

**RESEARCH ARTICLE****New Tools for Environmental Social Zoning in High Andean Areas**

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ARTICLE INFO	ABSTRACT
Received: Jul 12, 2024	Currently, global concern is focused on the sustainability of life on the planet, which is why the 2015-2030 agenda is named "sustainable development goals," aiming to promote actions that seek to mitigate the effects of anthropogenic intervention on natural spaces. However, the environment, understood as all biotic and abiotic components that constantly interact, must consider human beings as part of it and suppress the anthropocentric vision that has dominated this aspect in recent centuries. Therefore, it is essential to recognize which are the new social and environmental zoning tools that can be used in geographical areas that host ecosystems as rich as they are fragile, such as the High Andean regions. For this reason, this study aimed to reflect on the new tools for environmental social zoning in high Andean areas. It was a reflective review study in which narrative was used as a method of constructing knowledge and dialectics for the documentary analysis of a total of 74 articles. Within the final reflections, new questions are raised, including: How can we improve collaboration between scientists, local communities, and authorities to maximize the impact of new tools and approaches in zoning?
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**INTRODUCTION**

In a world marked by increasing concern for environmental sustainability and social equity, environmental social zoning has become a field of study and action of vital importance (Millán López, 2019). This discipline seeks to find a balance between conserving the natural environment and the well-being of the human communities that depend on it. In a global context of climate change and accelerated urbanization, the need to develop effective tools for zoning that consider both ecological and social aspects has become essential (Santiago Vera et al., 2019).

Globally, environmental social zoning has gained increasing relevance in conservation and sustainable development agendas. With the rise of urbanization and pressure on natural ecosystems, the international community recognizes the importance of balancing the preservation of the natural environment with the needs of human populations (Aguilar Revelo, 2019). In this context, numerous innovative tools and approaches have been developed for zoning, ranging from advanced geographic information systems to participatory community consultations (Rosales-Veitia & Marcano-Montilla, 2021; Hussein et al., 2024 ; Al-Zaqeba et al., 2024).

Latin America is a region of extraordinary importance in the context of environmental social zoning due to its rich biodiversity and the close relationship between local communities and their natural environments. Zoning has therefore become a fundamental tool for managing natural resources, protecting critical ecosystems, and promoting inclusive development (Eniele Sonaglio & da Silva Bueno, 2009; Pratiwi et al., 2024). From the Andes ecosystems to the Amazonian rainforests and

coastal mangroves, Latin America hosts a diversity of landscapes that require adapted and sensitive approaches to local needs (Salinas-Castro et al., 2019).

The High Andean regions, located in the high mountains of Latin America, represent a unique and fragile ecosystem that combines particular environmental and social challenges (Jara-Peña, 2017). These areas are characterized by their rugged topography, extreme climatic conditions, and biodiversity adapted to altitude conditions (Puelles Condori et al., 2022). At the same time, they are home to rural communities rooted in millennia-old traditions that directly depend on these ecosystems for their subsistence (Suárez-Almiñana et al., 2021). For this reason, environmental social zoning in the High Andean regions becomes crucial due to the need to balance the conservation of these fragile environments with the well-being of local populations (Ramírez et al., 2015).

In this sense, it is recognized that environmental social zoning in the High Andean zones represents a multidimensional and highly relevant challenge today. These areas host unique ecosystems and human communities rooted in ancestral traditions, facing increasing threats related to climate change, environmental degradation, and socioeconomic vulnerability (Fernández-Llamazares et al., 2014). In this context, reflecting on new tools for environmental social zoning presents an urgent necessity and invaluable opportunity, which justifies the study in its contribution to understanding new tools for environmental social zoning in High Andean areas. This offers a space for critical reflection on their utility, applicability, and potential to address current and future challenges in these ecologically and culturally significant regions.

In light of the above, the research question was: What are the most promising technological and methodological tools for environmental social zoning in High Andean areas, and how are they contributing to biodiversity conservation, water management, and sustainable development in these areas? This question helped shape the study's intent, which sought to reflect on new tools for environmental social zoning in High Andean zones.

