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# Water Quality in Chile: The Role of Protected Areas

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# Water Quality in Chile: The Role of Protected Areas [*]

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Preliminary draft - Comments Welcome

## Abstract

This paper examines the effect of protected areas on water quality, particularly water purification. We focus on the impact these areas have on the concentrations of four water-related pollutants, including phosphorus, nitrogen, arsenic, and sulfates, from 1967 to 2018 in Chile. We construct buffers of several distances around water monitoring stations and consider those that intersect with at least one protected area upriver as treated. To estimate these effects, we employ a variety of estimation methods. Overall, the results show consistent suggestive evidence of a negative short-term effect on nitrogen concentrations, localized within a maximum distance of 10 km, ranging from -18.4% to -32.6% at different buffer sizes, equivalent to an average reduction of -.14 to -.26 mg/L. For phosphorus, arsenic and sulfates concentrations we found no significant effect. Additionally, there are potential differences in baseline concentration levels between treated and control water monitoring stations (WMS). This research aims to comprehend the potential influence of PAs on water quality by using novel estimation techniques and comparing different methodologies, filling the literature gap on this topic in the Chilean context.

**Keywords:** phosphorus, nitrogen, arsenic, sulfates, water quality, protected areas, event study, difference-in-differences, staggered difference-in-differences.
**JEL Classification:** Q51, Q53.

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# 1 Introduction

The world's water-related ecosystems are being degraded at an alarming rate. Over the past 300 years, more than 85% of the planet's wetlands have been lost (United Nations, 2022). The loss of wetlands generates changes in the distribution and exchange of major elements and pollutants, and the loss of biotic and habitat diversity at many scales (Bedford & Preston, 1988). Wetlands can be significant due to their role in nutrient retention and water purification. They remove nitrogen and phosphorus, which are essential for preserving water quality and maintaining the balance of nutrients in water bodies (Widney et al., 2018). Water quality is fundamental because it affects humans through clean drinking water, coastal recreation, and safe contact water, among many others (Keeler et al., 2012).

In this context of biodiversity loss, Protected Areas (PAs) emerge as a public policy tool based on nature. PAs are defined as "[a] clearly defined geographical space, recognized, dedicated and managed (...), to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (IUCN, 2008).

PAs, initially conceived to protect landscapes, have evolved to serve more complex conservation, economic, and social objectives. These include contributing to climate change mitigation and to local communities and national income; they directly affect people's well-being through health, social relationships, provision of goods and other mechanisms (Watson et al, 2014). Latin America is the most protected region in the world, with a total area of 8.8 million km$^2$ (21.4%), including terrestrial and marine protected areas (Álvarez et al., 2021).

PAs protect ecosystems that provide a range of ecosystem services, including cultural, provisioning and regulating services (Dasgupta, 2021). They provide water regulation through the role of land cover in regulating runoff and river discharge (de Groot, 2006).

The establishment of PAs in Chile began in the early 20th century, initially to control land and address geopolitical needs, and has evolved through various phases focusing on conservation, tourism, and geopolitical control (García and Mulrennan, 2020). Multiple factors have driven their establishment, including regulating the timber trade, protecting non-productive fiscal lands, preserving scenic beauty (Basic and Arriagada, 2012), and with increasing emphasis in recent years, protecting and conserving viable samples of Chile's biodiversity and ecosystems (Figueroa, 2015; Folchi, 2015). Given this context, we explore the potential impact of protected areas on water quality in the case of Chile, where approximately 23.42% of the national territory is under conservation, including both public and private protected areas (Pliscoff, 2022).

Increasing water demand, urbanization, and additional pressures such as climate change have led to more stringent water quality policies in developed countries. This trend aligns with the objectives outlined in the sixth Sustainable Development Goal (SDG), which aims to ensure availability and sustainable management of water and sanitation for all (United Nations, 2022).

Although water quality legislation has become more stringent in developed countries, concerns have shifted from general surface water quality to more specific issues, such as preserving the quality of lakes to maintain specific ecosystem qualities. However, access to safe drinking water remains a major concern for developing countries, particularly in regions with large rural areas without centralised water services. For instance, there is an increased interest in the quality of water near the points of extraction for human consumption, as improving it can reduce water treatment costs (Olmstead, 2010). The presence of PAs in these areas could potentially improve water quality, providing economic and environmental benefits.

In Latin America, 77 million people lack access to safe water; 51 million of these people live in rural areas and 26 million in urban areas (World Water Council, 2006).

In Chile, the challenge of water access is particularly acute in rural areas, where 12% of the population resides, and 47% of rural households are not connected to the Public Water Network (RPA). This situation is more pronounced in the southern regions where a greater proportion of the rural population is located and faces a higher absence of service. Overall, 56% of rural households rely on untreated natural water sources (World Bank Group, 2021). Additionally, it has been ranked as the 16th highest country with extremely high water stress in the world (World Resources Institute, 2023) and as the 10th most water-risk-prone country out of 142 countries (OECD, 2017).

Based on these considerations, this paper aims to answer the following questions: Does the designation of protected areas affect these water quality parameters? Furthermore, are there differences in water quality related to distance from the protected area?

To measure this effect, according to the geographical location of the water monitoring stations (WMS) and protected areas, we create buffers of 3, 5, 7, and 10 km around the WMS and define as treated the WMS with at least one PA upriver within their buffer (for more details see section 4). Estimation is made using staggered differences-in-differences.

The results show consistent suggestive evidence of a negative short-term effect on nitrogen concentrations, localized within a maximum distance of 10 km, ranging from -18.4% to -32.6% at different buffer sizes, equivalent to an average reduction of -.14 to -.26 mg/L. For phosphorus, arsenic and sulfates concentrations we found no significant effect. Additionally, there are potential differences in baseline concentration levels between treated and control water monitoring stations (WMS).

This research aims to comprehend the potential influence of PAs on water quality by using novel estimation techniques and comparing different methodologies, filling the literature gap on this topic in the Chilean context. The rest of the paper is structured as follows. Section 2 provides a review of relevant related literature. Section 3 describes the data, while Section 4 outlays the empirical approach. Section 5 describes the results, and Section 6 shows a robustness analysis of the results. Section 7 concludes and discusses model limitations and results.

## 2 Literature review

**History of PAs in Chile.** The establishment of PAs in Chile was initiated in the first decade of the 20th century when the Chilean government created in September of 1907, the "Malleco Fiscal Reserve", the first fiscal forestry reserve of the country. This first PA was a pioneer initiative in Latin America (Folchi, 2015), and according to García and Mulrennan (2020) was a strategy used by the Chilean settler-state to control recently colonized lands in the southern regions of the country. Afterward, there were three other phases of the expansion of PAs: Phase 2 (1925-1979), in which extensive territories were bounded as a means of protecting wilderness for tourism development, scientific rationales, and geopolitical control of remote and bordering territories; Phase 3 (1980- 1999) oriented to a re-territorialization process which supported the enforcement and reorganization of conservation territories as spaces free from people under a central state PA system; and, Phase 4 (2000- 2020) defined by efforts to counter territorialization, with non-state actors playing a critical role in the conversion of private lands to state property for PA expansion (García and Mulrennan, 2020).

Apart from this mostly geopolitical and territorial view of Chile's PAs system creation and expansion; from a socioeconomic development-oriented view, it seems that the establishment of PAs in Chile has been driven and characterized, for almost a century and a half, by multiple factors. The factors include conservationist impulses, regulating the timber trade, protecting nonproductive fiscal lands for agriculture and livestock, preserving scenic beauty (Basic and Arriagada, 2012) and with increasing emphasis in the last thirty-five years, protecting and conserving living and viable samples of Chile's biodiversity and ecosystems (Figueroa, 2015; Folchi, 2015).

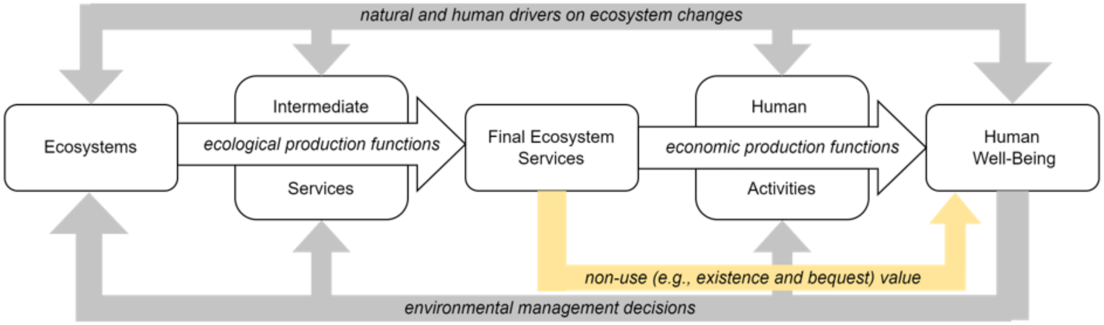
**Protected Areas.** The concept of PAs covers a broad range of terrestrial and aquatic regions, each governed by different management methodologies. These methods range from highly restrictive areas, where human access is severely limited, to less strict regions, where conservation coexists with human activities and sustainable resource extraction. The International Union for Conservation of Nature (IUCN) has classified PAs into six categories based on their management objectives. The definition includes areas that are committed to the protection and maintenance of biodiversity, as well as natural and cultural resources, through legal or other effective means. The categories are: I) Strict protection, subdivided into strict nature reserves and wilderness areas; II) Ecosystem conservation and protection (i.e., National park); III) Conservation of natural features (i.e., Natural monument); IV) Conservation through active management; V) Landscape/seascape conservation and recreation; and VI) Sustainable use of natural resources (IUCN, 2008).

Because of their coverage and effectiveness in preserving natural ecosystems, protected areas are increasingly recognized for maintaining ecosystem processes that promote ecosystem service provision (World Resources Institute, 2005; Turner and Daily, 2008). Ecosystem services are the processes and conditions that are mediated by ecosystems and their biodiversity and that sustain and enhance human life (Nelson and Daily, 2010). The services of ecological systems and the natural capital stocks that produce them are critical to the functioning of the Earth's life support system. They contribute to human well-being, both directly and indirectly, and thus represent a part of the total economic value of the planet (Costanza et al., 1997).

The Common International Classification of Ecosystem Services (CICES) was developed to address the relationship between humanity and nature, providing a system that identifies the ways ecosystems contribute to human well-being. These services can be classified into three main groups: provisioning, regulating, and cultural services. Provisioning services include the provision of materials and energy, regulating and maintenance services are related to the regulation of ecosystem processes, and cultural services correspond to non-material benefits such as spiritual experiences and aesthetic values (Dasgupta, 2021). A conceptual map presented by Bruins et al. (2017), shown in Figure 1, illustrates the interrelationships between ecosystems, ecosystem services, and human well-being.

PAs provide various ecosystem services, including water purification and regulation. The land cover in these areas influences runoff regulation and river discharge, factors that are crucial for water quality and ecosystem health. This role of land cover in managing water flow and filtering pollutants contributes to the natural processes of water purification and regulation (de Groot, 2006). There are well-being benefits related to water quality, such as clean and safe drinking water, recreational water masses, natural sources, among others. Because of their diverse mechanisms, Keeler et al. (2012) present a water quality assessment model integrating biophysical and economic models for their valuation. Lara et al (2021) study the early response of streamflow to forest restoration inside the *Reserva Costera Valdiviana* finding an increase in streamflow of 40% to >100% in most years.

Figure 1: Respective roles of ecological production and economic benefit functions in the enhancement of human well-being.



**Notes:** A conceptual map illustrating the interrelationships between ecosystems, ecosystem services, and human well-being. *Final ecosystem services* are the direct outputs from the environment that humans find valuable, like clean water or natural landscapes. By contrast, pollutant sequestration by aquatic biota or maintenance of ecological diversity are *intermediate services*.
Source: Own elaboration based on Bruins et al. (2017).

**The Economics of Water Services.** Olmstead (2010) argues that drinking water provision has a high net economic benefit. However, because of drinking water regulation, the benefits of controlling surface water pollution are closely related to the ecosystems' health and recreational interests but not to people's health. As in industrialized countries, the demand for water standards intensifies, in developing countries millions of people do not have access to safe drinking water. In these later countries, or countries with a high percentage of rural areas, the quality of surface water and wells may be more relevant to people's health.

Figueroa (2010) estimates a 50.661.161 annual US$ valuation for Chilean PAs water purification (81,8 annual US$/ha of wetland). Based on the values from Brander et al. (2006) meta-analysis, they estimate the economic value of the water purification service for the ecosystems of wetlands, lakes, lagoons, dams, reservoirs, peat bogs, and other wetlands at a national level.

Research also indicates that the presence of forests within a certain radius upstream from water intake points can lead to significant water treatment cost savings, they considered a 1 to 10 km buffer within the catchment area[1] as treated area. The results show that forests within a 2 km radius upstream from the water intake point have the most sizeable and statistically significant cost saving effect (Liu et al., 2022). On the other hand, Westling

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[1] Area with a natural boundary where all surface water drains to a common channel to form rivers or creeks. Area of land where water collects when it rains (DES, 2021).

et al. (2020) limits the upstream area to 100 km from the treatment plant (30 km analysis was also conducted but with very little within variation). They found that upstream forests lead to lower levels of E. coli in downstream water and indicate the same effect on turbidity (although not significant). Considering the width of Chile is 177 km on average, we follow Liu et al. (2022) as it is more suited to the chilean case.

Hamid et al. (2020) summarize various natural and anthropocentric factors as determinants responsible for conditioning stream water quality parameters. Some relevant local variables to consider in the analysis are water temperature, air temperature, flow/discharge, light, conductivity, nutrients (nitrogen and phosphorus), land-use, urbanization, industrial activities and riverine ecosystems. Several of these factors also have a seasonal component. Other relevant variables identified in the literature are anthropogenic pressure (Cejudo et al., 2021), the surface area of the protected area (Brander et al., 2006), and visitation rates to the protected area (Hadwen et al., 2007). Additionally there is simultaneity between water quality and visitation in coastal recreational areas (Furey et al., 2022).

**Water Quality.** Keeler et al. (2012) provide a template of the constituents that can be used to evaluate water quality, such as phosphorus, nitrogen, temperature, sediment and dissolved organic carbon (DOC).

We are particularly interested in the change in concentration of phosphorus, nitrogen, arsenic and sulfates. Phosphorus is essential for plant life, but an overabundance can speed up eutrophication. It is often associated with agricultural fertilizers, manure, organic wastes, and industrial effluent (USGS, 2018b). Nitrogen is associated with sewage and fertilizers. An overabundance can cause several adverse health and ecological effects (USGS, 2018a). Arsenic, which is highly toxic in its inorganic form, is naturally present at high levels in the groundwater of several countries, including Chile. It is often associated with the mining industry (WHO, 2022). Finally, sulfates naturally occur in drinking water. Is of particular concern to risk groups, and is associated with industrial activity (EPA, 2012).

Overall, the potential health effects of phosphorus, nitrogen, arsenic and sulfates concentrations in water highlight the importance of protecting and preserving natural areas that can provide clean and safe water. In addition, effective water treatment and monitoring programs are essential to ensure water is free from harmful contaminants. Policymakers, public health officials, and other stakeholders have an important role to play in protecting human health and ensuring that future generations have access to clean and safe water.

# 3 Data

Information on protected areas comes from the Pliscoff (2022) dataset, from the *Ministerio de Medio Ambiente* (MMA) and *Corporación Nacional Forestal* (CONAF) from 1907 to 2022. Monthly data on phosphorus, nitrogen, arsenic and sulfates concentrations come from monitoring stations, part of the *Superintendencia de Servicios Sanitarios* (SISS) and *Dirección General de Aguas* (DGA)'s network from 1960 to 2018. Meteorological data also come from the DGA, and the georeferenced data from the *Infraestructura de Datos Geoespaciales* (IDE) and *Biblioteca de Congreso Nacional* (BCN). Elevation data comes from SRTM 1-Arc Second DEM tiles obtained from NASA Earthdata. These tiles were downloaded using the SRTM Downloader plugin in QGIS. The DEM was used to obtain the elevations to determine treated and control units (more detail on treatment definition and variables in Section 4).

**Protected Areas.** Pliscoff (2022) provides an updated description of the PAs, including their location, surface area, and ecosystem information. As shown in Figure 2, the largest number of protected areas are mostly located in Southern Chile, specifically in the *Los Lagos*, *Aysen* and the *Magallanes* regions, as well as in the *Valparaiso* region[2].

Figure 2: Total Chilean Protected Areas

**Notes:** This figure shows a map of chilean national protected areas considered in this study. The largest number of protected areas are mostly located in Southern Chile, specifically in the *Los Lagos*, *Aysen* and the *Magallanes* regions, as well as in the *Valparaiso* region.
Source: Own elaboration with Pliscoff (2022) data.

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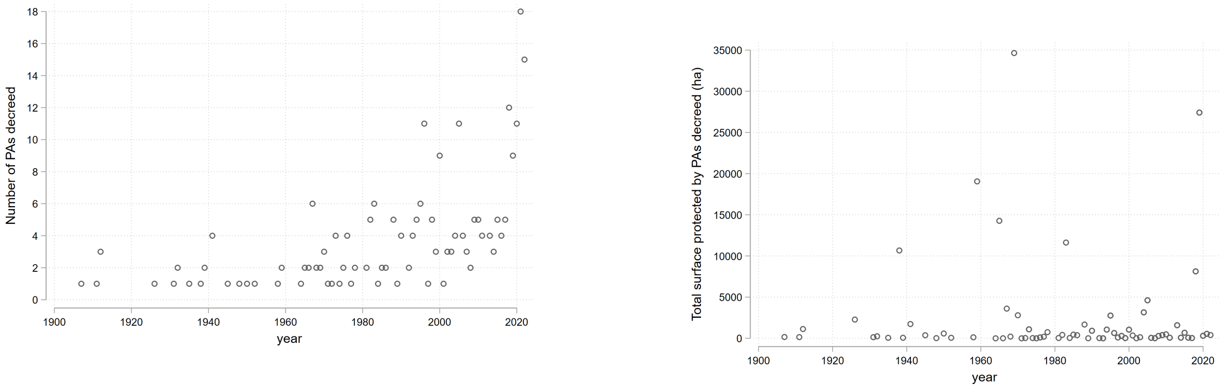
[2] See Section 7.0.4 of the Appendix for lists of all PAs.

