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Monographic issue

Climate Change Impacts in the Province of Petorca, Valparaiso Region, Chile (1980–2020)

University of Oviedo – Department of Medicine
Unit for Research in Emergency and Disaster

Letter from the editor

The Emergency and Disaster Reports is a journal edited by the Unit for Research in Emergency and Disaster of the Department of Medicine of the University of Oviedo aimed to introduce research papers, monographic reviews and technical reports related to the fields of Medicine and Public Health in the contexts of emergency and disaster. Both situations are events that can deeply affect the health, the economy, the environment and the development of the affected populations.

The topics covered by the journal include a wide range of issues related to the different dimensions of the phenomena of emergency and disaster, ranging from the study of the risk factors, patterns of frequency and distribution, characteristics, impacts, prevention, preparedness, mitigation, response, humanitarian aid, standards of intervention, operative research, recovery, rehabilitation, resilience and policies, strategies and actions to address these phenomena from a risk reduction approach. In the last thirty years has been substantial progress in the above-mentioned areas in part thanks to a better scientific knowledge of the subject. The aim of the journal is to contribute to this progress facilitating the dissemination of the results of research in this field.

This monographic issue explores the variety and intensity of the climate change impacts in the Province of Petorca at the Valparaiso Region of Chile from 1980 to 2020.

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ORIGINAL RESEARCH

Climate Change Impacts in the Province of Petorca, Valparaíso Region, Chile (1980–2020)

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ABSTRACT

Introduction: Climate change driven by anthropogenic activity represents one of the greatest challenges facing humanity, with profound implications for ecosystems, economic activities, and human well-being. Chile is considered a highly climate-vulnerable country due to its geographical, climatic, and socio-environmental characteristics. Within this national context, the Province of Petorca, located in the northern sector of the Valparaíso Region, has emerged as one of the areas most severely affected by climate variability and prolonged drought.

Methods: The study aims to identify and quantify the effects of climate change in the Province of Petorca between 1980 and 2019. Following the PRISMA methodology, a systematic review and analysis of official and non-official data sources were conducted, including meteorological records, hydrological data, agricultural censuses, and climate-risk assessments.

Results: The results indicate a sustained decline in precipitation, significant reductions in river discharge, rising air temperatures, increased potential evapotranspiration, accelerated desertification, and severe soil erosion. These climatic changes have substantially affected water availability, agricultural productivity, livestock activities, and local demographic dynamics, leading to socio-economic stress and population displacement in rural areas.

Conclussions: The findings highlight the urgent need for integrated, territorially focused climate-adaptation and water-governance strategies in highly vulnerable semi-arid regions such as Petorca.

Keywords: climate change; drought; water scarcity; desertification; agriculture; Petorca Province; Chile

INTRODUCTION

Climate change—particularly the anthropogenic influence on climatic systems—has become the greatest challenge facing humanity in contemporary times [1]. Its relationship with human well-being and poverty is increasingly evident. If left unmitigated, climate change could push approximately 132 million people into poverty over the coming decade, reversing hard-won development gains. Although international financial flows for adaptation have increased by approximately 35% in recent years, they remain insufficient to address current and projected needs, particularly in developing countries [2].

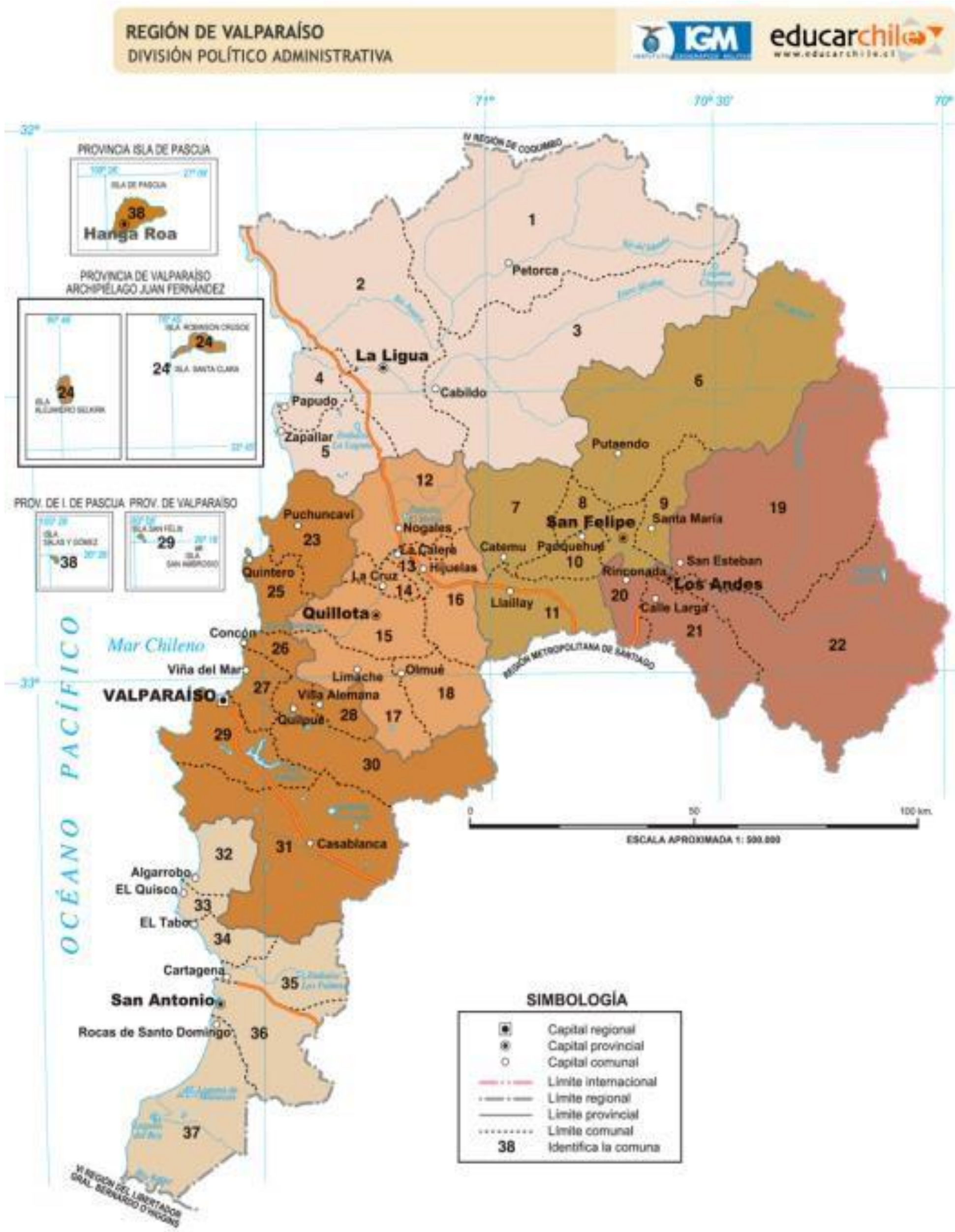
Chile is considered highly vulnerable to climate change, meeting most of the nine vulnerability criteria established by the United Nations Framework Convention on Climate Change (UNFCCC). These include the presence of low-lying coastal areas, arid and semi-arid zones, forested regions, areas prone to natural disasters, territories affected by drought and desertification, urban zones with high atmospheric pollution, and mountain ecosystems [3].

According to the Ministry of the Environment, the Valparaíso Region is the most climate-vulnerable region in Chile. Projected impacts include increases in minimum, mean, and maximum temperatures across all municipalities, accompanied by a significant decline in precipitation. These trends, combined with shifts in wind patterns and increased soil and vegetation dryness, are expected to heighten the probability of forest fires. Additionally, reduced snowfall accumulation in the Andean foothills is anticipated, leading to lower river flows. The abandonment of agricultural land due to prolonged drought has also been identified as a growing concern [4].

The Province of Petorca, located in the northern sector of the Valparaíso Region (see maps 1 and 2), covers an area of 4,589 km², making it the largest province in the region. It extends longitudinally from the Andes Mountains to the Pacific Ocean and latitudinally between 32°05′ and 32°40′ S. The province lies approximately 220 km north of Santiago de Chile and 190 km east of Valparaíso, the regional capital. Administratively, it comprises the municipalities of Petorca, Papudo, Zapallar, Cabildo, and La Ligua, the latter serving as the provincial capital [5].

