Iniciativa Andina de Montañas

VULNERABILITY AND ADAPTATION TO CLIMATE CHANGE IN HIGH MOUNTAIN AREAS OF THE ANDEAN REGION

Regional Synthesis

PROLOGUE

This document presents the most important contributions of a study produced for the **Andean Mountain Initiative** (AMI) with the purpose of contributing to regional, national, and local processes of climate change adaptation in high Andean communities and ecosystems. The study titled **"Vulnerability and Adaptation to Climate Change in High Mountain Areas of the Andean Region: Argentina, Bolivia, Chile, Colombia, Ecuador, Peru, and Venezuela"** provides a regional perspective on key elements for decision-making in adaptation by analyzing available information on vulnerability to climate change in the Andes at the watershed and continental levels. Special emphasis is placed on economic activities such as agriculture, livestock farming, and tourism, which are the primary livelihoods in local communities, and their relationship with water resources in high Andean areas.

The study analyzes seven basins, one for each country, which have been selected and characterized in coordination with the focal points of the member countries of the AMI. It includes a situational diagnosis and recommendations for reducing climate vulnerability in the Andes, as well as the identification of knowledge gaps and priority topics for adaptation work in the region.

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IKI INTERNATIONAL CLIMATE INITIATIVE

[1] The Andean Mountain Initiative (AMI) is a voluntary platform composed of the seven countries that share the Andes mountain range: Argentina, Bolivia, Colombia, Chile, Ecuador, Peru, and Venezuela. AMI aims to strengthen regional dialogue and promote joint actions for the sustainable development of the Andean mountains. More information can be found at: https:/iam-andes.org/

1 CLIMATE CHANGE IN THE HIGH ANDES: CURRENT SITUATION AND FUTURE OUTLOOK

To gain a perspective on climate action in the Andes, it is essential to analyze climate change and its effects on an ecosystem, socioeconomic, and water resources level. Climate scenario projections in the Andean territory estimate that temperature increases will be particularly pronounced at higher altitudes, reaching an increase of up to 0.2°C per decade in areas higher than 3,000 meters above sea level [1].

Changes in precipitation patterns, on the other hand, vary significantly across the region, with variations in annual rainfall averages ranging from a decrease of up to 3% in some areas to an increase of up to 10% in others [2]. While ecosystems like the puna in Argentina and Bolivia [3] and sections of the *páramos* (tropical alpine grasslands of the Northern Andes) in Ecuador [4] and Venezuela [5] are projected to experience temperature increases and reduced annual precipitation, in other regions like many *páramos* in Colombia [6], the Áncash region in Peru [7][124], and the Magallanes region in Chile [8], both temperature and annual precipitation are expected to increase.

Scenarios indicating temperature increases and decreased precipitation imply alterations in the hydrological cycle, resulting in effects such as increased evapotranspiration, accelerated glacial melting, changes in river flow, and reductions in water availability. These changes will directly impact populations dependent on rivers originating in the high mountains and key ecosystems responsible for water supply and regulation, such as *páramos*, punas, and wetlands [9]. Basins with a negative water balance will experience water stress conditions, affecting populations and their agroecosystems [10] (examples can be seen in Argentina [11], Ecuador [12], and Peru [13]). Additionally, there are challenges related to the supply of drinking water. In some countries within the AMI, the portion of the rural population with access to potable water systems barely exceeds 30%.

The high Andean socio-ecosystems are particularly vulnerable to climate change due to higher rates of temperature increase and their dependence on water from the mountains [9]

HOW WILL THE CLIMATE IN THE ANDES CHANGE?

VENEZUELA [5]

Minimum temperatures in the high Andean zone (2030-2060).

Up to -80% in more than half of the country by the end of the century (2100).

COLOMBIA [6]

Up to 1°C per decade in *páramo* zones (2030).

From 10% to 30% in the Andean region, with increased intensity of precipitation in *páramo* areas (2030).

Leyend

- Increase in the annual average temperature under the RCP 8.5 scenario.
- Increase in the % of annual precipitation under the RCP 8.5 scenario.
- Decrease in the % of annual precipitation under the RCP 8.5 scenario.
- Increase or decrease in annual precipitation under the RCP 8.5 scenario.

ECUADOR [4]

Up to 0.66°C per decade in *páramo* zones (2011-2040).

Between -30 to 50mm/year in precipitation in the Andean region (2011-2040).

BOLIVIA [87]

Up to 2°C in the high plateau (2050).

From 10% to 30% in precipitation (2050).

ARGENTINA [3]

Up to 1°C in San Juan, Mendoza, Salta, and Jujuy (2030).

Overall, notably in the northwest (2030).

PERU [13]

Between 0.5°C to 2.5°C in the Andes (2030).

Precipitation +/-15% in the Andean region (2030).

9% decrease in precipitation in Puno (2030).

CHILE [8]

Up to 2°C in the high Andean and Mediterranean Andes ecoregion (2030).

Up to 20% decrease in precipitation in the North.

Severe droughts in the central-south (2030-2060).

IMPACTS OF CLIMATE CHANGE IN THE HIGH ANDEAN REGION

AGRICULTURE

The impact of climate change on agricultural activities is conditioned by variations in meteorological factors such as rising temperatures, increased maximum precipitation, decreased annual precipitation, changes in frost frequency, and wind intensity. The cascading effect of these variations affects the essential conditions for agricultural activities. Changes in tolerance limits for key Andean crops like potatoes, quinoa, oca, wheat, and corn [14] are anticipated, altering their yields, as well as reducing soil fertility, changing the population dynamics of pollinators and pests [16][17], and intensifying frost occurrences, among other effects.

