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Smelting and Refining Copper in Chile: The Importance of Local Pollutants

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SMELTING AND REFINING COPPER IN CHILE: THE IMPORTANCE OF LOCAL POLLUTANTS

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Abstract

This work aims to illustrate the importance of local pollutants in the copper smelting and refining process. While there is a benefit to the global atmosphere of smelting and refining all copper in Chile, as shown by Sturla et al. (2020), it is necessary to take into account that, if such a policy is implemented, the country will have to bear a high pollution burden. Thus, this work addresses aspects that cannot be left out of a policy for copper concentrate: i) recognize the problem, ii) identify the most important pollutants, iii) review national and international literature, iv) identify problems associated with health and the environment, v) show the example of a slaughter area in Chile, and vi) refer to some estimated costs for the identified impacts. The work has a more informative than conclusive role, fundamentally as an input for a public policy for Chilean copper.

Keywords: Copper Mining, Local Pollutants, Health, Environmental, Slaughter Areas, Public Policy.

JEL Classification: Q32, Q42, Q56,

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1.1 INTRODUCTION

Smelting and refining all the copper ore in Chile on the one hand helps to reduce global greenhouse gas (GHG) emissions (Sturla et al., 2020), but on the other hand, by concentrating this process in one country (in spite of 12 countries), greatly affects the local population and environment through concentrating the pollutants. Due to these effects, it is necessary to carry out a detailed analysis of the local pollutants involved and their potential negative impacts, since that impact should be taken into account in public policies surrounding copper.

Copper smelters and refiners are an important source of toxic pollutants for both humans and the environment. These pollutants include arsenic, which is an extremely toxic and dangerous element. Others are sulphur dioxide, which is an indirect greenhouse gas, and nitrogen oxides, which are direct greenhouse gases. Exposure to different gases and unwanted elements in the ecosystem can cause serious damage to the human body, from headaches to genetic damage, cancer, or poisoning. This is especially a concern when it comes to children since are the most sensitive to these pollutants due to their size and that they are growing. Many countries like Mexico and Chile have had this sort of issue. Another factor is the reduction of biodiversity in the affected environment. There can be contamination of the water with heavy metals or phenomenon such as acid rain. Toxins can also show up in agricultural produce, which obviously affects the consumers of such produce. Soil can be made practically unusable, and the air can become toxic. In addition, it contributes to climate change with the emission of greenhouse gases. The main local pollutants are Copper, Sulphur Dioxide, Nitrogen Oxides, Lead, Arsenic, Cadmium, Mercury, Zinc and Selenium.

In Chile the most important smelters and refineries are Chuiquicamata and Potrerillos from the state-owned Codelco, which are also refineries; Caletones of Codelco, Altonorte of Glencore, Chagres of Anglo American, which is also a sulfuric acid plant; Hernán Videla Lira of Enami; and lastly, Ventanas of Codelco, also a refinery and a sulfuric acid plant, an emblematic case of contamination.

Of course, copper producers are not alone in creating pollution. Ventanas, for example, is located in an industrial area with coal thermoelectric plants, chemical industries, along with other industry. They have contaminated the Quintero-Puchuncaví area to such an extent that it has been declared, by environmental groups, as a slaughter area. According to many studies carried out in the area over several years, there are many toxic and polluting elements in soil, area, and most importantly in the sea — fishing is another important industry in the area. The methods of study have varied widely atmospheric samples, soil samples, sea sediment samples, rainwater samples, and household dust, showing that pollution has affected all aspects of local life. Those that have caused adverse effects on marine life and human life, even raising the potential risk of children living in the area to have cancer.

Beyond quality of life, environmental pollution causes economic damage that can be quantified from health and remediation expenses. People getting sick costs additional health resources and is a loss of productivity; cleaning toxins out of the local environment is often quite expensive and time consuming. Of interest to this paper is the possibility to estimate the costs of specific pollutants, allowing us to evaluate the costs of copper smelting.

