	920.9	227	8 966.9 ±1 997.1	22 692.9 ±4 363.9	903.6 ±173.8	9.8 ±1.9

Source: Prepared by the authors with data from the research.

Table 3 shows that the Ecological Park registered higher values in the quantity of CO removed (242.67±43.06 g year^{-1}), NO_2 removed (959.15±170.18 g year^{-1}), O_3 removed (11 560.73±2 051.22 g year^{-1}), SO_2 removed (2 069.47±367.19 g year^{-1}), amount of PM2.5 particles (603.59±107.09 g year^{-1}) and PM10 particles removed (4 653.66±822.51 g year^{-1}). On the other hand, the Main Square had lower values for CO removed (73.1±17.7 g year^{-1}), NO_2 removed (288.9±69.8 g year^{-1}), O_3 removed (3 482.8±841.7 g year^{-1}), SO_2 removed (623.5±150.7 g year^{-1}), and PM2.5 particles (181.8±43.9 g year^{-1}) and PM10 particles removed (1 396.5±337.5 g year^{-1}).

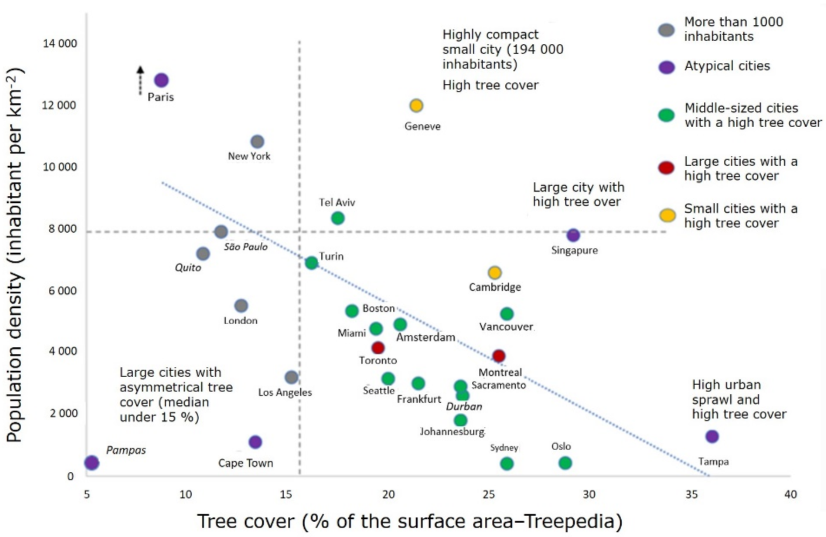
Table 3. Air pollutants removed in the two open spaces of *Pampas* city, *Huancavelica*, Peru.

Location	**Removed carbon monoxide (CO) (g year^{-1})**	**Removed nitrogen dioxide (NO_2) (g year^{-1})**	**Removed ozone (O_3) (g year^{-1})**	**Removed sulphur dioxide (SO_2) (g year^{-1})**	**Removed particulate matter 2.5 (g year^{-1})**	**Removed particulate matter 10 (g year^{-1})**
Main Square	73.1 ±17.7	288.9 ±69.8	3 482.8 ±841.7	623.5 ±150.7	181.8 ±43.9	1 396.5 ±337.5
Ecological Park	242.7 ±43.1	959.2 ±170.2	11 560.7 ±2 051.2	2 069.5 ±367.2	603.6 ±107.1	4 653.7 ±822.5
Total	315.8 ±60.7	1 248.1 ±140.0	15 043.5 ±2 892.9	2 692.9 ±517.9	785.4 ±151.0	6 050.2 ±1 160.0

Source: Prepared by the authors with data from the research

Based on the total value of tree cover (0.00897 km^2) and the surface area comprising the city of *Pampas* (74.6 km^2), the green space per capita factor was estimated to be 1.14 m^2.

Figure 4 shows the roster of data from 27 cities worldwide, from which it was concluded that, as population density decreases, the tree cover increases.



Source: Modified from Lüttge and Buckeridge (2023).

Figure 4. Ratio of tree cover (%) to population density per km^2 in 27 cities.

The economic value of the ecosystem services provided annually by the urban vegetation in the open spaces of *Pampas* was calculated. In terms of carbon stored, the Ecological Park recorded the highest values: economic value with USD 3 279±582 kg^{-1}, quantity of vegetation individuals, economic value of carbon sequestration with USD 131±23 kg^{-1} year^{-1}, economic value of avoided runoff with USD 18±3 kL^{-1} year^{-1}, and economic value of pollutants removed with USD 58 000±10 000 kg^{-1} year^{-1} (Table 4).

Table 4. Economic value in dollars (USD) represented by the ecosystem services provided by the two assessed open spaces.

Location	EVCS ($ kg^{-1})	EVCSeq ($ kg^{-1} year^{-1})	EVAR ($ kL^{-1} year^{-1})	EVPR ($ kg^{-1} year^{-1})
Main Square	988±239	39±10	5±1	17 000±5 000
Ecological Park	3 279±582	131±23	18±3	58 000±10 000
Total	4 267±821	170±33	23±4	75 000±15 000

EVCS = Economic value of carbon stock; EVCSeq = Economic value of carbon sequestration; EVAR = Economic value of avoided runoff; EVPR = Economic value of pollutants removed.

