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Water technology market in Chile: Business opportunity

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THESIS
ABSTRACT

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Chile has a status of Latin American reference of progress with mining being the key economic activity. Despite rapid economic growth and high standards of life, water quality in the country is highly affected by mining. The thesis aims to get in-depth understanding of the current water situation in Chile and research the connection between water quality, water availability and mining activities in the country.

Thus, the thesis represents an overview of the current state of the Chilean water market, including detailed information on water market, mining industry and water quality. Due to particular interest in the connection between water quality and mining industry, a detailed description of the Antofagasta Region with the highest concentration of mining activities in the country is given in every part of the thesis.

As a summary report of the WaterCare project, conducted by Kajaani University of Applied Sciences and CEMIS, implemented in 2016, the author concludes that the Chilean water market offers outstanding business opportunities for CEMIS development.

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1 INTRODUCTION

1.1 Introduction to the Topic

The thesis is written as a summary report, which provides an in-depth water market analysis of Chile. The study is part of the WaterCare project conducted by Kajaani University of Applied Sciences and CEMIS in 2016, aiming to create preconditions and prepare piloting projects for the Finnish cleantech companies that will be implemented in the target countries (Chile, Peru and Palestine) together with local organizations in the Middle East and Latin America.

The study supports the final goal of the project to get an in-depth understanding of the situation and needs of the people in the target markets. Rural areas of the target countries receive special attention and the project's aim is to provide the population with clean water and simultaneously monitor the contamination of the water resources.

Thus, the report presents a complete overview of the current state of the Chilean water market, including detailed information on water market, mining industry and water quality in the country. Due to particular interest in connection between water quality and mining industry, a detailed description of the Antofagasta Region (II) with the highest concentration of mining activities in the country is given in the report. The region has the highest investments in copper and other mining activities in the country according to the mining projects 2015-2024 (COCHILCO 2015).

The analysis is based on information available from different state institutions, the press and the market, processed for the purpose of the study.

The study objectives and contents are defined as providing the project team with an understanding of the water market, mining industry and water quality and availability in Chile (particularly in reference to the influence of mining industry on water quality and availability in the country).

1.2 Research Problems and Questions

The main goal of the thesis is to conduct a research, which brings in depth understanding of the water situation in Chile and needs of the Chilean society. To fulfil the purpose and to indicate right workflow and results, other research questions supporting the main one have to be developed.

Regardless globalization, the world is culturally and economically diverse and it is important to have a clear picture of a foreign country involved in the research process. The main interest of the research is the economic situation of the country and the population statistics, which are discussed in Chapter 2.1.

WaterCare project is about integrating water technologies, thus, the Chilean water market will be studied in Chapter 2.2. The main points about the water market are water regulations, water consumption by different economic sectors and water market in Antofagasta.

Due to economy of the country, mining remains the country's main activity, which can have a significant influence on the water market. Mining is studied in Chapter 2.3.

Proceeding with the aforementioned questions, it is necessary to analyse the connection between water situation and mining in the country and the analysis is presented in Chapter 2.4, which describes water quality and water availability in Chile.

Finally, giving the accurate answers to the previous questions, discussion, further recommendations and conclusions regarding the research are made in the last chapters, Chapter 3 and Chapter 4, answering the main question of the research: what is the water situation in Chile?

1.3 Research Method

The thesis is written in a form of qualitative marketing research, which seeks to extend the boundaries of knowledge about the project's area of operations – Chilean water market. (Smith & Albaum 2005, p.4)

The data collection technique used in the thesis includes observing the secondary data from such sources as public governmental information, periodicals and professional journals, studies published by different institutions, trade associations and trade press, commercial databases and other world-wide online sources. The technique essentially means reviewing literature and data sources, collected for any other purpose than the research at hand. Visual materials are also used in the study to present numbers and statistic data in a way convenient for the reader.

Moreover, in order to conduct a deep, reliable and constructive research, the author concentrates on searching for the information being accurate, current, sufficient, available and relevant.

1.4 WaterCare Project, CEMIS

CEMIS is a contract-based joint Centre for Measurement and Information Systems of Kajaani University of Applied Sciences, the Universities of Jyväskylä and Oulu and VTT Technical Research Centre of Finland Ltd. The main areas of competence of the centre are research and training in the field of process and environmental measurements in bio economy, sports, exercise and well-being measurements, vehicle informational and measurement systems, the mining industry and game and stimulator technology. CEMIS' vision.is to be an attractive international partner in cooperation in developing new metrological and information systems expertise. (CEMIS 2015)

WaterCare project is conducted by Kajaani University of Applied Sciences and CEMIS in 2016, aiming to address the acute needs of monitoring water resources and to provide affordable high-tech water treatment technologies by consolidating Finnish cleantech technologies developed by different Finnish companies in a comprehensive offering. The project involves areas of the world where water management is a major issue – South America and the Middle East. The target countries of the project are Peru, Chile and Palestine.

The main goal of the project is to create preconditions and prepare piloting projects for the Finnish cleantech companies that will be implemented in the target countries together with local organization in the Middle East and Latin America. In addition, in-depth market analysis from the target markets as well as social and economic studies regarding the impact of the implemented technologies are expected to be written. The current thesis provides in rigorous market analysis of one the target countries – Chile

2 LITERATURE REVIEW

The literature review draws a clear picture of the Chilean water market by firstly analysing the country's economic situation, secondly investigating the water market itself, thirdly continuing with the overview of the mining industry and finally evaluating the connection between the water market situation and the mining activity in the country.

2.1 Economic Profile of Chile

Economy

Chile has been one of Latin America's fastest-growing economies over the past decade. However, according to the World Bank statistics (2016), the economy had experienced a slight slowdown due to the end of the investment cycle in the mining sector and the decline in copper prices and private consumption: following the 2010-2012 economic expansion, GDP growth fell to 1.9 per cent in 2014 and 2.1 per cent in 2015. The unemployment rate also rose slightly, from 5.7 per cent in July 2013 to 5.8 per cent in January 2016.

Despite the expected slowdown of the economic growth in 2016, to an estimated 1.9 per cent in light of low copper prices and the lack of recovery of domestic demand, the economy is expected to recover slowly in 2017-2018 thanks to increasing copper prices and levels of private investment. Forecast for 2017 is a growth rate of 2.1 per cent. (World Bank 2016)

Nevertheless, the country still faces important problems. It is estimated, in order to provide a solid foundation for supporting and enhancing the country's medium- and long-term growth and for reaching more inclusive growth, macroeconomic management must be fiscally responsible. Despite strong growth over the past 20 years, Chile's per capita income still drops short of that of higher-income countries (in 2014, the per capita income of US$ 21 980 was still significantly below the average of US$ 41 035 for OECD countries).

Additionally, structural changes to drive productivity increases and improve access to and quality of social services should be implemented for a more inclusive growth. Energy deficits and dependence on copper exports continue to be a source of vulnerability.

All in all, thanks to ambitious structural reforms, Chile has maintained its status as a Latin American reference of progress whose creative public policies have become international models of good governance.

Population

The last official census in Chile was held in 2012, which placed the population of 16 634 603 people. Based on the latest United Nations estimates, in August 2016 the population in Chile is 18 154 955. Chile is predicted to have a slow growth of the population, reaching 21 600 685 in 2050 and as a global trend, population is aging: the median age is 34.7 in 2016, becoming 47 in 2050 (Wordometers 2016).

Despite Chile has a total area of 756 102 km^2 (the 38th largest country in the world), it is a relatively sparsely populated country due to harsh geography caused by the Andes mountain range. The population density is approximately 24 persons per 1 km^2 and the highest concentration of the population is in major urban cities as of 2015: Santiago 6.507 million; Valparaiso 907 000 people; Concepcion 816 000. (CIA 2015). The detailed information about the country's density by commune is presented on a map in the appendices' list (Appendix 1/1).

According to the World Bank, currently rural population reaches its historical minimum with 10.5 per cent of the total population in 2015 (32 per cent in 1960). The Central Intelligence Agency states that in 2015 improved water sources are available for 99.7 per cent of urban population, 93.3 per cent of rural population and 99 per cent in total. Sanitation facility access have 100 per cent of urban population, 90.9 per cent of rural population and 99.1 per cent in total.

2.2 Water Market

Chile's geographic and climatic diversity leads to irregular and paradoxical distribution of water resources on a national level, with the scarce situation in the Atacama Desert in the north and the North and South Ice Camps in the southern zone, accounting the biggest reserves of water in the world. Therefore, while in the southern zone a great abundance of water exists, reaching levels of 160 000 cubic meters annually per habitant (m^3 / habitant / year) of water availability in some regions, the northern zone of the country is very arid, with an availability of water resources of less than 500 m^3 / habitant / year. (Chile Sustentable 2010)

Development of the current water market in Chile has a long history dating back to 1855 when the first water rights licenses were issued with the last update in 2005, which addresses the social equity and environmental issues. Therefore, water is considered as a direct matter of water market regulations itself, i.e. water pollution control, and environmental regulations.

Brief History of Water Regulations in Chile

The history of water regulation in Chile starts in 1855 when the State Civil Code granted licenses to private parties for exclusive use of water and continues almost hundred years later in 1951 with the Water Code adopted to provide a system of water rights administration.

The new Water Code of 1967 is created in line with agrarian law reform and replaces the Water Code of 1951. Its purpose is to empower landowners to receive water and the Code attempts to redistribute water as a component of the government's strategy to reform agrarian policy by strengthening government control of water and reallocating water rights. The reforms lead to political changes in the country and a new government introduces a new Water Code of 1981 (current National Water Code).

The aim of the new Water Code from 1981 is to improve efficiency of creation and operation of Chilean free-water market. The Code introduces a system of regulation of water market, with the executive power of the government charged with the authority to plan, regulate and promote the appropriate use of all water. The General Water Bureau (DGA), under the Ministry of Public Works, carries out all the measurement, research and granting water use rights and the Water Cadastre records all water rights and transactions. One of the focuses of the Code is to modify regulations in the field of irrigation and agriculture and to facilitate the proper operation of the market. Moreover, it gives greater power to private stakeholders to invest in both domestic and agricultural water uses, water system maintenance and provides a significant role of water companies in water supply and sanitation management.

The fifteen-year process of the 1981 Water Code modification led to the reform in 2005, which addresses the social equity and the environmental issues. The main changes include giving the president authority to exclude water resources from economic competition in cases where necessary to protect the public interest. In addition, the General Water Bureau (DGA) is obliged to consider environmental aspects in the process of establishing new water rights, charge a license fee for unused water rights and limit requests for water use rights to genuine needs.

All in all, the water market system is designed to promote more efficient uses of water, but the downturn of the system is the concentration of Chile's water rights ownership in a few hands of big private mostly foreign corporations. The situation leads to an assault on the country's surface and groundwater sources, causing ecological strain in many areas and creating tensions between local communities and the corporations. (Chile Sustentable 2010)

Water Rights and Water Companies

Water rights in Chile provide full ownership of the water use in a specific area to their holders, who may freely transfer or encumber them without any limitation (the procedure conducted according to the Civil Code, through the execution of a public deed, which shall be recorded in the Water Property Registry of the corresponding Real Estate Registrar). Water rights are granted by the General Water Bureau (DGA) through a technical procedure initiated by a request files by any person. The grant is free and is given in perpetuity to private companies, without payments for the use of water, any specific taxes, payments of sewage (except for the integration to the urban sewage system), but a company is charged for the non-usage. Granting and transferring of water rights regarding freshwater and underground water are regulated by the Water Code (maritime water has its own regulations). Any transfer of a water right shall be recorded in the Water Public Cadaster of the DGA, for purposes of maintaining an administrative public record regarding these rights. (Eyzaguirre 2016).