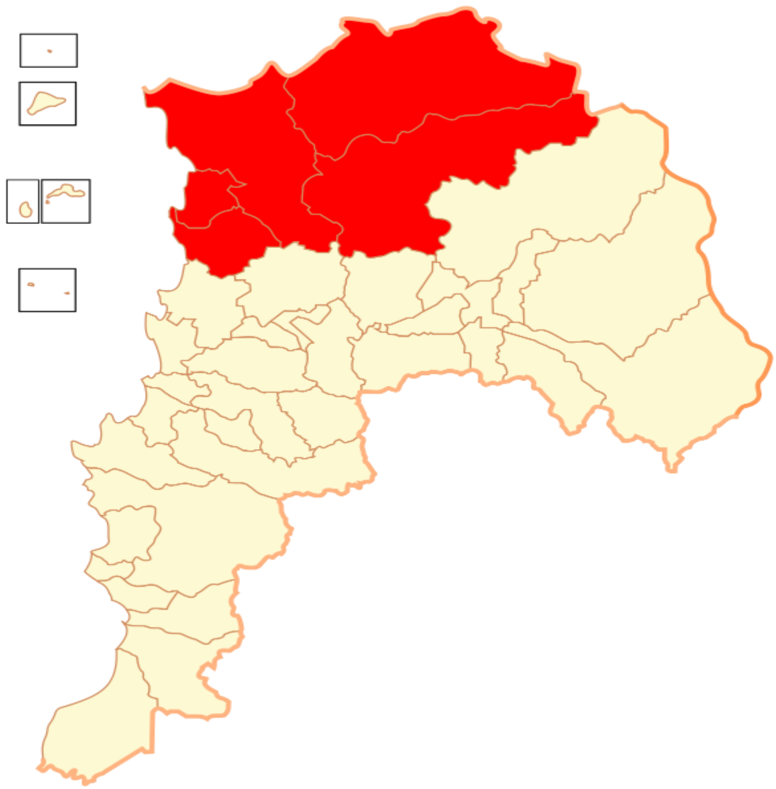
Due to its interior and pre-Andean location, the province has a temperate semi-arid climate with moderate temperatures, averaging around 20 °C during spring–summer and approximately 6 °C in autumn–winter. The soils display favourable conditions for high-quality fruit production [6]. Vegetation in valley areas is generally sparse, typical of dry-climate grasslands, with denser shrub formations in ravines and wetlands near springs. The central valley is particularly suitable for fruit cultivation and early vegetable production [7].

Map 1: Political and Administrative Division of the Valparaíso Region



Source: Instituto Geográfico Militar de Chile

Map 2: Petorca Province highlighted in red inside the Valparaiso area,

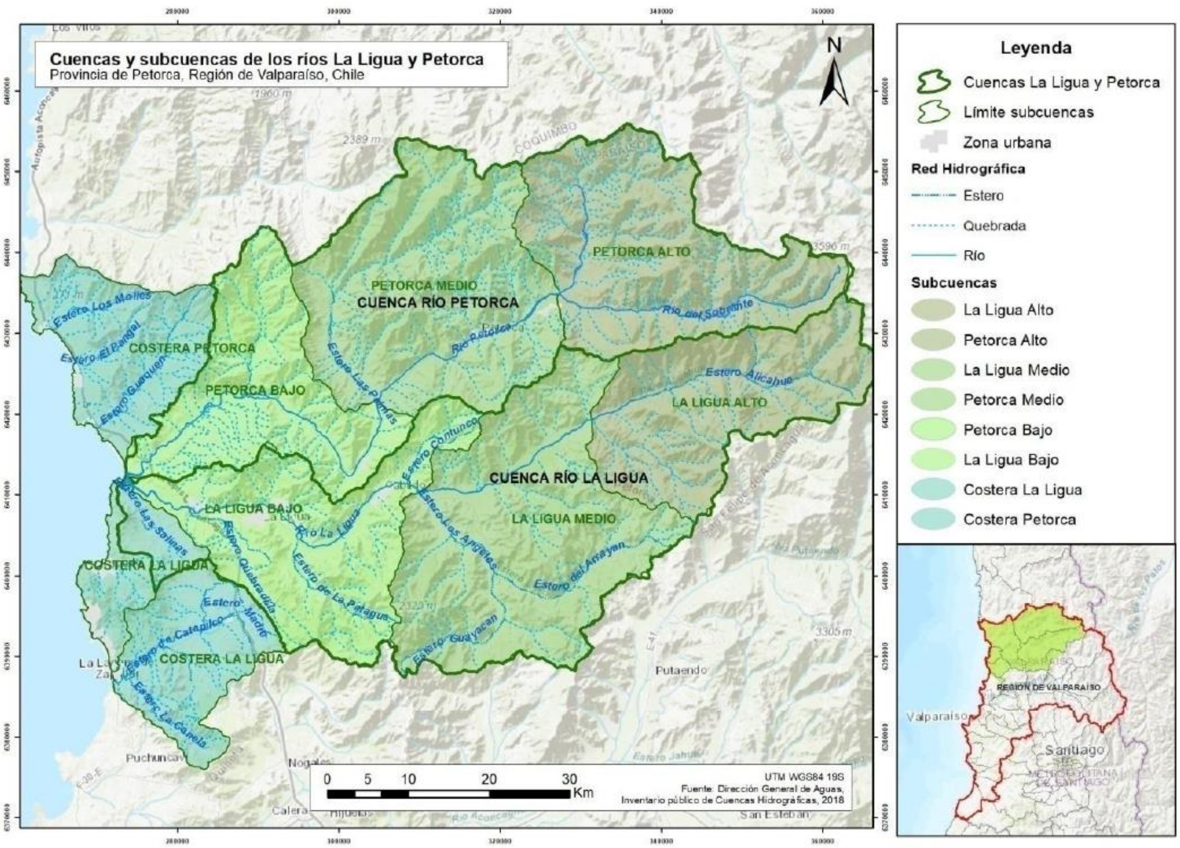


Source: Instituto Geográfico Militar de Chile

The main watercourses in the province are the Petorca and La Ligua rivers (see map 2), both originating in the Andes and discharging into the Pacific Ocean at La Ligua Bay. These rivers are essential for irrigation and agricultural activities [8]. Agriculture constitutes the primary economic sector—especially avocado and citrus production—positioning Petorca among Chile's leading agricultural export zones [9]. Mining is the second most important activity, centred on copper and gold extraction, along with non-metallic resources such as kaolin, feldspar, quartz, limestone, and ornamental stone [10].

As a result of climate change, Petorca currently faces an acute water-scarcity crisis. Chilean water legislation allows the declaration of water-scarcity zones during extraordinary droughts, granting special powers to the General Water Directorate (Dirección General de Aguas, DGA) to manage and allocate water resources [11–13]. Since 2010, Petorca has been repeatedly declared a water-scarcity zone, most recently under Decree No. 20 of February 8, 2022 [14].

Map 2: Basins and sub-basins of the La Ligua and Petorca rivers.



Source: Becker Rodriguez I. Impactos de la Escasez Hídrica en las Practicas de Uso de Agua de las Mujeres Rurales de la Comuna de Petorca, Universidad de Chile, 2021.

Given the abundance yet dispersion of information produced by governmental agencies, research institutions, and non-governmental organizations, this study aims to consolidate and analyse existing evidence on climate-change impacts in the Province of Petorca.

The primary objective is to identify and quantify environmental, economic, and demographic impacts related to climate change between 1980 and 2019, thereby contributing to an integrated understanding of the region’s vulnerability and informing future adaptation policies.

MATERIALS AND METHODS

This study followed PRISMA guidelines for systematic reviews to identify, select, and analyse relevant sources addressing climate-change impacts in the Province of Petorca. Primary data were obtained from official Chilean governmental institutions responsible for climate, water, and agricultural information, including the Ministry of the Environment, the General Water Directorate (DGA), the Chilean Meteorological Directorate, the National Irrigation Commission, and the Office of Agricultural Studies and Policies. These institutions provided official records on temperature, precipitation, and river discharge.

