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Nitrate Concentrations in Rural Potable Water Wells From Eight Regions of Chile

Daniela Margarita Fredes-Muñoz and Diego Julian San Miguel-Cornejo

Department of Conservation and Preservation of Water Resources, National Water Agency (DGA), Chile

Abstract: Nitrogen exists naturally forming part of the biotic and abiotic, but input from fertilizers overuse as nitrate is increasing it polluting water sources, impairing human and ecosystem's health. This is important in Chile when it's facing the warmest decade of the last century with a decrease in precipitation in the north and central macroregions. A groundwater quality monitoring network using rural water wells is managed since 2014 by the DGA in 8 Chilean regions: Coquimbo, Valparaiso, Metropolitana, O'Higgins, Maule, Ñuble, Biobio and Los Rios. The data gathered between 2014-2019 considers field parameters and nitrate, which are analysed in this paper to identify the physicochemical characteristics of the groundwater of the regions and its aquifers, and also to diagnose the nitrate concentration "state" using a warning limit of 30 mg NO_3/L and the maximum concentration recommended by the national guideline for potable use (NCh 409 of. 2005) of 50 mg NO_3/L. The results indicate that nitrate concentrations are mostly below 50 mg NO_3/L, with Coquimbo, Valparaiso and Metropolitana as the regions with the highest concentrations, and with quality improving towards south. Data length among regions and within aquifer is low calling for an urgent increase in monitoring frequency, mostly coverage. Nevertheless, it's possible to recommend preservation efforts of groundwater in aquifers from the 8 regions, and also highlight that aquifers Culebron-Lagunillas, "Sin Informacion", Aconcagua, Casablanca, Maipo, Cachapoal, Tinguiririca, Mataquito and Maule-Medio are not providing water with quality enough for potable purposes without nitrate treatment.

Key words: nitrate pollution, groundwater quality in Chile, Rural Water Wells (APR), National Water Agency (DGA) monitoring network

1. Introduction

Chile is a country located between parallels 17°29' and 55°58' south of the southern American continent, it limits north with Peru, east with Argentina through the Andes ranges, west with the Pacific Ocean and south with the Antarctica, it has a length of 4300 km and a surface of 756102.4 km^2. It's divided into 16 administrative regions, which are distributed along 4 macroregions; North, Centre, South and Austral [1] (Fig. 1). Chile's long and narrow geography allows for several types of weather and environment; desert in the far North, mediterranean valleys in the near North and Centre, and rain forest in the South and Austral areas [2]. Chile is considered privileged water wise because total mean runoff calculated from surface and groundwater reaches a national average of 51218 m^3/person/year, a value higher than the world average of 6600 m^3/person/year and even higher than the 2000 m^3/person/year considered as the target for a sustainable development [3]. However when breaking down this indicator within the macroregions the heterogeneity of the country is evident, e.g., in the Metropolitan region (Centre macroregion) the average runoff is below 500 m^3/person/year whereas in Aysen region (Autral macroregion) it reaches 2950168 m^3/person/year [4].

Since 2010 the regions between Coquimbo and La Araucania have experienced a decrease in precipitations close to a 30%, which has persisted since

Corresponding author: Daniela Margarita Fredes-Muñoz, Master, Environmental Chemist; research areas/interests: water quality. E-mail: daniela.fredes@mop.gov.cl.

then turning this last decade into the warmest in the last century. This event is called “mega drought” [5].

In Chile the use of groundwater for human consumption in urban areas reaches a 40% of the total consumption volume. For rural areas this percentage doubles (83%) from Metropolitana to Biobio [6]. This information is important when considering the drought scenario and the search for new water sources, with a preferential focus in less exploited aquifers (deeper ones) [7].

The diversity in water availability in Chile enables the development of a wide range of economic activities, being the most important mining and agriculture, the later representing 73% of the country’s water demand [8] and being the most inefficient activity related to water use according to SDG indicator 6.4.1 (Agriculture: 0.2 USD/m^3, Industry[1]: 15.6 USD/m^3 and Services: 71.0 USD/m^3) [9].

Agriculture is closely related to diffuse pollution and the increase of different compounds in water courses and aquifers such as nitrogen in its most common forms of ammonia and nitrate [10]. Nitrate is an inorganic compound found in nature playing an important role in the nitrogen cycle [11], the nitrate molecule is very soluble and it can be transported through water easily, traveling long distances on and below the surface [11]. Nitrate’s inputs to an ecosystem can come from urban areas and industry waste (animal farming), it can also be produced synthetically and used in many industrial purposes, such as explosives and fertilizer [12], being the latter one the most important anthropic source of the compound because it’s usually added to the crops in excess [10, 13].

Nitrogen lost to the environment affects surface water and groundwater, and it is recognized by FAO as the most common contaminant found in groundwater aquifers [10]. In the north of Chile agriculture practices causes an increase in salinity in groundwater and soils, this is associated mostly with the low precipitation rate within this macrozone and the efficiency of irrigation technology [14]. In the Central region, specifically in the Aconcagua Valley, another study was conducted indicating that even though nitrate concentrations didn’t reached alarming levels (observing a mean of 4.8 mg N-NO_3/L) it was found that around 52 kg N/ha/a are drained from the study area compared to 167 kg N/ha/a applied as fertilizer to the fields [15]. In southern Chile, where most of the larger lakes are distributed, an excess of nutrient input represents a mayor pollution problem because most of these lakes have low productivities (oligotrophic to mesotrophic) [16], and thus considered particularly threatened.

The recommended concentration of nitrate in drinking water is 10 mg N-NO_3/L (or 50 mg NO_3/L), this threshold’s objective is to avoid blue baby syndrome [17] and it basically means that no human being’s (or animal’s) health should be threatened by consuming this water. However, there is new information indicating that this threshold is too high [18], even the Environmental Protection Agency suggest that safety level is 1 mg N-NO_3/L [10].

Long period consumption studies of nitrate indicate that there was a correlation with lower height-for-age scores in childhood [19-21], and also there is evidence of a correlation with gastric cancer [22] and pathological changes in the thyroid gland (subclinical hypothyroidism and potentially cancer of the thyroid gland) [23].