There are two types of water rights addressing different legal nature in Chile: the consumptive and non-consumptive. (Chile Sustentable 2010)

The *consumptive* right refers to the right to consume water without having to return it to the source in order to be then reused by another user. This is the case in the rights requested for irrigation, mining, industrial and domestic use.

Non-consumptive rights are those that are requested for water use without consumption, as is the case for hydroelectric generation. This law requires extracted water to be returned to the same river from which it was extracted, without harming existing users downstream.

Thus, the consumptive water rights concessions are distributed among different water and sanitation companies according to the regions, that is shown in a table in the Appendix 2/3.

2.2.1 Water Pollution Control

All in all, there is no single regulatory regime and no single authority regulating water pollution in Chile. Similarly, there is not only one system in place for permits or other authorizations to deal with discharges or emissions into water sources. Various pieces of legislation which are related to emission or quality standards regulate water pollution, focusing on meeting them. Thus, water market and environmental situation in Chile are regulated by two decentralized agencies under the supervision of the President of the Republic via the Ministry of Public Works and the Ministry of Environment: the Superintendency of Sanitation Services (SISS) and the Superintendency for the Environment (SMA), respectively. Other institutions responsible for water pollution control are General Water Board (regulates the quality and quantity of water that may or may not receive discharges from other sources), General Directorate of the Maritime Territory and Merchant Navy (manages marine resources) and Ministry of Health (prevents any pollution that could pose or actually produce negative effects resulting from it, from reaching the general public). (Urrutia and Avilés 2015)

The Superintendency of Sanitation Services (SISS)

The Superintendency of Sanitation Services (SISS) controls water and sanitation services according to financial and quality norms within urban areas. The agency is responsible for the pricing of water (drinking + sewage), granting concessions, the supervision of health companies, particularly regarding quality of the service, the audit of liquid industrial waste generators industrial establishments – riles (tailings, industrial waste), who made discharges to public sewer systems. (SISS 2016)

The SISS grants concessions according to the Water Code regulations of water rights regarding granting and transferring freshwater and underground water (maritime water has its own regulations). Water rights provide full ownership to their title holders, who may freely transfer or encumber them without any limitation. The transfer of any water right is conducted according to the Civil Code and is recorded in the Water Public Cadastre of the DGA, for purposes of maintaining an administrative public record regarding these rights. (Eyzaguirre 2016).

Under the SISS supervision, water and sanitation companies, owning water rights, provide the water service for the citizens. Their main functions include providing their customers good quality drinking water in sufficient quantity; ensuring the continuity of service matching the governmental standards to its customers; continuously providing sewer service and its maintenance; charging the customers for the service and communicating with the customers. (SISS 2016)

The Superintendence for the Environment (SMA)

The Superintendence for the Environment (SMA), a takeover of CONAMA's regulatory role, runs, organizes and coordinates the monitoring and control of all environmental issues established by the law, including Environmental Qualification Resolutions (RCA), Prevention Plan and Environmental Decontamination measures, the composition of Environmental Quality Standards and Emission Standards, as well as Management Plans where appropriate. The agency was created by law in 2010, and became fully functional on 28 December 2012. The SMA has six regional offices across the country, including Antofagasta, Atacama, Valparaíso, Santiago, Biobío and Los Ríos. The agency aims to have offices in all regions of the country by 2018. (SMA 2015)

The SMA fulfils its main function (control and sanction) via receiving complaints made by citizens and organizations, by receiving whatever means of a fact of social connotation or through implementing an annual control programme.

According to the annual report from 2015, the SMA attempts a number of audits to the projects in line with Environmental Qualification Resolution (RCA). One direction of SMA activities is to implement a universal technical standard that allows a high level of verification processes throughout the country. The activity includes highly populated areas as well as remote areas with no population but requiring special attention, for example, manifestations of environmental heritage and biodiversity. The number of complaints received has grown since 2013 and most of them are concentrated in the Metropolitan region, followed by the region of Antofagasta (problems caused by mining) and Aysén (salmon farming). (SMA 2015)

2.2.2 Environmental Regulations in Chile

The main statutory framework of environmental regulations in Chile is given by the Environmental Act, by the provisions of which the Environmental Impact Assessment System (SEIA) was enacted in order to assess any project or activity that may cause an environmental impact during either construction, operation or shutdown phase. (Eyzaguirre 2016).

This Law established main environmental authorities: the Environmental Ministry, the Environmental Assessment Service (SEA), and the Council of Ministries for Sustainability. (Urrutia and Avilés 2015).

The Environmental Ministry is responsible for cooperating with the Chilean president in designing and applying policies, plans and programmes related to environmental matters, as well as the protection and preservation of biodiversity, renewable natural resources and water. It promotes sustainable development, the integrity of the environmental policy and its regulation.

The Environmental Assessment Service (SEA) assesses projects that according to the Environmental Act must be environmentally assessed prior its execution. The executive director has jurisdiction over national and multi-regional projects, and the regional departments and the Regional Assessment Commissions have jurisdiction over regional projects or activities.

The Council of Ministries for Sustainability is mainly in charge of proposing sustainable environmental policies to the president.

Additionally, as regards the main authorities with responsibility in environmental issues, Law No. 20,417/10, which amended the Environmental Act, established *the Environmental Superintendence (SMA)*, which is the public service responsible for the oversight of Environmental Qualification Resolutions (RCA), Prevention and Decontamination Plans, Environmental

Quality Standards and Emission Norms, Management Plans and any other environmental instrument established by law. (Eyzaguirre 2016).

Regarding regulatory framework, the Environmental Act is complemented by several other statutory provisions enacting specific regulations. Also, Chile now has specialized environmental courts whose function is to solve the environmental disputes that arise in our country.

Finally, considering the significance and particular nature of certain environmental matters, Chile has enacted specific environmental statutes regulating Hazardous Waste Management, regulating Emission Standards for Thermoelectric Power Plants, and regulating Emissions Standards for copper smelters and Arsenic Emitting Sources.

2.2.3 Economic Sectors, Water Consumption and Water Quality

Water consumption in different economic sectors experienced growth of nearly 100 per cent between 1990 and 1999, and 160 per cent between 1990 and 2002, a trend that continues nowadays. (Chile Sustentable 2010)

Distribution of water consumption in different economic sectors depends on key activities of the region. (Figure 1.). For instance, main demand for consumptive water use in Antofagasta region (II) is the highest in the sector of mining, followed by industrial usage, potable water and agriculture, while water consumption in the central regions is more concentrated in the sector of agriculture.

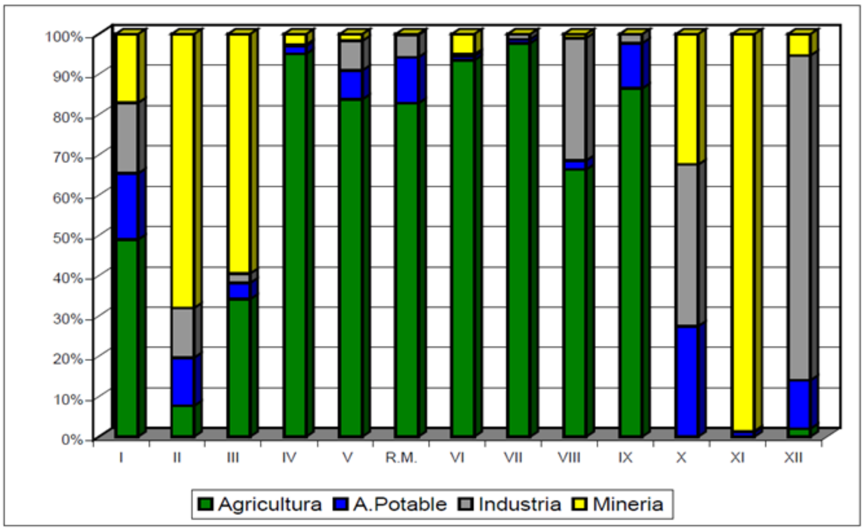

Figure 1. Demand for Consumptive Water Use in Chile, According to the Regions (in %). (DGA, 2007)

All sectors contribute to water contamination.

The *agribusiness* in Chile uses large amounts of pesticides, herbicides and fertilizers, all of which destroy watersheds, and, as well, over extracts local water sources to produce export commodities. Agriculture is mostly concentrated in the south and south-central regions with high water availability.

Massive *hydroelectric* development by transnational companies is threatening protected and indigenous areas all through Chile's southern region, where the water supplies are more plentiful.

"Critical deficit" of water is caused by the *mining* industry in the central north and northern regions where minerals are abundant. For instance, in Antofagasta Region, mining uses more than 1 000 litres of water a second, and mining companies hold almost 100 per cent of the groundwater rights. (Chile Sustentable 2010) Mining, at the beginning of the decade, consumes 3.5 million m^3 of water per year, which has continued to increase, also aggravating the environmental impact, such as drying watersheds, ponds, wetlands and salt flats; deteriorating ecosystems and generating desertification. This has affected local and indigenous communities, destroying their agriculture, livestock and local economies and causing mass migration to the cities.

Moreover, in the case of Antofagasta and Atacama regions, water consumption by mining is expected to grow. The Figure 2. shows current and future use of water for the productive sector in Antofagasta and Atacama regions. The graphs show the current consumption of water and the consumption in 10 and 25 years. Consumption is distributed among following sectors: agriculture (Agropecuario), drinking water (Agua Potable), industry (Industrial), mining (Minero), and others (Otros).