Crops like potatoes, beans, and carrots would lose their climatic suitability in areas where they are currently cultivated (e.g., in Colombia and Peru [15]) and would become suitable in higher-altitude regions. However, there are projected losses in suitable areas for these crops, because higher-altitude regions often have less-developed soils, but high diversity and endemism (e.g., *páramos* and punas), typically included under Protected Areas [54] [99]. On the other hand, crops from lower-lying areas like cassava, rice, and fruit crops will see an increase in climatic suitability in countries like Ecuador and Bolivia [97].

This would have consequences for the economic incomes of farmers, lead to the disappearance of ancestral practices, intensify the migration of rural communities, and increase food insecurity in the region [14]. Andean family agriculture is highly dependent on climatic conditions, which would create greater pressures on marginal productive areas where there are already limitations in access to optimal soils, infrastructure, financing, and basic services, in addition to the significant poverty levels of the population [1].

LIVESTOCK FARMING

There will be impacts on water sources and livestock watering points [18], disruptions in food availability [19], and a reduction in carrying capacity of pastures, among other effects [20]. In countries like Bolivia, Argentina, and Peru, available studies suggest that

[2] "Carrying capacity" refers to an ecosystem's ability to support grazing animal loads while maintaining its productivity and ecological integrity.

the performance of camelid, sheep, and goat livestock would be affected due to their dependence on natural ecosystem conditions [19] and the maintenance of natural pastures [21]. In Colombia, Ecuador, and Venezuela, thermal stress that could affect dairy production has been reported [22]. These impacts will be intensified by the already evident degradation and alteration in the productivity of fragile ecosystems such as *Páramos* and wetlands [98], affecting the future income and economic stability of livestock producers [23].

TOURISM

Activities like mountaineering, kayaking, hiking, climbing, and skiing will be affected by glacier retreat in countries like Chile [24], Argentina [25], Bolivia [26], Peru [27], Colombia [98], and Venezuela [99]. Reduced water flows will affect the development of water sports [28][8] and cause disruptions in the local flora and fauna, which are tourist attractions in destinations like the high Andean wetlands [4]. Decreased water supply could affect the provision of basic services like drinking water in lodging facilities [8], while an increase in the intensity of extreme events may impact access to tourist destinations. These impacts would decrease the flow of visitors in the region and affect the economic income of populations dependent on high mountain tourism [24].

ECOSYSTEMS

Spatial models predict contractions in the surface area of *páramo*, wetland, and puna ecosystems, reducing the distribution area of endemic species [29]. This is compounded by an increase in the presence of exotic species, vectors, and diseases originating from warmer elevations. This could lead to the extinction of native species [30][31][9], which are, in some cases, incapable of adapting to the new climatic conditions and increased competition. Species at risk include several rosette plants of the *Espeletia genus* in Colombia, Venezuela, and Ecuador [90], cushion plants like Distichia muscoides in Bolivia [91], and species of the genera *Agrostis, Poa, Festuca, and Arcytophyllum* in Peru [77]. Changes in the incidence of pathogenic fungi threatening the viability of specialist high mountain amphibian populations have also been reported; species like the spiny toad (*Rhinella spinulosa*) could see their populations decrease by up to 14% [98].

2 CLIMATE VULNERABILITY IN 7 STRATEGIC HIGH ANDEAN BASINS

Seven strategic basins were selected as case studies, one from each country in the Andean region: Argentina, Bolivia, Chile, Colombia, Ecuador, Peru, and Venezuela. This synthesis was developed based on information shared by the representatives of the member countries of the AMI, available literature, and primary information (interviews with key stakeholders). The study emphasizes rural livelihoods, particularly agriculture, livestock farming, and tourism, and their relationship with water resources in high Andean areas.

METHODOLOGY FOR SELECTING BASINS

The methodological framework for prioritizing the seven basins consisted of three phases:

1	**UNIT OF ANALYSIS**	The study area is defined based on four premises, depending on each national context: • Concept and classification of hydrological basins • Altitude of the area in relation to ecosystems or eco-regions • Significant surface area of the basin in high mountains • Headwaters of the basin located in the mountain range
2	**PRESELECTION OF BASINS**	Four basins were selected in each country through a multicriteria analysis based on: • Availability of information • National relevance • Institutional capacity and governance
3	**FINAL SELECTION OF BASINS:**	The basins were evaluated based on five criteria: • Climatic hazard (variation in annual average temperature and annual precipitation) • Vulnerable population (% women, % children, % elderly, % poverty, and % indigenous population) • Economically productive population in rural livelihoods (agriculture, tourism, and livestock) • Socio-environmental conflicts related to water resources and ecosystems Implemented adaptation projects
	RESULTS	The methodological framework allowed for the prioritization of seven hydrological basins with a high vulnerability to climate change in the Andean region.