Nitrate in aquatic ecosystems, particularly lakes, increases primary productivity (algal growth) which can alter considerably the equilibrium of the ecosystems, changing the diversity and population’s equilibrium [24]. In extreme cases a lake’s equilibrium can be disrupted in such a manner that most of the autochthonous species are lost [25].

Nitrogen compounds used as fertilizers boosts crop yields, which is essential for food security, however its management practices are causing pollution with

[1] Mining and quarrying, manufacturing, electricity, gas, steam and air conditioning supply, and constructions - MIMEC (ISIC B, C, D and F).

Fig. 1 General view of Chile and the Study area (Coquimbo, Valparaiso, Metropolitana, O'Higgins, Maule, Ñuble, Biobio and Los Rios).

known consequences in human and ecosystem health, leading to the conclusion that, as the current status indicates, it's a socially inefficient practice [10].

1.1 Water Quality Monitoring in Chile

The National Water Agency (Direccion General de Aguas, DGA) is a public entity dependent from the Ministry of Public Works of Chile. DGA's main task is to quantify, study and manage water, and for that purpose maintains a national monitoring network that gathers information on quantity and quality of water[2]. The water quality network is divided in three main areas: running waters, lakes and groundwater. The groundwater quality network used to have small reach within the country (70 wells in the territory until 2014), however since 2015 the monitoring network was redesigned increasing its density progressively to 737 wells to the present year [26]. This network is monitored in differentiated frequencies depending on the well's water quality [27].

Despite these improvements this monitoring effort is far from comprehensive and dense [16], as an example, water quality analysis by the DGA covers only inorganic components not considering biological parameters, mayor organic pollutants or incipient substances (e.g., microplastics, drugs, pharmaceutical products, etc.) which in general are not studied enough [10]. Several other public services in Chile have water quality monitoring efforts in place (in a smaller scale compared to the DGA), as also the private sector and academia to mention a few, however to date there's no system that consolidate all the information gathered on water quality.

Considering the acute degradation of water, the threats to human health, and the fact that nitrate concentrations in nature are low (meaning that high concentrations are indicatives of pollution) [28, 29] it's considered an urgent matter to socialize and share the state of water quality in Chile, particularly

[2] Chilean Water Code (Código de Aguas Chileno), available online at: https://www.bcn.cl/leychile/navegar?idNorma=5605.

groundwater which is "*hidden*" from the eye, so as the pollution that hinders it availability.

This study focuses on describing the concentration of nitrate in 8 regions of Chile from the characterization project leaded by the DGA and compare it with the national potable water standard addressed by the Norma Chilena of. 409/2005 (NCh 409/05) in order to establish its suitability for use and to discuss the possible threats to the receiving ecosystems.

2. Material and Methods

2.1 Sample Location

The samples were collected from Potable Rural Water wells (APR[3]) distributed along 8 regions in Chile: Coquimbo, Valparaíso, Metropolitana, Libertador Bernardo O'Higgins (O'Higgins), Maule, Ñuble and Biobio, y Los Rios. Ñuble and Biobío will be analized jointly because Ñuble used to be part of Biobio until recently (2017). The DGA has studied, characterized (hydraulically) and delimited Chilean aquifers from Coquimbo to mostly of El Maule region, from Ñuble to Los Rios there're preliminary studies only which provides a broader and less detailed delimitation of aquifer units compared to the northern regions of Chile [1, 4]. This is important because the monitoring stations (wells) were selected in order to represent the aquifer area, which in the case of Coquimbo to El Maule region was easy but in the southern regions was submitted to the preliminary aquifer delimitation by sector (Fig. 2).

2.2 Monitoring Frequency

The monitoring period encompasses between 2014 and 2019. Except for Metropolitana region the initial measurement in each region is the total amount of monitoring points per region, the measurements made in the following years belong to a subset of the initial monitoring effort (i.e., it does not represent new

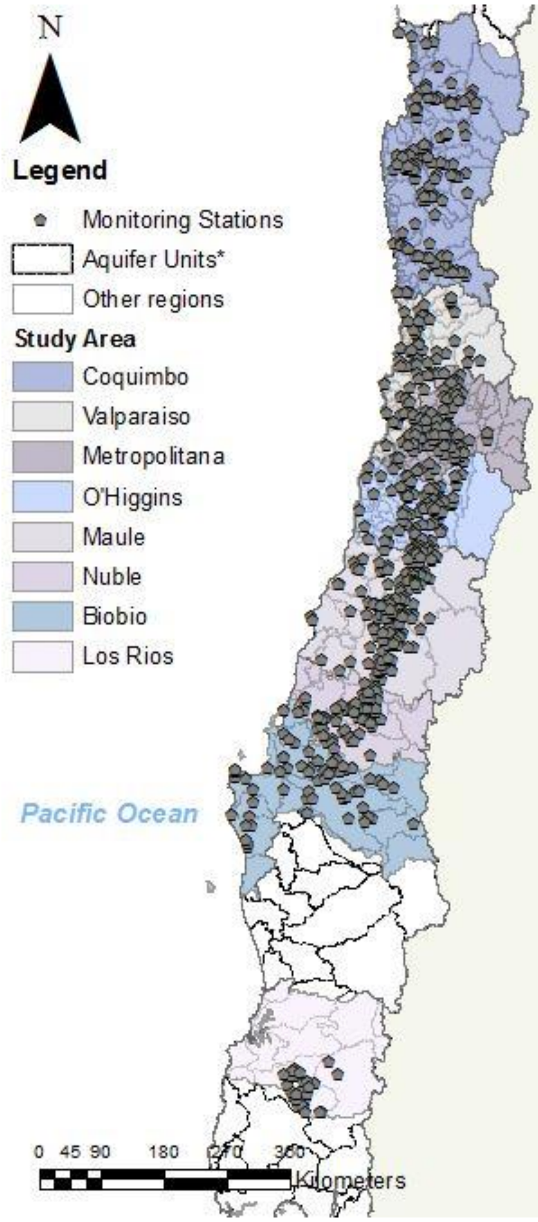


Fig. 2 Monitoring stations in the study area (Coquimbo, Valparaiso, Metropolitana, O'Higgins, Maule, Ñuble, Biobio and Los Rios) and the aquifer unit delimitation. *From Ñuble to the south the aquifer units have a preliminary delimitation only.

monitoring points necessarily), the amount of wells monitored depend on the water quality, if the quality was thought to be compromised for different uses the well was monitored on the next campaign programmed, if not its monitoring was postponed. The tool used to assess water quality is an indicator designed by DGA [30] which is currently used with minor modifications [31].