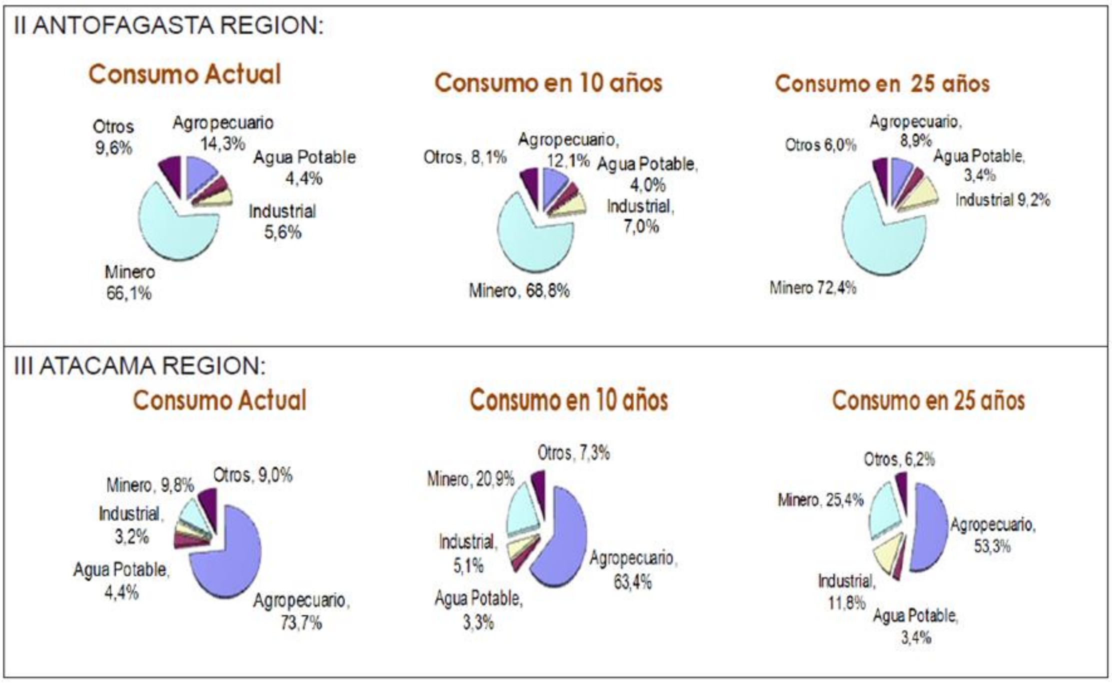

Figure 2. Current and Future use of Water for the Productive Sector in Antofagasta and Atacama Regions. (DGA, 2007)

2.2.4 Water Market in Antofagasta Region

Water Landscape

Antofagasta is the heart of Chilean mining operations with significant impact on the environment and water contamination in the region, deserving special attention. Moreover, according to the Chilean Copper Corporation (COCHILCO) from 2009, the Antofagasta region awaits an extreme deficit in terms of water consumption by 2025, forcing communities to optimize water resource system and improve water quality from the existing sources.

In spite the fact that Antofagasta region is home of Atacama Desert, it is one of the most arid places in the world, where there is limited flora and fauna, therefore, the natural water resources are extremely limited in the region. As it is shown in the Figure 3., it has a very small number of rivers and there are two critical watersheds in the region, Loa River (with its distributaries Río San Salvador, Río Salado and Río San Pedro) and Salar de Atacama (including Rio Vilama and Rio San Pedro).

Figure 3. Antofagasta Watersheds (Chile Atlas 2016)

Water supply from different water basins of the National Water Bank (BNA) covers certain areas (Table 1.). The biggest watershed in Antofagasta is Loa River (covering 33 081 km^2), followed by Quebrada Caracoles (18 295 km^2) and coastal area between Quebrada La Negra and Quebrada Pan de Ázucar (16 897 km^2), and the smallest is Fronterizas Salares Atacama – Socompa (4 055 km^2). There are two types of watersheds in Spanish: *exorreica* and *endorreica*. *Endorreica* stands for an isolated water basin, where there is no flow and the water stays in the same area and evaporates. *Exorreica* is a water basin connected with other water reservoirs via some water flow, e.g. a river. Despite of the covered area, all watersheds supply 100 per cent of the territory.

Table 1. Distribution of water supply in Antofagasta (Source: Chile Atlas 2016)

Name of Water Basin	Area, km2	Type of Watershed	Coverage (%)
Río Loa	33 081	Exorreica	(18 - 82)%
Costeras Río Loa - Quebrada Caracoles	8 377	Exorreica	100%
Fronterizas Salares Atacama - Socompa	4 055	Endorreica	100%
Endorreica entre Fronterizas y Salar Atacama	5 308	Endorreica	100%
Salar de Atacama	15 576	Endorreica	100%
Endorreicas Salar Atacama - Vertiente Pacífico	14 473	Endorreica	100%
Quebrada Caracoles	18 295	Exorreica	100%
Quebrada La Negra	11 347	Exorreica	100%
Costeras entre Quebrada La Negra y Quebrada Pan de Ázucar	16 897	Exorreica	100%
Endorreicas entre Frontera y Vertiente del Pacífico	15 618	Endorreica	100%

Water Companies

There are three water companies operating in Antofagasta region and providing water and sanitation service for the communities: Aquas Antofagasta S.A., Econssa S.A. and Tratacal S.A. (Appendix 2/3)

The previous owner of Aquas Antofagasta S.A. is a mining giant Antofagasta plc that has sold the water company to Empresas Públicas de Medellín (EPM) in 2015. New owner is a state-owned, industrial and commercial enterprise, which belongs to the municipality of Medellin, Colombia. EPM core business is providing electricity, gas, water, sanitation, and telecommunications in Latin America.

Econssa S.A. is a company owned by CORFO (99 per cent of ownership) (a Chilean governmental organization found to promote economic growth in Chile), which acts as a controller, and the Chilean State (1 per cent).

Shares of Tratacal S.A. are distributed among the Chilean engineering companies Icafal Investments S.A. (50 per cent), Hidrosan Engineering S.A. (25 per cent), and Sanitary Services Company S.A. San Isidro (25 per cent).

Figure 4. shows the location of operational areas, treatment plants, sewage and taps in Antofagasta, which are marked with the yellow color on the map.

Figure 4. Location of operational areas, treatment plants, sewage and taps in Antofagasta. (SISS, Google maps 2016)

Wastewater Treatment Plants

According to the legal powers and oversight, the Superintendency of Sanitation Services (SISS) is responsible for ensuring that the operation of the wastewater treatment plants (planta de tratamiento de aguas servidas, PTAS) is carried out in accordance with current legislation, through control actions on self-control, performing direct checks and inspections on the ground. The treatment of wastewater has increased in the country substantially in recent years, reaching a level close coverage to 83 per cent compared to the national urban population, which has gradually enabled the decontamination of the courses of surface and marine waters. (SISS 2016)

According to evaluation results of wastewater treatment plants in Antofagasta, done by SISS in 2016, not all plants comply with the standards. Most of the problems occur in the plants of Aquas Antofagasta S.A. Detailed results with the descriptions of the standards and wastewater treatment plants are presented in Appendix 3/2.

2.3 Mining Industry

Chile has outstanding abundance of mineral resources and mining is one of the most important economic activities of Chile. The Atacama Desert has the major deposits of copper, gold, silver, iron and mineral products coming from saltpans, such as nitrates (Cantallopts *et al.* 2014). Geographical distribution of mining divisions in Chile is shown in Appendix 4/1.

With regard to the evolution producer countries, Chile continues to be the first copper producer at world level, with one third of the world mine production and 4 246 000 tons in 2014 (Cantallopts *et al.* 2014). At the same time, the country is the most important copper exporter in the world, followed by Peru and China.

The Chilean Copper Commission (COCHILCO) is a specialized technical agency established in 1976, which advises the Chilean government on matters concerning the production of copper and copper byproducts and metals and industrial minerals mining, except coal and fuels. The agency is an original source of information about mining sector in Chile.

Mining industry suffers a problem of scarcity of water resources due to the location of mining reserves and the limited hydrological resources in the north of Chile, which leads to a conflict between the mining activity, other productive sectors and communities.

Moreover, mining operations generate massive waste management in Chile. In 2010, industrial waste output was 900 000 tons. It is estimated that on the average, each metric ton of fine copper generates 90 tons of tailings, 1.8 tons of slag and 36 000 tons of foundry dust. (Quirland *et al.* 2013)

2.3.1 Mission for 2015-2035

In 2015 Chile has launched the Chilean National Mining Program presenting the Chile's Mining Industry Roadmap (2015-2035), aiming to transfer the economy based on natural resources to a knowledge economy. Its vision is to achieve virtuous, sustainable and inclusive mining, which generates benefits to communities. (Valdés 2015)

The Programme claims a challenge of growing water and energy demand in the country, stating increase in electricity demand from 23 TWh to 40 TWh and increase of water consumption (fresh and seawater) of 66 per cent (14.8 m^3/s to 24.6 m^3/s) due decreasing grade of concentrate (Figure 5.). Use of seawater could increase over 40 per cent of costs associated to energy. In addition, it is expected an increase in generated tailings – in 10 years mining will duplicate tons removed. Thus, mining industry is concentrated on reducing waste of natural valuable resources in tailings.

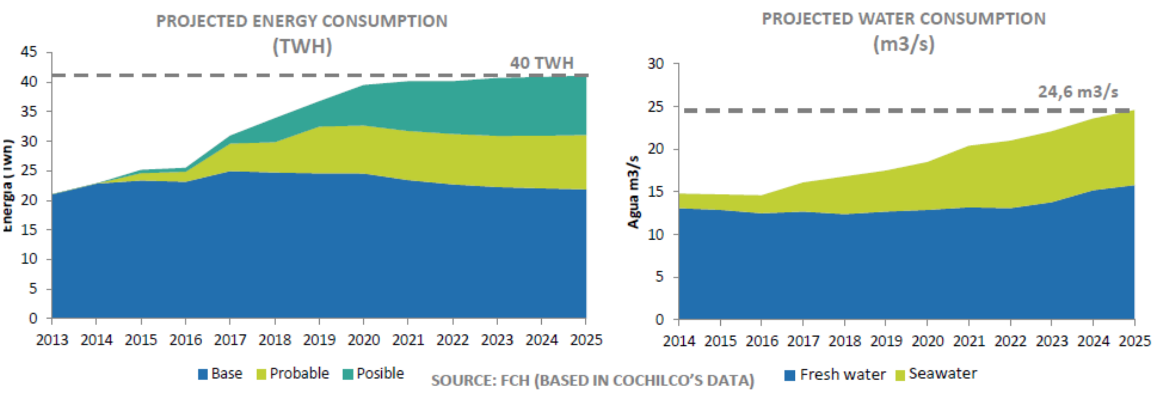

Figure 5. Projected energy and water consumption (COCHILCO 2015)

In line with this programme, Chile introduces water related projects. For instance, Aguamarina company implements a project of designing a system to remove particulate matter emission fixed points in the transfer of the ore crushing area using water and an organic compound produced by EPS bacteria algae, which captures dust by electrical charge.

2.3.2 Regulation of mining activities

According to the Chilean Constitution, all mines, including, among others, oil and gas reserves and mineral deposits, belong to the state with the absolute, exclusive, inalienable and imprescriptible ownership. Regarding all metallic and non-metallic (except for oil and gas) deposits, any person is entitled to request a mining concession in order to develop exploration or exploitation activities within them. (Eyzaguirre 2016).

Property rights over mines and mining concessions are different from property rights over surface lands where both mines and mining concessions are located. In this sense, the Chilean Constitution states that surface lands shall be subject to the obligations and limitations that the law may provide with the purpose of contributing the exploration, exploitation and processing of mines.

Mining companies in Chile, in addition to income tax, must pay a royalty for the extraction of non-renewable resources. The royalty is levied on the margin of profits obtained on sales of mining products and were in force until December 31, 2010 at a rate of 5 per cent (or 4 per cent when a royalty fix rate was agreed in a Foreign Investment Contract subscribed with the Chilean government before December 1, 2004), which was replaced by a progressive tax, with an effective tax rate between 5 and 14 per cent. (Trucco 2011)

The environmental aspect of the mining activities is controlled, for instance, by certain regulations to the discharge of industrial waste water. They establish the maximum concentration of pollutants allowed for wastewater discharges into the ocean or continental surface water within the territory, pollutants permitted for wastewater discharges into groundwater and pollutants permitted for industrial wastewater discharges into the public sewage by industrial facilities. (Eyzaguirre 2016).