Complementary information was gathered through a systematic search of non-official scientific and technical literature using academic platforms such as Google Scholar, ResearchGate, ProQuest, SciELO, Issuu, and Academia.edu. Search terms included "climate change in the Province of Petorca" and "water crisis in the Province of Petorca." Studies were screened based on relevance, geographic focus, methodological rigor, and the absence of explicit political or sectoral bias. Only publications directly addressing climatic causes and consequences in the province were included in the full analysis.

Meteorological precipitation data were obtained from the Chilean Meteorological Directorate's annual yearbooks, focusing on the Valley Hermoso and Longotoma stations because of their geographic representativeness and data continuity. River-discharge data were derived from sedimentary fluviometric stations located in the upper reaches of the Petorca and La Ligua river basins, minimizing the influence of water-abstraction activities [18,19].

Temperature and potential evapotranspiration data were obtained from the CAMELS-CL database, which integrates hydro-meteorological and physical catchment information across Chile [20]. These data were cross-validated with records from national meteorological authorities. Additional climate indicators were obtained from the Climate Explorer platform developed by the Center for Climate and Resilience Research (CR2), covering records from 1940 to 2015 [21].

Agricultural and livestock information was primarily sourced from the national agricultural censuses conducted in 1997 and 2007, supplemented by more recent sectoral studies when available [22]. Data processing, tabulation, and graphical analysis were performed using Microsoft® Excel® (Microsoft 365).

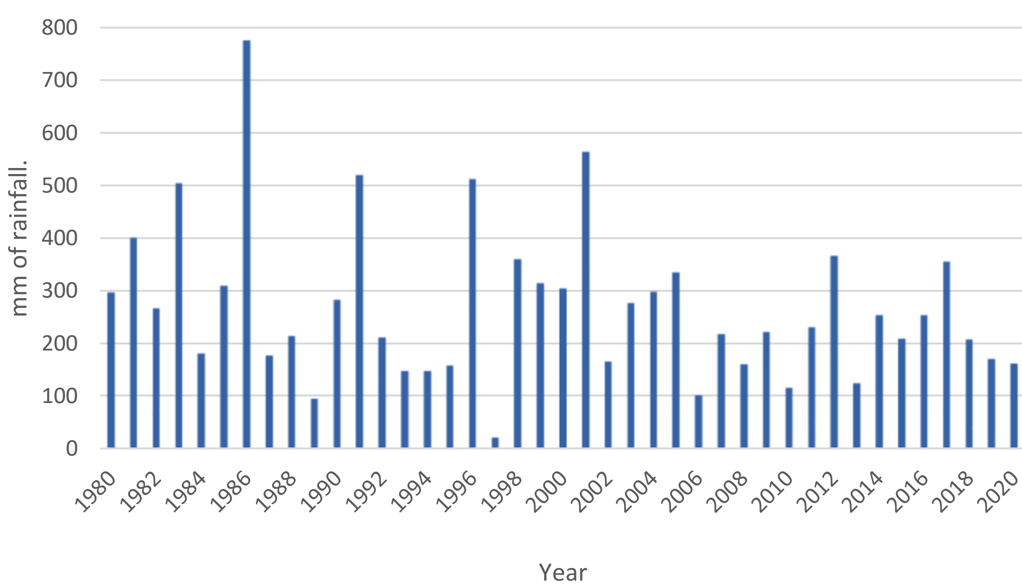
Cartographic information on climate risks, desertification, erosion, and water security was obtained from the Climate Risk Atlas developed by the Ministry of the Environment in collaboration with national and international research institutions [23].

RESULTS

Precipitation Trends

Analysis of historical precipitation records from the Valley Hermoso and Longotoma meteorological stations (Figure 1) reveals a sustained and marked decline in annual precipitation across the Province of Petorca between 1980 and 2019. Both stations show a clear negative trend, consistent with regional-scale drying processes observed in central–northern Chile [18,19]. Average annual rainfall declined progressively over the study period, with a pronounced decrease after 2000, coinciding with the onset of the so-called "mega-drought" affecting central Chile [21].

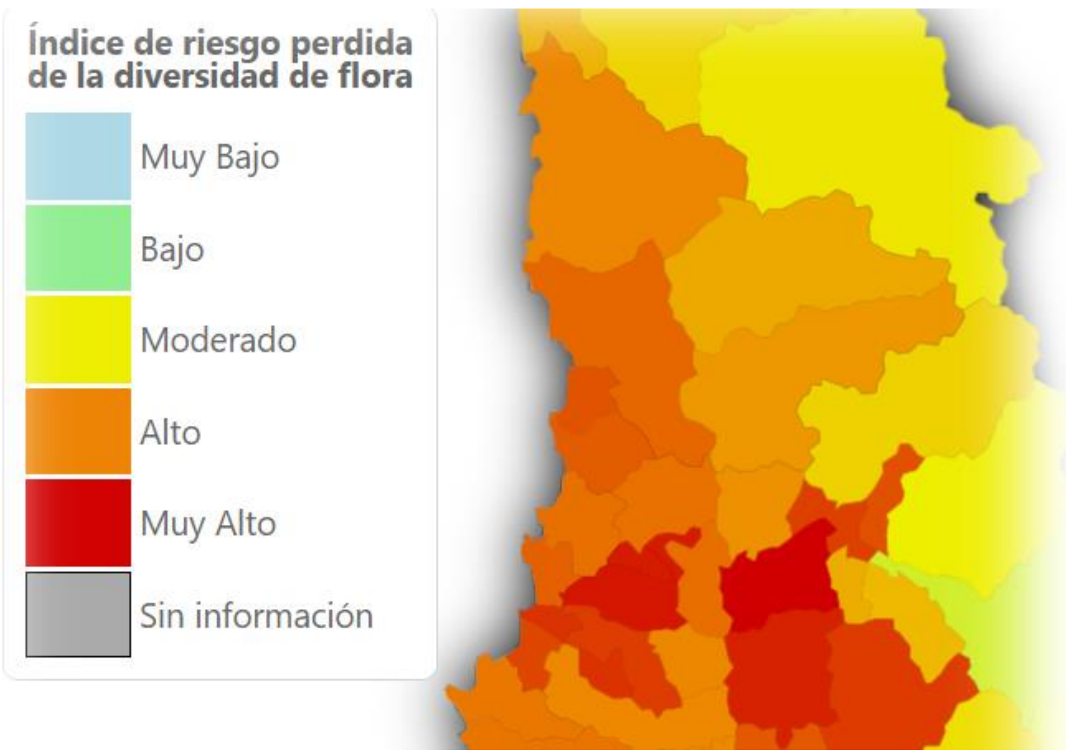
Figure 1: Annual Precipitation at Longotoma Weather Station (1980–2020).
Source: Prepared by the authors based on data from the Longotoma Meteorological Station.



Interannual variability remains high; however, the frequency of years classified as severely dry increased significantly during the last two decades of the record. While dry years in the 1980s and early 1990s were interspersed with relatively wet periods, post-2000 precipitation deficits became more persistent, reducing hydrological recovery between consecutive years. This cumulative effect has critically weakened surface- and groundwater-recharge processes in the province [23].

Changes in precipitation have also increased the risk of loss of plant diversity. Figure 2 illustrates the projected adverse effects on flora biodiversity associated with future changes in average annual precipitation in mainland Chile. The information is presented at the municipal level and shows that the entire province falls within moderate- to high-risk categories. The study area is highlighted within a blue circle.

Figure 2: Relative Index of Risk of Loss of Flora Diversity due to Changes in Precipitation. The Province of Petorca is highlighted in a blue circle.
Source: Ministerio del Medio Ambiente, Climate Risk Atlas, 2020.