## MATERIALS AND METHODS

A bibliographic review study was proposed, emerging from a reflective perspective that employed narrative as a method for constructing knowledge (Aguilera Eguía, 2014), but which also relied on dialectics as a documentary analysis technique that allowed contrasting ideas and delving into the work of previous authors (Ortiz Torres, 2011), thus presenting a new perspective regarding the social and environmental zoning technologies that can be implemented in High Andean regions.

This process of structuring and de-structuring knowledge was built through emerging categorization from document analysis. The documents were retrieved from databases such as Scopus, WoS, Scielo, Redalyc, and Google Scholar and selected through intentional sampling that led to the analysis of 74 articles directly addressing the management processes of development in regions with characteristics similar to those of the High Andean zones.

## RESULTS

### **Geographic Information Systems (GIS) in the context of social and environmental zoning**

Geographic Information Systems (GIS) play a crucial role in social and environmental zoning in the High Andean regions, starting with the collection of geospatial data (Molina et al., 2005). In these regions, where the topography is complex and varied, it is essential to have accurate and up-to-date

data to understand the dynamics of ecosystems and communities. In this regard, GIS allows for meticulous information gathering, from detailed mountain topography to the location of water bodies and the evolution of land use patterns (Chacón et al., 2020). This information provides a solid and reliable foundation for making informed decisions for the conservation of fragile ecosystems and the sustainable development of local communities (Goodchild & Haining, 2005).

However, the true strength of GIS in the High Andean zones lies in its ability to conduct detailed spatial analyses, which are crucial for identifying spatial patterns, such as erosion-prone areas, critical biodiversity locations, and potential environmental risks (Gaspari et al., 2011). Techniques such as slope analysis, water flow analysis, and habitat connectivity allow for evidence-based decisions regarding the delineation of conservation areas, identification of ecological corridors, and allocation of zones for sustainable development (Eniele Sonaglio & da Silva Bueno, 2009). These spatial analyses are essential for optimizing the management of natural resources in these geographically complex regions (Pineda & Suárez, 2014).

In this sense, the cartographic resources generated by these systems are powerful communication tools that allow various stakeholders to clearly and effectively understand zoning outcomes. By providing visual representations of priority conservation areas, ecological connectivity routes, and sustainable development zones, the maps generated by GIS facilitate informed decision-making and promote active community participation in environmental and social planning (Archetti et al. 2014; Mena et al., 2011).

In the context of the High Andean regions, GIS has been successfully applied in various initiatives. For example, in the delimitation of buffer zones around natural reserves, these systems have been crucial in identifying areas of greater environmental vulnerability (Kurniawati et al., 2020; Mayorga et al., 2022). Likewise, in sustainable agricultural development projects, they have been used to efficiently allocate land and promote agricultural practices that minimize soil erosion (Buzai, 2021). These practical examples demonstrate how GIS are versatile and effective tools in social and environmental zoning in these regions.

Despite their numerous benefits, implementing GIS in the High Andean zones is not without challenges and limitations. One of these is the availability of accurate and up-to-date data, especially in remote regions. Additionally, adequate training is required for local professionals to effectively use these tools, as long-term data management and investment in technology and training are critical aspects that must be addressed to maximize the potential of GIS in these areas.

### **Remote Sensing: Remote Technology for Accessing Social and Environmental Zoning**

Remote sensing as a remote technology has emerged as an essential tool in the context of social and environmental zoning in the High Andean zones (Sánchez-Díaz, 2018). This technology allows the acquisition of remote data via satellites, planes, and drones, providing a detailed and large-scale view of the terrain characteristics and environmental changes in these high-mountain regions (Ardila León & Quintero Delgado, 2013; Puerta, 2015; Riaño et al., 2001). For this reason, remote sensing has become an invaluable resource for understanding and addressing the environmental and social challenges faced by these unique areas (Sancho Gómez-Zurdo et al., 2021; Villar et al., 2022).

One of the key applications of remote sensing in the High Andean zones is monitoring changes in land use, allowing the tracking of the evolution of agricultural, forest, and urban areas over time (Rosales-Veitia & Marcano-Montilla, 2021b). This is essential for identifying patterns of environmental

degradation, the expansion of agriculture, or uncontrolled urbanization and for taking proactive measures in social and environmental zoning planning (Valdez-Lazalde et al., 2006).