Variables such as year of establishment and type of management for public PAs are provided by the national register of protected areas from Ministerio de Medio Ambiente (MMA) and confirmed with Corporación Nacional Forestal (CONAF) data, which also provides visitations data. Self-reported dates of private protected area decrees were obtained online.

The first protected area in Chile was created in 1907. This policy has been increasingly implemented, particularly in recent decades (see Figure 3). On the other hand, the total surface area protected by PAs by year of designation indicates growth in the amount of land safeguarded for conservation purposes. The annual increase in PA's surface has been poor in most years, some years produce the largest changes in total protected area, which shows heterogeneity.

Figure 3: Historical growth and expansion of PAs in Chile



a) Number of PAs by Designation Year

b) Total Surface Protected by PAs Designation Year

**Notes:** Figure in panel a) illustrates the number of PAs established each year, showing a general increase over time, particularly in recent decades. Figure in panel b) depicts the total surface area protected by PAs by year of designation, indicating growth in the amount of land safeguarded for conservation purposes. The increase in the surface of protected areas per year has been poor in most years, some years produce the largest changes in total protected area, which shows heterogeneity.
Source: Own elaboration based on Pliscoff (2022) and cross-referenced with the specific designation dates of the PAs.

Table 1 provides an overview of the distribution and surface area of PAs, categorized into public and private. Public Protected Areas, encompassing 181 areas, display considerable size variation, with a mean size of 84,624 hectares. This category includes various forms of protection like Natural Monuments, National Parks, National Reserves, and Nature Sanctuaries. National Reserves stand out with the highest mean size of 307,445 hectares and a high standard deviation. In comparison, the 85 Private Protected Areas are relatively smaller, averaging 3,782 hectares in size.

Table 1: Distribution and surface of PAs in Chile by PA category

| **Type** | **Number (N)** | **Size (in hectares)** | | |
|---|---|---|---|---|
| | **Count** | **Mean** | **p50** | **sd** |
| Public Protected Areas | 181 | 84,624 | 2,842 | 369,454 |
| Natural Monuments | 81 | 13,324 | 565 | 44,362 |
| National Parks | 17 | 2,070 | 134 | 3,961 |
| National Reserves | 41 | 307,445 | 52,695 | 721,951 |
| Nature Sanctuaries | 42 | 64,132 | 12,821 | 193,527 |
| Private Protected Areas | 85 | 3,782 | 496 | 8,728 |
| Total | 266 | 62,912 | 2,018 | 310,564 |

**Notes:** This table presents the distribution and surface of public and private protected areas in Chile. The metrics include the number of areas (N), mean size, median size (p50), and standard deviation (sd) of size (in hectares). The data were compiled from the national registry and represent the status as of 2022.
Source: Own elaboration based on Pliscoff (2022).

**Water Quality.** We use the monthly water quality data from 1960 to 2018 coming from 1936 WMS and for 102 parameters [3], and focus exclusively on the effect of PAs on phosphorus, nitrogen, arsenic and sulfates [4].

Table 2 presents the descriptive statistics for these parameters. The mean concentration levels (mg/L) of these parameters reveal distinct patterns. Sulfates exhibit the highest mean concentration (141.487 mg/L), followed by Nitrogen (0.809 mg/L), which are considerably larger values compared to Phosphorus (0.115 mg/L) and Arsenic (0.123 mg/L). In terms of median concentrations, a similar pattern is observed, with Sulfates and Nitrogen having higher medians compared to Phosphorus and Arsenic. The standard deviation for all parameters is large, particularly higher in sulfates, showing a widespread dispersion in concentration levels.

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[3] This study uses officially curated and cleaned data. The DGA has previously identified and rectified any outliers or potential data errors during the data processing stage. Therefore, our dataset exhibits the same or potentially lower variance compared to the raw data, and the influence of atypical values is reduced. For more details about the data depuration process see section 3.2 of DGA (2019).

[4] The results presented in this paper are based on interpolated data. For a detailed explanation of the interpolation process, refer to Appendix Section 7. Details on interpolation distribution comparison and comparative results are available upon request.

Table 2: Descriptive statistics of the parameters

| **Parameter** | **Number (N)** | **Concentration levels (mg/L)** | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Count** | **Mean** | **sd** | **min** | **p25** | **p50** | **p75** | **max** |
| Phosphorus | 93,692 | 0.115 | 0.411 | 0.0001 | 0.008 | 0.024 | 0.075 | 12.068 |
| Nitrogen | 89,621 | 0.809 | 2.202 | 0.0005 | 0.072 | 0.183 | 0.543 | 31.129 |
| Arsenic | 127,181 | 0.123 | 0.833 | 0.0005 | 0.0005 | 0.002 | 0.009 | 20.000 |
| Sulfates | 169,225 | 141.4 | 266.9 | 0.0005 | 4.394 | 49.75 | 174.66 | 3,938.6 |

**Notes:** This table shows the descriptive statistics of the parameters concentrations levels (mg/L). The differences between the mean and median values, coupled with the large differences between the 75th percentile and maximum values for all parameters, suggest the presence of outliers and positive skewness in the distributions.
Source: Own elaboration based on data obtained from DGA.

Looking at the variability of the parameters, we observe that sulfates exhibit the highest variability ($sd = 266.965$), indicating a wide range of sulfate concentrations across the different observations. Nitrogen and Arsenic also show variability ($sd = 2.278$ and $sd = 0.957$), while phosphorus exhibits the lowest variability ($sd = 0.497$). The differences between the mean and median values, coupled with the large differences between the 75th percentile and the maximum values for all parameters, suggest the presence of outliers and a positive skewness in the distributions, which might be important considerations for subsequent analyses.

Table 3 provides an overview of the temporal coverage for the parameters. Phosphorus data spans from 1987 to 2011, covering 299 periods, while nitrogen data ranges from 1987 to 2010 across 287 periods. Arsenic data has been monitored since 1987 and ends in 2018 with 377 periods. Sulfates have the longest monitoring duration, from 1967 to 2018, spanning 535 periods. This subset selection was based on the density of data available for each parameter, addressing the challenge of estimating the treatment effect with sufficient statistical power.

Table 3: Temporal coverage of the parameters

| **Parameter** | **First period** | **Last period** | **Periods** |
|---|---|---|---|
| | **YYYYmMM** | | **T** |
| Phosphorus | 1987m2 | 2011m12 | 299 |
| Nitrogen | 1987m1 | 2010m11 | 287 |
| Arsenic | 1987m1 | 2018m5 | 377 |
| Sulfates | 1967m5 | 2018m11 | 535 |

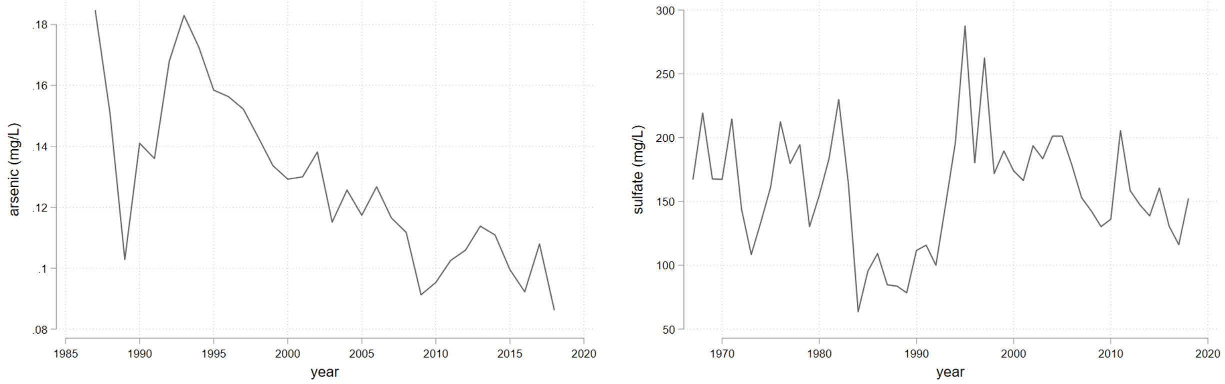
**Notes:** Table 3 provides an overview of the temporal coverage for the parameters (in YYYYmMM format). Phosphorus data spans from February 1987 to December 2011, covering 299 periods, while nitrogen data ranges from January 1987 to November 2010 across 287 periods. Arsenic data has been monitored since January 1987 and ends in May 2018 with 377 periods. Sulfates have the longest monitoring duration, from May 1967 to November 2018, spanning 535 periods.
Source: Own elaboration based on data obtained from DGA.

Figure 4 displays time series graphs for phosphorus, nitrogen, arsenic, and sulfates, providing a visual representation of trends and fluctuations of these parameters over time.

Figure 4: Time series of the parameters

a) Phosphorus

b) Nitrogen



c) Arsenic

d) Sulfates

**Notes:** Figure 4 displays the average time series graphs for phosphorus, nitrogen, arsenic, and sulfates concentration levels (mg/L) for all WMS in the country.
Source: Own elaboration based on DGA and SISS data.

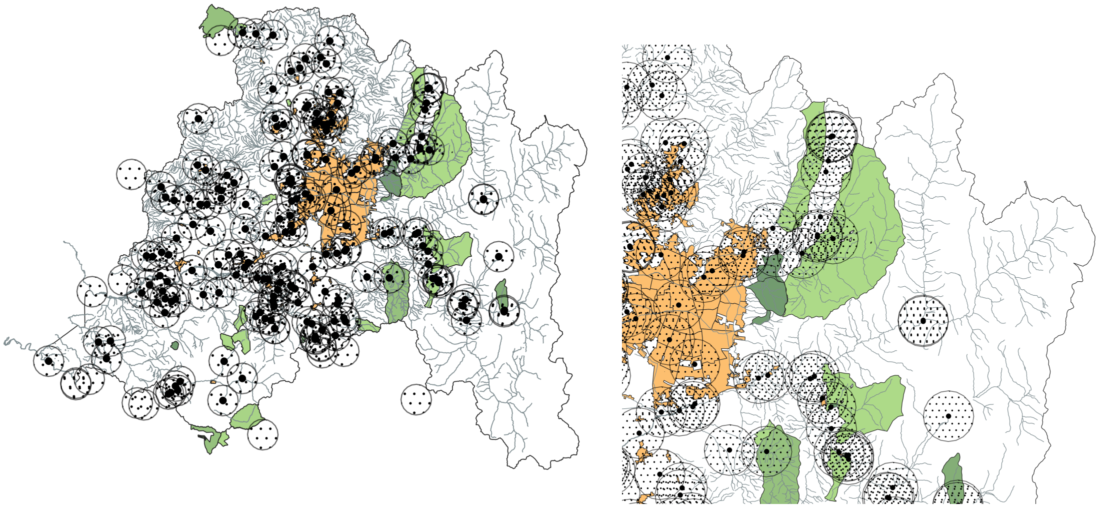
# 4 Empirical approach

This research aims to analyze the influence of protected areas on these parameters within their neighborhood using information obtained from WMS. To this end, we follow Liu et al. (2022) and construct a range of buffers, including 0, 3, 5, 7, and 10 km, around each WMS according to their geographical location to define different treatments. In particular, we define a treatment group as the WMS whose buffer intersects with at least one PA located at a higher elevation. In contrast, the control group is composed of WMS with either no overlap with any PAs or overlap with PAs situated at a lower elevation. The reason for this is based on the dynamics of hydrology, due to the flow of water, which allows us to understand the spatial variation in the effect of a PA designation, providing a detailed understanding of the localized effect of PA on water quality.

Figure 5 provides a geographical representation of the treatment. The maps show the WMS as black dots, the PA as green polygons and the urban areas as orange polygons. Each WMS is surrounded by a buffer of 5 km to illustrate the potential treatment zone. As depicted in the illustration, the buffer may overlap or not with a protected area.

Table 4 presents a breakdown of the percentage of "treated" WMS for each parameter and buffer size. The percentage of treated indicates the share of treated WMS within each specific buffer size. As anticipated, the percentage of WMS treated gradually rises as the buffer size increases for all parameters, peaking at 10 km. This observed trend indicates that with the expansion of buffer size, a larger area is considered proximal, thereby elevating the likelihood of WMS being classified as "treated". Arsenic has a slightly higher percentage

Figure 5: Overview of PAs and urban areas in the Metropolitan Region



**Notes:** Figure 5 provides a geographical representation of the treatment. The maps show the WMS as black dots, the PA as green polygons and the urban areas as orange polygons. Each WMS is surrounded by a buffer of 5 km to illustrate the potential treatment zone. As depicted in the illustration, the buffer may overlap or not with a protected area.
Source: Own elaboration based on Pliscoff (2022), CONAF, DGA, BCN and IDE.

of "treated" than phosphorus, and phosphorus has a higher percentage of "treated" than nitrogen, for all buffer sizes. For sulfates, the statistical power of the estimates is a concern since the highest percentage of WMS treated is only 6.4%.

Table 4: Percentage of "treated" according to each treatment variable and parameter

| **Parameter** | **Percentage of treated (%)** | | | | | | **WMS (N)** |
|---|---|---|---|---|---|---|---|
| | **0km** | **3km** | **4km** | **5km** | **7km** | **10km** | **Count** |
| Phosphorus | 3.6 | 13.8 | 15.8 | 16.4 | 21.8 | 29.9 | 419 |
| Nitrogen | 3.7 | 13.8 | 15.8 | 16.4 | 21.7 | 29.8 | 419 |
| Arsenic | 3.5 | 14.0 | 16.0 | 16.7 | 22.5 | 30.8 | 453 |
| Sulfates | 3.7 | 4.8 | 5.0 | 5.1 | 5.6 | 6.4 | 535 |

**Notes:** Table 4 provides a breakdown of the percentage (%) of "treated" WMS for each parameter, specifically phosphorus, arsenic, nitrogen, and sulfates, across a range of buffer sizes, including 0, 3, 5, 7, and 10 km. The percentage of "treated" indicates the percentage of WMS within each specified buffer size that has been treated (i.e. a WMS whose buffer intersects with at least one PA located at a higher elevation).
Source: Own elaboration.

The low percentage of WMS treated for sulfates suggests that the ability of the estimates to correctly detect an effect, if it exists, may be insufficient. This might increase type II errors, where we fail to detect a true effect due to the limited sample of treated stations.

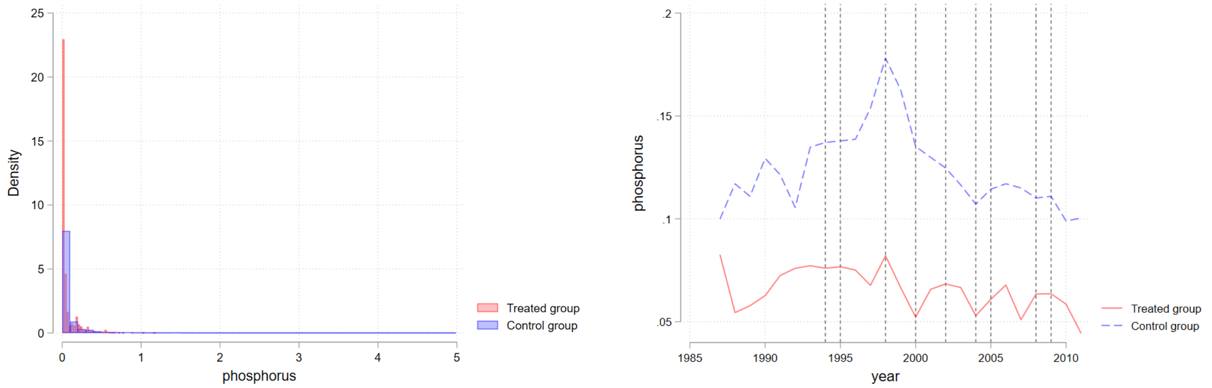
Note that power is higher when the treated group is larger since the main component of the variance of the difference-in-difference (DiD) estimator with few treated and many control groups comes from the variance of the treated groups (Ferman and Pinto, 2019). Hence, results regarding sulfates should be interpreted with caution.

Figure 6 presents the histograms and time series for each parameter, separated by treatment and control groups. The time series incorporates the years when treatment began, i.e. at least one higher elevation protected area was established within the WMS buffer zone. The histograms indicate a difference in concentrations levels between the treated and control groups for all parameters.