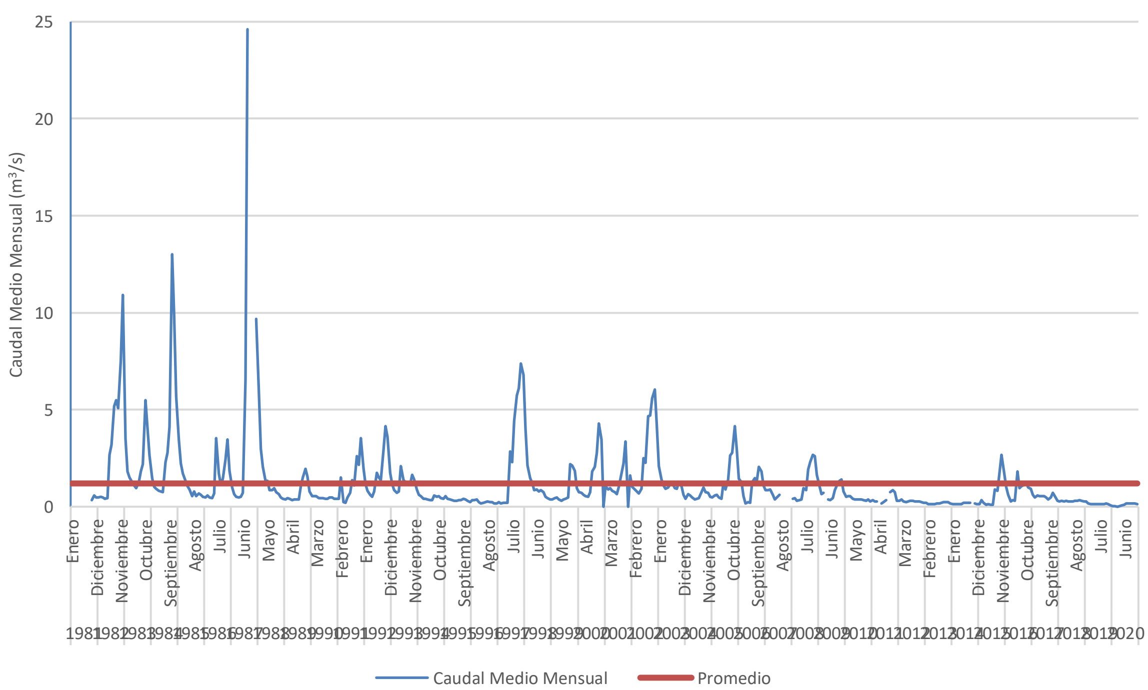
River Discharge

Hydrological data from fluviometric–sedimentary stations located in the upper basins of the Petorca and La Ligua rivers indicate a substantial reduction in mean annual discharge over the study period [18,19]. The decline in streamflow closely mirrors trends observed in precipitation, confirming a direct linkage between reduced rainfall and diminished surface-water availability.

The reduction in river discharge has been particularly pronounced during spring and summer months—periods of peak irrigation demand. This seasonal mismatch between water availability and agricultural needs has intensified water stress across the province. In several years after 2010, recorded flows approached critical minimum values, severely limiting irrigation, affecting aquatic ecosystems, and undermining the resilience of rural communities dependent on surface-water resources [11–14].

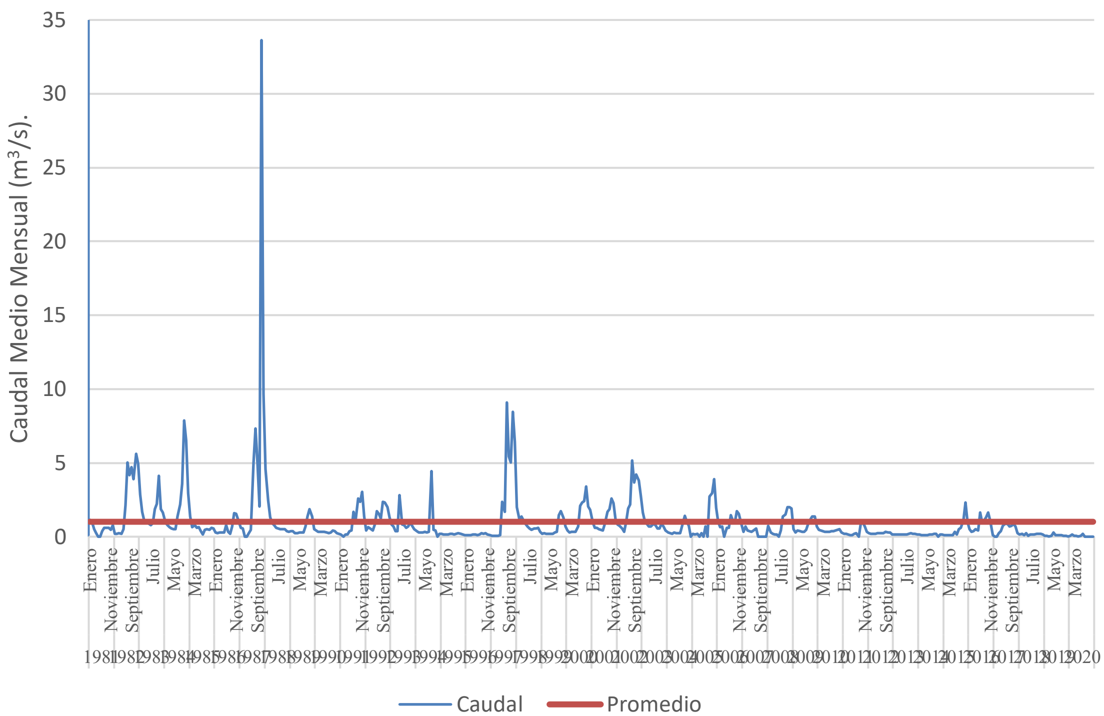
The hydrological station “Río Alicahue en Colliguay,” located in the La Ligua River basin, shows a clear trend of declining inflow. Figure 3 shows an initial low-flow period beginning in late 1993 and ending in mid-1997. From that point until early 2009, values remained near the long-term average. Thereafter, a continuous and marked decrease began, with values currently below the historical mean.

Figure 3: Average Monthly Flow Rates at the Alicahue River Station in Colliguay (1981–2020).
Source: Prepared by the authors based on data from the Alicahue River Station.



A similar pattern is evident at the “Sobrante en Piñadero” station in the Petorca River basin. As shown in Figure 4, two pronounced low-flow periods are observed: the first beginning in mid-1994, and the second beginning in late 2009 and extending to the present. Since 2009, recorded flows at both stations have approached zero, indicating that water inflow to both basins has been nearly nonexistent for over a decade.

Figure 4: Average Monthly Flow Rates at Sobrante en Piñadero (1981–2020).
Source: Prepared by the authors based on data from the Petorca River Station.

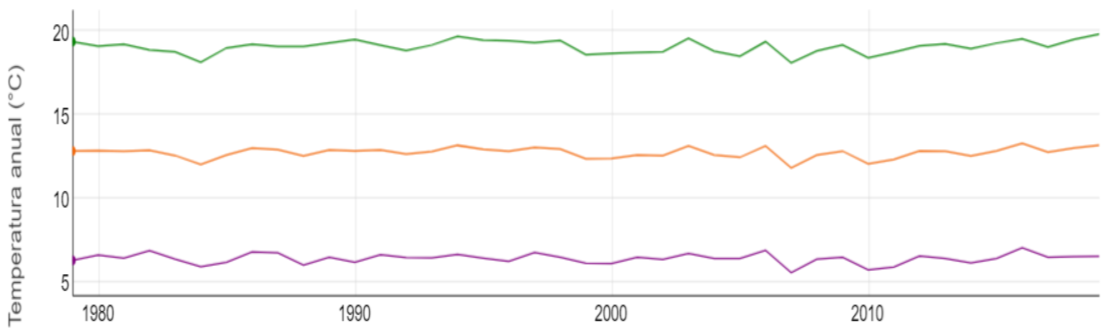


Temperature Increase and Potential Evapotranspiration

Temperature records obtained from the CAMELS-CL dataset and validated using national meteorological data show a consistent increase in mean annual air temperature across the Province of Petorca between 1980 and 2019 [20]. This warming trend affected minimum, mean, and maximum temperatures, with maximum temperatures showing the most pronounced increase during summer.