We start this paper going over each of the main local pollutants associated with the smelting and refining processes. Specifically, we focus on their effects on the environment and public health as documented in the literature, through notably most of that research comes from other locations. Secondly, we review the most important smelters and refineries in Chile along with other fixed emission sources. Subsequently, we discuss the specific case of the Quinteros-Puchuncaví is carried out. As mentioned earlier it is an industrial area considered as a "slaughter area" due to the multiple sanitary and environmental problems that have arisen in the area. Industries like the Ventanas smelter, four coal thermoelectric, ENAP maritime terminal, chemical industries like Oxiquim and many other industries are in the area. Then, we discuss some aspects about the economic costs associated with the industrial pollution and the specific pollutants, using international research on health and environmental pollution. Finally, we discuss the elements that need to be taken into account for an adequate analysis of the costs of increased copper smelting and refining in Chile.

1.2 LOCAL POLLUTANTS

1.2.1 Copper (Cu)

Only a small number of plants can live in copper rich soils, so copper can seriously impact agriculture depending on soil acidity of the soil and the presence of organic matter. It has a negative impact on the activity of microorganisms and earthworms. The decomposition of organic matter can decrease due to this. Animals can also absorb concentrations of copper that harm their health. Copper has been found to have a negative impact on soil in the Ventanas smelter area by causing a decrease in organic matter (Calisto, 2014). The same study also found copper impacting marine life. When examined, marine sediments from Quintero Bay, Chile, metal concentrations were found the suggest an anthropogenic origin related with copper which are most likely associated with by the copper smelter (Parra, et al., 2015). Also, in Quintero Bay, leaf samples were analyzed with a clear trend to increase the concentration of Cu with the proximity to the industrial complex (Gorena, et al., 2020).

1.2.2 Sulphur Dioxide (SO_2)

Sulphur dioxide is a colorless and toxic gas with an irritating odor and is a waste product generated from obtaining concentrates in the copper smelter. This pollutant reacts with humidity in the air and oxidizes in the atmosphere forming H_2SO_4 and lowering the pH of the rain, e.g. “acid rain.” Rain and snow deposit, it in the soil, a process degrades soil and the plants on it. Near the Caletones copper smelter, the soils have high levels of aluminum (González, 2011). The main sources of contamination in the Karabash geotechnogenic system are atmospheric emissions of copper smelter, one of the main components of which are sulfur dioxides. This results in acid rain with anomalous concentrations of heavy metals and metalloids, which are withdrawn from atmosphere and accumulated in the forest floor and upper soil (Gashkina, et al., 2014). In the town of Bor, Serbia, situated in the immediate vicinity of one of the largest copper smelters in Europe, environmental pollution resulting from the SO_2 gas, PM_{10} particles, arsenic, and copper are several times above the limit values prescribed by EU Directives which seriously endangers human health in this part of Europe. Because of the location of the smelter plant there is also a risk of pollution on a wider scale even in other countries such as Romania and Bulgaria (Nikolic, et al., 2009).

1.2.3 Nitrogen Oxides (NO_x)

Nitrogen oxide (NO) is a colorless, highly reactive gas that contributes to global warming. Another contributing gas is nitrogen dioxide, a toxic and irritating yellow brown gas. Like sulfur dioxide, they are created from obtaining concentrates in the copper smelter. This pollutant reacts with humidity in the air and oxidizes in the atmosphere forming H_2SO_4 and lowering the pH of the rain. It is deposited in ecosystems by rain and snow creating soil and plant degradation. Near Caletones copper smelter, the soils have high levels of aluminum (González, 2011).

1.2.4 Lead (Pb)

Lead is a highly polluting and toxic heavy metal and is often the result of mining operations of minerals that include lead in their chemical composition. Many copper mining areas from the Glogow Copper Smelter Protected Forest in Poland to other smelter locations in Poland, Russia, and the Karabash area have high lead levels in nearby soil ((Kostecki, et al., 2015; Kabala, et al., 2001; Smorkalov, et al., 2011; Tatsii, et al., 2017). High lead levels have also been found in the blood of children living near smelters in Mexico as well as in the soil (Carrizales, et al., 2005). Along with humans, lead can also affect marine life, effects on Lake Serebry bream's kidneys are suggested to be due to cadmium and lead (Gashkina, et al., 2014).