Figure 6: Histograms and time series of the parameters

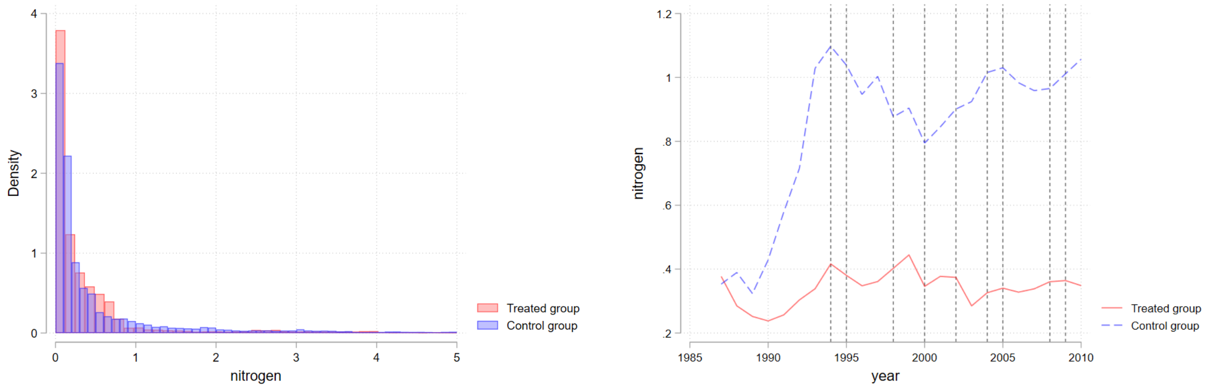
Histogram phosphorus - P

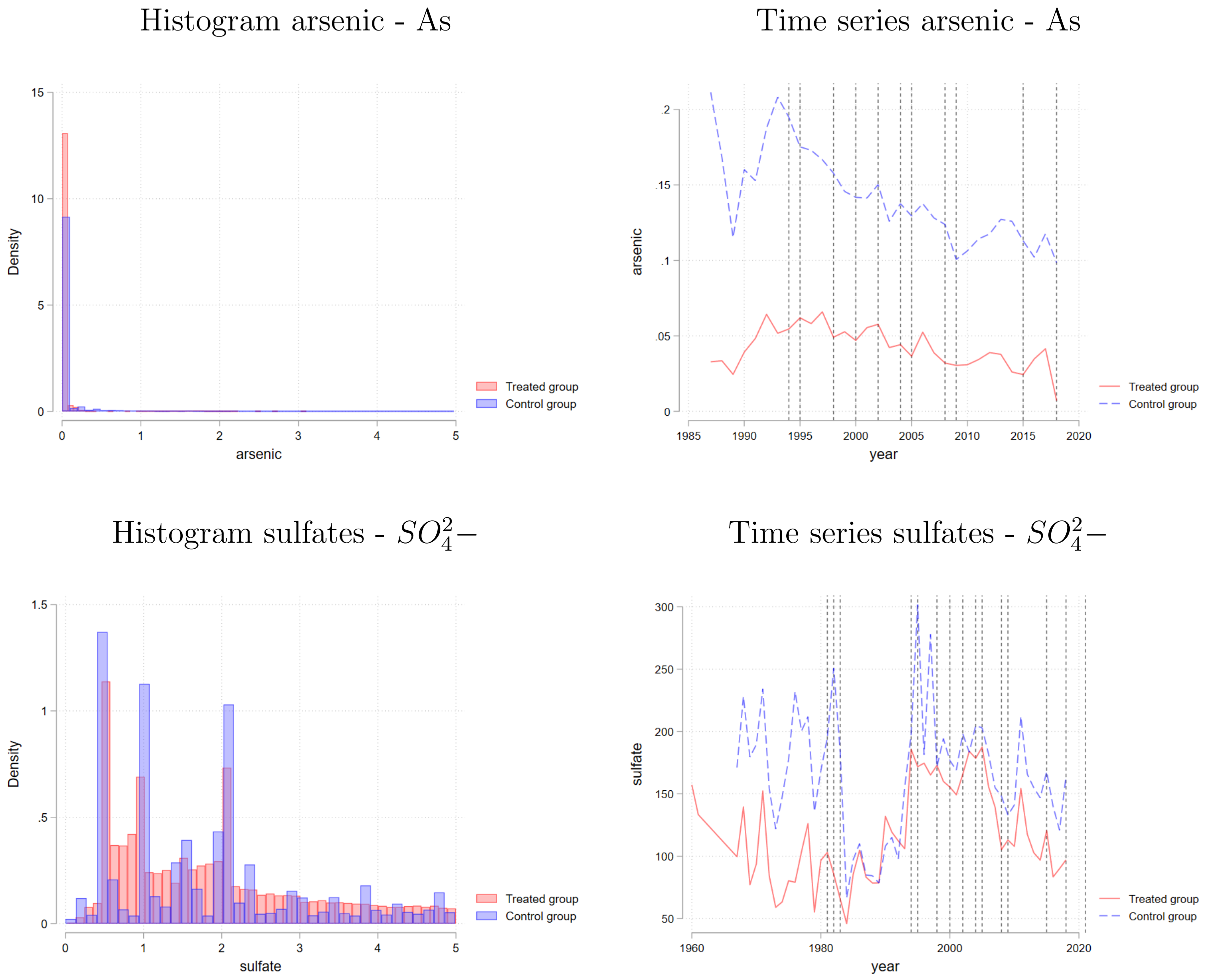
Time series phosphorus - P



Histogram nitrogen - N

Time series nitrogen - N




Histogram arsenic - As

Time series arsenic - As

Histogram sulfates - $SO_4^2-$

Time series sulfates - $SO_4^2-$

**Notes:** Figure 6 illustrates the histograms and time series of each parameter, separated by treatment and control groups. The time series also incorporates the years when treatment began, i.e., when at least one protected area at a higher elevation was established within the WMS buffer zone.
Source: Own elaboration based on DGA and SISS data.

The different levels of parameter concentrations between treated and control WMS suggest that PAs tend to have lower concentration levels of the parameters of interest. In the case of phosphorus and nitrogen, which are linked to agricultural runoff and urban waste, lower levels in PAs could be due to the absence or minimal presence of these activities. Similarly, for arsenic and sulfates, which can be influenced by industrial activities and natural geological processes, lower concentrations in PAs might indicate minimal industrial impact or the preservation of areas with naturally low levels of these elements.

As mentioned before, the establishment and development of PAs in Chile has historically been driven by multiple factors. Initially, in its early stages, the focus was on coping with geopolitical, territorial, and forest protection needs (García and Mulrennan, 2020). Starting from the 20th century, due to development, other factors emerged. These include nature conservation, regulation of the timber trade, protection of nonproductive fiscal lands, preservation of scenic beauty (Basic and Arriagada, 2012), and protection of viable samples of the country's biodiversity and ecosystems (Folchi, 2015; Figueroa, 2015). Consequently, it is relevant to note that, to the best of our knowledge, these factors that have guided the establishment and development of Chile's PAs, have not been related to or induced by water contamination issues, supporting the assumption of non-anticipation.

Water quality ($WQ_{it}$) represents any of the four selected parameters: phosphorus, nitrogen, arsenic, or sulfates (see Equation (1)) measured in terms of their concentration levels in mg/L at monitoring station $i$ at time $t$.

$$WQ_{it} \in \{\text{Phosphorus}, \text{Arsenic}, \text{Nitrogen}, \text{Sulfates}\} \tag{1}$$

A DiD logarithmic regression model is specified to capture the treatment effect, controlling for temporal variation, seasonal and basin effects, and distance to populated areas. Equation (2) illustrates the correlation between the logarithm of water quality ($WQ_{it}$) at the WMS $i$ at time $t$ with various control variables. The interaction between the treatment variable and the post-treatment period (variable of interest) is represented by $\text{treated}_{it} * \text{post}_t$. The variable $treated_{it}$ indicates whether the WMS was ever treated. The variables $\text{year}_t$ and $\text{season}_t$ correspond to fixed effects by year and season as a proxy for meteorological conditions. The regressor $\text{distance}_i$ is the minimum distance to a populated area to control for anthropogenic factors, and $\text{WMS}_i$ corresponds to a fixed effect by WMS. We estimate using clustering at the WMS level to correct for heteroscedasticity.

$$\begin{aligned} ln(WQ_{it}) = \beta_0 + \beta_1 \text{treated}_{it} * \text{post}_t + \beta_2 \text{treated}_{it} + \beta_3 \text{distance}_i + \sum_{t}^{Y-1} \beta_{4y} \mathbb{1}[\text{year} = \text{year}_t] \\ + \sum_{s}^{S-1} \beta_{5s} \mathbb{1}[\text{season} = \text{season}_s] + \sum_{i}^{N-1} \beta_{6i} \mathbb{1}[\text{WMS} = \text{WMS}_i] + \varepsilon_{it} \end{aligned} \tag{2}$$

We follow this estimation with an event study. This can be viewed as an extension of the principles of Granger causality (Granger, 1969). If the PA implementation is indeed the causal factor, any differences between treatment and control WMS should only appear after the introduction of the treatment. Before then, the differences between treated and untreated stations should remain constant.

To estimate the impact of the designation of a PA, we follow Clarke & Schythe (2020) and use 'Events' to denote a variable that records the time period 't' in which the event is adopted in WMS 'i'. Lags and leads are binary variables that show whether a WMS is a certain number of periods away from the establishment of a PA in a given period. We include J lags and K leads, with J=K=36 months in this case. The final lags and leads "accumulate" those beyond J and K periods, as shown in the Equations in (3).

$$\begin{aligned}
\text{Lag } J_{it} &= \mathbb{1}\left[t \leqslant \text{ Event }_i - J\right] \\
\text{Lag } j_{it} &= \mathbb{1}\left[t = \text{ Event }_i - j\right] \text{ for } j \in \{1, \ldots, J-1\}, \\
\text{Lead } k_{it} &= \mathbb{1}\left[t = \text{ Event }_i + k\right] \text{ for } k \in \{1, \ldots, K-1\}, \\
\text{Lead } K_{it} &= \mathbb{1}\left[t \geqslant \text{ Event }_i + K\right].
\end{aligned} \tag{3}$$

To capture the baseline difference between WMS where the establishment of a PA at higher elevation does and does not occur, one lag or lead variable is omitted. Following standard practice, as shown in Equation (4), this omitted case is the first lag (j=1).

$$\begin{aligned}
WQ_{it} = \alpha + \sum_{j=2}^{J} \beta_{1j}(\text{Lag } j)_{it} + \sum_{k=1}^{K} \beta_{2k}(\text{Lead } k)_{it} + \beta_3 \text{distance}_i + \sum_{t}^{Y-1} \beta_{4y} \mathbb{1}[\text{year} = \text{year}_t] \\
+ \sum_{s}^{S-1} \beta_{5s} \mathbb{1}[\text{season} = \text{season}_s] + \sum_{i}^{N-1} \beta_{6i} \mathbb{1}[\text{WMS} = \text{WMS}_i] + \varepsilon_{it}
\end{aligned} \tag{4}$$

Here $\mu_i$ and $\lambda_t$ are WMS and time fixed effects, and $\varepsilon_{it}$ is an unobserved error term. In this specification, the estimated effect is the aggregate effect, it considers both direct and indirect mechanisms. The direct mechanisms include the regulation of runoff and river discharge, along with the water pollution reduction measures implemented by the PA administration. Indirect mechanisms include land use restrictions, the influence of PAs on other ecosystem services, and overall management within the PAs.

The are a few threats to causality. First, the designation and location of PAs may be endogenous. Factors such as local water quality and the ecological or hydrological significance of the area might affect the PA designation and location. If an area is heavily contaminated, policymakers may consider it in the public interest to establish a PA, leading to an endogenous relationship between the treatment (PA placement) and the outcome (water quality). Similarly, regions of significant ecological importance may also be preferentially selected for conservation, a trend that aligns with the patterns observed in the data visualization discussed earlier. These preferential selections could suggest a potential non-randomness in the establishment of PA, which may introduce bias into the analysis.

Second, there could be a potential endogeneity in the placement of WMS, which could also bias our estimates. For instance, stations may be more likely to be located in areas with poor water quality or in regions that support sensitive environments, as well as in more populated regions. Monitoring a specific water source could be correlated with the water quality at that site, which might also bias the treatment effects.

Finally, another potential endogeneity is the presence of missing values, given that older data is more likely to be missing. It should be acknowledged that the starting points of data collection vary, as not all stations were established at the same time. This possible non-random missing data could lead to bias if the missing data correlates with our outcome of interest.

Although these factors present potential threats to identification our empirical strategy attempts to control for these factors, providing suggesting evidence of the relationship between PAs and water quality. This analysis can be viewed as a starting point for future research in water quality dynamics and environmental policies.

# 5 Results

This study investigates the effects of different treatment definitions on the four parameters of interest. The analysis mainly focuses on the 3 km results because there is suggestive evidence of local effects, so a more localized scope of analysis is required to identify the impact of treatment.

Table 5 presents the results of a DiD log-level regression analysis for the 3 km buffer treatment. The “treated” variable, is highly significant in almost all models (except sulfates), suggesting a difference in baseline concentrations between treated and control WMS. For phosphorus, the interaction between the treatment and post-treatment period was not statistically significant. However, the treated variable itself showed a significant negative effect.

In nitrogen, both treated and the interaction between treatment and post-treatment period are statistically significant. These findings suggest that the implementation of the treatment had a significant negative impact of 32.6% on nitrogen concentrations. Lastly, arsenic and sulfates analysis showed that the interaction term was not statistically significant.

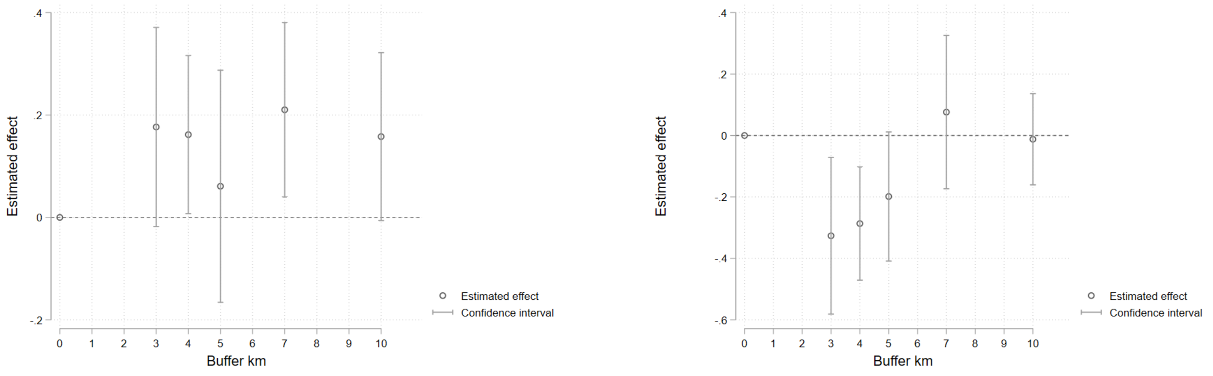
Table 5: Log-level regression results for the 3 km buffer treatment

| | Phosphorus<br>(1) | Nitrogen<br>(2) | Arsenic<br>(3) | Sulfates<br>(4) |
|---|---|---|---|---|
| Treated x Post | 0.177 | -0.326* | 0.149 | -0.024 |
| | (0.099) | (0.130) | (0.081) | (0.024) |
| Treated | -17.644*** | 0.776*** | -21.399*** | 0.023 |
| | (0.116) | (0.013) | (0.089) | (0.019) |
| Year FE | ✓ | ✓ | ✓ | ✓ |
| Season FE | ✓ | ✓ | ✓ | ✓ |
| WMS FE | ✓ | ✓ | ✓ | ✓ |
| Parameter mean | 0.115 | 0.809 | 0.123 | 141.4 |
| R-squared | 0.750 | 0.796 | 0.947 | 0.941 |
| Obs. | 93,692 | 89,621 | 127,181 | 169,225 |
| WMS | 419 | 419 | 453 | 535 |

**Notes:** Log-level regression results for the 3 km buffer treatment are presented in the table. Individual fixed-effects regression models are shown in each column. The models incorporate several fixed effects, such as year, season and WMS. Substantial observations are considered in each model, including multiple WMS. Robust std. err. adjusted for WMS clusters are given in parentheses alongside the coefficients. R-squared corresponds to overall R-squared. * p<0.1; ** p<0.05; *** p<0.01. The asterisks indicate levels of statistical significance, with * corresponding to 10%, ** to 5%, and *** to 1%.
Source: Own elaboration.

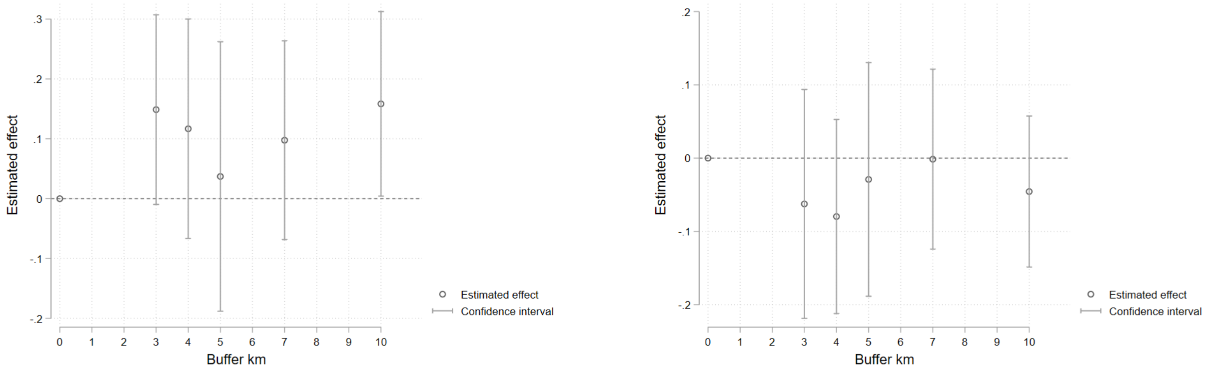
Figure 7 provides a graphical representation of the estimated log-level regression coefficients across various buffer sizes, ranging from 0 to 10 kilometers. The x-axis represents these buffer sizes, while the y-axis denotes the estimated coefficients with their corresponding confidence intervals.

Figure 7: Estimated log-level regression coefficients across various buffer sizes



a) Phosphorus

b) Nitrogen



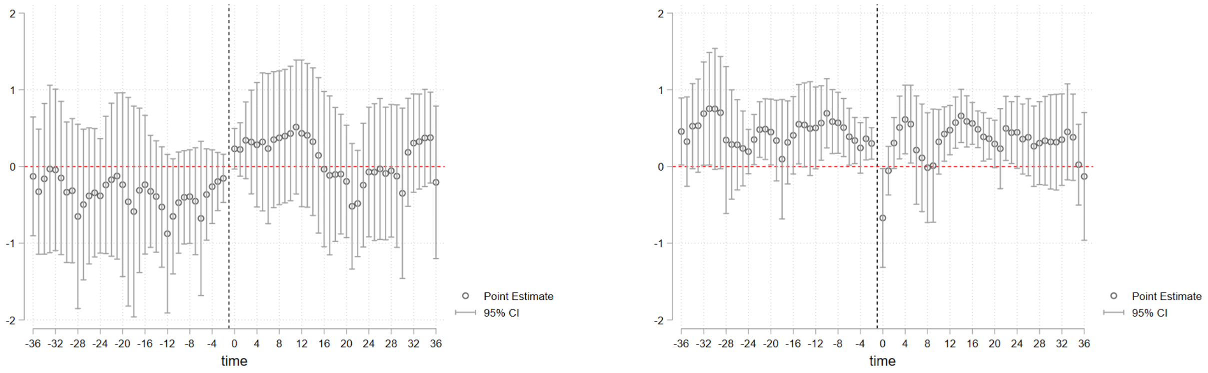
c) Arsenic d) Sulfates

**Notes:** Figure 7 provides a graphical representation of the estimated log-level regression coefficients for each parameter across various buffer sizes, ranging from 0 to 10 kilometers. The x-axis represents these buffer sizes, while the y-axis denotes the estimated coefficients with their corresponding confidence intervals. Source: Own elaboration.