Additionally, the possible environmental impacts that mining development projects, including oil and gas projects, may cause are environmentally assessed within the Environmental Impact Assessment System (SEIA).

Regulation bodies

The principle government agency responsible for the mining and energy policy of the country as well as for the legal organization of the mining industry is the Mining Ministry. The Codelco (National Copper Corporation), Cochilco (Chilean Copper Commission), Sernageomin (National Service of Geology and Mines), Enami (National Mining Corporation), Enap (National Petroleum Company), CCHEN (Chilean Nuclear Energy Commission) and CIMM (Centre of Mining and Metallurgical Research) are the main regulatory bodies under the supervision of the Mining Ministry. (Quirland *et al.* 2013)

COCHILCO (Chilean Copper Commission) is a highly specialized technical agency, created in 1976. Since then its main mission is to advise the Government on development, implementation and monitoring of policies, strategies and actions contributing to sustainable development of the national mining sector and to strengthen the contribution of this to the rest of the economy related to Chilean copper production and its by-products, as well as all metallic and non metallic substances, except coal and oil.

SERNAGEOMIN (National Service of Geology and Mining) is a decentralized public sector body with legal status and its own financing that was set up in 1980, and relates to the executive power of the government through the Ministry of Mines. Its aim is to produce and provide data, products and services by specializing in the field of mining and geology in order to meet the demands of state institutions, enterprises and public and private organizations and other stakeholders involved in geological and mining activities.

SONAMI (National Mining Society) is the institution that gathers and represents the large, medium and small-scale private mining companies (both metal and non-metal producing) to promote the development of private mining, to be benchmark for private mining activities and to represent its members before the authorities, providing information and support services to its members on technical, legal, labor, environmental, tax and economic policies.

CESCO (Centre of Copper and Mining Studies) is an independent, non-profit organization, created in 1984 to enable better development of mining potential for the development of the economies of minerals and metals producing countries and Chile by organizing activities, forums and panels for the dissemination of relevant topics that will maximize the benefits of the relationship between mining and development.

2.3.3 Mining projects in 2015-2024

Considering the aforementioned Chilean National Mining Program, sustainable mining continues to be the key economic activity of the country in 2015-2024, divided into copper mining and gold, iron and industrial ore mining, together accounting for 100 per cent of the mining activities in the country. Copper mining, with 31 projects, makes up 86.7 per cent of the total investments in the portfolio. Most of the copper mines are found in Antofagasta, which, with 13 projects receives 42.7 per cent of the total investment, of which 8 are in base condition and only one in potential. Gold, iron and industrial ore mining receive 13.3 per cent investment and the regions of operations are Antofagasta, Atacama and Coquimbo. (COCHILCO 2015) The information regarding investments in copper mining is presented in Table 2. and about gold, iron and industrial ore mining – in Table 3.

Table 2. Copper mining investment per region and project condition (COCHILCO, 2015)

Region	Region Total			Base		Probable		Possible		Potential	
	Project Quantity	Investment (MMUS$)	% of total investment	Project Quantity	Investment (MMUS$)	Project Quantity	Investment (MMUS$)	Project Quantity	Investment (MMUS$)	Project Quantity	Investment (MMUS$)
Tarapacá	3	6,222	8.1%	0	0	2	632	0	0	1	5,590
Antofagasta	13	32,966	42.7%	8	12,891	1	1,500	3	13,575	1	5,000
Atacama	6	11,138	14.4%	0	345	3	2,757	0	146	3	7,891
Coquimbo	2	1,814	2.3%	0	0	0	0	2	1,814	0	0
Valparaíso	2	8,141	10.5%	1	1,530	0	0	1	6,611	0	0
Metropolitana	1	504	0.7%	0	276	1	112	0	117	0	0
O´Higgins	2	6,249	8.1%	2	5,899	0	0	0	350	0	0
TOTAL	**31**	**67,035**	**86.7%**	**12**	**20,941**	**7**	**5,001**	**7**	**22,612**	**5**	**18,481**

Table 3. Investment in gold, iron and industrial ore mining, per region and project condition (COCHILCO, 2015)

Region	Region Total			Base		Probable		Possible		Potential	
	Project Quantity	Investment (MMUS$)	% of total investment	Project Quantity	Investment (MMUS$)	Project Quantity	Investment (MMUS$)	Project Quantity	Investment (MMUS$)	Project Quantity	Investment (MMUS$)
Antofagasta	2	1,168	1.5%	-	-	1	665	1	503	-	-
Atacama	7	6,001	7.8%	-	-	3	4,540	4	1,461	-	-
Coquimbo	2	3,086	4.0%	1	198	-	-	1	2,888	-	-
TOTAL	**11**	**10,255**	**13.3%**	**1**	**198**	**4**	**5,205**	**6**	**4,852**	**-**	**-**

2.3.4 Mining in Antofagasta

Antofagasta with the Atacama Desert and the Andes along the ocean is the heart of mining activities in Chile. It represents 32 966 millions of US dollars of Chile's investment for copper mining and other metals (see Figure 6.).

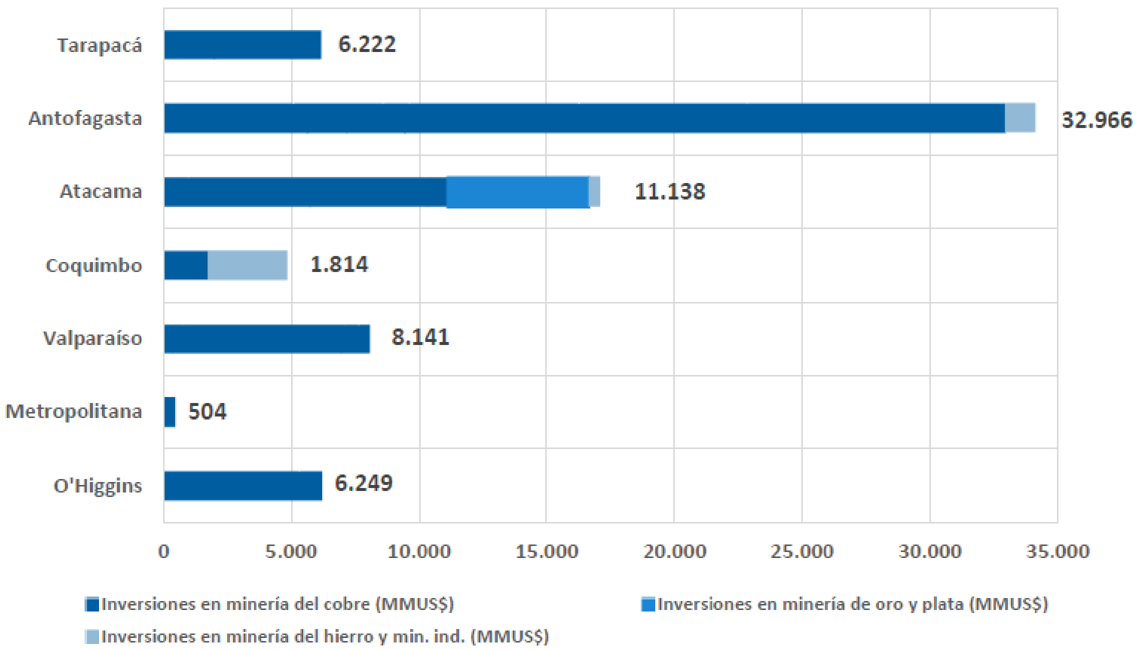

Figure 6. Total investment of the investment portfolio by regions for copper mining and others (COCHILCO, Projects 2015-2024)

Antofagasta has the highest concentration of mining production with the biggest mining divisions such as El Abra, Chuquicamata, Radomiro Tomic, Michilla, Spence, Centinela (combination of Esperanza and El Tesoro from 2014), Mantos Blancos, Lomas Bavas, Zaldívar, Escondida, Fundición Altonorte and El Peñón. (Quirland *et al.* 2013) The precise location of all mining deposits and mining companies in Antofagasta can be found in Appendix 5/1.

2.3.5 Illegal mining

> "Per kilogram of metal, informal and illegal mines are more dangerous for workers and do more environmental harm than large mines, where standards are easier to enforce." (Wharton School 2012)

Illegal mining camps are spread all over across the fringe of the Amazon in Latin America, creating hotbeds of forced prostitution and incredible level of pollution. Laborers work in horrific conditions in contaminated mud pits, breathing mercury flumes from gold purification in open oil drums. Nevertheless, miners defend the illegal type of mining as one of the few paths out of poverty in rural South America. For example, Chilean Atacama Desert provides an opportunity for low-scale copper mining with a lower number of gold mining operations. (Wharton School 2012)

Large mines are dangerous, but they are regulated and known, whilst small scale illegal mining is undetected and uncontrollable, therefore, in case of possible catastrophe actions cannot be taken immediately and quality standards for the mines' operations cannot be applied. Moreover, the processes used are not safe and not environmentally friendly, for example, gold and silver purification by cooking it in mercury uses two to three grams of mercury for every gram of gold, which ends up via evaporation in the environment and workers' bodies.

Illegal mining in Chile is mostly concentrated on seeking copper, which unlike gold requires processing in a capital-intensive plant before being sent to market. Chilean government claims to have succeeded in improving on-site safety and reducing pollution from small mines: a state-owned company called Enami is the sole buyer of ore from small and midsized miners.

However, these measures are inefficient with gold. The main common solutions at the moment are providing training for the employees, teaching them how to protect themselves and the environment while increasing their productivity, improving technologies (e.g. creating an affordable and easy-to-use technology for small scale mining), offering training and certification for the best practice of gold (in return, miners get higher prices for their gold). (Wharton School 2012)

2.4 Water Quality

Water quality in Chile varies throughout the country due to climatic variation along the extended area along the South Pacific Ocean, which is shown in Figure 7. (Region XIII is Región Metropolitana de Santiago).