1.2.5 Arsenic (As)

Arsenic is an extremely toxic metalloid normally found in the form of sulphide. It is a smelter waste from minerals that are contaminated with it, which is often the case with copper. Near a copper smelter in Bor, Serbia, the suspended particulate content of As was found to be consistently above the annual limit (Tasic, et al., 2017). In Huelva a copper smelter caused it to be one of the most arsenic particulate matter contaminated areas in Europe in 2001 and 2002 (Sánchez de la Campa, et al., 2007). Copper smelter workers are often exposed to high levels of arsenic, which results in health impacts. Chronic arsenic exposure involves increased risk to various forms of cancer and numerous non-cancer conditions, such as diabetes, skin diseases, chronic cough, and toxic effects in the liver, kidneys, cardiovascular system, and the peripheral and central nervous systems (Halatek, et al., 2014). Modeling of carcinogenic risk showed that dust ingestion was the most important pathway from arsenic, followed by inhalation (Fry, et al., 2020).

1.2.6 Cadmium (Cd)

Cadmium is one of the most toxic heavy metals. It is often found as a pollutant near copper smelters such as the one in Bor, Serbia, as well as other locations mentioned (Tasic, et al., 2017; Smorkalov, et al., 2011; Tatsii, et al., 2017). Cadmium has been found not only in soil and water but also in rice and vegetables grown near a copper smelter in China, and the hair and urine of local residents (Buyun Du, et al., 2020).

1.2.7 Mercury (Hg)

Mercury is an extremely toxic heavy metal and comes from the production of blister copper. Almost 400 kg of mercury is ejected into the atmosphere during production of 100.000 tons black copper at the Karabash copper smelter, leading to high contamination in atmospheric dust, soil, and lake sediment in the area (Tatsii, et al., 2017). In Fuyang, Zhejiang Province, secondary copper smelter China, the levels of soil mercury in the vicinity of the smelters have been substantially elevated following local smelting activities. The total accumulation of Hg in the topsoil of the study area of 10.9 km^2 is approximately 365–561 kg and of which 346–543 kg might be contributed by anthropogenic (Yin, et al., 2009).

1.2.8 Zinc (Zn)

Zinc is on its own a valuable metal, but is often found with copper, and thus is a copper smelting pollutant. Like the other minerals mentioned, it is often found polluting soil and water near copper smelters.

1.2.9 Selenium (Se)

Selenium is a nonmetal pollutant that is spread by dust from copper smelters. Like the others it has been found polluting in areas near smelters. Of particular interest, selenium concentrations in rainwater, soils and *alfalfa* at various sites from three different zones of Valparaíso, Chile, near the Ventanas Smelter (De Gregori, et al., 1999).

1.3 CHILEAN SMELTERS AND REFINERIES

1.3.1 Smelters

Figure 1 shows the seven largest Chilean smelters, of which five are state-owned companies such as Codelco and Enami. Notably the two with highest smelting capacity are state-owned, specifically Caletones and Chuquicamata, which are part of Codelco. Three of the seven are located in or near a slaughter area; these are Chagres, Hernán Videla and Ventanas.

Figure 1. Chilean smelters. Smelter owner, capacity of smelting in thousand tons, and if it is in or near a slaughter area.

Smelters	Owner	Capacity (ktpy)	Slaughter Area
Chuquicamata	Codelco	1.400	No
Caletones	Codelco	1.370	No
Altonorte	Glencore	1.160	No
Potrerillos	Codelco	680	No
Chagres	Anglo American	660	Yes
Hernán Videla L.	Enami	450	Yes
Ventanas	Codelco	430	Yes

Source: Own elaboration, based on Ramírez (2019).

1.3.2 Refineries

Figure 2 shows the three largest Chilean refineries are owned by the state through Codelco. One of them, the controversial Ventanas refinery of Codelco, is located in a slaughter area,

Figure 2. Chilean refineries. Refinery owner, capacity of refining in thousand tons and if it is in or near a slaughter area.

Refinery	Owner	Capacity (ktpy)	Slaughter Area
Chuquicamata	Codelco	540	No
Potrerillos	Codelco	130	No
Ventanas	Codelco	410	Yes

Source: Own elaboration, based on Ramírez (2019).

1.3.3 Other Pollutant Sources

Figure 3 shows other fixed pollutant sources in Chile such as oil refineries and coal thermoelectric plants. Most of these sources are located in or near slaughter areas; only one of the fourteen coal thermoelectric and one of the three oil refineries are not located in these areas.