For phosphorus, the estimated effect for the 4 km and 7 km buffer sizes are significant, suggesting a positive effect. However, this is not consistent across all buffer sizes. For arsenic and sulfates, no significant effect was found. For nitrogen, there is suggestive evidence of a localized negative effect within a maximum distance of 4 km, ranging from -32.6% at a 3 km buffer to -28.7% at a 4 km buffer, equivalent to an average reduction of -.26 to -.23 mg/L respectively. Beyond these limits, specially for buffer sizes of 7 km and 10 km, the effect is no statistically significant. This pattern suggests that the impact of the treatment is within a localized range, diminishing as we move further away from the PA.

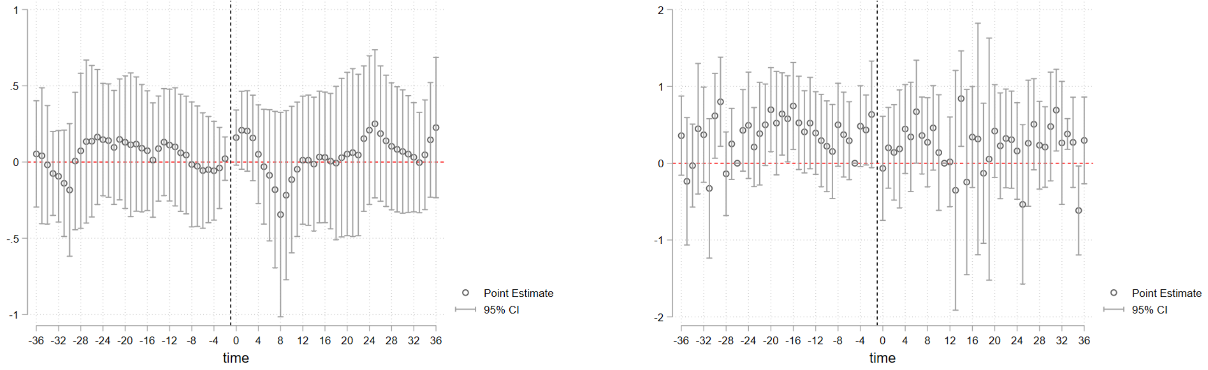
Figure 8 shows the event studies analysis for all parameters, estimating treatment effects from 36 months before treatment to 36 months after treatment. In this case, no significant effect is found for any parameter. For nitrogen, there is a possible constant positive difference that is maintained pre and post treatment and a potential negative short-term effect.

Figure 8: Event study results for the 4 km buffer treatment



a) Phosphorus

b) Nitrogen



c) Arsenic

d) Sulfates

**Notes:** Figure 8 presents the results of the event studies analysis for each parameter, estimating the treatment effect from 36 months before treatment to 36 months after treatment. Estimated for the 4km buffer treatment. No significant effect can be identified for any parameter. For nitrogen, there is a possible constant positive difference that is maintained pre and post treatment and a potential negative short-term effect. Source: Own elaboration.

Overall, the treatment has various effects depending on the specific parameter and definition of the treatment[5]. While further refinement of the estimates is needed, there is consistent suggestive evidence across different specifications of a negative short-term effect on nitrogen concentrations of a localized negative effect within a maximum distance of 4 km, ranging from -32.6% at a 3 km buffer to -28.7% at a 4 km buffer, equivalent to an average reduction of -.26 to -.23 mg/L. For phosphorus, arsenic and sulfates concentrations we found no significant effect. Additionally, the effect of 'treated' differs depending on the parameter. For phosphorus and arsenic, the coefficient for 'treated' indicates lower concentration levels

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[5] See section 7.0.4 of the Appendix for discussions on Regression Discontinuity and Macrozone Analysis.

in treated areas. Conversely, nitrogen shows a higher concentration in treated areas. For sulfates, the coefficient for ‘treated’ indicates no significantly different baseline concentration levels. The findings show that spatial effects should be considered in further modeling.

# 6 Robustness analysis

This section explores the robustness of our findings through two distinct methodologies: staggered adoption design and buffer coverage proportion analysis. The staggered adoption design addresses the temporal aspects of PA implementation, highlighting the complexities and potential biases in estimating treatment effects due to varying implementation times. On the other hand, the buffer coverage proportion analysis refines our treatment definition by focusing on the extent of PA coverage within the buffer zones around the WMS. These complementary approaches not only validate general results but also offer insights into the spatial-temporal dynamics of PAs’ influence on these parameters. For more detailed discussions on Regression Discontinuity and Macrozone Analysis, refer to section 7.0.4 in the Appendix.

## 6.1 Staggered adoption design

One concern arises regarding the fact that PAs are being implemented at different times. This staggered implementation, referred to by Athey and Imbens (2022) as “staggered adoption design”, could considerably impact the estimations derived from Equations (2) and (4). If a unit switches from being non-treated to being treated, this is the main source of variation in estimating $\beta$. If a unit has already switched to being treated and remains in this status over several periods, then, due to how the OLS regression estimator works, it will be treated as a control unit during these periods, as there is no variation in $treated_{it}$ (Goodman-Bacon, 2021).

The staggered implementation of PAs is estimated [6] using the $DID_M$ estimator for difference-in-differences with multiple periods and groups presented by de Chaisemartin and D’Haultfoeuille (2020). It only relies on common trend assumptions rather than homogeneous treatment effect assumptions and it identifies the effect of treatment on switchers, at the time they switch[7].

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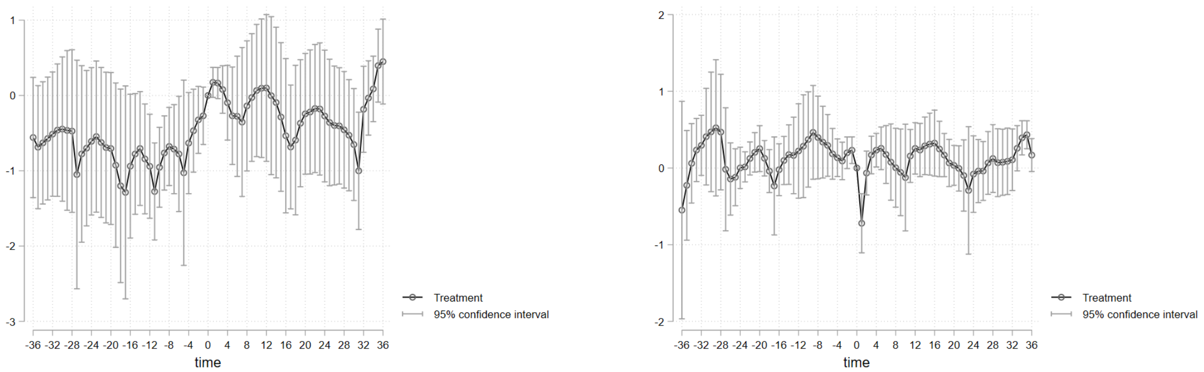
[6] We use the *did_multiplegt_dyn* command for the staggered implementation of protected areas, following the event-study estimators proposed by de Chaisemartin and D’Haultfoeuille (2020). This command accounts for lagged treatments and is suitable for various research designs, offering improved speed over its predecessor *did_multiplegt*. For a detailed comparison of these Stata commands and their applications in different scenarios, refer to the supplementary document by de Chaisemartin et al. (2023).

[7] For more detail about the methodology see section III in de Chaisemartin and D’Haultfoeuille (2020).

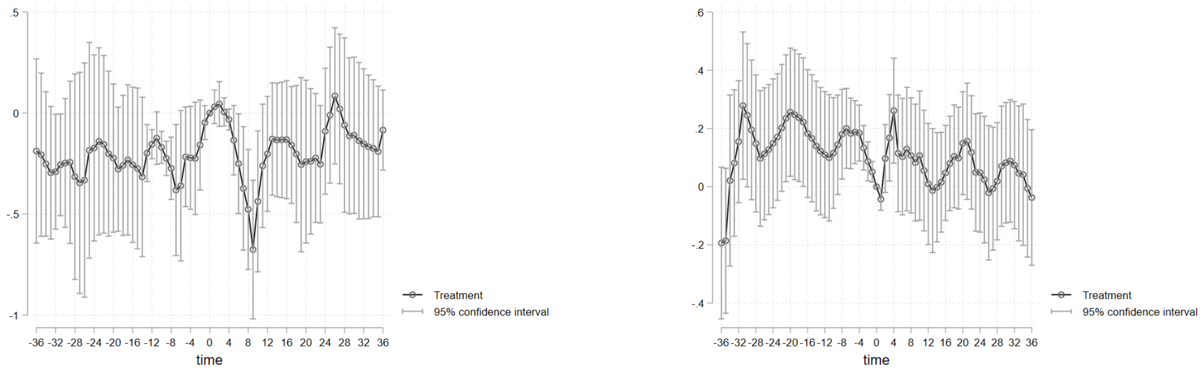
We estimate a dynamic specification with 36 pre-treatment and 36 post-treatment periods. We accounted for potential within-group correlations by clustering standard errors at the WMS level. The results presented in Figure 9 indicate non-significant effects in both pre-treatment (placebo) and post-treatment periods for phosphorus, nitrogen and sulfates. For arsenic, there is a possible negative short-term effect within the first year.

Figure 9: $DID_M$ estimator results for the 3 km buffer treatment



a) Phosphorus

b) Nitrogen



c) Arsenic

d) Sulfates

**Notes:** Figure 9 indicate non-significant effects in both pre-treatment (placebo) and post-treatment periods for any of the parameters studied. However, considering this design, it appears that the model may exhibit different seasonalities other than the ones included in the model (annual and by season), necessitating further investigation into these variations.
Source: Own elaboration.

Additionally, considering this design, it appears that the model may exhibit other temporal dynamics than the ones included in the model (annual and season), necessitating further investigation into these variations.

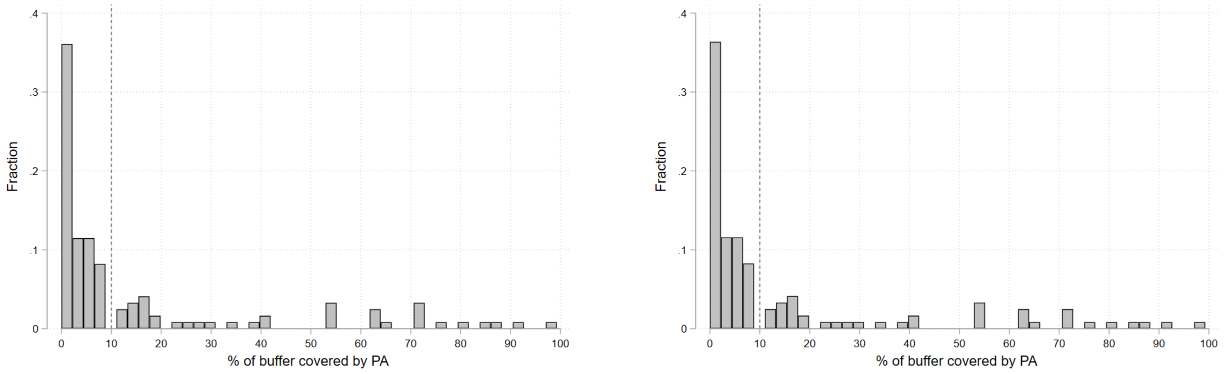
## 6.2 Buffer coverage proportion by PAs

Another concern is the relatively broad definition of the treatment. The treatment, as defined in this research, aims to analyze the impact of PAs on water quality by examining the data from WMS within a set buffer zones. The treatment group includes WMS with any part of their buffer intersecting at least one PA at a higher elevation. The control group comprises WMS without such overlap or with overlaps at lower elevations. This approach might lead to including WMS in the treated group that only intersects minimally with the buffer, affecting the precision of our treatment categorization.

In this estimation, we refine our treatment variables and focus exclusively on observations where a PA is within a 10 km radius. Initially, any WMS intersecting with at least one PA at a higher elevation was considered "treated". Now, the treatment group is limited to WMS with a PA intersection equal to or exceeding 10% of the buffer area. WMS not meeting this criteria are categorized as controls. This adjustment aims to provide a more accurate assessment of the impact of PAs on water quality by considering the PA coverage within the proximity of each WMS.

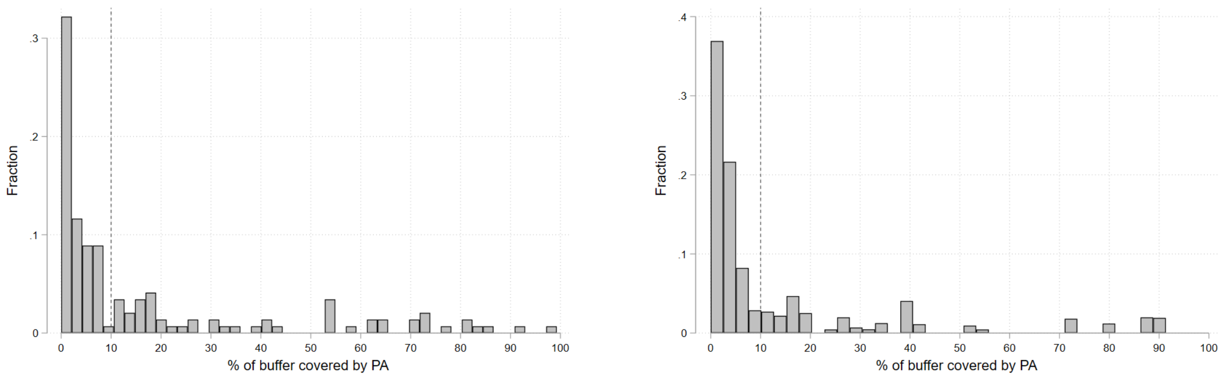
The histograms in Figure 10 show the distribution of WMS based on the percentage of their buffer zones covered by PAs for each parameter. A significant concentration of WMS falls within the lower percentage coverage, particularly below the 10% threshold, showing that a significant number of stations are minimally intersected by PAs.

Figure 10: Histograms of WMS Buffer Coverage by Protected Areas



a) Phosphorus

b) Nitrogen



c) Arsenic

d) Sulfates

**Notes:** The histograms show the distribution of WMS based on the percentage of their buffer zones covered by PAs. Each histogram corresponds to one of the four water quality parameters: phosphorus, nitrogen, arsenic, and sulfates. A significant concentration of WMS falls within the lower percentage coverage, particularly below the 10% threshold, showing that a significant number of stations are minimally intersected by PAs.
Source: Own elaboration.

Table 6 presents a breakdown of WMS by treatment status and parameters. The table categorizes WMS into 'treated' and 'control' groups based on the revised criteria of PA intersection. Ranging from 27.27% to 32.54% percentage of WMS across all parameters falls into the treated category.

Table 6: Distribution of WMS by treatment status and parameters for the 10 km buffer

| Parameter | WMS | Treated (> 10%) | Control |
|---|---|---|---|
| | (N) | (%) | |
| Phosphorus | 144 | 27.78 | 72.22 |
| Nitrogen | 143 | 27.27 | 72.73 |
| Arsenic | 169 | 32.54 | 67.46 |
| Sulfates | 83 | 27.87 | 72.13 |

**Notes:** Table 6 presents a breakdown of WMS by treatment status and parameters. The table categorizes WMS into 'treated' and 'control' groups based on the revised criteria of PA intersection. It shows the number of stations in each category, providing an overview of the distribution of WMS across the different parameters.
Source: Own elaboration.

Table 7 presents the results of a difference-in-difference (DiD) log-level regression analysis for the 10 km buffer with this new treatment. The "treated" variable, is highly significant in all models, suggesting a difference in baseline concentrations between treated and control WMS. For phosphorus, arsenic and sulfates, the interaction between the treatment and post-treatment period was not statistically significant. In nitrogen, the implementation of the treatment had a significant negative impact of 18.4% on nitrogen concentrations, equivalent to an average reduction of -.14 mg/L.

Table 7: Log-level regression results for the 10 km buffer treatment with new treatment variable

| | Phosphorus<br>(1) | Nitrogen<br>(2) | Arsenic<br>(3) | Sulfates<br>(4) |
|---|---|---|---|---|
| Treated x Post | -0.006 | -0.184*** | 0.077 | -0.140 |
| | (0.067) | (0.052) | (0.123) | (0.101) |
| Treated | 1.053*** | 0.238*** | 1.246*** | -3.123*** |
| | (0.065) | (0.039) | (0.122) | (0.098) |
| Year FE | ✓ | ✓ | ✓ | ✓ |
| Season FE | ✓ | ✓ | ✓ | ✓ |
| WMS FE | ✓ | ✓ | ✓ | ✓ |
| Parameter mean | 0.115 | 0.809 | 0.123 | 141.4 |
| R-squared | 0.783 | 0.810 | 0.939 | 0.919 |
| Obs. | 32,065 | 30,701 | 44,847 | 4,878 |
| WMS | 144 | 143 | 169 | 83 |

**Notes:** Log-level regression results for the 10 km buffer treatment are presented in the table. Individual fixed-effects regression models are shown in each column. The models incorporate several fixed effects, such as year, season and WMS. Substantial observations are considered in each model, including multiple WMS. Robust std. err. adjusted for WMS clusters are given in parentheses alongside the coefficients. R-squared corresponds to overall R-squared. * p<0.1; ** p<0.05; *** p<0.01. The asterisks indicate levels of statistical significance, with * corresponding to 10%, ** to 5%, and *** to 1%.
Source: Own elaboration.

# 7 Conclusions

This paper aims to explain the potential impact of protected areas on water quality in Chile, specifically the effect of protected areas on four parameters: phosphorus, nitrogen, arsenic and sulfates. The analysis performed identifies potential effects and establishes correlations as a step toward understanding the causal relationships between these variables.

Overall, the treatment has various effects depending on the specific parameter and definition of the treatment. However, there is consistent suggestive evidence across different specifications of a negative short-term effect on nitrogen concentrations, localized within a maximum distance of 10 km, ranging from -18.4% to -32.6% at different buffer sizes, equivalent to an average reduction of -.14 to -.26 mg/L. For phosphorus, arsenic and sulfate concentrations we found no significant effect. The varied effects of being ‘treated’ show the potential differences in baseline concentration levels between treated and control WMS.

The most significant limitation is the technical difficulty in defining the catchment areas, which could have helped to create a more accurate treatment variable. In addition, there is a significant lack of controls, such as streamflow, temperature, precipitation, and dynamic land-use data for all WMS examined in this study. Moreover, the lack of granular (monthly) data on designation dates is also an issue, which affects the precision of treatment application.