ELEVATION CONSIDERATIONS:

COUNTRY OF THE AMI	MINIMUM ALTITUDE CONSIDERED (m.a.s.l.)	JUSTIFICATION	ANALYZED BASINS
ARGENTINA	3800	Altitudes higher than 3800 meters above sea level (m.a.s.l.) were considered, corresponding to the Puna ecoregion (3800-4000 m.a.s.l.) and High Andes (>4000 m.a.s.l.)	27
BOLIVIA	3800	Altitudes higher than 3800 m.a.s.l. were considered, coinciding with the Bolivian altiplano region that hosts high Andean ecoregions such as the puna.	27
CHILE	3500	Altitudes higher than 3500 m.a.s.l. were considered, corresponding to the high Andean vegetational belt of the Central Andes of Chile.	30
COLOMBIA	2900	Altitudes higher than 2900 m.a.s.l. were considered, corresponding to the beginning of the *páramo* line, considered a high Andean ecosystem.	15
ECUADOR	3200	Altitudes higher than 3200 m.a.s.l. were considered, corresponding to the beginning of the *páramo* line, which is considered a high Andean ecosystem.	16
PERU	4000	Altitudes above 4000 m.a.s.l. were considered, corresponding to the line from which glacier ecosystems have been inventoried in the country.	41
VENEZUELA	2800	The Andean Northern Paramo and the Merida Mountain Range *páramo* ecoregions were considered, which are mostly located at altitudes higher than 2800 m.a.s.l. [121].	14

[3] For Ecuador, this study is only complementary to the efforts carried out within the framework of its National Climate Change Adaptation Plan, which included conducting climate risk studies at the national level and has provided inputs to guide the territorial intervention of its adaptation programs and projects until 2027.

[4] Climate hazard refers to climate-related physical events or trends, including the physical impacts of these events.

PRIORITIZED BASINS

BERMEJO RIVER BASIN
ARGENTINA

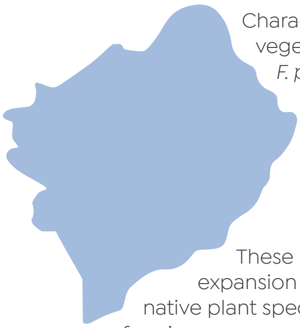
Characteristics – High Andean Zone

This region encompasses the ecoregions of the High Andes and the puna, characterized by cold climates low precipitation and the presence of plant species typical of steppe formations growing on mountain slopes and periglacial areas, as well as grasslands and some *Polylepis* forests. In the high mountains there are around 266 glaciers of vital importance to hydrological contribution and extensive areas of high Andean wetlands.

Projections

These ecosystems will face alterations in primary productivity, reduced water flows, loss of vegetative cover, desertification, erosion, and other climatic impacts. These changes will be intensified primarily by extensive livestock farming, mainly involving sheep, goats, and camelids, which are the primary economic activities in the high mountain regions of the basin.

SALAR DE UYUNI BASIN
BOLIVIA



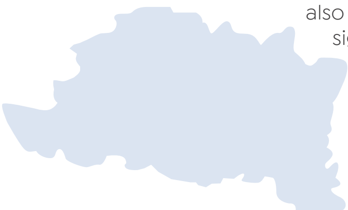
Characteristics – High Andean Zone

Characterized by the presence of desert puna in the subnival and nival zones, with low vegetative cover, highlighting grass species like *Jarava (Stipa) matthei, Festuca petersonii*, and *F. potosíana*. It also includes part of the Los Lipez wetland, a RAMSAR site that harbors a rich biodiversity.

Projections

These ecosystems will be affected by climate change, intensifying the impacts caused by the expansion of agricultural frontiers associated with the quinoa boom, which has led to the loss of native plant species, desertification, and the replacement of ancestral economic practices like camelid farming.

MAIPO RIVER BASIN
CHILE



Characteristics – High Andean Zone

It encompasses five ecosystems associated with vegetative formations: sclerophyllous forest, thorny forest, high Andean steppe, high-altitude herbaceous vegetation, and low-altitude shrubland. It also features the presence of glaciers covering 2.55% of the basin area, which provide significant water contributions to the entire Metropolitan Region of Chile. Additionally, the basin contains numerous high Andean wetlands and meadows.

Projections

It has been observed that rising temperatures and decreasing precipitation associated with climate change have led to a reduction in glacier surface area and the water bodies of high Andean wetlands. This has increased the vulnerability of communities regarding water resource availability, negatively impacted livestock due to wetland deterioration, and adversely affected mountain tourism due to glacier retreat.

SOGAMOSO RIVER BASIN
COLOMBIA

Characteristics – High Andean Zone

The Maipo River Basin comprises 11 ecosystems, with the *páramo*, peatlands, high Andean wetlands, and nival and periglacial ecosystems being particularly noteworthy. These ecosystems have become more vulnerable due to the intensification of climate change, characterized by rising temperatures and altered precipitation patterns.

Projections

The impacts include glacier retreat in the Sierra Nevada del Cocuy, loss of biodiversity in the *páramos*, and a decrease in the quality and surface area of water bodies in wetlands. Impacts on the productivity of high Andean crops such as potatoes have also been observed, with intensified precipitation during winter periods leading to significant losses. This scenario is expected to intensify from 2030 to 2070.

ESMERALDAS RIVER BASIN
ECUADOR

Characteristics - High Andean Zone

The area encompasses 16 ecosystems, with a significant presence of glacier and periglacial zones, which are of great importance to mountain communities. *Páramos* and wetlands serve as crucial sources of water supply, forage, and essential medicinal herbs in the economic dynamics of the surrounding populations.

Projections

These ecosystems will face rising temperatures, which will reduce the quality and surface area of water bodies and promote glacier melt. Furthermore, significant biodiversity losses are expected, considering their status as hotspot ecosystems. Scientific evidence indicates that staple crops such as potatoes and onions, which form the basis of agriculture in the high Andean region, will be affected by climate change. The production of milk will also be altered due to thermal stress and changes in forage availability for livestock.