[3] Agua Potable Rural in spanish.

In Table 1 is the summary of the total amount of monitoring opportunities performed during the study period.

2.3 Analysis Methods

The samples were collected using the national monitoring standard for groundwater quality (Norma Chilena 411/11 of 98)[4]. The equipment used to monitor pH, electrical conductivity (EC) and temperature was a Hanna® multiparameter probe, model HI 98129, and for oxidation-reduction potencial (ORP) a Hanna probe, model HI 98121 was used. A well index card was filled collecting information about the well and its operator (dynamic/static level, depth, water treatment, address, email, phone number, etc.), however it wasn't possible to acquire detailed information about the well screen to identify from which part of the aquifer the sample was being taken.

The wells are equipped with a pump to extract water, which is working constantly, so there was no need to purge the well in most of the cases[5]. There were some cases where purge was performed if considered necessary (usage was not as frequent as needed).

The samples were preserved to analyse nitrate using Standard Methods recommendations (Ed. N°22, 2012). The analysis methodology for nitrate was from Standard Methods 4500-NO3 Ed 22 (2012) from 2014 to 2019. During 2016 two different methodologies were used; Standard Method 4110 B Ed. 22 (2012) and ME-16-2007, this last method is based in Standard Methods for the Examination of Water and Wastewater. APHA. AWWA. WEF. 21th edition 2005, Part 4500-D: Nitrate Selective Electrode Method.

Table 1 Measurement opportunity per region during the study period. Blank cells indicate no measurement.

Region/Year	2014	2015	2016	2017	2018	2019
Coquimbo			119	15	44	17
Valparaiso		49	21	10	26	8
Metropolitana		46	46		94	73
O'Higgins	70	40	20	18	15	6
Maule				150	50	14
Ñuble-Biobio					105	12
Los Rios						28

Calculations of summary statistics and graphs were performed using RStudio (Version 1.3.959) software.

3. Results and Discussion

3.1 General Description of Field Measurements of Each Aquifer Unit per Region

The following analysis is developed to identify the main chemical characteristics of the water in each aquifer unit and region presenting a table with a summary of the main statistics (Table 2). To illustrate the conductivity variability within a region was used a box plot graph with the following characteristics: the limits of the box are the first (P_{25}) and third (P_{75}) quartiles, the middle bar is the median, the dots are the outliers and the whiskers are the minimum and maximum values calculated as follows (IQR: Interquartile range):

$$\mathrm{Min} = P_{25} - 1.5\ \mathrm{IQR}$$

$$\mathrm{Max} = P_{25} + 1.5\ \mathrm{IQR}$$

In Coquimbo we observe a wide range of conductivities, encompassing a range between 147 and 7082 uS/cm (Table 1). The aquifers with the highest conductivity medians are Culebron-Lagunillas (1826 uS/cm) and those under the category "Sin Informacion"[6] (5291 uS/cm) (Fig. 3). The pH values indicate that all the samples fall within neutral (6.5-7.8 pH units) and slightly basic ranges (7.8-9.0 pH units), not lowering from 6.5 nor increasing over 8.5 pH units [32] (Table 1), indicating that the samples provide an oxidant environment for chemical reactions [25].

In Valparaiso the conductivity has a minimum of 177 and a maximum of 2208 uS/cm (Table 2). The

[4] Calidad del agua – Muestreo – Parte 11. Guía para el muestreo de aguas subterráneas.

[5] When wells are not used often the water retained in it changes compared to the water from the aquifer, that's why a well that is pumping constantly will provide a better representation of water quality from the aquifer.

[6] The areas with no hydrogeological studies fall under a general category named "Sin Informacion" which means "No information".

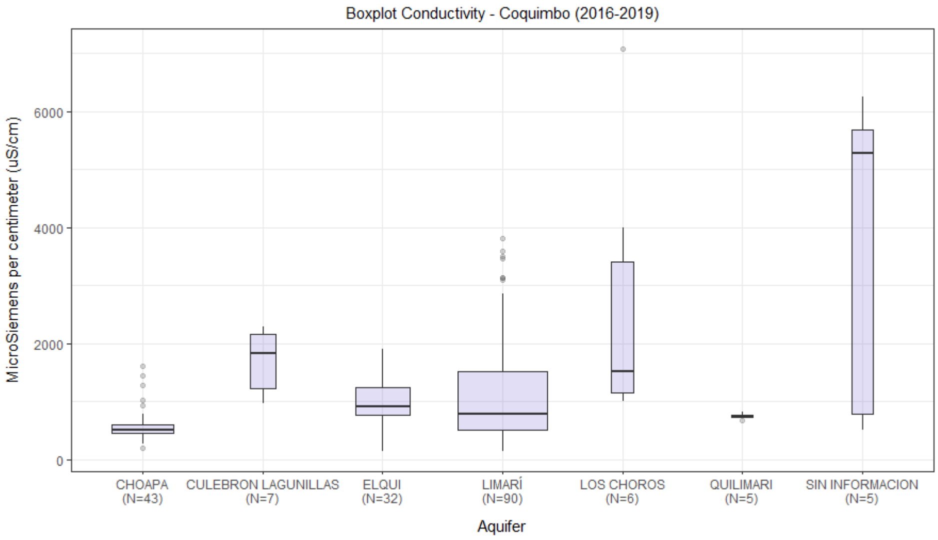
aquifers with the highest medians were Estero Puchuncavi (2063 uS/cm), Maipo Desembocadura (1988 uS/cm) and Estero Guaquen (1671 uS/cm) (Fig. 3). The pH values were located mostly in the neutral range (6.4 and below 7.7 pH units) [32]. The ORP values indicate that the water provides an oxidant environment with values located between -49 and 688 mV (Table 2) [25].