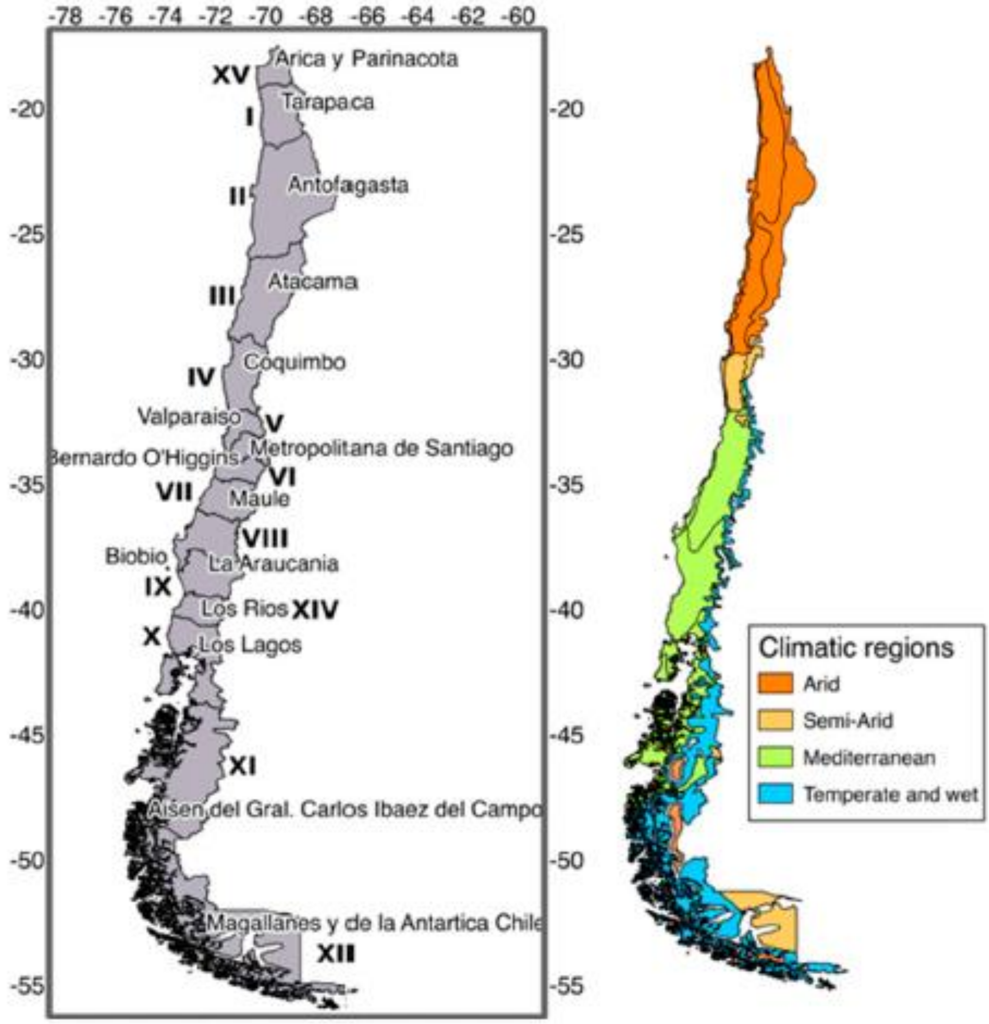

Figure 7. The names and numbers of all Chilean administrative regions and the climatic regions (Aitken et al. 2016, based on the Chilean State Catalogue of Geospatial Data, 2015)

To describe water quality of the country, it is convenient to split the country into three geographic zones: North (administrative regions XV, I – IV), Central (V – VIII, XIII, XIV) and South (IX – XII). The greatest emphasis in the description is made to the North Zone, particularly Antofagasta region, considering major mining operations and therefore the highest stress on quality and quantity of water. The water quality in the Central Zone is better that in the North, although the area is also affected by the Andean metallogenic deposits. The South Zone is characterized by excellent water quality due to few mining activities, higher water rates and the vegetation coverage, reducing erosion and suspended solids. (Muñoz *et al.* 2007).

In 2010 the University of Santiago de Chile has assessed the spatio-temporal dynamics of chemical species dissolved in 12 rivers of central-northern Chile in order to determine the contribution of mining to river contamination. The Elqui showed the highest historical mean concentrations of arsenic, copper and lead. The Aconcagua had the highest concentration of mercury and a large chromium concentration, while the Rapel river showed elevated concentrations of copper and molybdenum. Arsenic and copper in the Elqui had positive annual slopes. Sulphate concentration exceeded 100 mg L^{-1} in nine rivers, and in seven of them it had positive annual slopes. The findings suggest that mining pollution is the main process contributing to this increasing annual trend in arsenic, copper and sulphate. Therefore, it is necessary to identify the main sources of heavy metals associated with mining activities in order to improve the water quality of these rivers. (Pizarro et al. 2010) The summary of water problems in the country, including aforementioned and next ensuing, with detailed allocation of common metals in water is given in the Appendix 6/1.

The following maps (Figure 8.) show unbalanced water distribution in Chile. The information displays the annual rainfall (data from the Ministry of the Environment), river flow (the National Institute of Statistics), aquifer recharge, dam storage (Valde's-Pineda *et al.*) and the water availability and water balance for the central and northern regions of Chile. The data clearly shows that the water distributed unequally and while the South Zone has sufficient water resources, the North is an extremely arid area. Moreover, according to the World Bank statistics, the balance deficit between supply and demand of water is expected to increase in the central and northern regions: in the Far North to - 1 602 MM m^3 / year, in the Near North – 1 299 MM m^3 / year and in Central Chile – 2 844 MM m^3 / year. (Aitken *et al.* 2016)

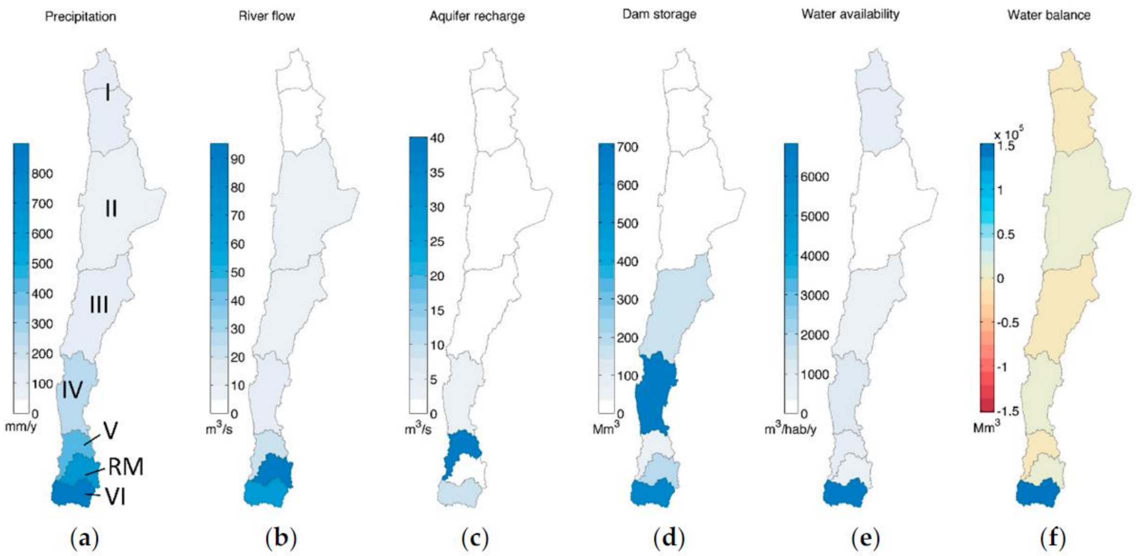

Figure 8. Maps displaying the values of (a) precipitation; (b) river flow; (c) aquifer recharge; (d) dam storage; (e) water availability and (f) water balance by region. (Aitken *et al.* (2016), based on the Chilean State Catalogue of Geospatial Data, 2015)

Chilean waters have elevated levels of metals and metalloids, caused by a complex interaction of hydraulic, hydrological and anthropogenic factors, which are difficult to differentiate by virtue of lack of comprehensive measurements and quantitative geochemical models.

The main contribution is associated with lithology of the country and the presence of highly fractured volcanic rocks, subject to natural leaching process. Anthropogenic factors affecting water pollution throughout the country are untreated municipal wastewater, agriculture, industrial effluents and mining.

Chile monitors water quality in the country via the network of water quality monitoring stations. The stations measure fundamental parameters determining water quality such as temperature, pH, dissolved oxygen, electrical conductivity and other. Metals and minerals concentration are measured as well: aluminum, arsenic, cadmium, cobalt, copper, chromium, iron, manganese, mercury, molybdenum, nickel, silver, lead, selenium, zinc, calcium, chloride, magnesium, potassium, sodium, sulfate, boron and others. The network allows constant monitoring of the quality of water resources both surface and underground. Figure 9. presents location of water monitoring stations.

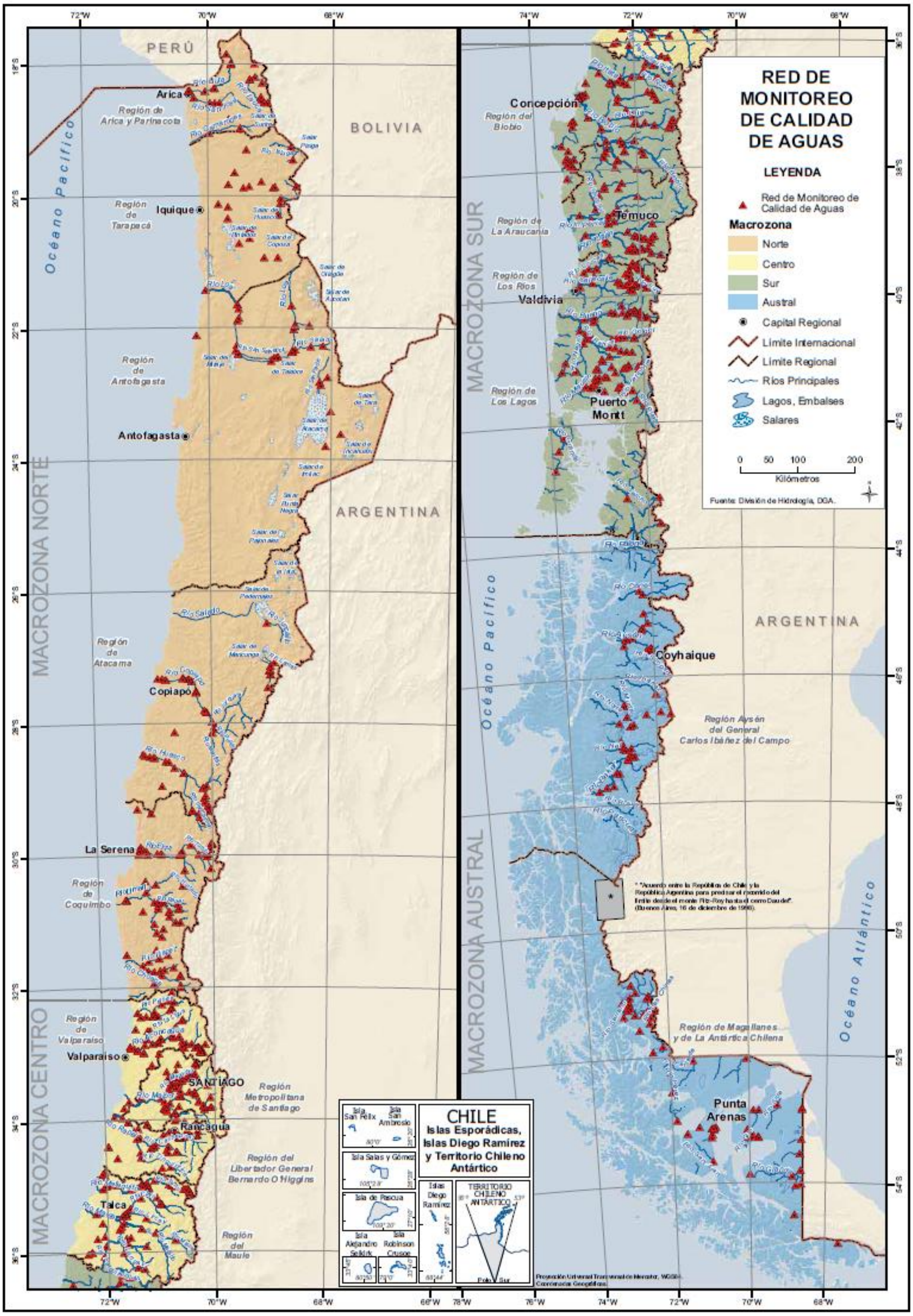

Figure 9. Water quality monitoring stations in Chile (Chile Atlas 2016)

2.4.1 Common metals in water

There are certain metals widespread in all mining related countries, such as lead, mercury and arsenic. This section presents discussions about lead and mercury concentrations in Chile. Arsenic is studied throughout description of North, Central and South Zones.