SANTA RIVER BASIN
PERU

Characteristics - High Andean Zone

Four ecosystems are identified in the area: wetlands (bofedales), periglacial and glacial zones, jalca, and wet puna grasslands. These ecosystems serve as important water supply sources for the districts located in the high mountains. Notably, there is extensive glacier coverage, covering approximately 37% of the basin, which serves as a significant source of water recharge for bodies of water like the Santa River, supplying water for domestic and agricultural use in the communities. Moreover, glacier contributions are crucial for sustaining other ecosystems in the region.

Projections

In recent decades, the glacial retreat process has accelerated [79] and it is estimated that by 2050 the impacts associated with water availability due to melting ice and the disappearance of glaciers will be more evident. This will affect other ecosystems -such as wetlands- due to the reduction in runoff [80]. Water acidification processes have been documented in some areas of glacial retreat and activities such as rainfed agriculture that also depend on glacial runoff will be affected.

CHAMA AND MOTATAN RIVER BASIN
VENEZUELA

Characteristics - High Andean Zone

The region is characterized by the presence of forests, shrubland ecosystems, and rosette formations in the *páramo*, with a high degree of endemism. Two ecoregions are identified: Montane Forest, notable for its epiphytic species of mosses, ferns, and bromeliads; and the *Páramo* of the Cordillera de Mérida, characterized by a wide diversity of specialized grassland, shrubland, and rosette communities, with over 60 endemic species in the *Espeletia genus*. High Andean wetlands are a prominent feature, crucial for livestock development and as water sources for agriculture.

Projections

There is evidence of the expansion of the agricultural frontier, overgrazing, and the intensification of climate change, which generates losses of ecosystem services and biodiversity, soil erosion and compaction, and reduced fertility [86]. Although there could be an increase in the climatic suitability of the potato and carrot crops due to their altitudinal displacement, a reduction in the potential area for the development of these crops is expected as these will move towards areas of *páramo* ecosystems included in Areas Under the Special Administration Regimen (ABRAE for its Spanish acronym), economically affecting communities and their food security.

MAJOR HAZARD, VULNERABILITY, AND EXPOSURE VARIABLES

IN THE HIGH ANDEAN PRIORITIZED BASINS

ESMERALDAS RIVER BASIN
PICHINCHA, COTOPAXI, IMBARURA
ECUADOR

- 3.711.798
- 68,471% (> 3.200 m.a.s.l.)
- 1.265.942 (50%)
- 68,63%
- 0,62°C
- 44.198 (0,58%)
- 238.636
- 2.592 (0,1%)
- -5% a 15%

Source: INEC (2010) & Ecuador's Platform on Climate Change Adaptation

SANTA RIVER BASIN
ANCASH, LA LIBERTAD
PERU

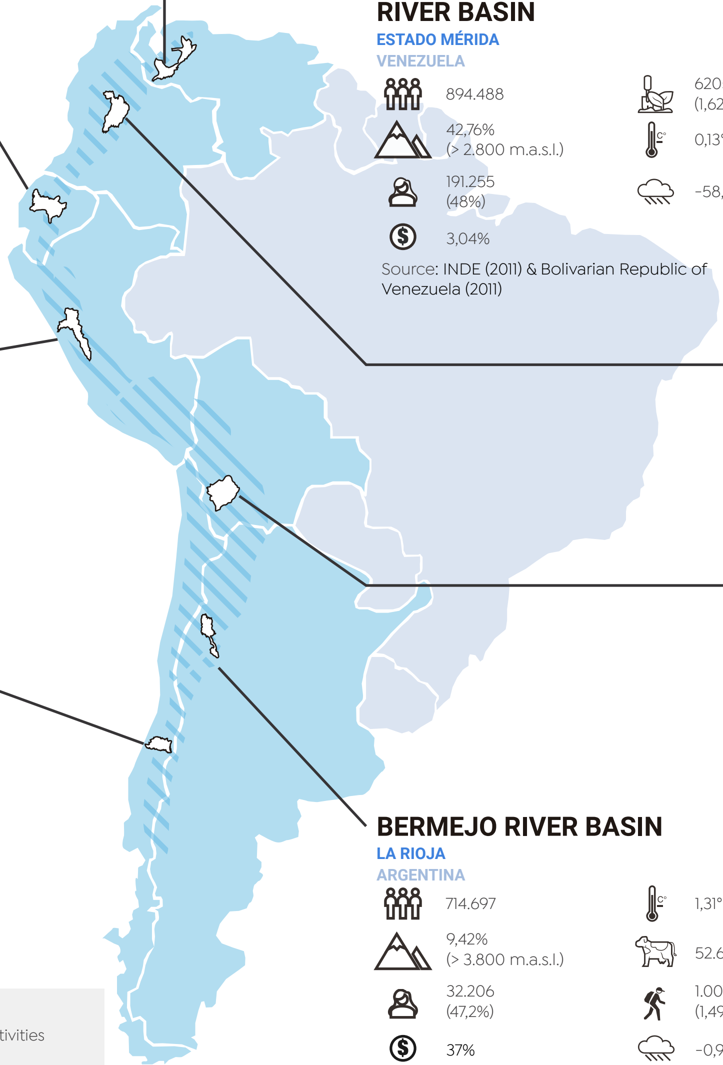
- 896.974
- 34,51% (> 4.000 m.a.s.l.)
- 158.589 (50%)
- 30,02% – 43,88%
- 297.217 (48%)
- 817.712
- 3,2°C
- -15% a 60%