Future research should delve into the intensive and extensive effects of PA implementation, including analyses differentiated by forest and administrative type. The incorporation of a structural model to analyze the behavior of parameter concentrations for a deeper understanding of the localized impact of PAs. Additionally, a localized analysis by watershed could provide more useful results for the integration into interdisciplinary studies. Identifying the causality of these relationships could lead to more targeted and effective environmental public policies in the future.

# References

Álvarez Malvido, M., Lázaro, C., De Lamo, X., Juffe-Bignoli, D., Cao, R., Bueno, P., Sofrony, C., Maretti, C. y Guerra, F. (Editors). (2021). Latin America and the Caribbean: Protected Planet Report 2020. Ciudad de México, México; Cambridge UK; Gland, Switzerland; Bogotá, Colombia: RedParques, UNEP-WCMC, CMAP-UICN, WWF, CONANP and IAPA Project

Athey S. and Imbens G. W. Design based analysis in Difference In Differences settings with staggered adoption. Journal of Econometrics, 226(1):62–79, 2022. ISSN 03044076. doi: https://doi.org/10.1016/j.jeconom.2020.10.012. URL: link. Annals Issue in Honor of Gary Chamberlain.

Basic, Zlowenka and Arriagada, Rodrigo. Conservación de la biodiversidad y áreas protegidas en Chile. 2012. Revista Agronomía y Forestal UC Revista N° 46.

Bedford, B.L., Preston, E.M. Developing the scientific basis for assessing cumulative effects of wetland loss and degradation on landscape functions: Status, perspectives, and prospects. Environmental Management 12, 751–771 (1988). https://doi.org/10.1007/BF01867550

Florax, Raymond & Brander, Luke & Vermaat, Jan. (2006). The Empirics of Wetland Valuation: A Comprehensive Summary and a Meta-Analysis of the Literature. Environmental & Resource Economics. 33. 223-250. 10.1007/s10640-005-3104-4.

Bruins, R.J., Canfield, T.J., Duke, C., Kapustka, L., Nahlik, A.M. and Schäfer, R.B. (2017), Using ecological production functions to link ecological processes to ecosystem services. Integr Environ Assess Manag, 13: 52-61. https://doi.org/10.1002/ieam.1842

Cejudo, E., Acosta-González, G., Ortega-Camacho, D., & Ventura-Sanchez, K. (2021). Water quality in natural protected areas in Cancun, Mexico: a historic perspective for decision makers. Regional Studies in Marine Science, 48, 102035. https://doi.org/10.1016/j.rsma.2021.102035.

D. Clarke and K. Tapia Schythe. Implementing the panel event study. IZA Discussion Papers 13524, Institute of Labor Economics (IZA), 2020.

Clarke, Damian (2022). Microeconometrics: Methods of Causal Inference (Master in Economics). Class Notes.

Costanza, R., d'Arge, R., de Groot, R. et al., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260 (1997). https://doi.org/10.1038/387253a0

Dasgupta, P. (2021), The Economics of Biodiversity: The Dasgupta Review. (London: HM Treasury)

C. de Chaisemartin, X. D'Haultfoeuille, and A. Deeb. TWOWAYFEWEIGHTS: Stata module to estimate the weights and measure of robustness to treatment effect heterogeneity attached to two way fixed effects regressions. Statistical Software Components, Boston College Department of Economics, Feb. 2019a.

C. de Chaisemartin, X. D'Haultfoeuille, and Y. Guyonvarch. DID MULTIPLEGT: Stata module to estimate sharp Difference in Difference designs with multiple groups and periods. Statistical Software Components, Boston College Department of Economics, May 2019b.

C. de Chaisemartin and X. D'Haultfoeuille. Two way fixed effects estimators with heterogeneous treatment effects. American Economic Review, 110(9):2964–96, September 2020. doi: 10.1257/aer.20181169. URL https://www.aeaweb.org/articles?id=10.1257/aer.20181169.

C. de Chaisemartin, X. D'Haultfoeuille, Mélitine Malézieux and Doulo Sow. Comparing the did_multiplegt and did_multiplegt_dyn Stata commands.

de Groot, R. (2006). Function-analysis and valuation as a tool to assess land use conflicts in planning for sustainable, multi-functional landscapes. In Landscape and Urban Planning (Vol. 75, Issues 3–4, pp. 175–186). Elsevier BV. https://doi.org/10.1016/j.landurbplan.2005.02.016

Department of Environment and Science, Queensland (2021) Hydrology – Catchment and subcatchment, WetlandInfo website, accessed 9 October 2023. Available at: https://wetlandinfo.des.qld.gov.au/wetlands/ecology/processes-systems/water/hydrology/landscape.html

DGA (2019). Mapa Hidroquímico de Chile, SIT N°448, Ministerio de Obras Públicas, Dirección General de Aguas, División de Conservación de Recursos Hídricos, Santiago, Chile, Realizado por DICTUC S.A.

Sulfate in Drinking Water. United States Environmental Protection Agency.

Bruno Ferman, Cristine Pinto; Inference in Differences-in-Differences with Few Treated Groups and Heteroskedasticity. The Review of Economics and Statistics 2019; 101 (3): 452–467. doi: https://doi.org/10.1162/rest a 00759

Figueroa, E. 2010. Valoración económica detallada de las áreas protegidas de Chile. Proyecto GEF-MMA-PNUD, Santiago.

Figueroa, E. (2015). Áreas Protegidas, Bienestar Social y Fuente de Oportunidades para los Chilenos; in J. Simonetti and G. Simonetti-Grez (eds.), Conservando el Patrimonio Natural de Chile: El Aporte de las Áreas Protegidas; PNUD, GEF, Ministry of Environment-Chile and Kauyeken. pp. 91-108. Santiago Chile. 2015.

Folchi, E. (2015). Historia de las Áreas Protegidas en Chile; in J. Simonetti and G. Simonetti-Grez (eds.), Conservando el Patrimonio Natural de Chile: El Aporte de las Áreas Protegidas; PNUD, GEF, Ministry of Environment-Chile and Kauyeken. pp. 91-108. Santiago Chile. 2015.

Furey, R. P., Merrill, N. H., Sawyer, J. P., Mulvaney, K. K., & Mazzotta, M. J. (2022). Evaluating water quality impacts on visitation to coastal recreation areas using data derived from cell phone locations. PLOS ONE, 17(4), e0263649. https://doi.org/10.1371/journal.pone.0263649.

García, M. and Mulrennan, M. E. (2020). "Tracking the History of Protected Areas in Chile: Territorialization Strategies and Shifting State Rationalities." Journal of Latin American Geography, vol. 19, no. 4, 2020, pp. 199–234. JSTOR, https://www.jstor.org/stable/48619107.

C. W. J. Granger. Investigating Causal Relations by Econometric Models and Cross Spectral Methods. Econometrica, 37(3):424–38, July 1969.

Goodman-Bacon, 2021. Difference in differences with variation in treatment timing. Journal of Econometrics, 2021. ISSN 0304 4076. doi: https://doi.org/10.1016/j.jeconom.2021.03.014

Hadwen, W. L., Hill, W. M., & Pickering, C. M. (2007). Icons under threat: Why monitoring visitors and their ecological impacts in protected areas matters. Ecological Management and Restoration, 8(3), 177-181. https://doi.org/10.1111/j.1442-8903.2007.00364.x

Hamid, A., Bhat, S.U. & Jehangir, A. Local determinants influencing stream water quality. Appl Water Sci 10, 24 (2020). https://doi.org/10.1007/s13201-019-1043-4

Hamzah, F. B., Mohd Hamzah, F., Mohd Razali, S. F., Samad, H. (2021). A Comparison of Multiple Imputation Methods for Recovering Missing Data in Hydrological Studies. In Civil Engineering Journal (Vol. 7, Issue 9, pp. 1608–1619). Ital Publication. https://doi.org/10.28991/cej-2021-03091747

IUCN (2008). Guidelines for Applying Protected Area Management Categories. Gland, Switzerland: IUCN. x + 86pp. WITH Stolton, S., P. Shadie and N. Dudley (2013). IUCN WCPA Best Practice Guidance on Recognising Protected Areas and Assigning Management Categories and Governance Types, Best Practice Protected Area Guidelines Series No. 21, Gland, Switzerland: IUCN. Dudley, N. (Editor).

Keeler, B. L., Polasky, S., Brauman, K. A., Johnson, K. A., Finlay, J. C., O'Neill, A., Kovacs, K., & Dalzell, B. (2012). Linking water quality and well-being for improved assessment and valuation of ecosystem services. Proceedings of the National Academy of Sciences, 109(45), 18619–18624. https://doi.org/10.1073/pnas.1215991109

Lara, A., Jones, J., Little, C., & Vergara, N. (2021). Streamflow response to native forest restoration in former Eucalyptus plantations in south central Chile. Hydrological Processes, 35(8), e14270. https://doi.org/10. 1002/hyp.14270

Liu, Z., & Huang, H. (2022). Valuing water purification services of forests: A production function approach using panel data from China's Sichuan province. Environment and Development Economics, 1-20. doi:10.1017/S1355770X21000425

Decreto 7, Artículo Sexto Transitorio de la Ley 21.105, Ministerio De Ciencia, Tecnología, Conocimiento E Innovación, (2019). Gobierno de Chile.

Nelson EJ, Daily GC. Modelling ecosystem services in terrestrial systems. F1000 Biol Rep. 2010 Jul 22;2:53. doi: 10.3410/B2-53. PMID: 21173858; PMCID: PMC2990460.

OECD, 2017. The governance of water infrastructure in Chile. In Gaps and Governance Standards of Public Infrastructure in Chile: Infrastructure Governance Review. Paris: OECD Publishing.

Olmstead, S. M. (2010). The Economics of Water Quality. Review of Environmental Economics and Policy, 4(1), 44–62. https://doi.org/10.1093/reep/rep016

Pliscoff, P. (2022). Actualización de la base de datos de áreas protegidas públicas y privadas de Chile para realizar un análisis de representatividad y de riesgo climático de ecosistemas bajo escenarios de cambio climático.

Turner, R.K., Daily, G.C. The Ecosystem Services Framework and Natural Capital Conservation. Environ Resource Econ 39, 25–35 (2008). https://doi.org/10.1007/s10640-007-9176-6

USGS, 2018a. Nitrogen and Water. U.S. Geological Survey, Water Science School.

USGS, 2018b. Phosphorus and Water. U.S. Geological Survey, Water Science School.

QGIS.org, 2022. QGIS Geographic Information System. QGIS Association. QGIS Desktop 3.22.11 version. http://www.qgis.org

United Nations (2022). UN Water, SDG 6 snapshot in Chile, 2022. Downloaded from https://sdg6data.org on 25 July 2023

The Sustainable Development Goals Report 2022, United Nations. ISSN: 2518-3915. Editor: Lois Jensen.

Watson, J., Dudley, N., Segan, D. et al. The performance and potential of protected areas. Nature 515, 67–73 (2014)

Westling, N., Stromberg, P. M., & Swain, R. B. (2020). Can upstream ecosystems ensure safe drinking water—Insights from Sweden. Ecological Economics: The Journal of the International Society for Ecological Economics, 169(106552), 106552. https://doi.org/10.1016/j.ecolecon.2019.106552

WHO, 2022. Arsenic. World Health Organization.

Widney, S., Kanabrocki Klein, A., Ehman, J. et al. The value of wetlands for water quality improvement: an example from the St. Johns River watershed, Florida. Wetlands Ecol Manage 26, 265–276 (2018). https://doi.org/10.1007/s11273-017-9569-4

World Bank Group. Chile - Informe Rural 2021 (Spanish). Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/193131621327775848/Chile-Informe-Rural-2021

World Resources Institute (2005). Ecosystem and Human Well-Being - Synthesis. https://wedocs.unep.org/20.500.11822/8701.

World Resources Institute, 2023. 25 Countries, Housing One-quarter of the Population, Face Extremely High Water Stress. By Samantha Kuzma, Liz Saccoccia and Marlena Chertock. https://www.wri.org/insights/highest-water-stressed-countries

World Water Council (2006). Water Problems in Latin America. World Water Council, 4th World Water Forum, 2006.

# Appendix

## A1. Interpolation distribution comparison

We use a data interpolation approach to establish continuity and completeness of the dataset for each WMS for the period of analysis. The interpolation process begins by identifying the earliest and latest dates for which data are available for each WMS. Three interpolation methods were employed: linear interpolation, a combination of interpolation and extrapolation, and polynomial interpolation. The latter involved fitting a polynomial model to the data, utilizing squared and cubed terms to account for non-linear trends.

The interpolations are evaluated based on the difference in statistical moments such as mean, standard deviation and percentiles between the interpolated distribution and the original distribution. We set extreme values from the interpolation that were outside the range of the original data to either the observed minimum or maximum. Upon evaluation, the linear interpolation was selected for all parameters to use for further analysis as it more closely preserves the statistical moments of the original sample, especially the mean.

In this analysis, the original and interpolated distributions of the parameters are compared[8]. Table 8 shows that a significant increase in sample size is observed after interpolation, indicating a higher density of data for analysis. This is particularly important for large panel data event studies.

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[8] Details on the interpolation process and comparative results are available upon request.

Table 8: Comparison of sample sizes before and after interpolation

| Parameter | Original sample | Interpolated sample |
|---|---|---|
| | (N) | |
| Phosphorus | 20,780 | 93,692 |
| Nitrogen | 21,149 | 89,621 |
| Arsenic | 30,343 | 127,181 |
| Sulfate | 30,656 | 169,225 |

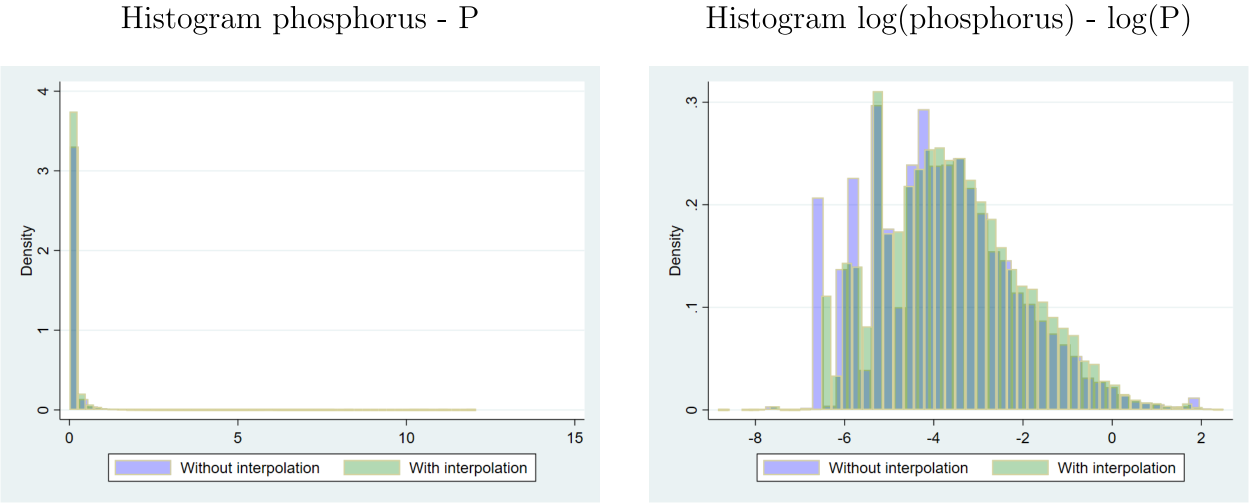
**Notes:** Comparative view of sample sizes (N) before and after the data interpolation process for all parameters: phosphorus, nitrogen, arsenic, and sulfates. The interpolated sample sizes show a substantial increase across all parameters.
Source: Own elaboration.

Sections 7.0.1, 7.0.2, 7.0.3, and 7.0.4 present tables showing the differences between various moments of the interpolated and original distributions. These sections also include histograms both in level and logarithmic forms. Overall, the distributions do not show significant differences in their statistical moments across any of the parameters, suggesting a general consistency between the interpolated and original data sets.

### 7.0.1 Phosphorus

Table 9: Phosphorus concentration levels (mg/L) distribution comparison

| Level | N | mean | SD | Min | p25 | p50 | p75 | Max |
|---|---|---|---|---|---|---|---|---|
| Raw data | 20,780 | 0.116 | 0.498 | 0.0001 | 0.006 | 0.020 | 0.062 | 12.068 |
| Interp. data | 93,692 | 0.116 | 0.412 | 0.0001 | 0.008 | 0.024 | 0.075 | 12.068 |
| Difference | 72,912 | 0.000 | -0.086 | 0.0000 | 0.002 | 0.004 | 0.013 | 0.000 |
| Logarithm | N | mean | SD | Min | p25 | p50 | p75 | Max |
| Raw data | 20,780 | -3.817 | 1.643 | -8.837 | -5.116 | -3.912 | -2.781 | 2.491 |
| Interp. data | 93,692 | -3.609 | 1.592 | -8.837 | -4.798 | -3.730 | -2.590 | 2.491 |
| Difference | 72,912 | 0.209 | -0.051 | 0.000 | 0.318 | 0.182 | 0.190 | 0.000 |

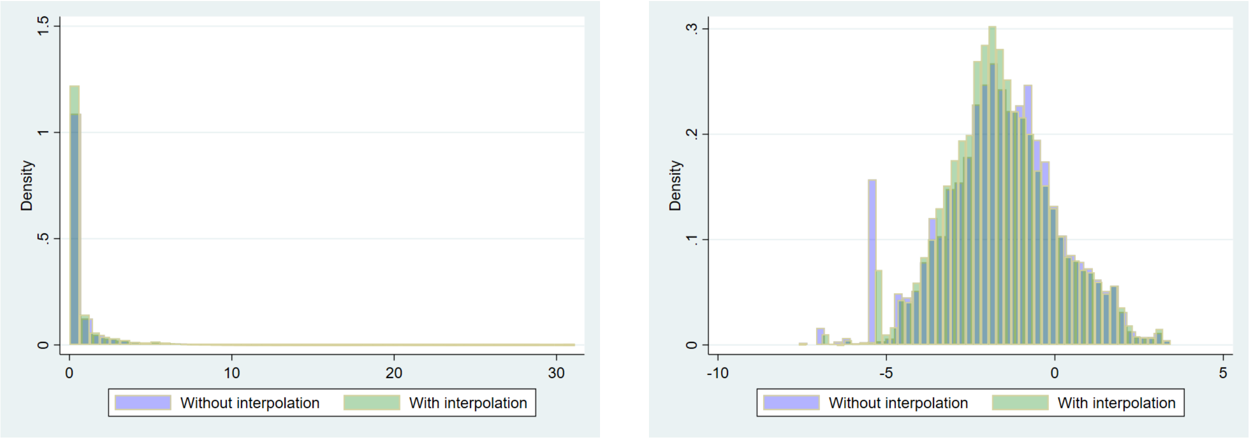


**Notes:** This figure shows the differences between various moments of the interpolated and original distributions of phosphorus concentration levels (mg/L). The left histogram depicts the distribution in its original scale, while the right histogram presents the distribution on a logarithmic scale.
Source: Own elaboration.