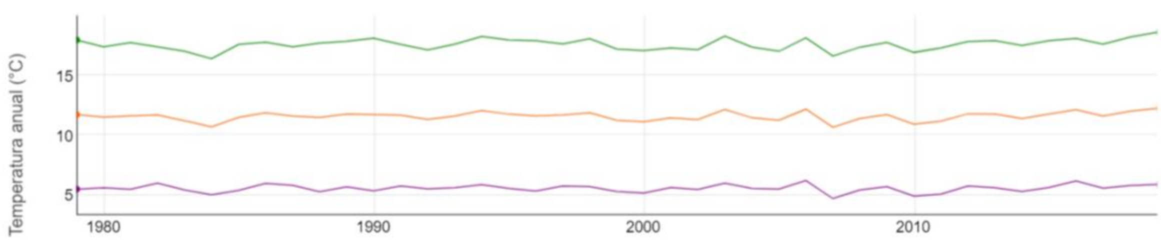
In the Province of Petorca, the annual averages of both maximum and minimum temperatures increased during the study period. Figure 5, compiled using data from the Río La Ligua Station in Placilla, shows upward trends in all temperature variables. In 1980, the annual average maximum temperature was 19.11 °C, rising to 19.83 °C in 2019—the highest value of the period. Minimum temperatures increased from 6.30 °C in 1979 to 6.54 °C in 2019, with the highest value recorded in 2016 (7.06 °C).

Figure 5: Annual Temperature (Max–Average–Min) at Río La Ligua Station in Placilla.
Source: https://camels.cr2.cl/



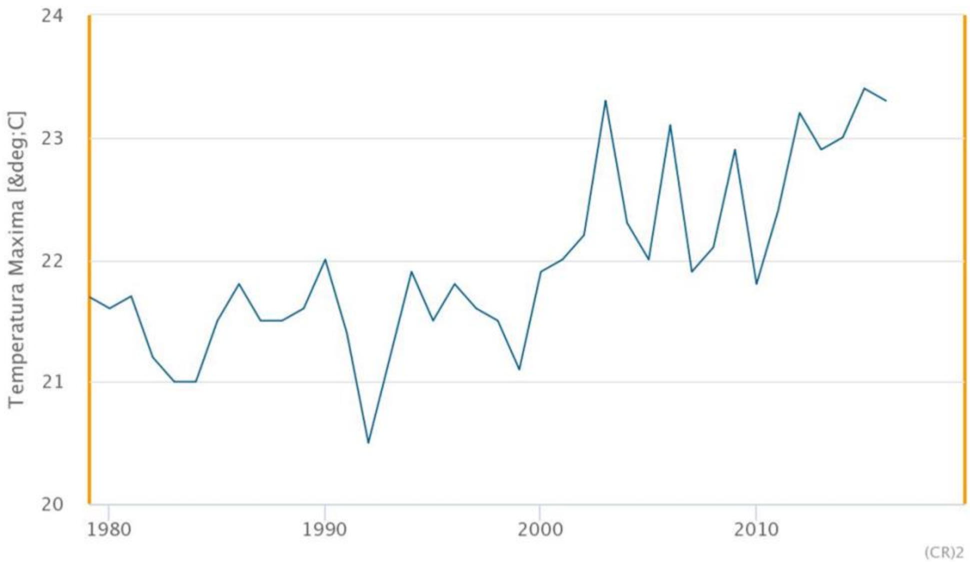
A similar trend is observed in the Petorca River basin at the "Río Petorca en Peón o Hierro Viejo" station (Figure 6). The annual average maximum temperature increased from 17.39 °C in 1980 to 18.61 °C in 2019. Minimum temperatures rose from 5.61 °C in 1980 to 5.88 °C in 2019, with the highest value recorded in 2006 (6.21 °C).

Figure 6: Annual Temperature (Max–Average–Min) at Río Petorca Station in Peón o Hierro Viejo.
Source: https://camels.cr2.cl/



Some stations show even more pronounced warming trends. For example, the Alicahue station, located in the central part of the study area, shows a steady increase in maximum temperatures, with 2016 values exceeding those of 1980 by 1.7 °C (Figure 7).

Figure 7: Maximum Daily Temperature at Alicahue Station.
Source: Alicahue River Station.



Potential evapotranspiration is a key parameter in the Earth–atmosphere energy balance, the detection of plant water stress, crop-yield prediction, water-balance calculations, and the climatic characterization of different areas. It represents the combined water loss through soil evaporation and plant transpiration under ideal conditions and is a good estimator of crop water requirements.

As a direct consequence of rising temperatures, potential evapotranspiration rates increased substantially throughout the province. Higher evapotranspiration has intensified soil-moisture deficits, reduced effective rainfall, and increased irrigation requirements for agricultural production. These processes have further aggravated water-scarcity conditions, particularly in rainfed agricultural areas and marginal lands [21].

In the Petorca River basin, data from the Río Petorca Station in Peón o Hierro Viejo show that evapotranspiration remained relatively stable until around 2010, after which a sustained increase began (Figure 8), indicating high vegetation water stress. For the La Ligua River basin, data from the Placilla station show a similar pattern (Figure 9). The Climate Risk Atlas (ANNEX 6) confirms that the regions of Valparaíso and Metropolitana have some of the highest reference-evapotranspiration values in the country, with the study area highlighted.

Figure 8: Potential Evapotranspiration at Río Petorca Station in Peón o Hierro Viejo.
Source: https://camels.cr2.cl/

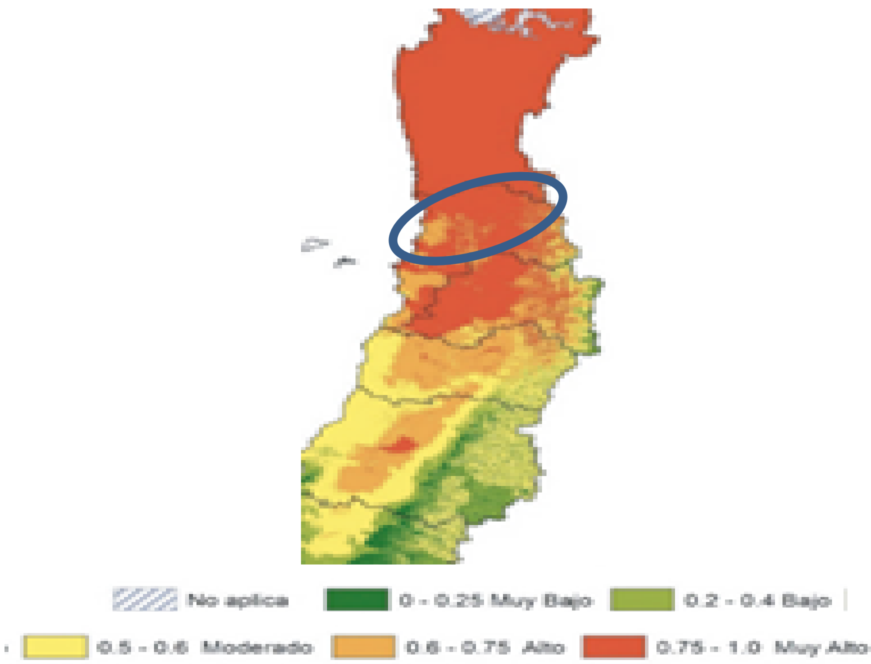
Figure 9: Potential Evapotranspiration at Río La Ligua Station in Placilla.
Source: https://camels.cr2.cl/

Desertification and Soil Erosion

One of the main consequences of rising temperatures and decreasing rainfall is the accelerated advance of desertification. In Chile, the Atacama Desert has progressively expanded southward at an approximate rate of 500 meters per year. This shift is transforming the Mediterranean climate—historically characterized by scrublands and sclerophyll forests—into a semi-arid or even desert landscape. Whereas the desert once reached La Higuera, it is now approaching Ovalle, 150 km further south. The hyper-arid zone, formerly limited to areas around La Serena and Los Vilos, is now extending into the Valparaíso Region, displacing arid and dry conditions from localities such as Petorca toward the Metropolitan Region.