Lead (Pb)

Most of the problems with lead in Chile are caused not by the mining industry or mining activities. The most common way of lead contamination is through consumption goods or materials brought from other countries.

For instance, leaded gasoline is a frequent source of lead contamination, which was banned in 2001 (SESMA Chile 2002), but large amounts of fine lead particle still persist in highly populated cities as city soil and home soil, and as ground contamination near highways. Other sources include paints used before 1997, food, e.g. vegetables grown near highly populated cities, and point sources of contamination, e.g. practice of battery repair and recovery by small enterprises or as family projects and painters, welders, and mining or smelting workers are exposed to the metal at work. Lead is not as common metal in Chile as in Peru, therefore, lead exposure at mining and smelting work is rare and mostly accidental. (Tchernitchin *et al.* 2004)

In addition, there are few special cases of lead contamination.

In Antofagasta the main source of pollution was powdered lead mineral concentrates, mainly lead sulfide containing about 26.5 per cent lead according to measurements made at the Institute of Public Health in Chile, Chilean Ministry of Public Health. The mineral comes by railroad from Bolivia and it is transported through the city and openly stored near densely populated parts of the city. Chile is obliged to transport and keep the mineral in its ports until exported by sea to other countries according to an old international treaty between both countries. Until 2002 - 2003, the mineral had been stored at open sites in Antofagasta, allowing lead-containing particles being spread all over the region.

The second issue with lead occurs in Arica. First of all, the hazardous minerals from Bolivia are also stored in Arica, secondly, the city's population was affected by "toxic raw material for industrial purposes" imported by Promel from the Swedish company Boliden Metal in accordance with an arrangement to recycle the waste. The material was deposited without any protection in the suburbs of Arica between 1983 - 1985, where, a few years later, new low-income dwellings were constructed and residents were exposed for more than 10 years. The hazardous pile was moved slightly further from human habitation in 1998, but the area of original location is still contaminated. The case is on-going and the recent news show that the issue has been processed in court and it is called "the largest transnational corporate accountability case ever brought in a European court outside of the UK, and the first to be brought in Scandinavia". (EDLC n.d.)

Mercury (Hg)

> "Chile needs to adopt measures to detect mercury contamination in populations at risk. Furthermore, strict controls need to be incorporated to eliminate the origin of mercury release, something that has only been partially accomplished within the last few years." (Barrios-Guerra 2004)

Mining activities in Chile, essential for the economy of the country, are concentrated between Regions I and IV, contributing to chemical contamination of nearby rivers and the ocean, mostly coastal waters (particularly semi-closed bodies of water – bays) and the biota. For instance, in San Vicente Bay, waste discharges released into the ocean include sewage, industrial residues, residues from fishing and mining industries, hydrocarbons, petrochemical derivatives, oils, and detergents, making the Bay the most contaminated in the country. From the beginning of 1990s, Chile made a great effort to decrease contamination though governmental organizations, nongovernmental organizations, universities, governmental and private mining industries. (Barrios-Guerra 2004)

The principal problem of mercury use and contamination is the inappropriate use of small and independent mining operations, which still employ the same processes of gold and silver exploitation as in the 16th century. The direct and obvious solution of the problem is a change of mentality concerning the environment by means of educational programs and implementation of environmentally friendly technologies at an affordable cost.

Moreover, there has been an increase in mercury use by industry and society (toys and battery-operated artifacts) that follows an inverse pattern in developing countries to that in developed countries.

The major source of mercury contamination in Chile is water, where mercury can pass efficiently from one biological compartment to another. This bioavailability increases the accumulation of mercury through all the levels of the food chain up through humans. The critical areas of mercury contamination are Regions I, II, III, IV, V, and VIII and the Metropolitan Region. Mercury is present in soil, river, bays (water, sediment, and material in suspension), and seafood (fish, shellfish, algae, etc.) and the concentration is higher than those accepted by the international community. (Barrios-Guerra 2004)

2.4.2 North Zone

The North Zone is characterized by elevated levels of arsenic, boron, lithium, sodium and potassium, caused by a strong contribution from naturally occurring ore deposits. In the northernmost regions (XV, I, II, and III) there are several metallic formations rich in arsenic, which are subject to natural leaching process. The average sediment load is low due to low flow rates, although the scarce vegetation coverage results in high erodibility. Sporadic rain events during the "Bolivian winter" season (December-March) cause transient surface runoff that brings high sediment loads to rivers, whereas normally strong solar radiation generates high levels of water evaporation, increasing the concentration of chemical species. A lack of comprehensive measurements and quantitative geochemical models makes it difficult to differentiate the natural background level of metals and metalloids from the contribution of the same species from anthropogenic sources. The waters of North Zone are rich in particular metals, lead and mercury, causing waters contamination and developing health problems in the communities. (Muñoz *et al.* 2007).

Arsenic concentration in the rivers of Antofagasta region is associated with volcanic and geothermal origin (Cáceres 1999; Sancha 2000; DGA-Chile 2006). Arsenic concentration in the river Loa basin is higher in the confluence with Rio Salado, where the occurrence of arsenic is associated with chlorine, sodium, and boron, and the area next to Calama city (Chiu-Chiu, Ayquina and San Pedro de Atacama), where arsenic occurrence is associated with sulphate and copper (II) cations. (Perez-Carrera, Cirelli 2010)

Table 4. Range of arsenic (As) in river water in northern Chile (DGA-Chile 2006), mg/L

River	**As, mg/L**
Vilama	0.6 to 0.7
San Pedro	0.4 to 0.5
Toconce	0.6 to 0.9
Lequena	0.15 to 0.35
Loa	1.5 to 2.5

Table 5. Arsenic (As) water concentration in rural towns in northern Chile (Cáceres 1999), mg/L

Town	**As, mg/L**
Lasana	0.40
Toconce	0.40
Talabre	0.37
Caspana	Good quality
Chiu-Chiu y Ayquina	0.80
San Pedro de Atacama	0.75
Toconao	Good quality
Socaire – Ca'mar	0.28

Water basins in North Zone

Lauca (Región de Arica y Parinacota)

Chemical composition of the river is determined by high salinity overflows from Cotacotani lake and lixiviates from ignimbrites and andesites. High carbonates, calcium and magnesium suggest connection with dolomitic rocks from Oxaya formation. High solar radiation coupled and small flows produce increased salt concentrations. Water quality of the river varies from good to fair. Metals presented in waters are boron (2 ppm), arsenic and cyanide. (Muñoz *et al.* 2007).

Tarapacá (Región de Tarapacá)

The upper part of the catchment presents high concentrations of metals. Metallogenic streaks are believed to be the biggest contributors. Soil quality and high solar radiation produces high salinity. Water quality and quantity are variable and dependent on the season. Water quality varies from good to poor. Salinity, high boron (13 ppm), sodium (300 ppm), chloride (800 ppm) concentrations are named the main problems of the river basin. (Muñoz *et al.* 2007).

Loa (Región de Antofagasta)

High arsenic and salts content occurring naturally due to Salado river (salado means salty in Spanish). Intense rain events have been coupled to water quality episodes involving extremely high arsenic and metal concentrations in suspended solids. Although some studies indicate anthropogenic causes, the evidence is not conclusive. The quality varies from good to poor and sodium, boron (40 ppm), chloride and arsenic are the main issues in the area. (Muñoz *et al.* 2007).

According to the information from 2003, the waters are heavily enriched in arsenic (average: 1 400 μg/l) and boron (average: 21 000 μg/l). The quality of water is named extremely poor along the tributary Salado, mainly fed by the El Tatio geothermal waters that are very rich in arsenic (up to 27 000 μg/l) and other components. Sediments from the Rio Loa and its tributaries have arsenic contents in the range of 26 – 2 000 mg/kg (mean value of 60 samples: 320 mg/kg), and reach 11 000 mg/kg at El Tatio. The extreme arid conditions, high evaporation, and the lack of low arsenic tributaries contribute to maintain high concentrations of arsenic and other components in the Rio Loa water. The main source of arsenic in the Rio Loa basin is considered to be natural, i.e. linked to the lithologies in the area. Smelter emissions and mining wastes, as well as the arsenic-rich effluents from the water treatment plants, possibly represent additional sources. (Romeroa *et al.* 2003)

Salar de Atacama (Región de Antofagasta)

The river has high concentrations of salts with major contribution from local soil lithology (evaporates). Potassium, boron and lithium are mined in evaporation ponds. Detailed geochemical studies and being carried out by mining companies, involving groundwater flow models coupled to geochemical balances. The water quality varies between fair and poor, sodium, potassium, chloride, boron and lithium concentrations are high. The basin has a high amount of arsenic due to the natural volcanic activity, an abundance of ore deposits, and human activities.

Copiapó (Región de Atacama)

Local lithology coupled to low stream flows introduces ions along the watershed. Moderate salinity, boron, arsenic concentrations. The river has low sodium and high sulphate concentration. (Muñoz *et al.* 2007).

The *Candelaria project* from 2008 by the Compañia Contractual Minera Candelaria (CCM Candelaria), a former joint venture of Phelps Dodge Corporation of the USA and Sumitomo Metal Corporation of Japan, currently owned by Freeport-McMoRan Copper & Gold, Inc., focuses on proper disposal of tailings with impoundment technology as well as effluent leakage prevention of remaining 20 per cent of untreated waste water. (Blacksmith Institute 2009)

Elqui (Región de Coquimbo)

The Elqui river watershed has been studied by the cooperation of Chilean and Spanish universities in 2005, with the conclusion made that the Elqui river is highly contaminated with arsenic exceeding by up to three orders of magnitude the average for river waters. There are three main reasons of contamination: natural regional geology and hydrothermal (mineralizing) processes, unroofing-erosion-oxidation-leaching of As-Cu rich sulfide ores and mining activities at the high-altitude (> 4 000 m above sea level) Au-Cu-As El Indio mine. (Oyarzun *et al.* 2006)

The El Indio mineral deposit hosted large veins of massive sulfides, including the important presence of enargite. Before mining activities were implemented, river Toro had shown very large arsenic concentrations (0.36-0.52 mg 1^{-1}). Mining activities led to an increase of these values, reaching 1.51 mg 1^{-1} in 1995. Other rivers had arsenic concentration of 0.33 (Turbio) and 0.11 mg 1^{-1} (Elqui). The USEPA regulations for drinking water is 0.01 mg 1^{-1} arsenic, and about 10 per cent of the total arsennic data from the river Elqui (and 70 per cent from the river Turbio) are above the maximum level allowed by the Chilean law for irrigation water (0.1 mg 1^{-1}).

The mine has been closed in 2002 but environmental problems caused by El Indio mining activities are still topical. The Figure 10. presents a map of Elqui watershed, including location of sampling stations used in the study.