Discussion

Overall, the biodiversity and the ecosystem services it provides are essential for humans (Verones & Dorber, 2023), and one of the strategies to conserve biodiversity is *in situ* conservation, which focuses on protecting species in their natural habitat (Singh, 2024). However, one of the main problems affecting it is the use of exotic species (Badii et al., 2015). In *Pampas*, 77.8 % of the urban vegetation species in the two open spaces assessed are exotic and require management measures due to the consequences of their use, such as damage to public health (caused by pests and diseases) and the correct functioning of the ecosystem, and the displacement of native taxa (Rodríguez, 2001).

In both areas, 227 individuals of urban vegetation were recorded, *i. e.*, less than the 391 individuals reported in four parks located in *Texcoco*, Mexico (Martínez-Trinidad et al., 2021), and the 1 325 individuals identified in five parks in the same city (Mancilla et al., 2024).

The ecosystem services determined in the open spaces of *Pampas* differ from those documented in Stockholm, Sweden: microclimate regulation, recreational and cultural values, air filtering, wastewater treatment, and rainwater drainage (Bolund & Hunhammar, 1999).

As for the amount of carbon stored, the values obtained (5.25 Mg in the Main Square and 17.44 Mg in the Ecological Park) are lower than those reported for five parks in *Texcoco*, Mexico (8.26 Mg, 29.21 Mg, 22.41 Mg, 22.65 Mg, and 160.05 Mg) (Mancilla et al., 2024). The difference lies in the amount of urban vegetation inventoried.

An annual economic value of USD 75 million was estimated for removed air pollutants in the two open spaces under study, which was higher than the annual economic value for air purification (USD 406 769.14 to USD 579 620.14) reported in public parks and garden squares in Warsaw, Poland; while the economic value of carbon stored (USD 4 267 000 t^{-1}) was lower than the cited range of USD 24.1 million to USD 31.3 million in Warsaw's urban areas (Szkop, 2022).

The total value of carbon sequestration in the two open spaces was USD 170 000 t^{-1} $year^{-1}$, which is higher than that estimated in an urban forest in Brescia, Italy (USD 2 560.52) (Masiero et al., 2022). Factors such as extension, vegetation type, and utilized methodology influence the calculation of the economic value of ecosystem services.

Pampas city is far from the trend, which is why it is defined as an atypical city. The tree cover of the Ecological Park and the Main Square is 0.012 % of the district's surface area, and the population density was 105.1 inhabitants km^{-2}. A green area factor per capita of 1.14 m^2 was recorded, which differs significantly from the 9 m^2 per inhabitant that constitutes the minimum threshold recommended by the World Health Organization (ONU, 2015). In fact, 7.86 m^2 of tree cover per inhabitant —*i. e.*, 7.87 times the current tree cover area calculated in the two open spaces in

Pampas— is required to meet this threshold. However, the green area factor of the open spaces in *Pampas* is higher than the 0.86 m^2 factor documented in the five parks of *Texcoco*, Mexico (Mancilla et al., 2024).

Pampas has great potential to develop as a green city (Lüttge & Buckeridge, 2023) because of its low population density. The green city is an innovative approach that addresses environmental challenges and promotes sustainable urban development (Azizi & Kouddane, 2024). However, if decision-makers fail to show interest in creating or opening green areas, the city of *Pampas* will continue to be considered an atypical city with little tree cover.

The reduction of ecosystem services hurts the urban economy (Olgun et al., 2024). Conversely, the abundant presence of vegetation not only improves the city's image in the eyes of tourists and visitors but also enhances its local economy. This highlights the importance of generating activities that will promote the creation and maintenance of green areas (Figueroa & Díaz-Galiano, 2018) —a much-needed resource in the city of *Pampas*, the lack of which results in economic losses.

One of the constraints observed in the research was the limited perception of the locals, as they are not aware of the economic value of the ecosystem services provided by open spaces, which causes them to be undervalued. Others are the environmental conditions, such as frosts and droughts, which also affect the quality and quantity of the ecosystem services.

Conclusions

In the two open spaces, there is a notable lack of equity in the distribution of species abundance; this could suggest the need to diversify urban vegetation with native species to improve vegetation cover, reduce impervious areas, and increase the ecosystem services for the benefit of the population.

The Ecological Park surpasses the Main Square in terms of density and ecosystem services because it exhibits a larger surface area and a more abundant vegetation, a larger tree cover, more carbon storage and sequestration, as well as a greater amount of avoided runoff, all of which allows its contribution to the improvement of air quality to be greater. However, at the *Pampas* city level, the green area per capita factor remains low, highlighting the need to increase the tree cover.

The Ecological Park has the higher annual economic value for the ecosystem services it provides. Information on the economic value is important because it enables decision makers to address the real issues of open spaces in order to maintain these common areas in good condition and thus contribute to a better life quality for the city's inhabitants.

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Conflict of interest

The authors declare that they have no conflicts of interest.

Contribution by author

Jairo Edson Gutiérrez-Collao: manuscript development and statistical analysis; Frank Alex Chahuaylacc De La Cruz: interpretation of the results; Lizeth Nayely Juñuruco Pituy and Ronald Julian Chihuan Quispe: data analysis; Nataly Lujan Huamani and Christian Edinson Murga-Tirado: revision of the manuscript; Elvia Luzmila Torres Flores and Yhimy Yhon Huayllani Agui: statistical analysis.

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