A 2016 study titled *Update of Desertification Figures and Maps; Land Degradation and Drought in Chile at the Commune Level* determined that four of the five communes in the Province of Petorca—Cabildo, La Ligua, Petorca, and Papudo—are at moderate risk of desertification. The more recent report, *National-Scale Update of the Desertification, Land Degradation and Drought Maps (DDTS)* (January 2021), identified the entire study area as being at *High* or *Very High* risk of desertification. A section of this map is presented below in Figure 10, with the study area highlighted in blue.

Figure 10: Map of Risk of Desertification, 2021
Source: Nationwide update of the Desertification, Land Degradation and Drought (DDTS) maps of Chile.



Currently, the Province of Petorca represents the front line of desertification due to its position along the northern boundary of the Valparaíso Region. The province suffers significant land degradation and losses in Gross Value of Production (GVP), estimated at over 8,466 million pesos per year. Cabildo, Petorca, and La Ligua are the communes that record the greatest GVP losses.

Cartographic analyses from the *Climate Risk Atlas* reveal a marked expansion of areas affected by desertification within the province [23]. Large portions of inland and pre-Andean zones now exhibit moderate to severe land degradation. Declining precipitation, rising temperatures, vegetation loss, and unsustainable land-use practices have accelerated soil erosion processes.

Soil is essential for agricultural productivity; the loss and degradation of this resource fuel desertification and diminish landscape quality. It also supports fodder production, which is critical for the region's livestock.

In the Petorca Basin, eroded areas appear in diverse forms and intensities, reflecting the fragility of local ecosystems. Contributing factors include rugged topography—dominated by hills and mountains—severe vegetation loss, and climate–soil interactions. Agricultural activities that lack sustainable forage management further exacerbate degradation.

In 2010, severe and very severe erosion classes affected 25.9% of the province, while 19.6% of the surface showed no erosion. When considering only eroded areas, the severe and very severe categories increased to 32.1%, mainly in the northeastern hills of the province. Soils without erosion or with light erosion covered 23% of the provincial territory, located primarily in the southeastern region and the agricultural valleys of the La Ligua and Petorca rivers.

A 2019 study showed that the Commune of Petorca had 48% of its area classified as severely or very severely eroded, while Cabildo had 36% in the same categories—the highest in northern Valparaíso. Potential erosion risk is also extremely high: 79.2% of soils in Petorca and 70.6% in Cabildo fall within high and very high potential erosion classes.

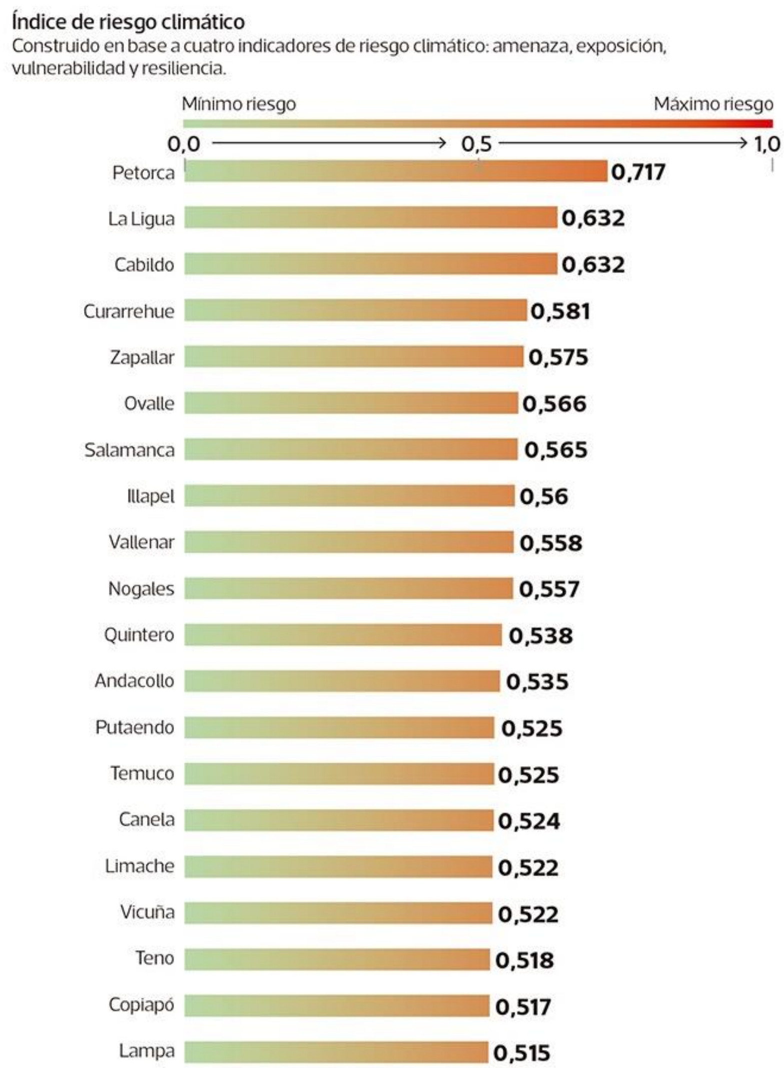
Soil erosion is most intense on slopes and in areas where native vegetation has been replaced by intensive agriculture. Loss of fertile topsoil reduces productivity and increases sediment loads in rivers, further degrading water quality and reservoir capacity [23].

Climate change and the processes described above will generate multiple impacts, including:

I. Higher average temperatures, increasing water consumption.
II. Rising 0°C isotherm levels, reducing snow accumulation and affecting glaciers—critical drought reserves.
III. Higher-altitude rainfall, generating rapid surface runoff.
IV. Sudden increases in river flows, triggering landslides, flooding, and elevated turbidity in drinking-water sources.
V. Continued declines in annual rainfall, reducing basin water availability despite occasional torrential events.

A 2015 study determined that four of the five communes in the province were among those at highest national risk of agroclimatic disaster (Figure 11).

Figure 11. Climatic Risk Index by Areas
Source: La Tercera Newspaper, 2015



Impact on Water Resources and Availability

Climate change is altering water resources through shifts in precipitation and temperature that affect river flows and water volumes. Unlike most rivers in central Chile that have snow-fed regimes, the Petorca and La Ligua rivers receive little snowmelt, making them especially vulnerable. The province faces one of the most severe water crises in Chile, leading the DGA to repeatedly renew water scarcity decrees since 2010.

Availability of Drinking Water

In 2014, significant water shortages affected La Ligua, Cabildo, and Petorca. Urban drinking-water supply, administered by ESVAL S.A., remained secure, but rural areas relied heavily on tanker trucks. In Cabildo, four localities—about 4,000 people—depended on water delivery. La Ligua reported 16 localities in emergency, affecting 12,212 people. Petorca relied on pipelines built by the Directorate of Hydraulic Works (DOH) and tanker trucks for remaining sectors. ESVAL's 2020 Sustainability Report notes that water extraction sources were 41.76% surface and 58.24% groundwater (compared to 44.66% and 55.34% in 2019), reflecting increasing dependence on groundwater due to prolonged drought.

A 2021 request to the Superintendence of Sanitary Services confirmed that drinking-water supply for urban centers was assured through new well drilling, agreements with farmers, and tanker truck reinforcement. No rationing was expected in the short or medium term, although ongoing monitoring was recommended due to worsening drought.

In 2018, emergency funds totaling 481 million pesos were allocated for tanker truck distribution. In 2019, Petorca supplied 2,180 people with tanker-delivered water. In Papudo, 20 families in Las Salinas and Pullally have relied on tanker trucks since 2008. La Ligua has 30 rural drinking-water systems (APR), 14 of which are in emergency; in 2020, 6,190 residents received tanker water (136,739 m³). However, tanker delivery generates severe supply constraints. Petorca reports that 1,000 residents receive fewer than 50 liters per person per day, far below the WHO minimum recommendation of 100 liters.

Local authorities have adopted several measures. In 2016, Petorca created the Office of Water Affairs—the only one of its kind in the region—to support rural water management, river protection, community oversight, and technical assistance. In 2018, the *Water for Petorca* plan was launched, including an investment of 15.6 billion pesos and 28 measures to improve APR systems. Two desalination plants were also planned in Pullally and Longotoma with capacities of 67 l/s and 48 l/s, expected to supply 44,000 people by 2035.