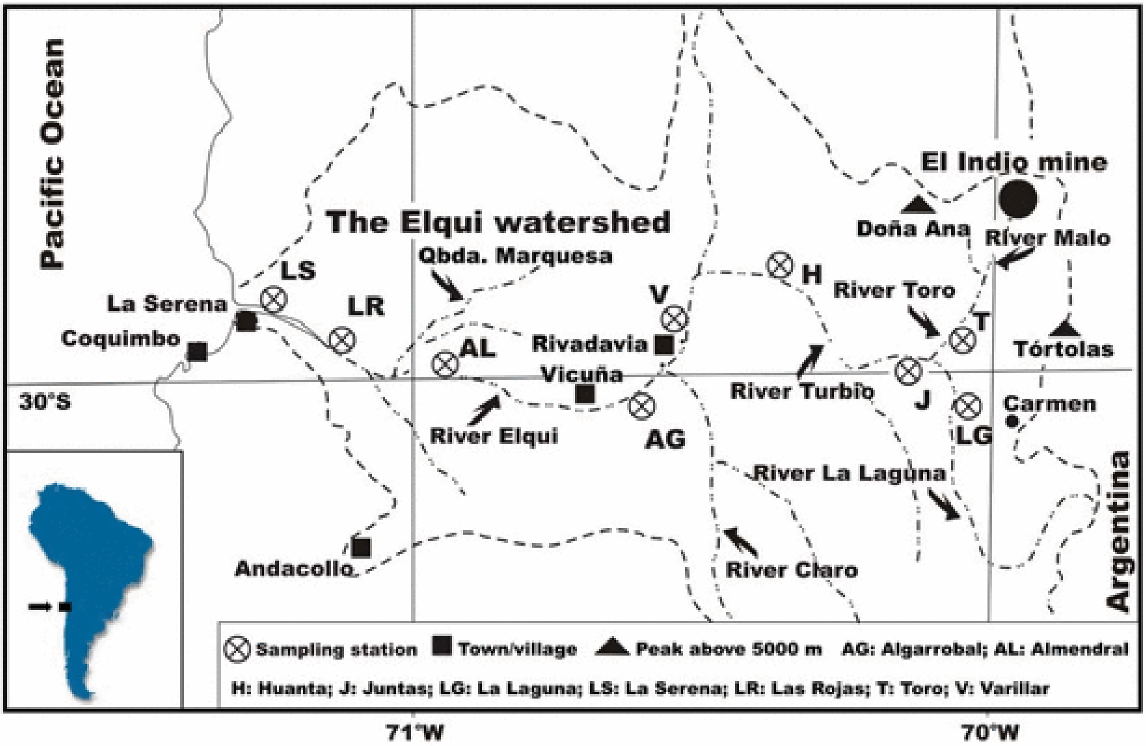

Figure 10. The Elqui watershed, including location of sampling stations (Oyarzun *et al.* 2006)

Limari (Región de Coquimbo)

Local lithology contributes to background metal concentrations. In general, water quality is good, but shallow groundwaters impact surface water quality with high chloride, sulphate and magnesium. (Muñoz *et al.* 2007).

Petorca (Región de Valparaíso)

Metallogenic streaks contribute to background metal concentrations, particularly manganese and copper. Abundant sedimentary material from colluvial and alluvial deposits. High sediment content during storm events due to low vegetation. Nevertheless, the water quality is stated to be good. (Muñoz *et al.* 2007).

2.4.3 Central Zone

Central Zone, presented by Aconcagua, Maipo, Rapel, Maule and Biobio water basins, is also affected by Andean metallogenic deposits, contributing to the levels of metals in waters, although there is substantial dilution compared to the North Zone, and consequently a better overall water quality. Waters in the northern section of the Central Zone are more turbic, caused by higher surface runoffs coupled with increasing, but still limited vegetation coverage. However, as vegetation cover increases southwards, turbidity decreases. Towards the south of Central Zone more abundant clays and limestone make waters more alkaline. The water quality varies from good to poor, with an exception in waters of Biobio, where high rainfall and vegetation coverage produces outstanding water quality. (Muñoz *et al.* 2007).

All in all, local lithology of the zone contributes to metal concentrations in water. For instance, Aconcagua river has a high concentration of manganese, copper and iron, coming from metallogenic streaks. Moreover, groundwater adds sulphate and manganese downstream. Metallogenic streaks in the river Rapel area, bring high copper, manganese and molybdenum content. Maule river is rich in clay and limestone originating from volcanic activities. (Muñoz *et al.* 2007).

Lithology of *Maipo* river basin produces background concentrations of copper, aluminum, chromium, lead and molybdenum, and alkaline conditions. There are ongoing debates between the community living in the area and the mining giant, Antofagasta plc., about the water quality of the river. The community of Caimanes claims the Mauro tailing dam from the Pelambres copper mine for diverting the natural course of the Pupio estuary. Chile's Supreme Court has ruled in favor of the people, however, no actions have been taken by Antofagasta plc. Location of the project is Maipo river's upper basin in San José de Maipo, about 150 km from Santiago in the Cordillera province. The plants will be located in the Colorado river sub-basin (see Figure 11.). In addition, the Alto Maipo Hydroelectric Project, partially owned by Antofagasta plc. (40 per cent), which was planned in 2007 and with an estimated ending in 2019, endangers the irrigation waters for agriculture and accelerates the melting of glaciers and recharging of aquifers which will leave behind almost 400 square miles of barren land. The project, planned in order to meet the energy needs of the Pelambres mine, is claimed for threatening the safe supply of drinking water to 7 million people in Santiago and doing irreversible and long lasting damage to communities and the environment.

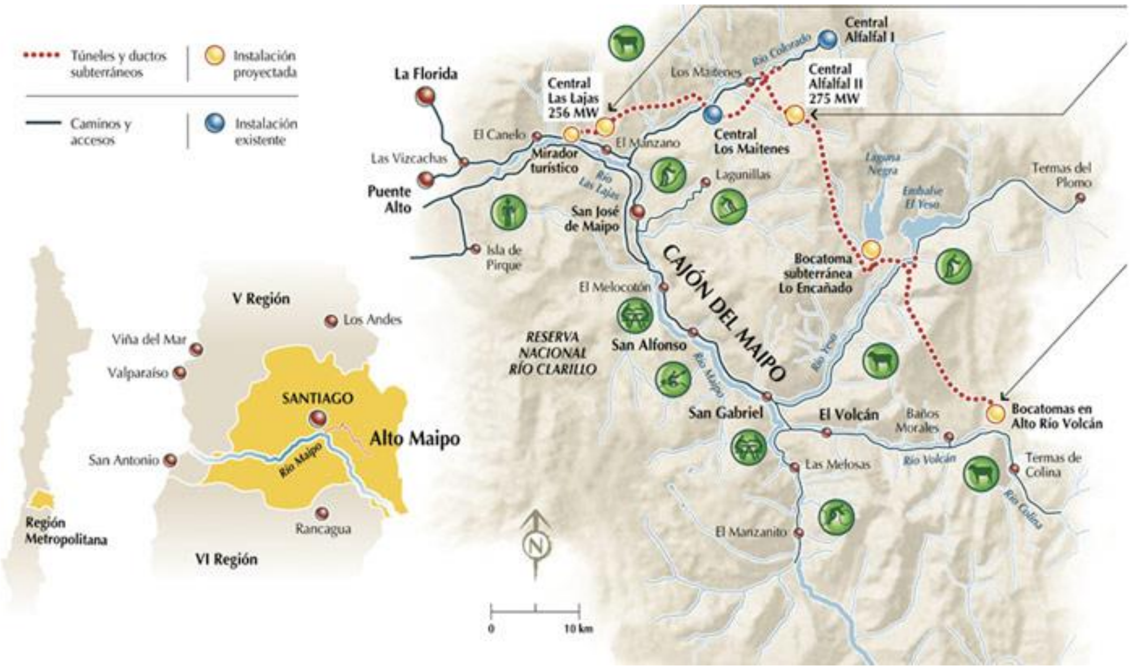

Figure 11. Location of the Alto Maipo Hydroelectric Project (GEODATA 2007)

2.4.4 South Zone

Most important water basins in South Zone are Imperial, Valdivia, Maullin, Aysen, Serrano and Cisnes. Flow rates in the zone are substantially higher and vegetation coverage in dense, reducing erosion and suspended solids, but increasing the dissolved organic carbon from the degradation of vegetation. Lakes from ice and snowmelt towards the southern end show higher turbidities; however, this turbidity decreases down to negligible levels as the water moves downstream from the lake drainage. (Muñoz *et al.* 2007).

Water quality in South Zone varies from good to excellent, for example, Serrano has an excellent water quality due to ice and snowmelt and Aysen river has an elevated content of chromium, copper, boron and manganese because of the clay particles in water. The downturn of the quality is caused by the natural conditions of the environment. Valdivia river has some metal contribution from groundwater from soil leaching. Cisnes is high in copper and aluminum content due to the local ore deposit. Maullin has an organic contribution from *nadi* soil.

Imperial river is highly affected by volcanic activity. *Trumao*, a characteristic soil in this catchment, introduces acidic conditions. However, lower in the catchment, limestone introduces alkalinity, counteracting the effects of the traumas. (Muñoz *et al.* 2007).

3 CONCLUSION

This chapter summarizes the key results and presents answers to the research questions and the research problem. In addition, it provides recommendations and suggestions for the commissioning party based on the research findings.

Chile has a status of Latin American reference of progress despite the slowdown of the economic growth in 2016 due to the end of the investment cycle in the mining sector and the decline in copper prices and private consumption - the economy is expected to recover in 2017 - 2018. The economic growth of the country has a positive social influence resulting in access to improved water and sanitation services by the population, reaching 99 per cent of improved water source and sanitation facilities starting from 2013 (World Bank 2016).

In addition, Chile is the world leader in copper production, followed by China and Peru (USGS 2012). The country is among the biggest producers of other minerals such as gold, silver, iron and mineral products coming from saltpans (nitrates), thus, mining is the crucial activity of the Chilean economy. However, mining is hazardous for the environment and water contamination is a pressing topic in Chile. Chilean National Mining Program, launched for the period 2015 - 2035, aims to transfer the economy based on natural resources to a knowledge driven economy. The country is interested in virtuous, sustainable and inclusive mining, which generates benefits to communities.

Due to climatic variation throughout the country, water quality varies as well. Water in the central-northern Chile is highly affected by geology, volcanic activity, natural organic process and mining activities. Mining pollution is named by the University of Santiago de Chile (2010) to be the main process contributing to increased level of arsenic, copper and sulfates. Meanwhile, Chile has excellent water quality in the South.

To sum up, the population of Chile has an access to sanitation facilities and water, but the water quality is still a problem in the northern part of the country. Most of the water problems are caused by the economic activities, specifically water contamination by mining operations. The problem is extensive and comprehensive to deal with and the government encourages mining companies to decrease negative environmental effect of their operations, for example, using desalinated water. The companies are interested in new technologies that solve the problem, thus, Chile offers promising business opportunities for CEMIS development, particularly the WaterCare project, and the key partners are expected to be the mining companies.

Further studies about Chile are recommended to be made in future. Since the world is changing constantly, updating the secondary data is needed, particularly, information about up-to-date technologies, statistics and situation in general. Moreover, in-depth literature review in Spanish can be conducted. Ideally, a trip to Chile visiting the key areas such as Antofagasta Region would bring a better insight to the situation.