Source: INEI (2017) & SENAMHI (2021)

MAIPO RIVER BASIN
REGIÓN METROPOLITANA
CHILE

- 7.291.762
- 1,7% (> 3.500 m.a.s.l.)
- 63.661 (49%)
- 4,42%
- 1,61°C
- 310 (0,37%)
- 1.523.343
- 549 (0,44%)
- -15,41% a -16,55%

Source: INE (2017) & MMA (2018)



CHAMA AND MOTATAN RIVER BASIN
ESTADO MÉRIDA
VENEZUELA

- 894.488
- 42,76% (> 2.800 m.a.s.l.)
- 191.255 (48%)
- 3,04%
- 6205 (1,62%)
- 0,13°C
- -58,13%

Source: INDE (2011) & Bolivarian Republic of Venezuela (2011)

SOGAMOSO RIVER BASIN
CUNDINAMARCA, BOYACÁ, SANTANDER
COLOMBIA

- 1.712.155
- 69% (> 2.900 m.a.s.l.)
- 603.363 (49%)
- 34,8%
- 0,83°C
- 35.118 (0,03%)
- 735.281
- 10.797 (0,91%)
- -10% a 40%

Source: DANE (2014) & IDEAM (2015)

SALAR DE UYUNI BASIN
POTOSÍ, ORURO
BOLIVIA

- 80.903
- 100% (> 3.800 m.a.s.l.)
- 40.265 (48%)
- 65,8%
- 1,9°C
- 41.391 (51,16%)
- 126.034
- 154 (0,38%)
- -0,5% a 0,25%

Source: INE (2012) & Torrico (2021)

BERMEJO RIVER BASIN
LA RIOJA
ARGENTINA

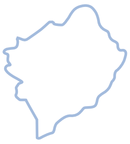
- 714.697
- 9,42% (> 3.800 m.a.s.l.)
- 32.206 (47,2%)
- 37%
- 1,31°C
- 52.601
- 1.001 (1,49%)
- -0,99% a -1,06%

Source: INDEC (2010) & SIMARCC (2021)

Leyend

- Residents in the entire basin
- % Inhabitants in the high Andean zone (considered altitude)
- Women in the high Andean zone (Percentage)
- % of the population in poverty
- Temperature change by 2030 - RCP 8.5 Scenario
- Population engaged in agricultural activities
- Total livestock heads
- Population employed in tourism (Percentage)
- Percentage change in precipitation by 2030 - RCP 8.5 Scenario

IDENTIFIED ADAPTATION PROJECTS WITH IINFLUENCE ON THE PRIORITIZED BASINS

Basin	Project Name — Responsible Institution (Year of Initiation)
BERMEJO RIVER **ARGENTINA** 	◦ Irrigation Systems Reconfiguration Project for La Rioja - Ministry of Agriculture, Livestock, and Fisheries (2020) ◦ Sustainable Landscape and Livelihoods Recovery Project - Ministry of Environment and Sustainable Development - National Parks Administration (2021) ◦ Support for the Preparation of REDD+ "Environmental and Socio-economic Diagnosis of Forest Basins - Bermejo Forest Basin" - Ministry of Environment and Sustainable Development (2016) ◦ Wetlands of Argentina Regions - Wetlands International in collaboration with the Ministry of Environment and Sustainable Development (2016) ◦ Information System for Integrated Water Resource Management - Province of La Rioja - Ministry of Agriculture, Livestock, and Fisheries (2012)
SALAR DE UYUNI **BOLIVIA** 	◦ Building Climate Resilience in Rural Families in Bolivia Program - Ministry of Rural Development and Land (2021) ◦ "Quinoa/Camelid Agri-food System: Promotion of Family Agriculture in the Bolivian Altiplano" Project - FAO (2014) ◦ Pro-Camelid Program - Ministry of Rural Development and Land (2016)
MAIPO RIVER **CHILE** 	◦ GEF Mountains: Mountain Biological Corridors - Ministry of the Environment (2016-2022) ◦ Volunteers for Water - Cajón del Maipo Communal Environmental Committee (2022) ◦ Santiago Water Fund: Reforestation and Water Recovery in the Maipo River Basin - The Nature Conservancy and CONAF (2019) ◦ Guanaco Reintroduction - Institute of Ecology and Biodiversity (2017) ◦ Water Scenarios 2030 - Chile Foundation (2016) ◦ MAPA Project: Vulnerability and Adaptation to Climate Variability and Change in the Maipo River Basin in Central Chile - IDRC Canada (2012-2016)
SOGAMOSO RIVER **COLOMBIA** 	◦ Boyacá Adapts to Climate Change - Boyacá Autonomous Corporation and Pedagogical and Technological University of Colombia (2021) ◦ Water Management Plan in the Central Region - Central Region RAPE (2021) ◦ *Páramos* Project - Central Region RAPE (2018-2021) ◦ Conservation, Restoration, and Management of Ecosystems and Biodiversity - Boyacá Regional Autonomous Corporation (2020) ◦ Wetland Godparent - Cundinamarca Regional Autonomous Corporation (2020) ◦ BanCO2 - Masbosque ONG Corporation (2013-2020) ◦ Water Reservoirs - Yarumo Foundation, Cundinamarca Regional Autonomous Corporation (2017)
ESMERALDAS RIVER **ECUADOR** 	◦ Climate-Smart Livestock Project (GCI) - FAO (2006-2020) ◦ Building Climate Change Adaptation Capacities through Food and Nutritional Security Actions in Vulnerable Afro-descendant and Indigenous Communities in the Colombia-Ecuador Border Area - Ministry of Environment and Water (2018) ◦ Increasing Resilience to Climate Change through the Protection and Sustainable Use of Fragile Ecosystems: ProCamBío II - GIZ (2017)
SANTA RIVER **PERU** 	◦ Glacial Origin Lakes in Peru: Evolution, Hazards, and Impacts of Climate Change (GLOP) - National Institute for Research on Glaciers and Mountain Ecosystems (INAIGEM) (2019-2022) ◦ Peru Grows Project - National Institute for Research on Glaciers and Mountain Ecosystems (INAIGEM) (2019-2021) ◦ Permafrost Project - National Institute for Research on Glaciers and Mountain Ecosystems (INAIGEM) (2019-2021) ◦ Glaciers Project - CARE Consortium, University of Zurich (2012-2021) ◦ HAME Project: Sustainable and Climate-Resilient Management of High Andean Ecosystems, Regional Initiative for Bolivia, Colombia, Ecuador, and Peru - OAS General Secretariat, CONDESAN, and University of Zurich.
CHAMA AND MOTATAN RIVER **VENEZUELA** 	◦ Last Glacier in Venezuela - University of the Andes (2019) ◦ Andean *Páramo* Project: Management and Conservation of Wetlands and *Páramos* in Venezuela - Successful Experiences in Climate Change Adaptation in the Mixteque *Páramo*, Mérida (2007-2012) ◦ Mucuposadas - Andes Tropicales Program Foundation ◦ Andes Sur Project - Andes Tropicales Program Foundation