Water for Irrigation

The La Ligua Basin contains extensive irrigation infrastructure: 190 canals (246.2 km), 46 minor reservoirs, and 8 major reservoirs serving 1,906 users over 7,441 hectares. Yet water availability has dropped sharply, even as agricultural area expanded.
In 2013, INDAP and GORE financed 218 irrigation projects totaling nearly 2 billion pesos.
To mitigate irrigation shortages, authorities granted a concession to construct the *Las Palmas Reservoir*, with a capacity of 55 million m³ and two dams (70 m and 10 m high). A 57-km feeder channel will transport water from the Petorca River. The reservoir will support 640 farmers and more than 2,800 hectares of agriculture, also supplying rural drinking water. Total cost: USD 200 million.

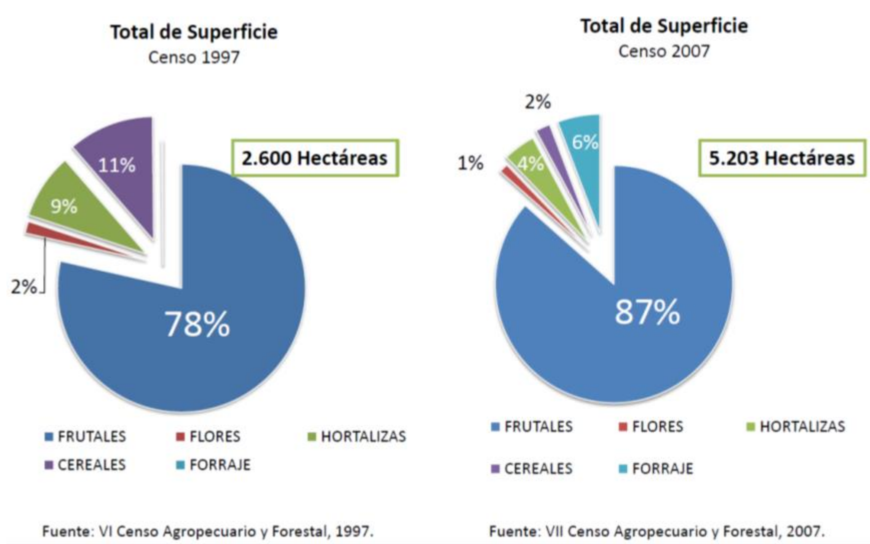
Impact on Economic Activities

Agriculture is the primary economic activity in the province, with 6,900 hectares planted in the Petorca Valley and 8,700 hectares in the La Ligua Valley, mainly with avocados and lemons. Mining—particularly copper and gold extraction—is the second most important activity.

Forestry and Agricultural Sector

Drought has significantly reduced crop yields, led to orchard abandonment, and caused livestock mortality. Agriculture consumed 92% of basin water in 2011 (1.47 m^3/s), compared to 3% for drinking water and 5% for mining. By 2016, agricultural demand rose to 2.687 m^3/s (Petorca) and 2.527 m^3/s (La Ligua).
Agricultural emergencies were declared across all municipalities due to water shortages, allowing delivery of fodder and emergency support. Cultivated area increased sharply between 1997 and 2007, especially water-intensive fruit trees, as shown in Figure 12.

Figure 12: Comparison of Total Area Planted and by Crop Type, 1997–2007
Source: SURHGE – Petorca (2012)



Despite declining water availability, cultivated area grew by 50.03%, raising basin-wide irrigation demand. After 2007, however, severe drought caused more than 6,000 hectares of fruit plantations—mainly avocados—to be abandoned by 2014, resulting in 5,000 job losses and major economic impacts. By 2020, the governor reported that agricultural land had decreased from 15,000 to 9,000 hectares.

Impact on the Livestock Sector

Livestock has declined due to lack of water and fodder. Figures 13–16 show reductions in cattle, goats, sheep, and pigs between the 1997 and 2007 censuses. These trends intensified after 2007. Livestock numbers declined further, especially among small-scale farmers, who lacked access to irrigation and water rights [22].

Figure 13: Comparison of Cattle Numbers in Petorca Province, 1997–2007.
Source: Author`s elaboration based on data obtained from ODEPA.

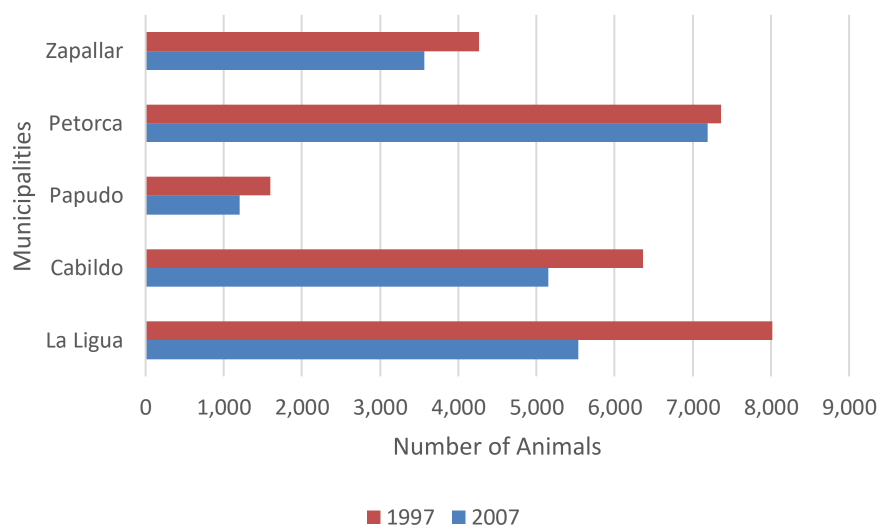


Figure 14: Comparison of Goat Livestock Numbers in Petorca Province, 1997–2007.
Source: Author`s elaboration based on data obtained from ODEPA.

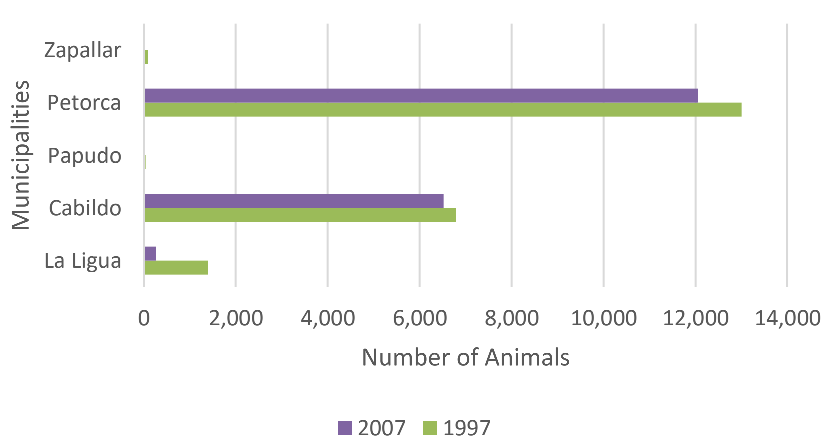


Figure 15: Comparison of Sheep Livestock Numbers in Petorca Province, 1997–2007.
Source: Author`s elaboration based on data obtained from ODEPA.