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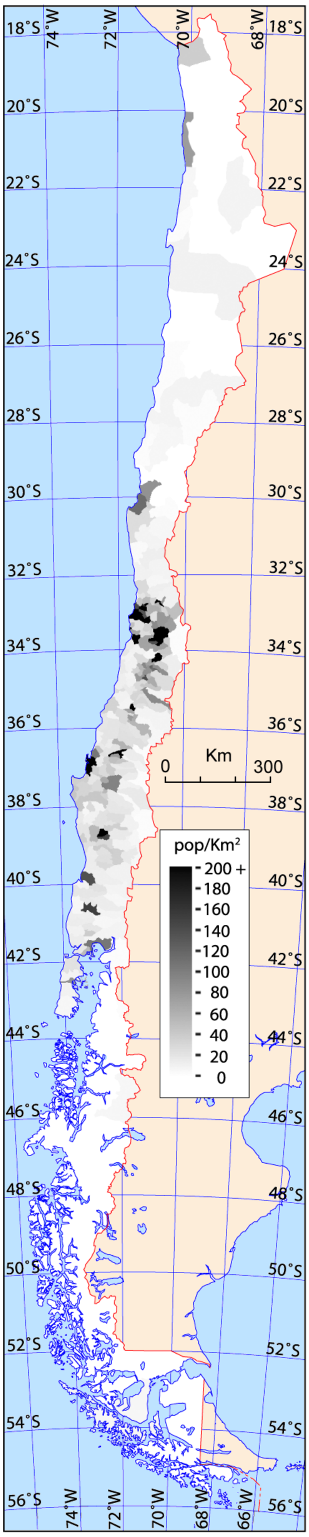
APPENDIX 1/1. Map of Chile population density by commune. (National Census Data 2002)



APPENDIX 2/3. Distribution of water concessions in the regions in 2016. (SISS 2016)

Region	**Water Company**
Región de Arica y Parinacota	Aguacor S.A. Aguas del Altiplano
Región de Tarapacá	Aguas del Altipl ano
Región de Antofagasta	Aquas Antofagasta S.A. Econssa S.A. Tratacal S.A.
Región de Atacama	Aguas Chañar
Región de Coquimbo	Aquas del Valle Aguas La Serena Norte ESSETO ESSSI
Región de Valparaíso	Coopagua ESVAL Immobiliaria Norte Mar S.A. Los Molles Sanitaria El Molino Uno y Cia Ltda. 15
Región Metropolitana de Santiago	Aguas Andinas Aguas Cordillera Aguas de Colina Aguas Lampa Aguas Las Lilas Aguas Manquehue Aguas San Pedro S.A.

	Aguas Santiago Norte S.A. Aguas Santiago Poniente BCC S.A COSSBO El Colorado EMAPAL ESSA ESSSI Huertos Familiares Izarra de Lo Aguirre La Leonera Llanos del Solar S.A. Melipilla Norte NOVAGUAS Santa Filomena S.A. Santa Rosa del Peral SELAR S.A. Sembcorp Aguas Chacabuco S.A. Sembcorp Aguas Lampa Sembcorp Aguas Santiago SEPRA S.A Servicios Sanitarios La Estación SMAPA 29
Región del Libertador General Bernardo O'Higgins	ESSBIO VI (Ex-ESSEL)
Maule Región del Maule	Aguas Nuevo Sur

	Aguas San Pedro S.A Cooperativa Maule Cooperativa Sarmiento Econssa Chile Sagrada Familia
Región del Biobío	Aguas San Pedro S.A ESSBIO VIII ESSBIO VIII
Región de La Araucanía	Aguas Araucanía Comité de Agua Potable y Alcantarillado Quepe S.A ECONSSA S.A. ESSSI
Región de Los Lagos	Aguas San Pedro S.A. Empresa Sanitaria Sur S.A. ESSAL ESSSI X
Región Aisén del General Carlos Ibáñez del Campo	Aguas Patagonia
Región de Magallanes y de la Antártica Chilena	Aguas Magallanes
Región de Los Ríos	Aguas Décima Essal S.A.

APPENDIX 3/2. Evaluation Results of Wastewater Treatment Plants (PTAS) in Antofagasta, Chile. (SISS 2016)

The table shows evaluation results of wastewater treatment in Antofagasta done by SISS in 2016. The table presents the company-owner providing wastewater treatment service, name of the wastewater treatment plant, and its compliance with certain regulations. The results of evaluation are different every year.

The table specifies what kind of regulation is applied to PTAS. The D.S. 90/00, from 03/09/06, regulates the discharge of pollutants to surface marine and inland waters. NCh 1333/78 is a Chilean Standard on water quality requirements for different uses.

Remarks clarify some details about authorization. The PTAS Sierra Gorda and Baquedano were obliged to report in February 2016 instead of January 2016. The PTAS Lodos Antofagasta doesn't have an authorization according to the regulations, but has a monitoring program authorized by RES. SISS No.1020 dated 03/21/2014 as part of dealership.

Water Company	Name of PTAS	Regulation	201601	201602	201603	201604	201605
AGUAS DE ANTOFAGASTA S.A.	ES - MEJILLONES	D.S. 90/00	NO CUMPLE	CUMPLE	CUMPLE	CUMPLE	CUMPLE
AGUAS DE ANTOFAGASTA S.A.	ES - TAL TAL	D.S. 90/00	NO CUMPLE	NO CUMPLE	CUMPLE	CUMPLE	CUMPLE
AGUAS DE ANTOFAGASTA S.A.	ES - TOCOPILLA	D.S. 90/00	NO CUMPLE	CUMPLE	CUMPLE	CUMPLE	CUMPLE
AGUAS DE ANTOFAGASTA S.A.	PTAS - SIERRA GORDA (9)	NCh 1333/78	-	CUMPLE	CUMPLE	CUMPLE	CUMPLE

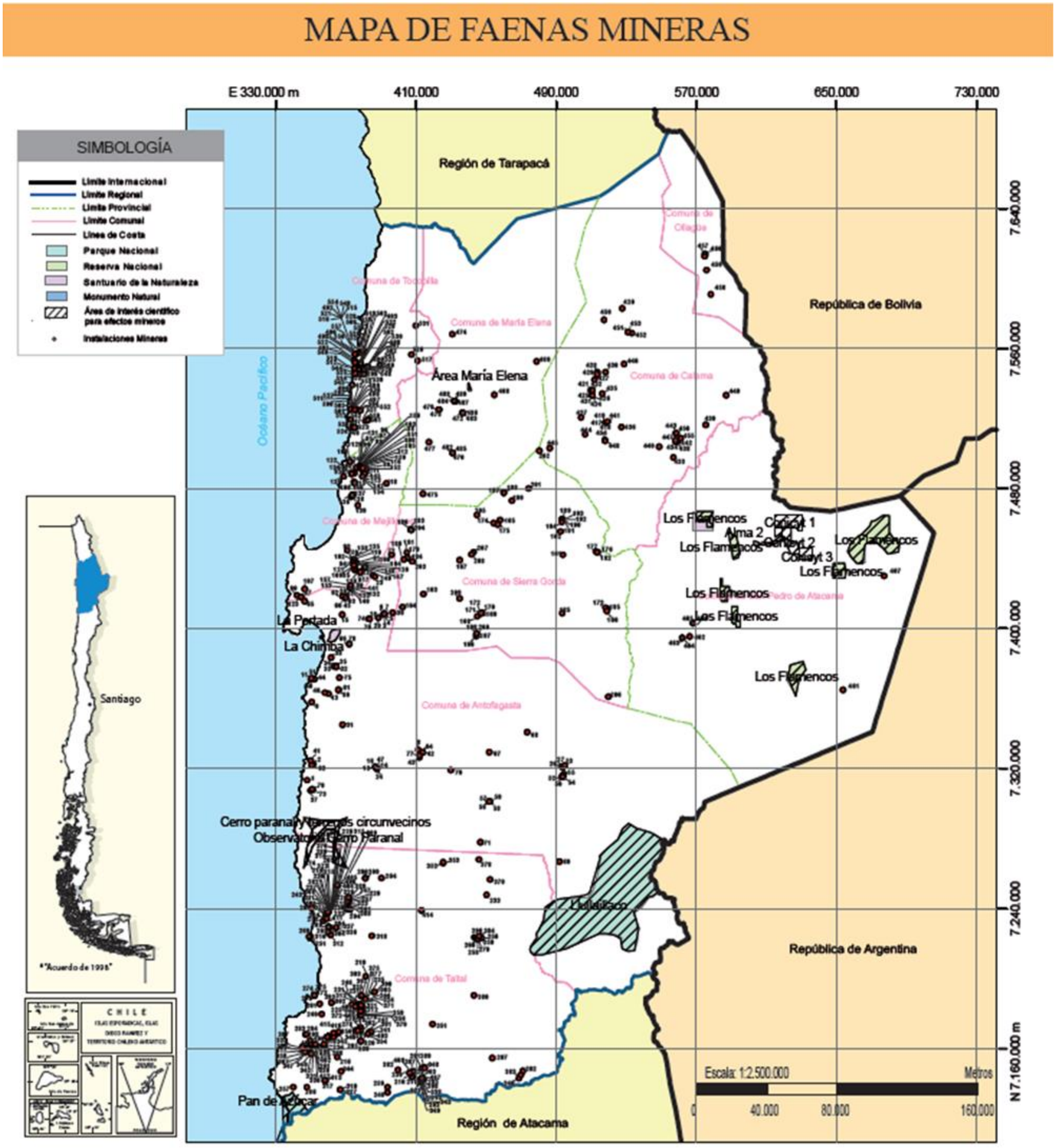
AGUAS DE ANTOFAGASTA S.A.	PTAS – BAQUEDANO (10)	NCh 1333/78	-	CUMPLE	CUMPLE	CUMPLE	CUMPLE
AGUAS DE ANTOFAGASTA S.A.	ES - GRAN ANTOFAGASTA	D.S. 90/00	CUMPLE	CUMPLE	CUMPLE	NO CUMPLE	CUMPLE
EMPRESA CONCESIONARIA DE SERVICIOS SANITARIOS S.A.	PTAS - LODOS ANTOFAGASTA (7)	-	CUMPLE	CUMPLE	CUMPLE	CUMPLE	CUMPLE
TRATACAL S.A.	PTAS - CALAMA	D.S. 90/00	CUMPLE	CUMPLE	CUMPLE	CUMPLE	CUMPLE

(9) (10) PTAS Sierra Gorda and Baquedano autorizada para aplicación de cargo tarifario en enero de 2016, en consecuencia, tiene obligación de informar a partir de febrero de 2016.

(7) PTAS - LODOS ANTOFAGASTA no cuenta con autorización tarifaria y no debe cumplir con una norma de emisión específica ya que cooresponde a una planta que entrega agua de servicio a empresas mineras, sin embargo cuenta con un programa de monitoreo autorizado por RES. SISS N° 1020 de fecha 21.03.2014 debido a que pertenece a una concesionaria.

APPENDIX 4/1. Geographical distribution of mining divisions in Chile. (Quirland et al. 2013)

APPENDIX 5/1. Location of mining deposits and mining companies in Antofagasta (National Mining and Geology Service, SERNAGEOMIN 2011)



Nota: Coordenadas UTM, referidas al datum PSAD 56.