Additionally, remote sensing is also used to assess forest cover in the High Andean zones, which includes detecting changes in forest density, identifying areas prone to deforestation, and monitoring the health of forest ecosystems (Segura M & Trincado, 2003). This data is essential for identifying priority conservation areas and supporting the sustainable management of forest resources (Suárez Londoño et al., 2017).

However, it is understood that this technology plays a crucial role in predicting the impacts of climate change in the High Andean zones, as it allows the monitoring of climatic variables such as temperature, humidity, and precipitation patterns over time (Collado, 2001). This is essential for understanding how climate change is affecting these ecosystems and how local communities can effectively adapt (Sacristán Romero, 2005).

Furthermore, these tools are also used to plan ecological connectivity routes in the High Andean zones (Giménez & Pedro Castaño, 2018). This involves identifying natural corridors that allow species to move between fragmented habitat areas (Carnevale et al., 2007). These corridors are crucial for biodiversity conservation in these regions, and remote sensing helps determine their optimal location (Camas Guardamino & Mamani Sinche, 2022).

Despite their benefits, remote sensing presents challenges such as the need for specialized equipment and training. However, as technology advances and becomes more accessible, it is expected to play an increasingly central role in social and environmental zoning in the High Andean zones, as it provides a unique window into these regions, enabling more accurate and sustainable decision-making that balances environmental conservation with the well-being of local communities.

### **Climate Change Models for Development Management in the High Andean Zones**

Climate change models have become an essential tool for development management in the High Andean zones because they allow the projection of future climate change scenarios in these regions, which is crucial for planning social and environmental zoning (Palacios Chacón & Serrano Vincenti, 2011). Given the significant impacts of climate change in the High Andean zones, from changes in rainfall patterns to glacier retreat, models help anticipate and mitigate these effects (Panduro Bazán de Lázaro, 2020; Ulloa et al., 2008).

One of the main uses of climate change models in the High Andean zones is predicting changes in precipitation patterns, allowing the projection of how precipitation may vary in intensity, duration, and seasonality in the future (Osorio Nuñez, 2022). This information is essential for water management, as communities heavily depend on mountain water sources for their needs (Pons et al., 2018).

Additionally, climate change models are also used to assess the impact on water resources in the High Andean zones, including predicting changes in water availability and managing risks related to extreme climatic events such as floods and droughts (Arrieta & Arpi, 2021). Therefore, the information generated by these models is essential for decision-making in water infrastructure planning and the sustainable management of resources (Suastegui Cruz, 2021).

Climate change models also help identify vulnerable areas in the High Andean zones, allowing the detection of areas prone to landslides, soil erosion, or floods due to climatic changes (Ramírez et al., 2015). These identifications enable the delimitation of critical zones that require specific mitigation and adaptation measures (Fernández et al., 2015).

It is noteworthy that the information generated by climate change models is directly integrated into development planning in the High Andean zones, including identifying suitable areas for renewable energy projects, promoting sustainable agricultural practices, and planning climate-resilient human settlements (Jodar-Abellán et al., 2018). For this reason, they are considered a fundamental tool for ensuring sustainable development in a context of constant climate change (Millán López, 2019).

Despite their usefulness, climate change models face challenges such as uncertainty in projections and the need for high-resolution data. However, as technologies advance and model precision improves, they are expected to play an increasingly important role in development management in the High Andean zones, as they provide a fundamental vision for decision-making that balances environmental conservation and the well-being of local communities in a constantly evolving climate context.

### **Environmental Monitoring Sensors: Understanding the Dynamics of the Environment**

Environmental monitoring sensors have become an essential tool for understanding the dynamics of the environment in the High Andean zones, as they allow continuous data collection on environmental parameters such as water quality, air quality, and temperature (Perea Ardila et al., 2021). This information is essential for environmental management and decision-making in planning social and environmental zoning in these regions (Gamboa-Soto, 2020).