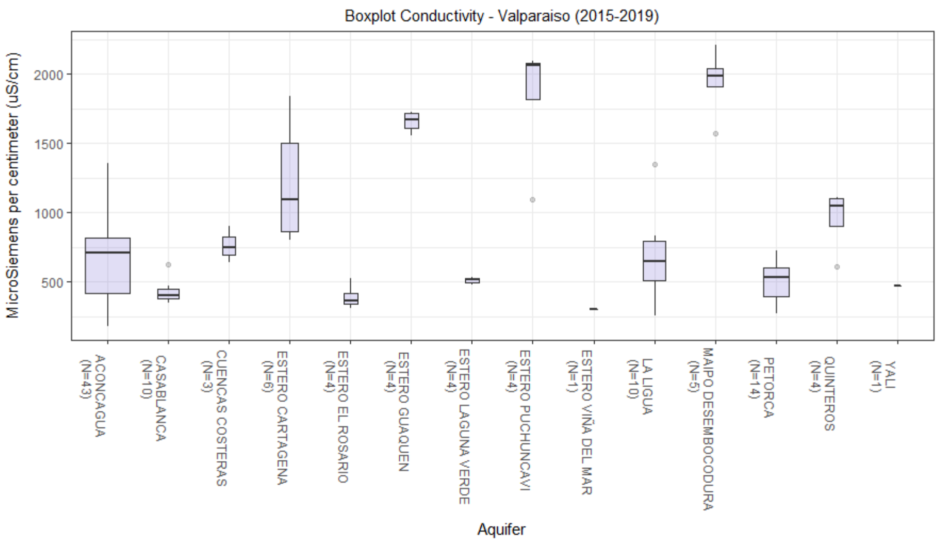
The Metropolitana region has a conductivity range between 125 and 2222 uS/cm (Table 1), identifying that the aquifers Maipo (1113 uS/cm) and Yali (662 uS/cm) have the highest conductivity medians (Fig. 3). The pH values of the region are distributed mostly along neutral and slightly basic values [32], with the lowest value equal to 6.5 and an upper value of 8.9 of pH units (Table 1) [32]. The ORP values indicate that the water provides an oxidant environment with a range of 40 to 631 mV (Table 1).

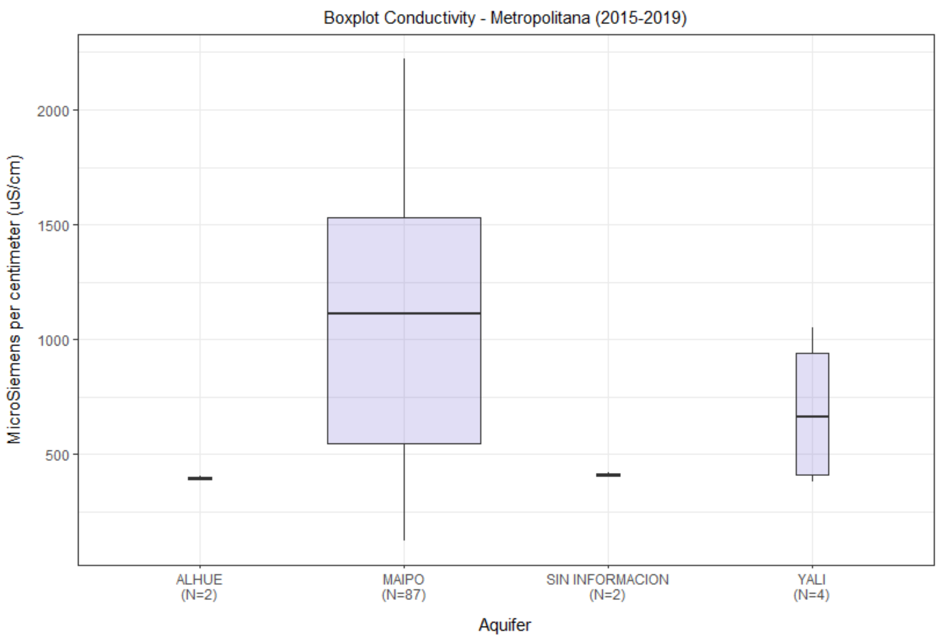
In O'Higgins the conductivity ranges between 148 and 2034 uS/cm, similarly to the ones in Valparaiso and Metropolitana but lower compared to Coquimbo which has higher values (Table 2). The later could be associated with lower precipitation rates in Coquimbo's latitude compared to Valparaiso,

Table 1 Statistical summary of field measurements and nitrate for Coquimbo, Valparaiso, Metropolitana, O'Higgins, Maule, Ñuble - Biobio and Los Rios. EC: Electrical conductivity, ORP: Oxidant-Redox Potencial, NO_3: nitrate.

Region	Parameter	N_{obs}	Min	Max	P_{25}	Median	P_{75}	Mean	Variance	Std.Dev
Coquimbo	EC	188	147	7082	508	764	1327	1127	1148106	1071
Coquimbo	ORP	183	-34	723	113	180	238	183	16556	129
Coquimbo	pH	188	6.2	8.4	6.9	7.2	7.4	7.2	0.1	0.4
Coquimbo	NO_3	195	0.010	168.700	1.671	5.950	17.950	14.903	621.202	24.924
Valparaiso	EC	113	177	2208	424	622	892	772	236993	487
Valparaiso	ORP	110	-49	688	143	251	368	270	31500	177
Valparaiso	pH	105	6.4	7.7	6.9	7.0	7.2	7.0	0.1	0.2
Valparaiso	NO3	114	0.010	111.100	8.818	18.550	31.650	23.638	408.264	20.206
Metropolitana	EC	95	125	2222	511	1017	1524	1049	345662	588
Metropolitana	ORP	135	40	631	207	286	355	281	12197	110
Metropolitana	pH	262	6.5	8.9	7.0	7.0	7.3	7.2	0.1	0.3
Metropolitana	NO_3	259	0.817	150.680	10.533	18.444	32.747	25.307	523.646	22.883
O'Higgins	EC	230	148	2034	478	618	783	640	68478	262
O'Higgins	ORP	75	-12	793	8	167	256	185	27866	167
O'Higgins	pH	231	5.9	8.1	6.8	7.1	7.4	7.1	0.2	0.4
O'Higgins	NO_3	169	0.010	64.200	10.700	20.400	30.000	21.616	220.283	14.842
Maule	EC	215	21	798	154	232	313	254	20677	144
Maule	ORP	160	3	631	139	210	270	224	14557	121
Maule	pH	215	6.0	8.4	6.7	7.1	7.3	7.0	0.2	0.4
Maule	NO_3	214	0.075	72.724	4.514	10.779	17.442	12.847	126.573	11.250
Ñuble-Biobio	EC	116	4	574	108	153	239	184	12026	110
Ñuble-Biobio	ORP	115	-46	371	66	84	117	95	4464	67
Ñuble-Biobio	pH	116	5.8	8.7	6.7	7.1	7.5	7.1	0.3	0.6
Ñuble-Biobio	NO_3	117	0.090	51.860	1.860	4.930	11.340	8.087	84.673	9.202
Los Rios	EC	28	104	361	165	208	262	214	5082	71
Los Rios	ORP	28	-128	428	-59	71	123	54	16908	130
Los Rios	pH	28	6.4	8.0	7.1	7.3	7.5	7.3	0.1	0.3
Los Rios	NO_3	28	0.010	10.530	0.033	1.765	5.970	2.908	10.984	3.314