Figure 3. Other Chilean fixed sources. Shows type source, the name(s) of the source, the owner(s), if it is in or near a slaughter area and the source power in megawatts.

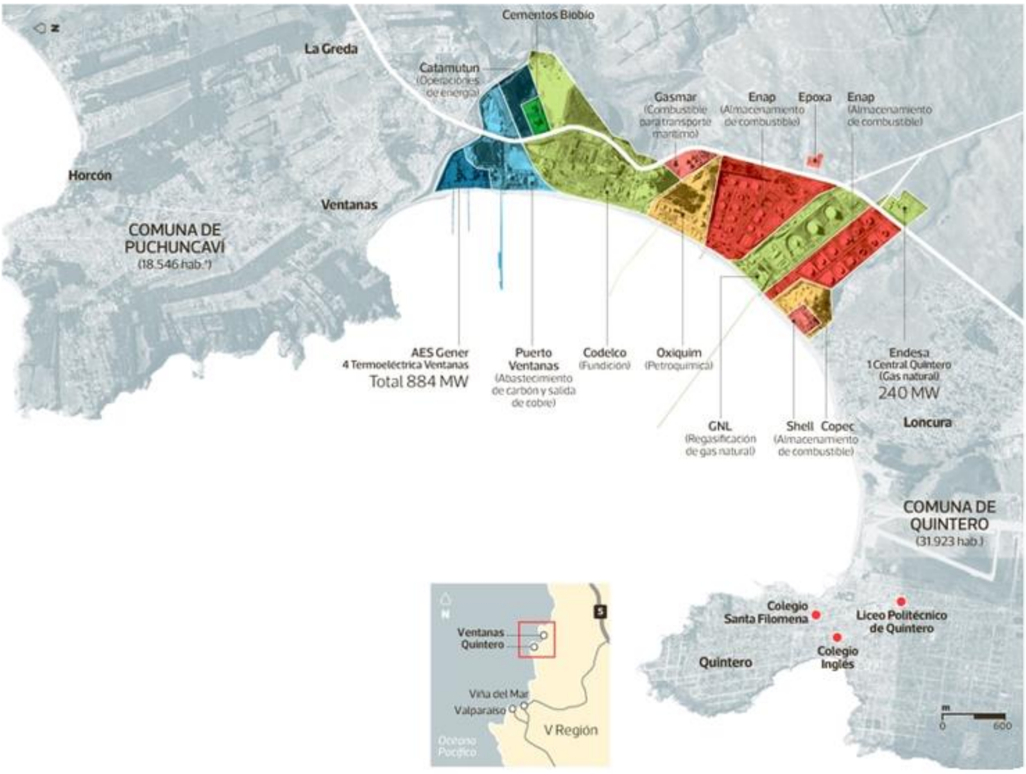
Source	Name	Owner	Slaughter Area	Power (Mw)
Oil Refinery	Aconcagua	Enap	Yes	-
Oil Refinery	Concepción	Enap	Yes	-
Oil Refinery	Gregorio	Enap	No	-
Thermoelectric	Tarapacá	Enel & Gas Atacama	No	158
Thermoelectric	Tocopilla U12-13-14-15	Engie	Yes	438
Thermoelectric	Norgener NT01-02	Aes Gener	Yes	275
Thermoelectric	CT Atacama	Engie & Andina	Yes	178
Thermoelectric	Mejillones CTM1-2	Engie	Yes	333
Thermoelectric	Angamos ANG1-2	Aes Gener	Yes	558
Thermoelectric	Cochrane CCH1-2	Aes Gener	Yes	550
Thermoelectric	Hornitos	Engie & Hornitos	Yes	178
Thermoelectric	IE1	Engie	Yes	375
Thermoelectric	Guacolda 1-2-3-4-5	Aes Gener	Yes	701
Thermoelectric	Ventanas	Aes Gener	Yes	322
Thermoelectric	Nueva Ventanas	Aes Gener	Yes	249
Thermoelectric	Bocamina I-II	Enel	Yes	445
Thermoelectric	Santa María	Colbún	Yes	342

Source: Own elaboration, based on Carmona (2018).