One of the main uses of environmental monitoring sensors is assessing water quality and managing water resources (Suárez-Almiñana et al., 2021). These devices allow the measurement of parameters such as contaminant concentrations, pH, and turbidity in rivers and water bodies, information that is crucial to ensure a safe potable water supply and protect ecosystems (Díaz García & González Pérez, 2022; Vázquez-Ochoa et al., 2021).

Environmental monitoring sensors are also used to assess air quality in these regions, including measuring atmospheric pollutants such as suspended particles, nitrogen oxides, and sulfur dioxide (Martínez-Abarca et al., 2022). Monitoring air quality is essential to protect the health of local communities and identify pollution sources that may require mitigation measures (Cuadros Cagua, 2017).

Additionally, these sensors provide the ability to perform long-term monitoring of environmental changes, allowing the tracking of trends in temperature, humidity, and other key parameters over the years, helping to understand how ecosystems are changing in response to climate change and other environmental pressures (Juárez Hipólito et al., 2019; Reyes-Ordoñez et al., 2020).

It is recognized that one of the key advantages of these tools is their ability to integrate data from multiple sources, as data from terrestrial sensors, satellites, and drones can be combined to obtain a complete picture of the environmental dynamics in the High Andean zones, which is essential for effective environmental management (García Rengifo & Durán-Ballén Ochoa, 2023; Pérez Vázquez et al., 2018).

Despite their usefulness, environmental monitoring sensors face challenges such as the need for regular maintenance and calibration and the management of large volumes of data. However, as technology advances and these challenges are addressed, these devices are expected to play an increasingly important role in understanding and managing the environmental dynamics in the High Andean zones, providing a fundamental vision for decision-making that balances environmental conservation and the well-being of local communities in a constantly evolving environmental context.

### **Culture and Socioeconomics: The Anthropogenic Component of Socio-Environmental Planning**

Culture and socioeconomics represent a fundamental component in socio-environmental planning in the High Andean zones. Understanding how local communities interact with their natural environment and how their socioeconomic activities impact ecosystems is essential for effective planning, recognizing that people are an inseparable part of environmental systems and that human decisions have a significant impact on the sustainability of these areas (Aguilar Revelo, 2019).

Culture in the High Andean zones is often deeply rooted in the relationship with the natural environment; their traditions, beliefs, and practices are closely linked to the land, water, and natural resources. Understanding these cultural connections is essential to respecting and preserving cultural heritage while seeking balance with conservation and sustainable development goals (Panduro Bazán de Lázaro, 2020; Ulloa et al., 2008).

In turn, socioeconomic activities such as agriculture, livestock farming, and mining have a direct impact on the environment in the High Andean zones. Resource extraction and agricultural expansion can lead to deforestation, soil erosion, and the degradation of fragile ecosystems. Therefore, socio-environmental planning seeks to understand and manage these impacts to minimize them and promote sustainable practices (Echeverri, 2009).

However, effectively integrating culture and socioeconomics into socio-environmental planning is not without challenges, including conflicts of interest, the need to balance conservation and development goals, and the lack of resources to implement appropriate strategies. Addressing these challenges is essential to achieving comprehensive and sustainable management of these regions (Fernández-Llamazares et al., 2014; Salinas-Castro et al., 2019).

As socio-environmental planning practices evolve, it is expected that the integration of culture and socioeconomics will remain a priority. This includes adopting more inclusive and adaptive approaches that recognize the interdependence between humans and their natural environment. In this regard, socio-environmental planning that effectively incorporates these elements seeks a harmonious balance between ecosystem conservation and the well-being of local communities in the High Andean zones.

### **Community Participation: Essential Scaffolding in Social and Environmental Zoning**

Community participation stands as essential scaffolding in social and environmental zoning in the High Andean zones, where local communities have a deep connection with the natural environment. Their active participation is fundamental. This approach must first recognize that the people residing in these areas are expert knowers of their territory and must be key partners in decision-making that affects their environment and quality of life (Córdova Aguilar, 2020; Gallo Álvarez & Sánchez Dávila, 2021).