Boxplot Conductivity - Coquimbo (2016-2019)
MicroSiemens per centimeter (uS/cm)
0
2000
4000
6000
CHOAPA (N=43)
CULEBRON LAGUNILLAS (N=7)
ELQUI (N=32)
LIMARÍ (N=90)
LOS CHOROS (N=6)
QUILIMARI (N=5)
SIN INFORMACION (N=5)
Aquifer


Boxplot Conductivity - Valparaiso (2015-2019)
MicroSiemens per centimeter (uS/cm)
500
1000
1500
2000
ACONCAGUA (N=43)
CASABLANCA (N=10)
CUENCAS COSTERAS (N=3)
ESTERO CARTAGENA (N=6)
ESTERO EL ROSARIO (N=4)
ESTERO GUAQUEN (N=4)
ESTERO LAGUNA VERDE (N=4)
ESTERO PUCHUNCAVI (N=4)
ESTERO VIÑA DEL MAR (N=1)
LA LIGUA (N=10)
MAIPO DESEMBOCODURA (N=5)
PETORCA (N=14)
QUINTEROS (N=4)
YALI (N=1)
Aquifer


Boxplot Conductivity - Metropolitana (2015-2019)
MicroSiemens per centimeter (uS/cm)
500
1000
1500
2000
ALHUE (N=2)
MAIPO (N=87)
SIN INFORMACION (N=2)
YALI (N=4)
Aquifer

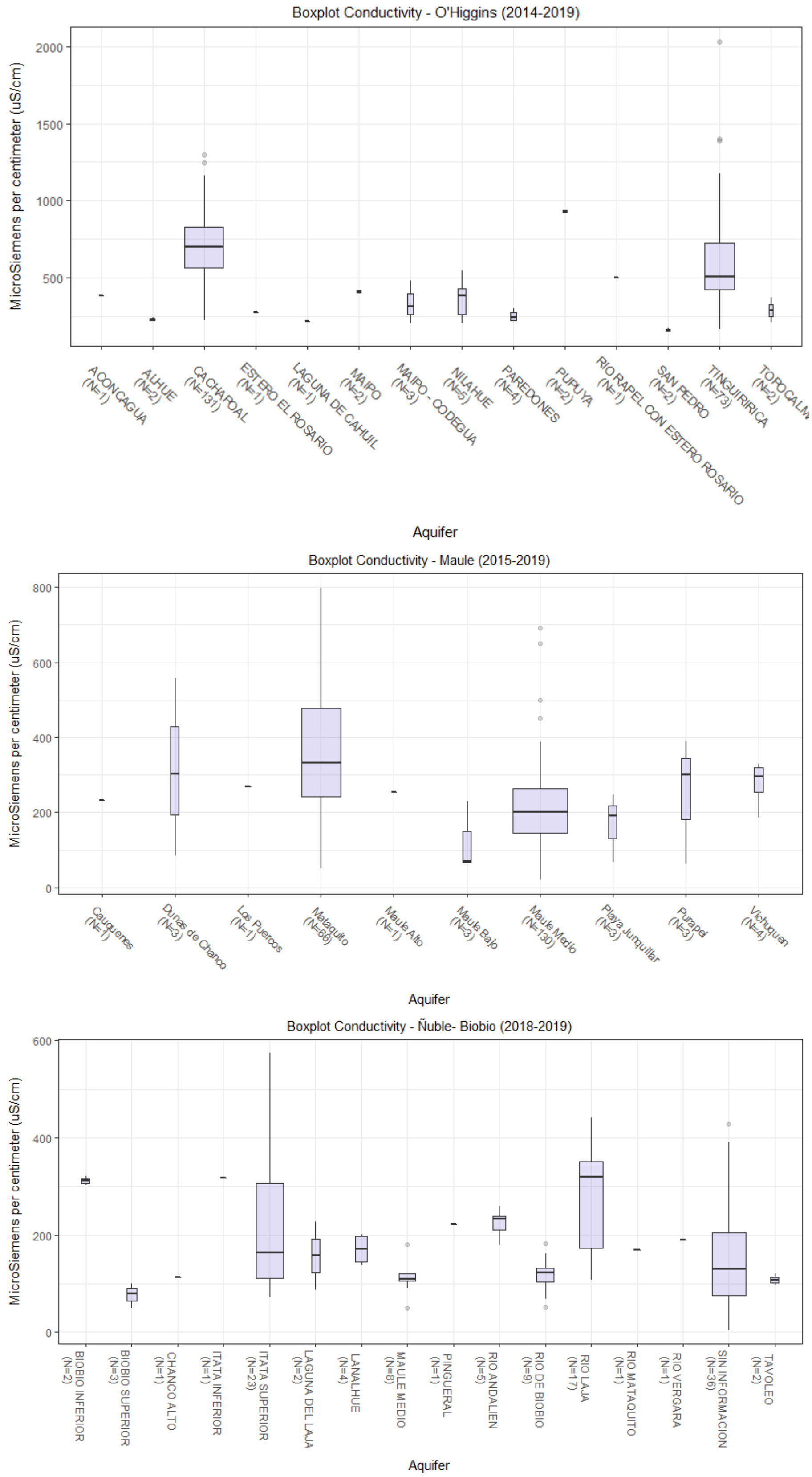


Fig. 3 Box plot of electric conductivity for Coquimbo, Valparaíso and Metropolitana regions. The width of the boxes is proportional to the number of observations. The graphs have different scales between regions.