STRATEGIC ANDEAN BASINS FACING CLIMATE CHANGE

SOCIAL VULNERABILITY

In sociodemographic terms, ethnic minorities are more vulnerable to climate impacts, because their livelihoods are highly dependent on the ecosystem services of high Andean areas. The cessation or reduction of these activities at the local level will lead to a decrease in their income, affecting their food security as well [32]. The Santa River, Esmeraldas River, and Salar de Uyuni basin have the highest indigenous population (>77%, 71%, 38% respectively), while in the others, ethnic minorities represent up to 10% of the population.

Women in rural areas are particularly vulnerable and are differentially affected by climate impacts. They have less access to education and information and face inequality in accessing economic resources and limitations on participation in decision-making [33]. Therefore, adaptation policies and actions should focus on closing gender gaps.

Regarding the population living in poverty, it was identified that the Salar de Uyuni, Bermejo River, and Sogamoso River basin have the highest percentage of population in poverty (65.83%, 36.73%, and 34.88% respectively). This results in significant limitations in responding to and adapting to the impacts of climate change.

Among the studied basins, populations of the Salar de Uyuni (Bolivia) and the Esmeraldas River (Ecuador) exhibit higher social vulnerability to climate change due to existing inequalities.

AGRICULTURAL ACTIVITIES

In general, climate change affects the productivity of different crops in the region [49]. However, the selected basins will experience differentiated impacts. For example, in the high Andean area of the Sogamoso River basins, a severe increase in the percentage of annual precipitation (+40%) has been projected, which will exceed the water requirements of essential crops like potatoes or onions, leading to partial or total losses. It will also result in nutrient leaching from the soil and an increase in problems associated with pests and diseases [50]. In the basins of Salar de Uyuni [51] and the Santa River [52], Esmeraldas River [53], and Chama-Motatán River [54], variations in rainy periods and the trend toward decreased precipitation may lead to water stress in crops such as quinoa, potatoes, onions, and vegetables, affecting their yield and production [55].

Regarding temperature increases, it is expected that basins whose irrigation systems are directly supplied by glacial origin rivers will be directly impacted by glacier retreat (including water acidification processes due to the exposure of rocks rich in pyrite), as is the case in the Santa River basins [56]. All these impacts will affect the development of agriculture, increasing the vulnerability of rural high mountain communities whose economic basis is subsistence production and/or commercialization.

LIVESTOCK FARMING ACTIVITIES

High Andean basins experience the impacts of climate change in various ways. In some cases, reduced precipitation affects the pastures that feed livestock (Bermejo River [108]), or livestock deaths due to droughts have been reported (Salar de Uyuni, Santa River [109][110]). In others, such as the Sogamoso River basins, increased rainfall would favor changes in pasture composition/structure, and rising temperatures would cause stress in cattle, reducing milk production [111].

Furthermore, the expansion of livestock farming occurs under unsustainable conditions that can affect the natural resources on which its development depends. In basins like the Maipo and Sogamoso rivers, livestock farming exerts pressure on wetlands [75][72], while in the Esmeraldas River, Chama-Motatán River, and Santa River basins, grazing has intensified soil erosion processes in the *páramo* [105][85][47].

TOURISM ACTIVITIES

The increase in temperatures will accelerate glacier retreat processes already evident in almost all Andean basins, affecting the development of mountain tourism activities such as hiking and climbing. Sports like skiing and climbing are practiced in some snow-capped mountains in the region, as is the case in the Maipo River, Sogamoso River (El Cocuy National Park), and Santa River (Huascarán National Park) basins, where glacier retreat is leading to a decrease in visitor flow and economic losses [13].