### 7.0.2 Nitrogen

Table 10: Nitrogen concentration levels (mg/L) distribution comparison

| Level | N | mean | SD | Min | p25 | p50 | p75 | Max |
|---|---|---|---|---|---|---|---|---|
| Raw data | 21,149 | 0.811 | 2.112 | 0.0005 | 0.069 | 0.200 | 0.590 | 31.129 |
| Interp. data | 89,621 | 0.809 | 2.203 | 0.0005 | 0.073 | 0.184 | 0.543 | 31.129 |
| Difference | 68,472 | -0.001 | 0.091 | 0.0000 | 0.004 | -0.016 | -0.047 | 0.000 |
| **Logarithm** | **N** | **mean** | **SD** | **Min** | **p25** | **p50** | **p75** | **Max** |
| Raw data | 21,149 | -1.629 | 1.751 | -7.601 | -2.674 | -1.609 | -0.528 | 3.438 |
| Interp. data | 89,621 | -1.591 | 1.624 | -7.601 | -2.623 | -1.694 | -0.611 | 3.438 |
| Difference | 68,472 | 0.038 | -0.127 | 0.000 | 0.051 | -0.085 | -0.083 | 0.000 |



Histogram nitrogen - N

Histogram log(nitrogen) - log(N)

**Notes:** This figure shows the differences between various moments of the interpolated and original distributions of nitrogen concentration levels (mg/L). The left histogram depicts the distribution in its original scale, while the right histogram presents the distribution on a logarithmic scale.
Source: Own elaboration.

### 7.0.3 Arsenic

Table 11: Arsenic concentration levels (mg/L) distribution comparison

| Level | N | mean | SD | Min | p25 | p50 | p75 | Max |
|---|---|---|---|---|---|---|---|---|
| Raw data | 30,343 | 0.179 | 1.228 | 0.0005 | 0.0005 | 0.002 | 0.011 | 20.000 |
| Interp. data | 127,181 | 0.124 | 0.833 | 0.0005 | 0.0005 | 0.002 | 0.010 | 20.000 |
| Difference | 96,838 | -0.055 | -0.395 | 0.0000 | 0.0000 | 0.000 | -0.002 | 0.000 |
| **Logarithm** | **N** | **mean** | **SD** | **Min** | **p25** | **p50** | **p75** | **Max** |
| Raw data | 30,343 | -5.538 | 2.290 | -7.601 | -7.601 | -6.215 | -4.510 | 2.996 |
| Interp. data | 127,181 | -5.601 | 2.221 | -7.601 | -7.601 | -6.215 | -4.656 | 2.996 |
| Difference | 96,838 | -0.063 | -0.070 | 0.000 | 0.000 | 0.000 | -0.147 | 0.000 |


Histogram arsenic - Ar

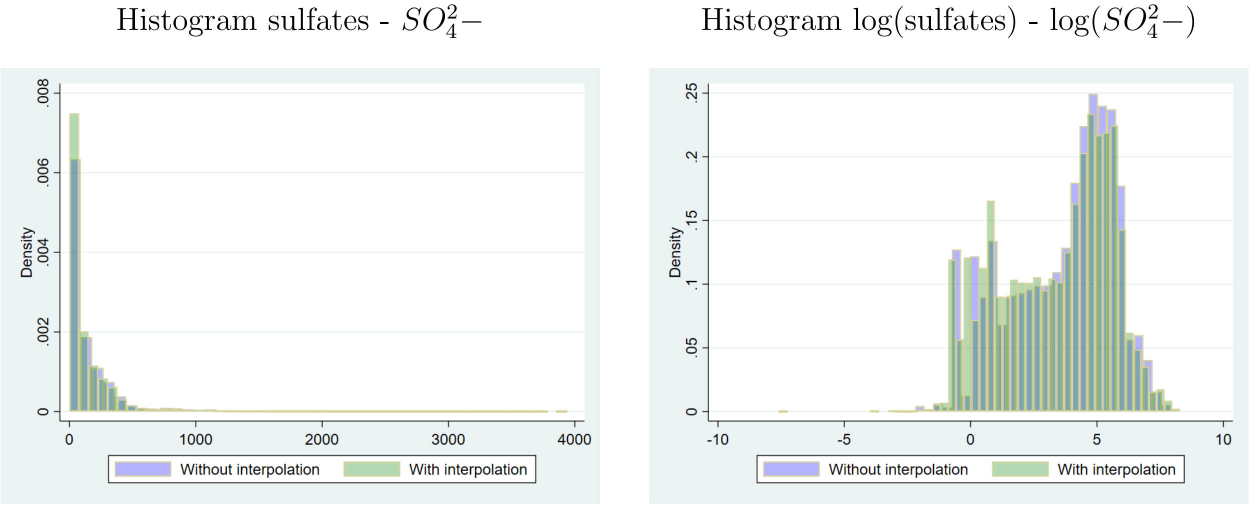
Histogram log(arsenic) - log(Ar)

**Notes:** This figure shows the differences between various moments of the interpolated and original distributions of arsenic concentration levels (mg/L). The left histogram depicts the distribution in its original scale, while the right histogram presents the distribution on a logarithmic scale.
Source: Own elaboration.

### 7.0.4 Sulfates

Table 12: Sulfates concentration levels (mg/L) distribution comparison

| Level | N | mean | SD | Min | p25 | p50 | p75 | Max |
|---|---|---|---|---|---|---|---|---|
| Raw data | 30,656 | 149.9 | 256.3 | 0.0005 | 6.8 | 63.9 | 189.3 | 3,938.6 |
| Interp. data | 169,225 | 141.5 | 267.0 | 0.0005 | 4.4 | 49.8 | 174.7 | 3,938.6 |
| Difference | 138,569 | -8.4 | 10.7 | 0.0000 | -2.4 | -14.1 | -14.7 | 0.0 |
| Logarithm | N | mean | SD | Min | p25 | p50 | p75 | Max |
| Raw data | 30,656 | 3.570 | 2.128 | -7.601 | 1.917 | 4.157 | 5.244 | 8.279 |
| Interp. data | 169,225 | 3.369 | 2.180 | -7.601 | 1.480 | 3.907 | 5.163 | 8.279 |
| Difference | 138,569 | -0.202 | 0.052 | 0.000 | -0.436 | -0.250 | -0.081 | 0.000 |


Histogram sulfates - $SO_4^2-$

Histogram log(sulfates) - $\log(SO_4^2-)$

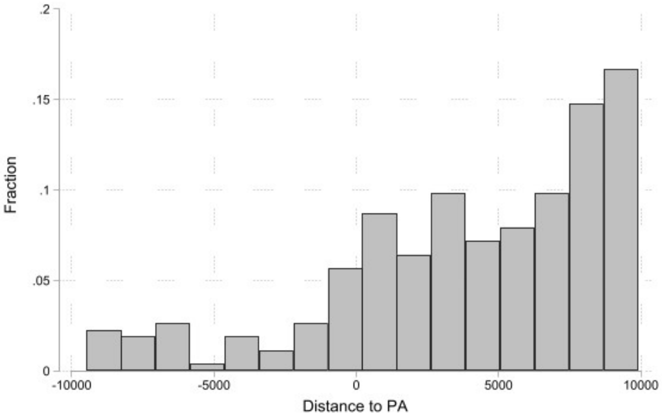
**Notes:** This figure shows the differences between various moments of the interpolated and original distributions of sulfates concentration levels (mg/L). The left histogram depicts the distribution in its original scale, while the right histogram presents the distribution on a logarithmic scale.
Source: Own elaboration.

## A.2 Other estimations

### Spatial Regression Discontinuity

The Spatial Regression Disconţiniuty (RD) approach is employed to investigate the local impact of protected areas on phosphorus, nitrogen, arsenic and sulfates. This method is handy for assessing the causal effects of interventions. In this case, the running variable is the distance from the WMS to the nearest PA, considering PAs upriver as the negative distances and downriver as the positive distances.

Figure 11: Distribution of the running variable



**Notes:** The figure illustrates the distribution of the running variable as the distance from the WMS to the nearest PA, considering PAs upriver as the negative distances and downriver as the positive distances, for WMS located within a maximum distance of 10 km from a PA. The distribution reveals a higher concentration of stations downriver compared to upriver locations.
Source: Own elaboration.

The distribution shown in Figure 11 reveals a higher concentration of stations downriver compared to upriver locations. As shown in Figure 12, the spatial RD estimator indicates no significant effect for any of the parameters studied. A critical limitation is the lack of statistical power, primarily due to the small number of treated observations for all parameters (7, 7, 5, and 12 for phosphorus, nitrogen, arsenic, and sulfates, respectively). This limitation makes it difficult to conclude the RD analysis[9].

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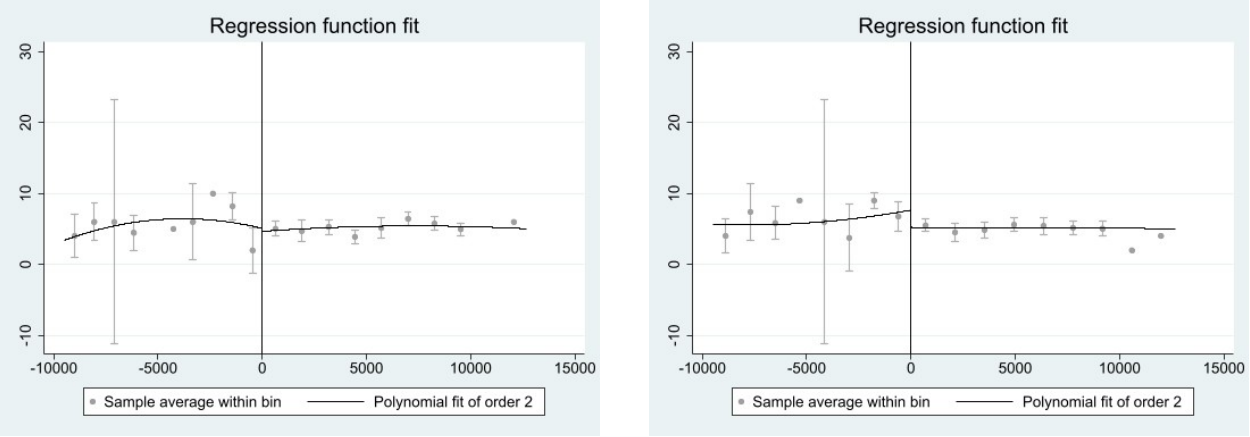
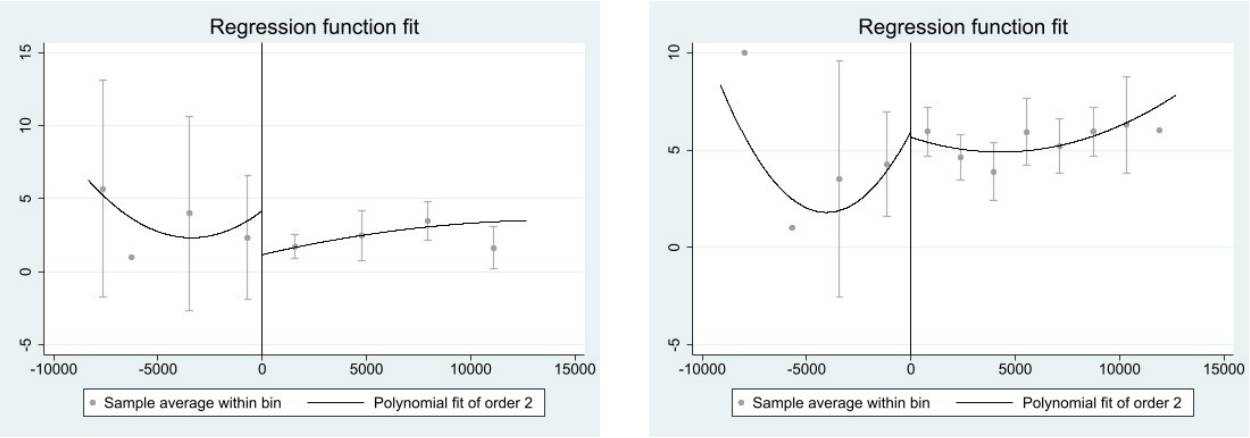
[9] Details on the RD analysis are available upon request.

Figure 12: Spatial RD estimator



a) Phosphorus b) Nitrogen



c) Arsenic d) Sulfates

**Notes:** Figure 12 indicates no significant effect for any of the parameters studied. A critical limitation is the lack of statistical power, primarily due to the small number of treated observations for all parameters (7, 7, 5, and 12 for phosphorus, nitrogen, arsenic, and sulfates, respectively). This limitation makes it difficult to conclude the RD analysis.
Source: Own elaboration.

## Macrozone analysis

To deepen our understanding of the regional impact of protected areas on the parameters, we conducted a macrozone analysis using a 3 km buffer treatment. Results are detailed in Table 13, revealing variations in treatment effects across different macrozones.

For phosphorus, a significant positive treatment effect is observed in the Central macrozone (9.8%, $p<0.1$) and Central-South macrozone (40%, $p<0.01$). Nitrogen shows a significant negative treatment effect in the Central (-14.8%, $p<0.05$), Central-South (-21.4%, $p<0.01$) and Southern (-66.1%, $p<0.1$) macrozones. Arsenic levels significantly increase in the Central (29%, $p<0.01$) and

Southern (14.2%, p<0.01) macrozones, while significantly decreasing in the Central-South (29%, p<0.1) macrozone. Sulfates show a significant decrease in the Central (-27.4%, p<0.01) and an increase in the Central-South (6%, p<0.05) and Austral (16.3%, p<0.05).

Table 13: Treatment by macrozone regression results for the 3 km buffer treatment

| | Phosphorus (1) | Nitrogen (2) | Arsenic (3) | Sulfates (4) |
|---|---|---|---|---|
| Northern x Treated x Post | - | - | - | 0.085 |
| | - | - | - | (0.073) |
| Central x Treated x Post | 0.098* | -0.148** | 0.290*** | -0.274*** |
| | (0.042) | (0.056) | (0.038) | (0.042) |
| Central-South x Treated x Post | 0.400*** | -0.214*** | -0.069* | 0.060** |
| | (0.033) | (0.026) | (0.027) | (0.022) |
| Southern x Treated x Post | 0.009 | -0.661* | 0.142*** | -0.038 |
| | (0.126) | (0.330) | (0.015) | (0.023) |
| Austral x Treated x Post | - | - | 0.107 | 0.163** |
| | - | - | (0.121) | (0.059) |
| Northern | 3.480*** | 0.190*** | 5.129*** | 5.159*** |
| | (0.016) | (0.014) | (0.012) | (0.012) |
| Central | 2.624*** | 2.728*** | 2.454*** | 4.263*** |
| | (0.003) | (0.002) | (0.003) | (0.006) |
| Southern | 0.095*** | -0.940*** | 0.013*** | 0.214*** |
| | (0.007) | (0.003) | (0.002) | (0.005) |
| Austral | -0.557*** | -0.092*** | 0.049*** | 1.984*** |
| | (0.011) | (0.010) | (0.005) | (0.006) |
| Treated | -0.521*** | 0.759*** | -0.031 | 0.155* |
| | (0.013) | (0.013) | (0.121) | (0.061) |
| Year FE | ✓ | ✓ | ✓ | ✓ |
| Season FE | ✓ | ✓ | ✓ | ✓ |
| WMS FE | ✓ | ✓ | ✓ | ✓ |
| Parameter mean | 0.115 | 0.809 | 0.123 | 141.4 |
| R-squared | 0.750 | 0.796 | 0.947 | 0.922 |
| Obs. | 93,692 | 89,621 | 127,181 | 169,225 |
| WMS | 419 | 419 | 453 | 534 |

**Notes:** The results indicate the heterogeneous impact of protected areas on water quality across various Chilean macrozones. The base category (omitted in the regression) for the estimation is Central-South. Individual fixed-effects regression models are shown in each column. The models incorporate several fixed effects, such as year, season and WMS. Substantial observations are considered in each model, including multiple WMS. Robust std. err. adjusted for WMS clusters are given in parentheses alongside the coefficients. R-squared corresponds to overall R-squared. * p<0.1; ** p<0.05; *** p<0.01. The asterisks indicate levels of statistical significance, with * corresponding to 10%, ** to 5%, and *** to 1%.
Source: Own elaboration.

This varied response suggests that regional environmental characteristics influence these outcomes. Phosphorus shows a positive or null effect. On the other hand, nitrogen shows a negative or null effect, indicating a reduction or no significant change in nitrogen concentrations post treatment. Arsenic and sulfates demonstrate varying effects depending on the macrozone.

The macrozone fixed effects show that the Northern and Central macrozones have significantly higher baseline concentrations of all parameters. The base category (omitted in the regression) for the estimation is Central-South. In contrast, the Southern and Austral macrozone have varying baseline concentrations depending on the macrozone.

Table 14 provides an analysis of the macrozone mean deviation regression results using a 3 km buffer treatment. The effects on phosphorus, nitrogen, and arsenic are found to be not statistically significant, indicating no substantial impact of the treatment on these parameters within the specified buffer zones. Conversely, sulfates exhibit a significant negative effect with a coefficient of -27.2% (p<0.1), suggesting a decrease in sulfate concentrations post-treatment.