Metropolitana and O'Higgins [33]. The aquifers with the highest conductivities medians are Pupuya with 928 uS/cm, Cachapoal with 700 uS/cm and Tinguiririca with 505 uS/cm (Fig. 3). The pH values of O'Higgins ranges from 5.9 to 8.1 pH units, indicating that the water samples locate in 3 categories; slightly acidic, neutral and slightly basic [32] (Table 1). ORP values indicate that the water provides an oxidant environment, however with a wider range (-12 to 793 mV) compared with the previous regions.

Maule has conductivity values that encompass from 21 to 798 uS/cm (Table 1), a range lower than Valparaiso, Metropolitana and O'Higgins. The aquifers with the highest conductivity median are Mataquito and Dunas de Chanco (332 and 302 uS/cm, respectively) (Fig. 3). The pH values of the region indicate that a neutral character is mostly seen in the water samples, being the lowest value of 6.0 and the highest 8.4 pH units [32]. The ORP data indicate that the water samples in all aquifers have values in the oxidant range between 3 and 631 mV (Table 1).

In Ñuble and Biobio the conductivities are at least two (2) times lower compared with the northern regions (Table 1). The fluctuation range goes from 4 to 574 uS/cm. The aquifer units with the highest median conductivities were Rio Laja and Rio Andalien[7] (319 and 234 uS/cm respectively) (Fig. 3). The pH values showed lower minimum values when compared with the northern regions, identifying a minimum of 5.8 and a maximum of 8.7 pH units, where most of the values locates in neutral ranges [32]. The ORP values also show certain differences compared with the northern regions because more values in the negative range appear (-46 to 371 mV) (Table 1).

As in Ñuble and Biobio, Los Rios region shows similar characteristics in conductivity, pH and ORP, observing samples more diluted, in a neutral range but with a lower minimum, and also oxidant but with a lower maximum respectively (Table 1). In Ñuble and Biobio the conductivity ranges from 104 to 361 uS/cm with a median of 207 uS/cm. The pH values are located in neutral values, in a range between 6.4 and 8.0. The ORP values ranged between -128 to 428 mV (Table 1).

3.2 Regional Nitrate Characterization by Aquifer Unit

As performed with conductivity, nitrate will be analysed by region and aquifer unit but using the raw data instead of boxplots. The use of raw data provide more detail of the distribution of nitrate concentrations between two (2) limits; 30 mg NO_3/L and 50 mg NO_3/L, being the first a warning level of concentrations moving away from natural values, and the second limit is the maximum nitrate concentration recommended for potable use (NCh 409/05).

In Coquimbo, Elqui, Choapa and Limari aquifer units have concentrations below and within the warning zone (30-50 mg NO_3/L), slightly below the recommendation for potable use (50 mg NO_3/L) (Fig. 4). The units Culebron-Lagunillas and "Sin Informacion" show values above 50 mg NO_3/L (Fig. 4), which means that water shouldn't be consumed without previous treatment. When zooming into the wells located in Culebron-Lagunillas and "Sin Información" units only one well has been monitored more than once (APR Caleta-Hornos in unit "Sin Información") increasing its nitrate concentration in every monitoring campaign going from 51.90 to 161.70 mg NO_3 g/L, whereas the rest of wells have one measurement in the study period, and locate in the unit Culebron-Lagunillas (Fig. 4). This implies that there could be more wells with concentrations like APR Caleta-Hornos but there is not enough records to detect it.

In Valparaiso most of the aquifers showed that water samples meet potable use limits considering nitrate, 7/14 units have concentrations below warning limits (30 mg NO_3/L), 3/14 units have concentrations within warning limits (30-50 mg NO_3 g/L) and 4/14 unit have concentrations above 50 mg NO_3/L, namely

[7] The units Itata Inferior and Biobio Infeior were not considered in this comparison because the low amount of records (N).

Aconcagua, Casablanca, Estero Cartagena and Maipo Desembocadura (Fig. 4). When one look closer into the wells with the highest concentrations it's possible to notice that despite the few measurements taken there are no signs of increase (Fig. 4). APR Lo Abarca in unit Estero Cartagena show the highest nitrate concentration in 2016 (111.1 mg NO_3/L); however more measurements in time are needed for a clear diagnosis of the aquifer unit and in each well.

As seen in Tables 1 and 2 the Metropolitana region is the one that has more measurements than the rest of the study areas. Most of the nitrate concentrations within the region locate below the maximum limit recommended for potable usage (50 mgNO_3/L), however it is possible to notice that only in Maipo unit the recommendation is overcomed several times (Fig. 5) When looking into the wells of Maipo unit it's possible to identify that APR La Esperanza-Santa Monica-Los Aromos separates from the rest of the wells increasing their concentration above 100 mg NO_3/L once in 2018 and twice in 2019 (Fig. 5) and APR Mallarauco register the highest concentration from all the wells with 150.68 mg NO_3/L in 2018 (Fig. 5).

In O'Higgins one will find that most of the aquifers have nitrate concentrations below the warning limit (30 mg NO_3 g/L), but there're two (2) aquifers that show concentrations higher than the recommendation for potable use: Cachapoal and Tinguiririca (Fig. 5). When breaking down this aquifers into the wells with concentrations above 50 mg NO_3g/L one will find that these have similar values, locating between 38.33 and 64.20 mg NO_3/L (except APR Paredones de Auquinco in 2016 with 9.30 mg NO_3/L in 2014). Nevertheless it is important to highlight that APR Cabaña Blanca-Santa Julia has a higher nitrate concentration in 2019 compared to the previous campaigns, whereas APR Los Romos-La Pedrina indicates the opposite with lower concentrations in 2019 compared to previous campaigns (Fig. 5).