Nature tourism is being affected by biodiversity loss and impacts on ecosystems [4], resulting in the loss of scenic beauty and cultural identity. For example, the Salar de Uyuni basin is considered vulnerable due to the darkening of the salt flat's surface as a result of droughts [95], and in the Maipo River basin, reduced water flows impact canoeing activities [112].

Populations whose main economic activity is tourism are already being affected, as seen in the case of the Santa River and Bermejo River basins, where it is expected that tourist demand will shift to less vulnerable and better-prepared areas [3].

PRIVATE SECTOR:
EXPERIENCES AND OPPORTUNITIES

The private sector is a key player in adaptation efforts to address climate change, making it important to advance actions related to climate change knowledge and its impact on value chains. It is also crucial to optimize their involvement in implementing adaptation measures that support the reduction of vulnerability in their productive activities and the socio-ecosystems that sustain them.

In the high Andean region, actions by the private sector that contribute directly or indirectly to adaptation processes have been identified. In most cases, this occurs through the financing of projects as part of corporate social responsibility initiatives, including the funding of programs that strengthen productive activities of communities such as livestock farming and tourism in Bolivia [124] and Venezuela [125][126], and the financing of conservation and restoration efforts in Colombia [127][128] and Chile [129]. Their involvement is also observed through the payment for environmental services model in Colombia [130] and participation in water funds in Ecuador [131].

In this regard, it is essential to highlight opportunities for the private sector to contribute to ecosystem-based adaptation, including the possibility of adopting new business models, identifying financial mechanisms for project development, and involving financial or banking institutions. These opportunities include:

1 OPPORTUNITIES FOR DEVELOPING BUSINESS MODELS IN ADAPTATION [132]

"Adaptation Enterprises" are those whose business model is focused on strengthening the adaptive capacity of the population or their livelihoods. These enterprises can be categorized as:

- **Generation of Information for Climate Change Adaptation:** Advisory services, provision of climate information, decision support tools (e.g., early warning systems).
- **Products and Services for Climate Change Adaptation:** Climate and physical risk management, such as rainwater harvesting technologies, climate risk transfer including insurance solutions.

2 OPPORTUNITIES FOR BUSINESSES TO IMPLEMENT EbA PROJECTS

By utilizing financial mechanisms such as payments for ecosystem services, carbon financing, debt-for-nature swaps, conservation trust funds, and other relevant approaches.

- **Financial Sector Opportunities:** Providing services tailored to the needs of micro, small, and medium-sized enterprises. Success cases, such as the "Microfinance for Ecosystem-based Adaptation (MEbA)" project, have shown how financial institutions can cater to the financial needs of businesses engaged in adaptation projects. [133]
- **Tourism Sector Opportunities:** Implementing programs for payments for ecosystem services, debt-for-nature swaps, or dedicated tax funds, where private sector contributions are used to finance EbA projects that enhance, recover, or conserve tourist attractions. For instance, the ADAPTUR project in Mexico is a successful example. [134]
- **Productive Sector Opportunities:** Adapting the production chain to contribute to the economic livelihood of rural communities and ecosystem conservation, such as the use of native crops. These initiatives support both economic sustainability and environmental conservation. [135]

3 INFORMATION AND KNOWLEDGE GAPS

Most Andean countries have information based on climate projections from Representative Concentration Pathways (RCPs) established by the IPCC. Argentina (SIMARCC), Ecuador (S-PRACC), and Chile (ARCLIM) have developed interactive platforms that facilitate data analysis at the local level and are open to the public. Countries like Peru, Ecuador, and Colombia have projections at the departmental or provincial level, and Venezuela has official national-level projections. Bolivia does not have official publications regarding climate projections, but studies like Tórico (2021) [87] provide an approximation of climate trends in the country. The heterogeneity of information in terms of time and scale increases the uncertainty of projected climate scenarios and can make it challenging to make more accurate decisions and formulate policies and adaptation plans at the local level.

Regarding agricultural information, it has been identified that most countries have published National Agricultural Censuses, which allow the identification of predominant crops in the Andean regions and their coverage area. Another important aspect is studies that assess the socioeconomic impact of climate change on agricultural producers, such as those developed for Peru, Ecuador, and Chile, related to the economic loss of crops such as potatoes, maize, beans, and wheat [55][102][103]. Colombia and Ecuador have initiated efforts to identify the vulnerability of communities in relation to agricultural land, land tenure, lack of public services coverage, etc.

On the other hand, studies on the vulnerability of livestock are scarce. The work of Tapasco (2015) [88], which estimated the impact of climate change on pasture biomass production and its effect on milk and meat production, is noteworthy. There is a gap in information regarding the impact of climate change on livestock species and South American camelids, except for some research conducted for sheep and cattle [8][88][104].

Research related to tourism has focused on the impact of the intensification of extreme events on access to tourist destinations, as well as the effect of deglaciation on tourism activities in mountains and snow-capped peaks.

An important challenge is the development of watershed-level studies that include economic and social impacts of climate change, although they have been identified in the Santa River basin in Peru and the Maipo River basin in Chile.