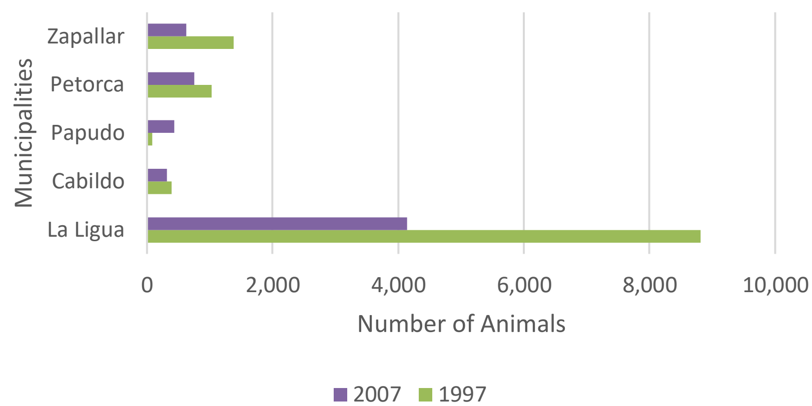
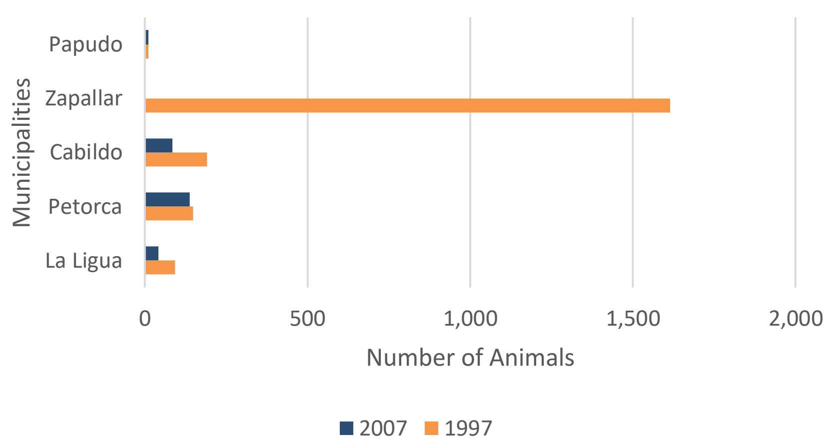


Figure 16: Comparison of Pigs Livestock Numbers in Petorca Province, 1997–2007.
Source: Author`s elaboration based on data obtained from ODEPA.



Impact on the Fishing Industry

Climate change alters hydrological and marine conditions, affecting the productivity, development, reproduction, and distribution of marine species. New or uncommon species have appeared near the coast, including jellyfish (Portuguese man-of-war), sharks, sunfish, bonito, and dwarf prawns. Meanwhile, traditional species such as hake have declined. Ocean acidification affects calcifying organisms such as mollusks, corals, sea urchins, and starfish by reducing growth rates and fertility. Conversely, certain algae and phytoplankton may proliferate, potentially causing hypoxia and fish mortality.

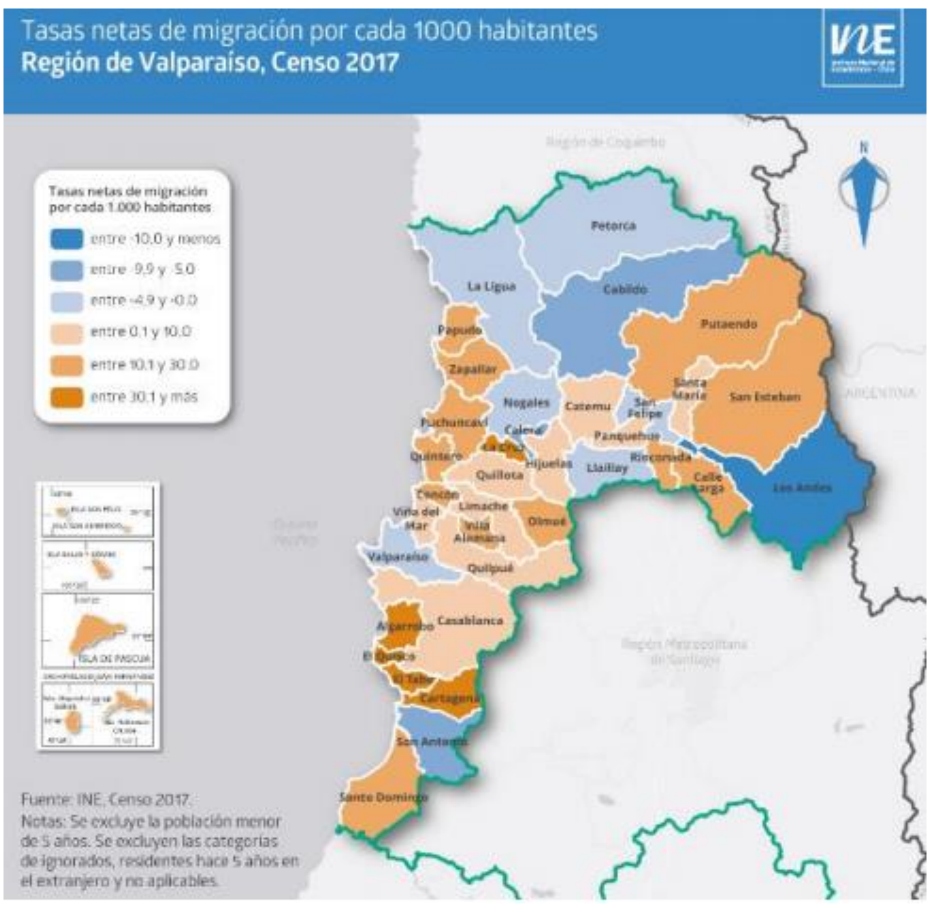
Demographic and Socio-Economic Effects

Rural population decline is evident across the province as seen in Figure 17, driven by prolonged drought, loss of livelihoods, and increased socio-economic stress [22]. Water scarcity has heightened dependence on tanker trucks, intensified conflicts over water allocation, and deepened social inequalities [11–14].

Demographic Impact

Although Chile has experienced rapid immigration growth—up 12.4% between 2018 and 2020—the Province of Petorca shows net out-migration. Loss of farmland, drying wells, and declining agricultural opportunities have pushed residents to leave, despite national migration trends.

Figure 17. Net Migration Rates per 1,000 Inhabitants, Valparaíso Region
Source: Instituto Nacional de Estadísticas de Chile



Cabildo shows the highest negative migration. Residents report that small farmers have abandoned their lands and moved south in search of water. Petorca and La Ligua also display negative migration, indicating that most of the province is undergoing demographic exodus linked to water scarcity and economic decline.

DISCUSSION

The results for 1980–2019 show clear evidence of the multidimensional impacts of climate change in a semi-arid territory with chronic water scarcity. The long-term decline in precipitation at both meteorological stations aligns with regional drying patterns associated with a poleward shift of the subtropical high and altered westerlies [1,3,21].

The significant reduction in river discharge confirms that climate forcing—not merely interannual variability—is a primary driver of hydrological depletion. Reduced surface runoff and diminished groundwater recharge have critically limited water availability, especially during irrigation demand peaks [18,19].

Rising temperatures and increased potential evapotranspiration intensify aridity, even in years with near-average rainfall. This mechanism is a key contributor to drought severity in Mediterranean and semi-arid systems [20,21].

Desertification and soil erosion reflect interactions between climatic stress and land use. Intensive agriculture, expansion into marginal areas, vegetation loss, and weak territorial planning have accelerated land degradation, consistent with observations in comparable regions [23].

Agricultural and livestock transformations reveal unequal adaptive capacities. Large-scale irrigated agriculture has persisted or expanded, while small producers have suffered severe productivity losses and limited access to water, leading to rural depopulation and heightened socio-economic vulnerability [9,11–14].

Overall, Petorca exemplifies how climate change operates as a “threat multiplier,” exacerbating pre-existing environmental, institutional, and social vulnerabilities. Its fragile socio-environmental system requires integrated adaptation strategies that prioritize long-term planning over short-term emergency responses.

CONCLUSIONS

This study shows that the Province of Petorca has experienced profound and persistent climate impacts between 1980 and 2019, including: declining precipitation, reduced river discharge, rising temperatures and evapotranspiration, accelerated desertification, diminished water availability, declining agricultural and livestock productivity, and increased socio-economic vulnerability.

These impacts result not only from climatic changes but also from structural factors such as land-use patterns, water governance, and social inequality. Water-intensive export agriculture, combined with prolonged drought and insufficient regulatory oversight, has amplified territorial vulnerability and social conflict.

Effective adaptation requires integrated water management, protection of ecological flows, restoration of degraded soils, equitable water access, and strengthened local adaptive capacities. Without structural reform, the impacts documented here will intensify under future climate scenarios.

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