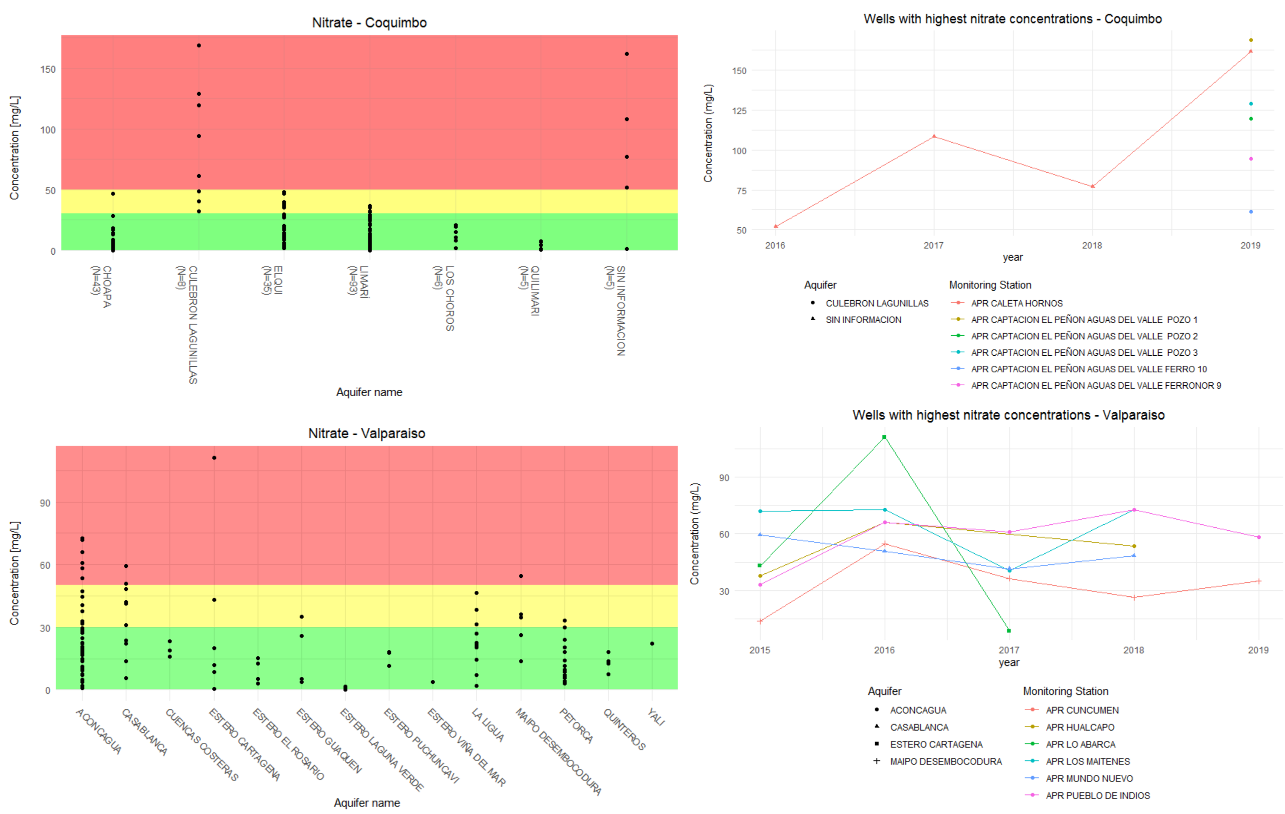


Fig. 4 Left side graph Nitrate Coquimbo and Valparaiso per aquifer unit and right side graph shows monitoring stations with the highest concentrations.

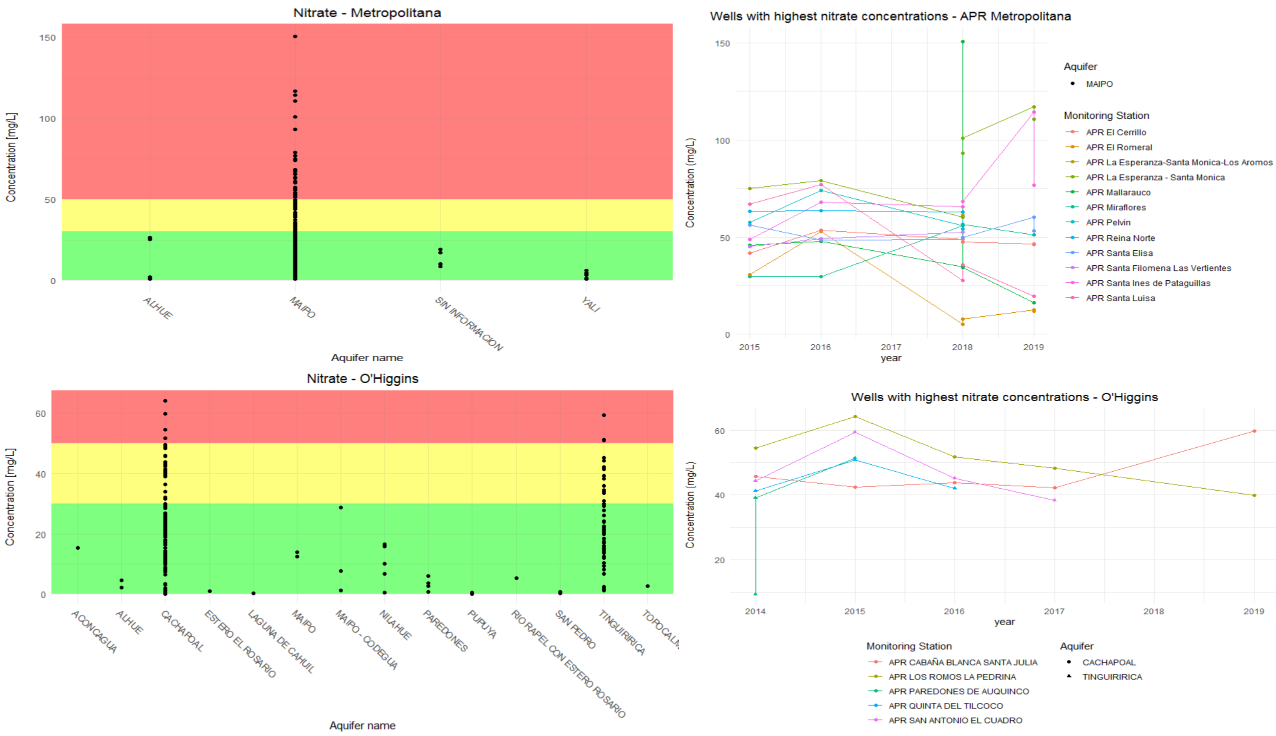


Fig. 5 Left side graph Nitrate in Metropolitana and O'Higgins per aquifer unit and right side graph shows monitoring stations with the highest concentrations.