In this sense, community participation is based on the rich cultural connection and deep local knowledge that communities in the High Andean zones possess, as they have ancestral traditions of sustainable resource management and a deep understanding of local ecology. Their participation ensures that this traditional wisdom is incorporated into planning and that decisions are culturally sensitive and sustainable (Bolívar Urquiza, 2021; Soares & García, 2014).

Furthermore, community participation allows consideration of the specific needs of local communities in social and environmental zoning, identifying community development priorities such as access to clean water, health services, and education, as well as the conservation of sites of cultural and ecological value (Monge-Rodríguez et al., 2022). Attention to local needs ensures that planning is inclusive and beneficial to the people living in these areas (Martelo & Pérez Macias, 2010). It is also essential for designing adaptive strategies in social and environmental zoning, as residents can provide valuable information on how they are experiencing the impacts of climate change and other environmental pressures, allowing strategies and policies to be adjusted to be effective in the long term (Carmona et al. 2022; Fernández et al., 2015).

Despite its importance, community participation can face challenges such as a lack of resources, inequality in access to decision-making, and the need to strengthen community capacity to participate meaningfully. Therefore, as socio-environmental planning evolves, it is expected that community participation will remain a fundamental pillar, allowing for more inclusive and collaborative approaches that recognize the knowledge and experience of local communities. Planning that effectively incorporates community participation seeks a harmonious balance between ecosystem conservation and the well-being of local communities in the High Andean zones.

### **Disaster Risk Management: The Future for Adequate Social and Environmental Zoning**

Disaster risk management emerges as a fundamental component in social and environmental zoning in the High Andean zones (Rosales-Veitia, 2021). In these regions prone to natural events such as landslides, floods, and avalanches, preparedness and risk mitigation are essential (Gallo Álvarez & Sánchez Dávila, 2021). This perspective recognizes that the safety of local communities and the protection of ecosystems are intrinsically linked and must be addressed comprehensively (Sifuentes Palomino et al., 2022).

In this sense, disaster risk management involves identifying and assessing natural risks affecting the High Andean zones, including characterizing threats such as landslides, river overflows, and extreme climatic events (Vera Rodríguez & Albarracín Calderón, 2017). It is considered an integral management approach as it seeks to understand the nature of existing and potential risks as a crucial apex for designing effective mitigation and response strategies (Torres Lima et al., 2021).

It is noteworthy that disaster risk management greatly benefits from integrating geospatial data such as risk maps and hazard models, which allow identifying vulnerable areas and planning prevention and response measures (Rosales-Veitia & Marcano-Montilla, 2021a). Geographic Information Systems (GIS) play a vital role in collecting and analyzing this data, supporting informed decision-making (Rosales-Veitia & Marcano-Montilla, 2013).

Disaster risk management also involves detailed planning of emergency responses, including the development of evacuation plans, early warning systems, and rescue strategies (Rosales-Veitia & Marcano-Montilla, 2022). Therefore, collaboration between local authorities, aid organizations, and

local communities is essential to ensure a coordinated and effective response in the event of a disaster (Gabriel Campos, 2017).

Despite its importance, disaster risk management faces challenges such as a lack of resources, the need to raise public awareness, and long-term planning in a climate change context (Rosales - Veitia & Marcano – Montilla, 2023). Overcoming these challenges is essential to ensure the safety of local communities and the sustainability of ecosystems in the High Andean zones (Reyes Rivera et al., 2022).

As socio-environmental planning evolves, disaster risk management will remain a crucial component. This involves a proactive approach to prevention and resilience and improving local capacities for response and recovery. Disaster risk management aims to ensure that social and environmental zoning in the High Andean zones is sustainable and safe, considering the natural events that may threaten both people and ecosystems.

## CONCLUSIONS

This article has delved into the reflection on the new tools and approaches necessary to address the complex task of social and environmental zoning in the High Andean zones. It has highlighted how advanced technologies such as Geographic Information Systems (GIS), remote sensing, and environmental monitoring sensors are transforming the way we understand and plan these high mountain regions. Additionally, it has emphasized the importance of community participation, disaster risk management, and the consideration of culture and socioeconomics as central elements in this reflective process. Reflection and constant adaptation are crucial to ensuring that these new tools not only improve the efficiency of zoning but also promote sustainability and the well-being of local communities in the High Andean zones. Ultimately, the path toward more effective social and environmental zoning in these areas depends on our ability to harmoniously integrate these innovations into the management of these fragile and diverse ecosystems.