Table 14: Macrozone mean deviation regression results for the 3 km buffer treatment

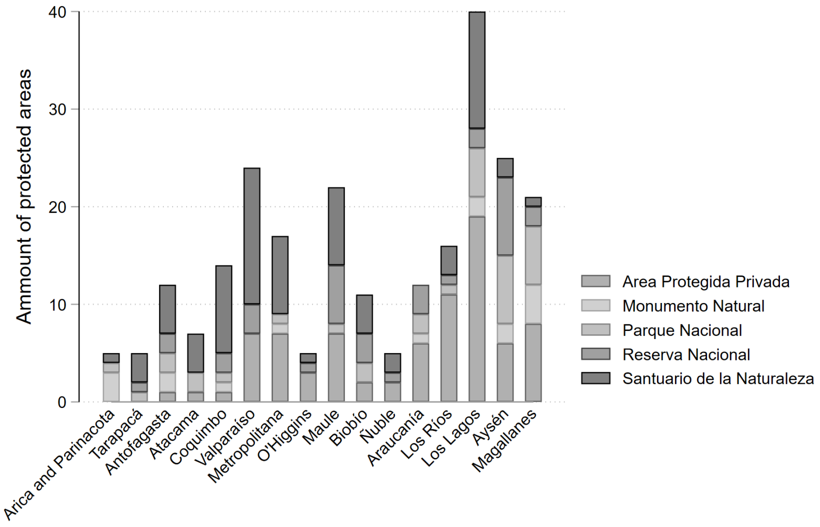
| | Phosphorus (1) | Nitrogen (2) | Arsenic (3) | Sulfates (4) |
|---|---|---|---|---|
| Treated x Post | 0.189 | -0.202 | 0.030 | -0.272* |
| | (0.163) | (0.270) | (0.063) | (0.119) |
| Treated | -1.421*** | 0.709*** | 0.664*** | 0.082 |
| | (0.164) | (0.012) | (0.069) | (0.111) |
| Year FE | ✓ | ✓ | ✓ | ✓ |
| Season FE | ✓ | ✓ | ✓ | ✓ |
| WMS FE | ✓ | ✓ | ✓ | ✓ |
| Parameter mean | 0.115 | 0.809 | 0.123 | 141.4 |
| R-squared | 0.619 | 0.741 | 0.717 | 0.836 |
| Obs. | 93,692 | 89,621 | 127,181 | 169,225 |
| WMS | 419 | 419 | 453 | 535 |

**Notes:** Table 14 presents the results of the macrozone mean deviation regression for the 3 km buffer treatment. Individual fixed-effects regression models are shown in each column. The models incorporate several fixed effects, such as year, season and WMS. Substantial observations are considered in each model, including multiple WMS. Robust std. err. adjusted for WMS clusters are given in parentheses alongside the coefficients. R-squared corresponds to overall R-squared. * p<0.1; ** p<0.05; *** p<0.01. The asterisks indicate levels of statistical significance, with * corresponding to 10%, ** to 5%, and *** to 1%.
Source: Own elaboration.

## A.3 Protected areas

Figure 13 shows the distribution of current protected areas by region and category. The data shows variations in conservation efforts across different regions and types of PAs, such as private protected areas, natural monuments, national parks, national reserves, and nature sanctuaries. The largest number of protected areas are mostly located in Southern Chile, specifically in the *Los Lagos*, *Aysen* and the *Magallanes* regions, as well as in the *Valparaiso* region.

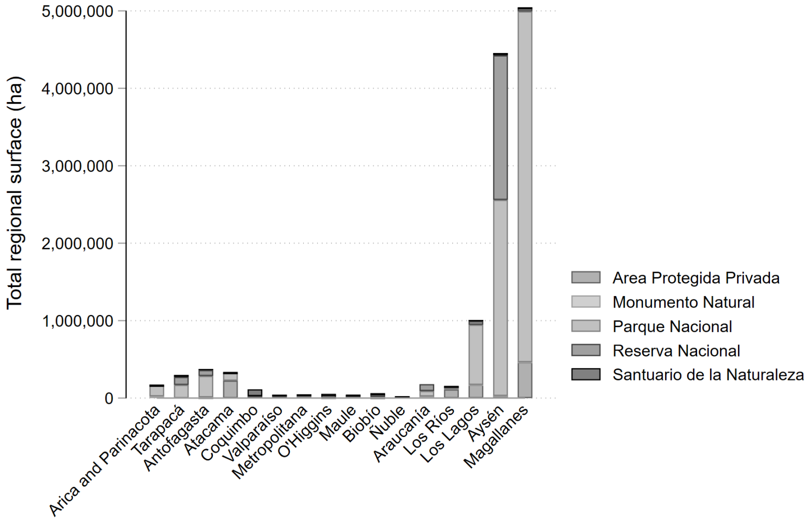
Figure 13: Amount of protected surface by region and conservation category.



**Notes:** Figure 13 presents a bar graph detailing the amount of surface protected by region and conservation category in Chile. The data shows variations in conservation efforts across different regions and types of PAs.
Source: Own elaboration based on Pliscoff (2022).

Figure 14 shows the surface of protected land, measured in hectares, within each region and by type of protection. The data show a marked heterogeneity. The regions of Los Lagos, Aysen and Magallanes account for the majority of the country's protected area.

Figure 14: Total regional protected surface by conservation category.



**Notes:** Figure 14 presents the surface of protected land, measured in hectares, within each region, and by type of protection. The data shows variations in conservation efforts across different regions and types of PAs.
Source: Own elaboration based on Pliscoff (2022).

Pliscoff (2022) database is considered as core in the investigation[10]. Although, three protected areas were eliminated from it, Parque Nacional Salar de Huasco, Parque Nacional Río Olivares, and Reserva Nacional Fundo Nonguen because they are not in CONAF's official record.

Tables 15, 16, 17, 18, and 19 show the list of natural monuments, national parks, national reserves, nature sanctuaries, and private protected areas considered in this study, respectively.

The original data of the protected areas characterization had duplicates, so we eliminated one of its polygons. The duplicated protected areas correspond to two protected areas of the same surface area and in the same location. These are categorized both as nature sanctuaries and private protected areas due to a lack of clarity on the category to which they correspond. We decided to eliminate the polygon registered as private protected areas, leaving only one of the duplicated observations corresponding to nature sanctuaries. Table 20 shows the list of duplicate protected areas, indicating the ones eliminated.

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[10] This means that the APs contained in it are the only ones that will be considered in this paper. All other datasets containing protected areas information are merged into this set of observed protected areas and 'new' PAs are dismissed.

Table 15: List of Natural Monuments

| N° | Name | Surface (km$^2$) | Region |
|---|---|---|---|
| 1 | Salar de Surire | 113,361 | Arica y Parinacota |
| 2 | Quebrada de Cardones | 113,264 | Arica y Parinacota |
| 3 | Paposo Norte | 75,319 | Antofagasta |
| 4 | El Morado | 30,187 | Metropolitana |
| 5 | Laguna de los Cisnes | 8,421 | Magallanes y la Antartica Chilena |
| 6 | Lahuen Nadi | 2,004 | Los Lagos |
| 7 | Dos Lagunas | 1,892 | Aysen |
| 8 | Cinco Hermanas | 1,766 | Aysen |
| 9 | Pichasca | 1,336 | Coquimbo |
| 10 | Cueva del Milodon | 1,186 | Magallanes y la Antartica Chilena |
| 11 | Contulmo | 0,770 | Araucania |
| 12 | Los Pinguinos | 0,678 | Magallanes y la Antartica Chilena |
| 13 | La Portada | 0,592 | Antofagasta |
| 14 | Cerro Ñielol | 0,569 | Araucania |
| 15 | Canquen Colorado | 0,262 | Magallanes y la Antartica Chilena |
| 16 | Islote Punihuil | 0,025 | Los Lagos |
| 17 | Picaflor de Arica | 0,012 | Arica y Parinacota |

Notes: This table shows a list of the 17 national natural monuments considered in this study. The surface area protected by each protected area is shown in $km^2$ and the respective region in which it is located.
Source: Own elaboration based on Pliscoff, 2022.

Table 16: List of National Parks

| N° | Name | Surface (km$^2$) | Region |
|---|---|---|---|
| 1 | Bernardo Ohiggins | 34456,820 | Aysen y Magallanes |
| 2 | Kawesqar | 27306,668 | Magallanes y la Antartica Chilena |
| 3 | Laguna San Rafael | 16909,137 | Aysen |
| 4 | Alberto de Agostini | 13931,095 | Magallanes y la Antartica Chilena |

Continued on next page

**Table 16 – continued from previous page**

| N° | Name | Surface (km$^2$) | Region |
|---|---|---|---|
| 5 | Pumalín Douglas Tompkins | 4213,621 | Los Lagos |
| 6 | Patagonia | 2982,632 | Aysen |
| 7 | Corvovado | 2837,088 | Los Lagos |
| 8 | Llullaillaco | 2679,012 | Antofagasta |
| 9 | Vicente Perez Rosales | 2275,166 | Los Lagos |
| 10 | Torres del Paine | 2145,112 | Magallanes y la Antartica Chilena |
| 11 | Volcan Isluga | 1695,950 | Tarapaca |
| 12 | Queulat | 1563,473 | Aysen |
| 13 | Isla Magdalena | 1561,532 | Aysen |
| 14 | Yendegaia | 1530,547 | Magallanes y la Antartica Chilena |
| 15 | Cerro Castillo | 1376,750 | Aysen |
| 16 | Lauca | 1372,109 | Arica y Parinacota |
| 17 | Puyehue | 1114,645 | Los Lagos |
| 18 | Melimoyu | 824,435 | Aysen |
| 19 | Conguillio | 584,759 | Araucania |
| 20 | Villarrica | 527,253 | Araucania y Los Rios |
| 21 | Nevado de Tres Cruces | 526,844 | Atacama |
| 22 | Hornopiren | 471,448 | Los Lagos |
| 23 | Llanos de Challes | 451,449 | Atacama |
| 24 | Pan de Azucar | 445,926 | Atacama |
| 25 | Chiloe | 417,986 | Los Lagos |
| 26 | Alerce Andino | 384,507 | Los Lagos |
| 27 | Cabo de Hornos | 372,917 | Magallanes y la Antartica Chilena |
| 28 | Alerce Costero | 244,898 | XIV/X |
| 29 | Isla Guamblin | 147,538 | Aysen |
| 30 | Rio Clarillo | 129,574 | Metropolitana |
| 31 | Laguna de la Laja | 123,011 | Bio Bio |
| 32 | Huerquehue | 120,225 | Araucania |
| 33 | Fray Jorge | 89,857 | Coquimbo |
| 34 | La Campana | 78,751 | Valparaiso |
| 35 | Morro Moreno | 73,074 | Antofagasta |
| 36 | Nahuelbuta | 65,921 | Araucania |
| 37 | Tolhuaca | 63,468 | Araucania |

Continued on next page

**Table 16 – continued from previous page**

| N° | Name | Surface (km$^2$) | Region |
|---|---|---|---|
| 38 | Pali Aike | 51,550 | Magallanes y la Antartica Chilena |
| 39 | Radal Siete Tazas | 39,965 | Maule |
| 40 | Palmas de Cocalan | 32,818 | Libertador Bernardo O Higgins |
| 41 | Nonguen | 28,639 | Bio Bio |

Notes: This table shows a list of the 41 national National Parks considered in this study. The surface area protected by each protected area is shown in $km^2$ and the respective region in which it is located.

Source: Own elaboration based on Pliscoff, 2022.

Table 17: List of National Reserves

| N° | Name | Surface (km$^2$) | Region |
|---|---|---|---|
| 1 | Las Guaitecas | 10663,416 | Aysen |
| 2 | Katalalixar | 7129,162 | Aysen |
| 3 | Las Vicunas | 2018,662 | Arica y Parinacota |
| 4 | Pampa del Tamarugal | 1025,223 | Tarapaca |
| 5 | Nuble | 749,427 | XVI/VIII |
| 6 | Los Flamencos | 733,050 | Antofagasta |
| 7 | Villarrica | 482,780 | Araucania |
| 8 | Rio Simpson | 419,018 | Aysen |
| 9 | Rio de los Cipreses | 380,387 | Libertador Bernardo O Higgins |
| 10 | Llanquihue | 338,669 | Los Lagos |
| 11 | Lago Palena | 337,405 | Los Lagos |
| 12 | Alto Bio Bio | 307,895 | Araucania |
| 13 | Las Nalcas | 201,476 | Araucania |
| 14 | Magallanes | 200,376 | Magallanes y la Antartica Chilena |
| 15 | Laguna Parrillar | 188,127 | Magallanes y la Antartica Chilena |
| 16 | Lago Carlota | 183,026 | Aysen |
| 17 | Altos de Pemehue | 182,710 | Bio Bio |
| 18 | Lago Las Torres | 167,277 | Aysen |

Continued on next page

**Table 17 – continued from previous page**

| N° | Name | Surface (km$^2$) | Region |
|---|---|---|---|
| 19 | Malleco | 158,221 | Araucania |
| 20 | Malalcahuello | 136,719 | Araucania |
| 21 | Ralco | 133,705 | Bio Bio |
| 22 | Lago Rosselot | 122,873 | Aysen |
| 23 | Futaleufu | 118,519 | Los Lagos |
| 24 | Altos de Lircay | 114,781 | Maule |
| 25 | China Muerta | 85,501 | Araucania |
| 26 | Mocho Choshuenco | 75,541 | XIV/X |
| 27 | Penuelas | 62,735 | Valparaiso |
| 28 | Robleria del Cobre Loncha | 60,077 | Libertador Bernardo O Higgins |
| 29 | Rio Blanco | 43,709 | Valparaiso |
| 30 | Las Chinchillas | 42,700 | Coquimbo |
| 31 | La Chimba | 25,834 | Antofagasta |
| 32 | Coyhaique | 22,349 | Aysen |
| 33 | Huemules de Niblinto | 21,812 | XVI/VIII |
| 34 | Isla Mocha | 20,293 | Bio Bio |
| 35 | Trapananda | 20,273 | Aysen |
| 36 | Radal Siete Tazas | 10,132 | Maule |
| 37 | Los Bellotos del Melado | 4,434 | Maule |
| 38 | El Yali | 3,656 | Valparaiso |
| 39 | Pinguino de Humboldt | 2,791 | Coquimbo |
| 40 | Los Queules | 1,428 | Maule |
| 41 | Laguna Torca | 1,379 | Maule |
| 42 | Los Ruiles | 0,580 | Maule |

Notes: This table shows a list of the 42 national Natural Reserves considered in this study. The surface area protected by each protected area is shown in $km^2$ and the respective region in which it is located.

Source: Own elaboration based on Pliscoff, 2022.

Table 18: List of national Nature Sanctuaries

| N° | Name | Surface (km$^2$) | Region |
|---|---|---|---|
| 1 | Río Cochiguaz | 490,713 | Coquimbo |
| 2 | Fundo Yerba Loca | 436,697 | Metropolitana |
| 3 | Estero Derecho | 316,229 | Coquimbo |
| 4 | Meullín-Puye | 280,837 | Aysen |
| 5 | Alto Huemul | 184,808 | VI/VII |
| 6 | Quebrada de Chacarilla | 160,697 | Tarapaca |
| 7 | Predio San Francisco de Lagunilla y Quillayal | 143,132 | Metropolitana |
| 8 | Valle de La Luna y parte de la Sierra de Orbate | 116,730 | Antofagasta |
| 9 | Los Nogales | 108,949 | Metropolitana |
| 10 | Predio Los Huemules del Ñiblinto | 100,813 | Bio Bio |
| 11 | Salar del Huasco | 99,499 | Tarapaca |
| 12 | El Zaino-Laguna El Copín | 66,482 | Valparaiso |
| 13 | Alerzales existentes en el Fundo Potrero de Anay | 62,242 | Los Lagos |
| 14 | Bahia Lomas | 54,103 | Magallanes y la Antartica Chilena |
| 15 | Humedales del Río Maullín | 44,675 | Los Lagos |
| 16 | Cajon del Río Achibueno | 43,474 | Maule |
| 17 | Río Cruces y Chorocomayo | 38,241 | Los Lagos |
| 18 | Humedales de la Cuenca del Chepu | 28,522 | Los Lagos |
| 19 | Predio Sector Altos de Cantillana | 27,428 | Metropolitana |
| 20 | Serranía el Cipres - Compañía de Tabaco | 27,361 | Valparaiso |
| 21 | Predio Cascada de las Animas | 25,578 | Metropolitana |
| 22 | Estero de Quitralco | 24,961 | Aysen |
| 23 | Huillinco-Cucao | 24,087 | Los Lagos |
| 24 | Raja de Manquehua-Poza Azul | 22,421 | Coquimbo |
| 25 | El Ajial | 21,339 | Metropolitana |
| 26 | Península de Hualpén | 21,227 | Bio Bio |
| 27 | Cerro Poqui | 20,369 | Libertador Bernardo O Higgins |
| 28 | Horcón de Piedra | 19,682 | Metropolitana |
| 29 | Humedales de Angachilla | 18,493 | Los Rios |
| 30 | Quebrada de Llau-Llau | 17,787 | Coquimbo |
| 31 | San Juan de Piche | 16,137 | Metropolitana |
| 32 | Laguna Tebenquiche | 12,986 | Antofagasta |
| 33 | Humedal La Boca | 11,293 | Coquimbo |
| 34 | Llancahue | 11,192 | Los Rios |

Continued on next page

**Table 18 – continued from previous page**

| N° | Name | Surface (km$^2$) | Region |
|---|---|---|---|
| 35 | Quebrada de La Plata | 11,008 | Metropolitana |
| 36 | Predio El Morrillos | 10,599 | Maule |
| 37 | Itata-Gualaguala | 9,032 | Antofagasta |
| 38 | Sector del Cerro El Roble | 8,953 | Metropolitana |
| 39 | Las Torcazas de Pirque | 8,255 | Metropolitana |
| 40 | Desembocadura Río Loa | 7,061 | Tarapaca |
| 41 | Cerro Santa Inés | 6,554 | Coquimbo |
| 42 | Humedal Salinas de Pullally-Dunas de Longotoma | 6,469 | Valparaiso |
| 43 | Humedales Costeros de Putú-Huenchullami | 4,969 | Maule |
| 44 | Área de Palma Chilena de Monte Aranda | 4,767 | Coquimbo |
| 45 | Acantilados Federico Santa María | 3,813 | Valparaiso |
| 46 | Humedal Costero de Totoral | 3,688 | Atacama |
| 47 | Ojo de Opache | 3,516 | Antofagasta |
| 48 | Cerro Dragón | 3,182 | Tarapaca |
| 49 | El Natri | 2,617 | Bio Bio |
| 50 | Laguna de Batuco | 2,587 | Metropolitana |
| 51 | Palmar El Salto | 2,581 | Valparaiso |
| 52 | Turberas de Púlpito | 2,403 | Los Lagos |
| 53 | Humedal de Reloca | 2,321 | Maule |
| 54 | Bahia Quilo | 2,282 | Los Lagos |
| 55 | Laguna Grande - Humedal Los Batros | 2,246 | Bio Bio |
| 56 | Desembocadura del Río Limarí | 1,889 | Coquimbo |
| 57 | Humedal Arauco -Desembocadura Río Carampangue | 1,600 | Bio Bio |
| 58 | Playa Tunquén-Quebrada Seca | 1,162 | Valparaiso |
| 59 | Desembocadura Río Copiapó | 1,153 | Atacama |
| 60 | Quebrada de Cordova | 1,067 | Valparaiso |
| 61 | Humedal de Tongoy | 1,065 | Coquimbo |
| 62 | Los Maitenes del Río Claro | 1,044 | Maule |
| 63 | Piedra del Viento y Topocalma | 1,022 | Libertador Bernardo O Higgins |
| 64 | Laguna Torca | 0,705 | Maule |
| 65 | Arcos de Calán | 0,645 | Maule |
| 66 | Islote y Lobería Iglesia de Piedra | 0,633 | Nuble |
| 67 | Bahia Quinchao | 0,623 | Los Lagos |
| 68 | Humedal de Tunquén | 0,611 | Valparaiso |
| 69 | Humedal del Río Maipo | 0,597 | Valparaiso |