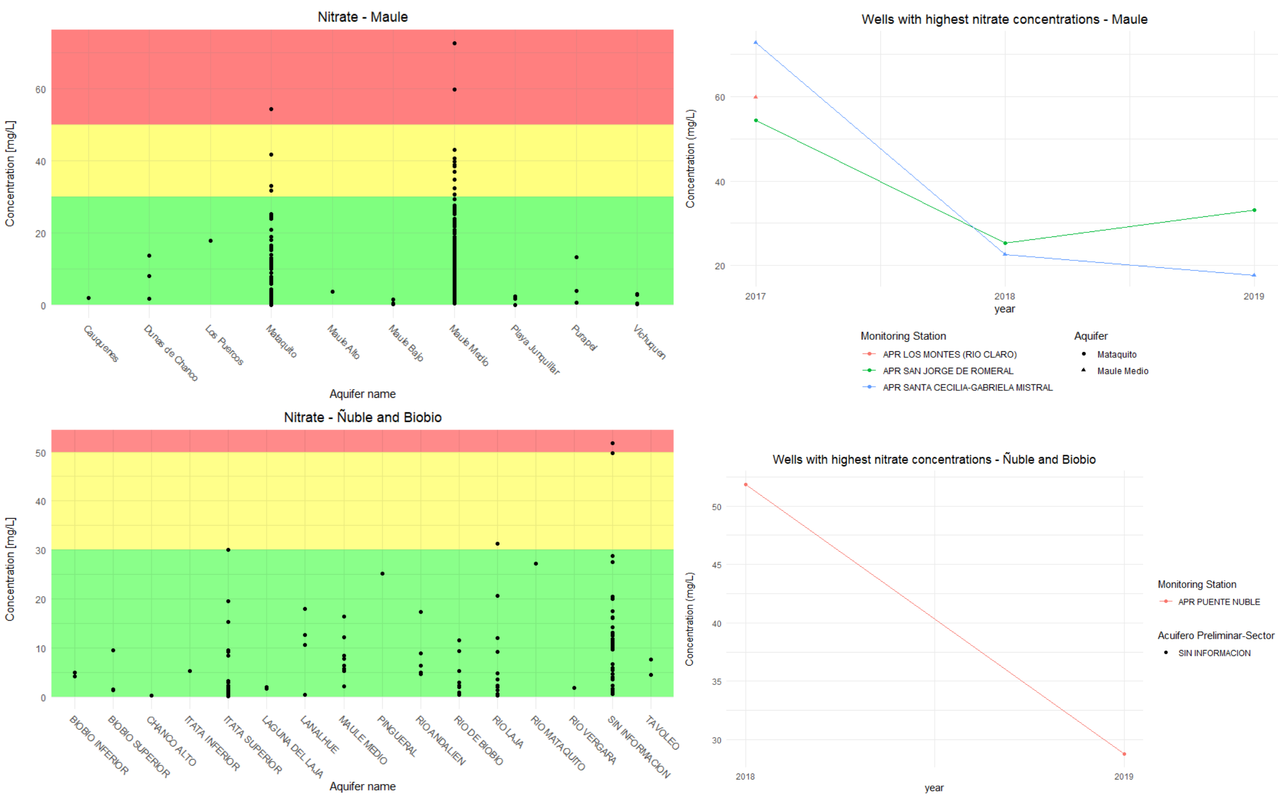


Fig. 6 Left side graph Nitrate in Maule and Ñuble and Biobio per aquifer unit and right side graph shows monitoring stations with the highest concentrations.

In El Maule, nitrate concentrations maintain below the warning limit (30 mgNO_3/L) in most aquifer units but there're two (2) with concentrations exceeding the recommendation for potable use: Maule-Medio and Mataquito (Fig. 6). When disaggregating this aquifers into the wells with concentrations above 50 mg NO_3/L one can observe that there're three wells with concentrations over the limit; APR Los Montes and Santa Celilia-Gabriela Mistral, both in unit Maule-Medio, and APR San Jorge de Romeral in unit Mataquito (Fig. 6).

In Ñuble and Biobio and also in Los Rios, the quality of water is better in nitrate compared to the northern regions of Chile (Table 1). In Ñuble and Biobio only one value locates above the recommendation limit for potable use (50 mg NO_3/L) (Fig. 6), and this happened in the well APR Puente Ñuble reaching 51.86 mg NO_3/L in 2018 (Fig. 6), however lowering the following campaign to 28.76 mg NO_3/L. No values above the recommendation for potable use were identified in Los Rios (Table 2) and thus no graph or figure was considered necessary.

4. Conclusion

Nitrate concentrations in the study area are mostly below 50 mgNO_3/L, which is the maximum limit recommended for potable use according to the national standard. However there're nitrate concentrations in warning limits in several aquifer units from Coquimbo to Biobio and this should arise concern for two reasons: 1) Concentrations will probable increase if no measures to manage, restrict or eliminate the source of nitrogen are taken, this is considering the current dynamic of nitrate sources (i.e., expansion of urbanization processes, fertilizer overuse, among others), and 2) there is not enough data (temporarily but most important spatially) to guide an effective management of nitrate pollution issues in Chile. This is particularly important considering that the drought is the current 'status quo' of the country since 2010, which implies the search for new water sources.

It is also recommended to gather more information about water level and depth of extraction (screens location) in order to identify how deep nitrate is traveling and concentrating. This is an important criterion to select a well's location.

Nevertheless, with the data in hand the quality considering nitrate seems to improve in the southern regions studied. This means that there should be a preservation management priority in this part of the country; on the other hand the northern regions should be followed closely when implementing new wells to extract water, particularly for human and animal use. The later represents an opportunity to synergise efforts between public services and other organizations related to the provision of potable water sources.

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