It is recognized that Geographic Information Systems (GIS) have proven to be essential tools in social and environmental zoning in the High Andean zones. Their ability to collect, analyze, and visualize geospatial data provides a solid foundation for informed decision-making. However, their effectiveness lies in their integration with other tools and approaches, such as community participation and consideration of local culture. The future of zoning in these regions will largely depend on how we leverage the power of GIS in conjunction with other key elements.

Additionally, remote sensing is understood to be an essential technology for accessing social and environmental zoning in the High Andean zones. Its ability to acquire remote data provides a detailed view of environmental changes and land use patterns in these high mountain regions. However, its true value lies in how this information is used to address environmental and social challenges. Remote sensing offers a unique window into these regions, but its real contribution lies in its effective integration with conservation and sustainable development strategies.

Climate change models play a critical role in development management in the High Andean zones. Their ability to project future climate change scenarios provides valuable information for social and environmental zoning planning. However, these models are tools that must be used with caution and context. Their utility lies in their integration with other data and approaches and their ability to guide adaptive decision-making in a constantly changing climate context.

Environmental monitoring sensors are essential instruments for understanding the dynamics of the environment in the High Andean zones. Their ability to collect continuous data on water quality, air quality, and other parameters is crucial for environmental management. However, their true power lies in their ability to provide real-time information that supports informed decision-making. Integrating these sensors into a holistic environmental management framework is essential to ensure sustainability in these sensitive regions.

Furthermore, the incorporation of culture and socioeconomics into socio-environmental planning in the High Andean zones is exhibited as a critical step toward a more comprehensive and equitable approach. These dimensions reveal the deep connection between people and their natural environment, as well as the influence of human activities on ecosystems. Reflection on these cultural and socioeconomic aspects in the context of social and environmental zoning allows for more effectively addressing local needs and priorities, promoting sustainable development that respects cultural diversity and the economic conditions of communities.

Community participation is positioned as a fundamental pillar in social and environmental zoning in the High Andean zones. This participation not only recognizes local expertise and knowledge but also promotes more inclusive and sustainable decision-making. The voice of local communities is essential to identifying needs, designing effective strategies, and ensuring that planning is truly representative of the people who reside in these unique areas.

Disaster risk management emerges as a crucial element in social and environmental zoning in the High Andean zones. Its focus on prevention and resilience is essential to protecting both local communities and fragile ecosystems from extreme natural events. Disaster risk management not only involves identifying threats but also planning effective responses and the active participation of communities. The future of zoning in these regions depends on how we address and mitigate disaster risks, ensuring a sustainable balance between protection and development.

As we reflect on the complexities of social and environmental zoning in the High Andean zones, crucial questions arise that will guide our future actions and recommendations. How can we improve collaboration between scientists, local communities, and authorities to maximize the impact of new tools and approaches in zoning? How can we ensure that community participation is inclusive and that the voices of marginalized populations are respected? What is the role of environmental education in building collective awareness about the importance of conservation in these regions? How can we effectively address climate change adaptation in zoning strategies? What specific measures can be taken to promote community resilience in the face of extreme natural events? These challenging questions must form the basis of our recommendations, driving concrete actions that address the unique complexities of zoning in the High Andean zones and promoting a sustainable balance between environmental conservation and human well-being.

## Author Contributions

**WWSQ:** He participated in the research with the central idea of the research, the design and writing of the manuscript.

**MRLGC:** He participated with the design, ideas on the topic and translation of the manuscript.

**CAPV:** Participated in the reference organization and writing and analysis of the manuscript.

GEC: Participated in the research by writing the materials and methods as well as in the translation of the manuscript.

JCFF: Participated in the research with the design and analysis of the results, such as translation.

The authors participated from the beginning to the end, that is, Topic, interests, and in the end we all read and approved the final manuscript.

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