Regarding agricultural activity, while qualitative studies indicate a likely impact on crop productivity, it is essential to estimate changes in crop coverage areas in the Bermejo River, Maipo River, Santa River, Sogamoso River, and Salar de Uyuni basins. For livestock farming, it is crucial to develop studies that address the spatial distribution and productivity variation of high Andean ecosystems and their effect on the sustainability of livestock production. Finally, for the tourism sector, an analysis of the impact on the cultural valuation of high Andean landscapes by residents and visitors is needed, as well as an analysis of the socio-economic impacts of tourism services, using the Maipo River basin as an example [28]. It is necessary to reinforce biodiversity and ecosystem service monitoring systems, particularly by replicating and strengthening initiatives like the GLORIA-Andes Network present in the Maipo River, Sogamoso River, and Chama-Motatán basins.

Closing these gaps should aim to generate relevant information to strengthen the adaptive capacity of residents, guide the scaling up of adaptation strategies, and develop policies, plans, or actions to reduce the vulnerability of the most affected systems. Examples of initiatives in this regard include:

- Developing climate scenario models at local scales to reduce current uncertainty.
- Updating agricultural censuses with trends in the most relevant crops in each country.
- Analyzing climate threats and their effects on plant growth, development, and production; vulnerability of agricultural products and livestock species; and socio-economic impacts.
- Evaluating tourist sites in various ecosystems and the socio-economic and cultural impacts on tourism resulting from climate change.
- Improving and strengthening the monitoring of meteorological and hydrological variables, including glacier monitoring, along with biodiversity and ecosystem services (e.g., water regulation, carbon storage, soil fertility).

4 REGIONAL RECOMMENDATIONS

AREAS OF WORK

Proposal of five working areas related to Ecosystem-based Adaptation (EbA)

SUSTAINABLE LIVESTOCK FARMING

- Sustainable Grazing Systems - Livestock rotation, definition of grazing limits, and proper animal stocking management.
- Implementation of Mixed Forage Banks - Diverse arrangements of herbaceous and shrub species with high nutritional value for forage production.
- Genetic Selection of Resilient Varieties - Genetic recovery and maintenance of resilient native livestock breeds adapted to extreme conditions and diseases.
- Sustainable Management of Camelids - Improvement of breeding techniques to enhance individual productivity and efficiency.

SUSTAINABLE AGRICULTURE AND AGROECOLOGY

- Conservation of Agrobiodiversity - Recovery and maintenance of local varieties with higher tolerance to extreme conditions.
- Agroecosystem Diversification - Various arrangements of crops, native plant species, and pastures to enhance functional diversity and resilience to climate change.
- Integrated Pest Management - Includes techniques like crop rotation, the use of biocontrol agents, and pheromone traps.

TRANSFORMATION OF TOURISM

- Towards Awareness Tourism - Ecotourism based on the use of cultural ecosystem services as an environmental education strategy, generating positive changes in visitor behavior.
- Strengthening Community Tourism Models - Adapting rural housing to accommodate tourists in areas of special cultural and ecosystem importance, allowing them to interact with rural livelihoods and appreciate the scenic beauty of high Andean ecosystems.

WATER SECURITY

- Rainwater Harvesting Systems - Rehabilitation or implementation of water storage and distribution systems incorporating ancestral technologies like amunas, trenches, artificial ponds (q'ochas), vegetative cover, terraces, ancestral canals, and slow-formation terraces.
- Efficient Agricultural Water Use - Implementation of integrated irrigation systems based on the use of efficient irrigation technologies, the restoration of terraces, and infiltration canals.

ECOSYSTEM AND BIODIVERSITY CONSERVATION

- Restoration of High Andean Ecosystems - Regeneration and conservation of high Andean ecosystems through the implementation of techniques such as passive and active restoration, reseeding, transplanting of regeneration cores, and mixed pasture planting.
- Ex Situ Species Repopulation Programs - Maintenance of threatened native populations through germplasm banks like botanical gardens, nurseries, or herbaria.
- Strengthening of Protected Areas - Enhancing the comprehensive management of protected areas, promoting the monitoring of their effectiveness, and co-management models with increased involvement of local communities.

ENABLING CONDITIONS

To ensure the implementation of the recommendations, a series of enabling measures are required, including:

- Strengthening capacities in local governments and the community, creating spaces for dialogue to design climate change adaptation measures, considering ancestral knowledge and perceptions, as well as a gender perspective.

- Improving public investment in climate change adaptation measures and facilitating resource mobilization for the implementation of technologies and financing by the private sector.

- Monitoring adaptation projects from their initial stages, establishing monitoring and evaluation indicators to visualize intervention results, as well as barriers and lessons learned.

- Strengthening governance and institutional capacity at the national, watershed, and local levels, developing territorial planning and climate change managing instruments, as well as management plans, establishing a legal framework for the decision-making process. Initiatives should have institutional support to ensure their implementation and replicability, and be compatible with the political and normative framework of the area of interest.

- Enhancing hydroclimatic and biodiversity monitoring by systematically collecting and analyzing information to detect change signals in relation to a baseline and promote the sustainability of regional monitoring initiatives (e.g., GLORIA-Andes network, Andean Forest Network, MIREM).

FINAL CONSIDERATIONS

Studies like this, which actively involve the countries of the Andean Mountain Initiative (AMI), complement the development of regional intervention proposals by facilitating the identification of common issues, strengths, and challenges that the countries in the region share.

The generation and dissemination of information based on science, evidence, and experiences contribute to the countries' and region's governance, strengthening decision-making processes based on a shared horizon.

With a common vision, it is hoped that opportunities can arise to design and implement collaborative programs, thereby advancing a concerted regional agenda for climate change adaptation in the Andes.

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