Continued on next page

**Table 18 – continued from previous page**

| N° | Name | Surface (km$^2$) | Region |
|---|---|---|---|
| 70 | Humedal Costero Putemun | 0,524 | Los Lagos |
| 71 | Laguna Conchalí | 0,509 | Coquimbo |
| 72 | Humedal costero Cariizal Bajo | 0,467 | Atacama |
| 73 | Granito orbicular | 0,400 | Atacama |
| 74 | Turberas de Aucar | 0,275 | Los Lagos |
| 75 | Rocas de Constitución | 0,243 | Maule |
| 76 | Parque Katalapi | 0,207 | Los Lagos |
| 77 | Curaco de Velez | 0,091 | Los Lagos |
| 78 | Turberas de Punta Lapa | 0,074 | Los Lagos |
| 79 | Humedal de la Desembocadura del Río Lluta | 0,066 | Arica y Parinacota |
| 80 | Islote Pajaros Niños | 0,045 | Valparaiso |
| 81 | Las Petras de Quintero y su Entorno | 0,040 | Valparaiso |
| 82 | Laguna El Peral | 0,039 | Valparaiso |
| 83 | Campo dunar de la Punta de Concón | 0,034 | Valparaiso |
| 84 | Humedales la Chimba | 0,022 | Antofagasta |
| 85 | Islote o Peñon de Peña Blanca | 0,020 | Valparaiso |

Notes: This table shows a list of the 85 national Nature Sanctuaries considered in this study. The surface area protected by each protected area is shown in $km^2$ and the respective region in which it is located.

Source: Own elaboration based on Pliscoff, 2022.

Table 23 shows the list of private protected areas without considering duplicates.

Table 19: List of Private Protected Areas (without duplicates)

| N° | Name | Surface (km$^2$) | Region |
|---|---|---|---|
| 1 | Parque Karukinka | 2991,849 | Magallanes y la Antartica Chilena |
| 2 | Comunidad Agrícola Diaguita Los Huascoaltinos | 2249,933 | Atacama |
| 3 | Parque Tantauco | 1069,867 | Los Lagos |
| 4 | Cerro Guido | 1037,174 | Magallanes y la Antartica Chilena |
| 5 | Reserva Biológica Huilo Huilo | 532,252 | Los Rios |
| 6 | Reserva Costera Valdiviana | 468,899 | Los Rios |

Continued on next page

**Table 19 – continued from previous page**

| N° | Name | Surface (km$^2$) | Region |
|---|---|---|---|
| 7 | Complejo Torres del Paine Matetic | 365,177 | Magallanes y la Antartica Chilena |
| 8 | San Ignacio del Huinay | 344,616 | Los Lagos |
| 9 | Parque Tepuhueico | 208,792 | Los Lagos |
| 10 | Territorio de Conservación Indígena de Quinquén | 179,131 | Araucania |
| 11 | Reserva Elemental Melimoyu | 161,663 | Aysen |
| 12 | Parque Andino Juncal | 145,882 | Valparaiso |
| 13 | Parque Hacienda El Durazno | 120,728 | Coquimbo |
| 14 | Parque Futangue | 96,187 | Los Lagos |
| 15 | Parque Guaiquivilo | 87,956 | Maule |
| 16 | Bien Nacional Protegido Laguna Caiquenes | 86,240 | Aysen |
| 17 | Parque Etnobotánico Omora | 75,560 | Magallanes y la Antartica Chilena |
| 18 | Santuario de la Naturaleza Los Huemules de Niblinto | 71,860 | Nuble |
| 19 | Reserva Explora | 61,680 | Magallanes y la Antartica Chilena |
| 20 | Reserva Las Torres | 46,235 | Magallanes y la Antartica Chilena |
| 21 | Parque Natural Aguas de Ramón | 36,558 | Metropolitana |
| 22 | Reserva Natural Pinguino Rey | 34,155 | Magallanes y la Antartica Chilena |
| 23 | Parque Tagua Tagua | 27,791 | Los Lagos |
| 24 | Parque del Estuario | 26,160 | Los Lagos |
| 25 | Parque Quizapú | 21,815 | Maule |
| 26 | Reserva Puritama | 21,638 | Antofagasta |
| 27 | Reserva Ecológica Oasis de la Campana | 21,625 | Valparaiso |
| 28 | Proyecto Pichimahuida, Valle Leones | 20,176 | Aysen |
| 29 | Bosques de Tinguiririca | 15,672 | Libertador Bernardo O Higgins |
| 30 | Reserva Nasampulli | 12,631 | Araucania |
| 31 | Estancia Primavera | 12,468 | Magallanes y la Antartica Chilena |
| 32 | Red de Parques Mapu Lahual | 11,792 | Los Lagos |
| 33 | Parque Natural San Carlos de Apoquindo | 10,427 | Metropolitana |
| 34 | Parque Natural Puente Ñilhue | 9,906 | Metropolitana |
| 35 | Parque Cerro Viejo | 8,908 | Valparaiso |
| 36 | Bosque Pehuen | 8,570 | Araucania |
| 37 | Parque Oncol | 8,109 | Los Rios |
| 38 | Colbún | 5,847 | Los Lagos |
| 39 | Punta de Vitts | 5,751 | Aysen |
| 40 | Parque Tricahue | 5,717 | Maule |
| 41 | Parque Ahuenco | 5,672 | Los Lagos |

Continued on next page

**Table 19 – continued from previous page**

| N° | Name | Surface (km$^2$) | Region |
|---|---|---|---|
| 42 | Humedales de Chepu | 5,279 | Los Lagos |
| 43 | Reserva Las Mulas | 5,079 | Maule |
| 44 | Santuario El Cañi | 5,035 | Araucania |
| 45 | Parque Natural Quebrada de Macul | 4,952 | Metropolitana |
| 46 | Predio Palmar de Lillahue | 4,914 | Metropolitana |
| 47 | Parque Cordillera Los Quemados | 3,929 | Maule |
| 48 | Reserva Madre Selva | 3,654 | Araucania |
| 49 | Reserva Ecológica Tesoro del Pangal | 3,509 | Valparaiso |
| 50 | Reseva Las Animas | 2,561 | Maule |
| 51 | Parque Aiken del Sur | 2,334 | Aysen |
| 52 | Aguila Sur | 2,322 | Metropolitana |
| 53 | Parque La Giganta | 1,895 | Valparaiso |
| 54 | Reserva Los Copihues | 1,771 | Maule |
| 55 | Termas de Sotomó | 1,710 | Los Lagos |
| 56 | Bioparque Austral | 1,511 | Los Lagos |
| 57 | Reserva Elemental Likandes | 1,479 | Metropolitana |
| 58 | Senda Nativa Romahue | 1,418 | Los Lagos |
| 59 | Área Silvestre Protegida Los Pellines | 1,332 | Nuble |
| 60 | Parque Juan Melillanca Huanqui | 1,176 | Los Lagos |
| 61 | Estación Biológica Senda Darwin | 1,161 | Los Lagos |
| 62 | Reserva Añihue | 1,010 | Aysen |
| 63 | Parque El Pudu | 0,956 | Los Lagos |
| 64 | Reserva Costera Punta Curiñanco | 0,846 | Los Rios |
| 65 | Parque El Boldo | 0,835 | Valparaiso |
| 66 | Parque Alfonso Brandt | 0,720 | Los Rios |
| 67 | Reserva Nahuelbuta Este | 0,573 | Araucania |
| 68 | DRC Don Weeden | 0,567 | Los Lagos |
| 69 | Parque Eólico de Lebu-Toro | 0,473 | Bio Bio |
| 70 | APP Cumbres de Pichoy | 0,454 | Los Rios |
| 71 | Predio El Encanto | 0,294 | Los Lagos |
| 72 | Altos de Cutipay | 0,262 | Los Rios |
| 73 | Reserva Ecologica Puquelinhue | 0,219 | Los Lagos |
| 74 | Parque CEA Nativo | 0,105 | Bio Bio |
| 75 | Parque Urbano El Bosque | 0,056 | Los Rios |
| 76 | Ecoreserva Quebrada Escobares | 0,054 | Valparaiso |

Continued on next page

**Table 19 – continued from previous page**

| N° | Name | Surface (km$^2$) | Region |
|---|---|---|---|
| 77 | Parque Nacional Las Palmas de Cocalán | 0,043 | Libertador Bernardo O Higgins |
| 78 | Estación Científica Altamira de Isla del Rey | 0,038 | Los Rios |
| 79 | Reserva Pelluco | 0,030 | Los Rios |
| 80 | Parque Punta de Lobos | 0,004 | Libertador Bernardo O Higgins |
| 81 | DRC Rocio Gonzalez | 0,003 | Los Lagos |

Notes: This table shows a list of the 81 national Private Protected Areas considered in this study. The surface area protected by each protected area is shown in $km^2$ and the respective region in which it is located.

Source: Own elaboration based on Pliscoff, 2022.

Table 24 show the list of duplicated private protected areas that were removed from the data and their respective nature sanctuary pair.

Table 20: List of duplicates pairs

| N° | Name | Type | Group |
|---|---|---|---|
| 1 | Laguna Tebenquiche | Santuario de la Naturaleza | 1 |
| 2 | Santuario de la Naturaleza Laguna Tebenchique | Area Protegida Privada | 1 |
| 3 | Península de Hualpén | Santuario de la Naturaleza | 2 |
| 4 | Santuario de la Naturaleza Península de Hualpén | Area Protegida Privada | 2 |
| 5 | El Natri | Santuario de la Naturaleza | 3 |
| 6 | Santuario de la Naturaleza El Natri | Area Protegida Privada | 3 |
| 7 | Estero Derecho | Santuario de la Naturaleza | 4 |
| 8 | Santuario de la Naturaleza Estero Derecho | Area Protegida Privada | 4 |
| 9 | Santuario de la Naturaleza Raja de Manquehua - Poza Azul | Area Protegida Privada | 5 |
| 10 | Raja de Manquehua-Poza Azul | Santuario de la Naturaleza | 5 |
| 11 | Quebrada de Llau-Llau | Santuario de la Naturaleza | 6 |
| 12 | Santuario de la Naturaleza Quebrada de Llau Llau | Area Protegida Privada | 6 |
| 13 | Cerro Santa Inés | Santuario de la Naturaleza | 7 |
| 14 | Santuario de la Naturaleza Cerro Santa Inés | Area Protegida Privada | 7 |
| 15 | Área de Palma Chilena de Monte Aranda | Santuario de la Naturaleza | 8 |
| 16 | Santuario de la Naturaleza Área de Palma Chilena de Monte Aranda | Area Protegida Privada | 8 |
| 17 | Laguna Conchalí | Santuario de la Naturaleza | 9 |
| 18 | Santuario de la Naturaleza Laguna Conchalí | Area Protegida Privada | 9 |
| 19 | Santuario de la Naturaleza Alto Huemul | Area Protegida Privada | 10 |
| 20 | Alto Huemul | Santuario de la Naturaleza | 10 |

Continued on next page

**Table 20 – continued from previous page**

| N° | Name | Type | Group |
|---|---|---|---|
| 21 | Cerro Poqui | Santuario de la Naturaleza | 11 |
| 22 | Cerro Poqui | Area Protegida Privada | 11 |
| 23 | Santuario de la Naturaleza Cerro Poqui | Area Protegida Privada | 11 |
| 24 | Piedra del Viento y Topocalma | Santuario de la Naturaleza | 12 |
| 25 | Santuario de la Naturaleza Piedra del Viento y Topocalma | Area Protegida Privada | 12 |
| 26 | Humedales de la Cuenca del Chepu | Santuario de la Naturaleza | 13 |
| 27 | Santuario de la Naturaleza Humedales de Chepu | Area Protegida Privada | 13 |
| 28 | Santuario de la Naturaleza Parque Katalapi | Area Protegida Privada | 14 |
| 29 | Parque Katalapi | Santuario de la Naturaleza | 14 |
| 30 | Bahia Lomas | Santuario de la Naturaleza | 15 |
| 31 | Santuario de la Naturaleza Bahía Lomas | Area Protegida Privada | 15 |
| 32 | Predio El Morrillos | Santuario de la Naturaleza | 16 |
| 33 | Santuario de la Naturaleza El Morrillo | Area Protegida Privada | 16 |
| 34 | Humedales Costeros de Putú-Huenchullami | Santuario de la Naturaleza | 17 |
| 35 | Santuario de la Naturaleza Humedales Costeros de Putú-Huenchullami | Area Protegida Privada | 17 |
| 36 | Humedal de Reloca | Santuario de la Naturaleza | 18 |
| 37 | Santuario de la Naturaleza Humedal de Reloca | Area Protegida Privada | 18 |
| 38 | Los Maitenes del Río Claro | Santuario de la Naturaleza | 19 |
| 39 | Santuario de la Naturaleza Maitenes del Río Claro | Area Protegida Privada | 19 |
| 40 | Fundo Yerba Loca | Santuario de la Naturaleza | 20 |
| 41 | Santuario de la Naturaleza Yerba Loca | Area Protegida Privada | 20 |
| 42 | Santuario de la Naturaleza San Francisco de Lagunillas y Quillayal | Area Protegida Privada | 21 |
| 43 | Predio San Francisco de Lagunilla y Quillayal | Santuario de la Naturaleza | 21 |
| 44 | Los Nogales | Santuario de la Naturaleza | 22 |

Continued on next page

**Table 20 – continued from previous page**

| N° | Name | Type | Group |
|---|---|---|---|
| 45 | Santuario de la Naturaleza los Nogales | Area Protegida Privada | 22 |
| 46 | Predio Cascada de las Animas | Santuario de la Naturaleza | 23 |
| 47 | Santuario de la Naturaleza Cascada de Las Animas | Area Protegida Privada | 23 |
| 48 | Santuario de la Naturaleza El Ajial | Area Protegida Privada | 24 |
| 49 | El Ajial | Santuario de la Naturaleza | 24 |
| 50 | Santuario de la Naturaleza Horcón de Piedra | Area Protegida Privada | 25 |
| 51 | Horcón de Piedra | Santuario de la Naturaleza | 25 |
| 52 | San Juan de Piche | Santuario de la Naturaleza | 26 |
| 53 | Santuario de la Naturaleza San Juan de Piche | Area Protegida Privada | 26 |
| 54 | Quebrada de La Plata | Santuario de la Naturaleza | 27 |
| 55 | Santuario de la Naturaleza Quebrada de la Plata | Area Protegida Privada | 27 |
| 56 | Santuario de la Naturaleza Cerro el Roble | Area Protegida Privada | 28 |
| 57 | Sector del Cerro El Roble | Santuario de la Naturaleza | 28 |
| 58 | Las Torcazas de Pirque | Santuario de la Naturaleza | 29 |
| 59 | Santuario de la Naturaleza Las Torcazas de Pirque | Area Protegida Privada | 29 |
| 60 | Laguna de Batuco | Santuario de la Naturaleza | 30 |
| 61 | Santuario de la Naturaleza Laguna de Batuco | Area Protegida Privada | 30 |
| 62 | Santuario de la Naturaleza El Zaino - Laguna El Copín | Area Protegida Privada | 31 |
| 63 | El Zaino-Laguna El Copín | Santuario de la Naturaleza | 31 |
| 64 | Serranía el Cipres | Santuario de la Naturaleza | 32 |
| 65 | Santuario de la Naturaleza Serranía El Ciprés | Area Protegida Privada | 32 |
| 66 | Santuario de la Naturaleza Humedal Salinas de Pullally - Dunas de Longotoma | Area Protegida Privada | 33 |
| 67 | Humedal Salinas de Pullally-Dunas de Longotoma | Santuario de la Naturaleza | 33 |
| 68 | Palmar El Salto | Santuario de la Naturaleza | 34 |

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**Table 20 – continued from previous page**

| N° | Name | Type | Group |
|---|---|---|---|
| 69 | Santuario de la Naturaleza Palmar el Salto | Area Protegida Privada | 34 |
| 70 | Santuario de la Naturaleza Humedal de Tunquen | Area Protegida Privada | 35 |
| 71 | Humedal de Tunquén | Santuario de la Naturaleza | 35 |
| 72 | Quebrada de Cordova | Santuario de la Naturaleza | 36 |
| 73 | Santuario de la Naturaleza Quebrada de Córdova | Area Protegida Privada | 36 |
| 74 | Humedal del Río Maipo | Santuario de la Naturaleza | 37 |
| 75 | Santuario de la Naturaleza Humedal del Río Maipo | Area Protegida Privada | 37 |
| 76 | Santuario de la Naturaleza Campo Dunar de la Punta de Concón | Area Protegida Privada | 38 |
| 77 | Campo dunar de la Punta de Concón | Santuario de la Naturaleza | 38 |
| 78 | Santuario de la Naturaleza Altos de Cantillana | Area Protegida Privada | 39 |
| 79 | Predio Sector Altos de Cantillana | Santuario de la Naturaleza | 39 |

Notes: This table shows a list of the 79 duplicates considered in this study, their category and their duplicate pair. In the case of Cerro Poqui there is a triplicate.

Source: Own elaboration based on Pliscoff, 2022.