1.4 THE QUINTERO-PUCHUNCAVÍ SLAUGHTER AREA

It is an industrial area considered as a slaughter area due to the multiple sanitary and environmental problems that have arisen in the area. Polluters include the Ventanas smelter, four coal thermoelectric plants, the ENAP maritime terminal, chemical industries like Oxiquim, along with many other industries. Figure 4 shows the Quintero-Puchuncaví industrial complex and some of the industries located in the area, which are close to many schools. These are; Catamutun, Cementos Biobío, Ventana's Port, Gasmar, Oxiquim, Enap, Epoca, GNL, Shell, Copec and Endesa. Codelco appears in green with an approximately area of 5 km^2, corresponding to the Ventanas smelter and refinery, which has a smelting and refinery capacity of 430 and 410 thousand tons per year.

Figure 4. Map of Quintero-Puchuncaví industrial complex. It shows some industries and schools located in the zone.



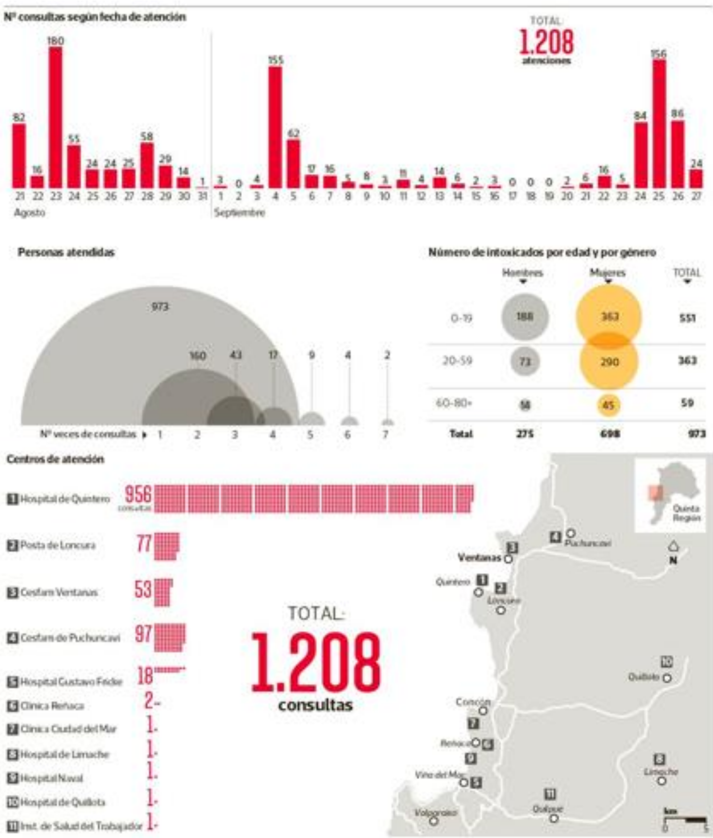
Source: Sandoval, et al. (2018).

Due to the exposure of different pollutants in the area, the population may suffer from many health difficulties. Headache, vomiting, tachycardia, and respiratory issues are some of the reactions that residents of the sector could present due to exposure to toxic gases. Cases of mothers with spontaneous abortions have been reported, along with fetal and infant health issues including growth retardation, cognitive and intellectual deficits, microcephaly, and craniofacial malformations. Regarding arsenic, long-term exposure increases the risk of developing bronchopulmonary, bladder, kidney and urinary tract cancer, liver and skin, risk of myocardial infarction and strokes. This carcinogenic risk is particularly high for children between 1 and 5 years old, along with other genetic damage (Tapia-Gatica, et al., 2020). Tapia-Gatica (2020) specifically assessed the non-carcinogenic and carcinogenic health risks due to exposure to trace elements in soil and indoor dust in Puchuncaví valley. Indoor dust was more important than soil in terms of human exposure to trace elements because it was so polluted, and the amount of time people spend at home. Carcinogenic risk due to arsenic exposure was above the threshold value in the population of young children (from 1 to 5 years old) in all studied areas, including the controls, and in children (from 6 to 18 years old) in the exposed area. Such risk values are classified as unacceptable by the US Environmental

Protection Agency, requiring some target intervention from the Chilean government (Berasaluce, et al., 2019). The environmental effects in the area are very intense, highlights the year 2018, according to Figure 5:

- Number of queries: 1,208
- People served: 973
- Intoxicated men: 275
- Intoxicated women: 698

Figure 5. Environmental effects at 2018 year in Quintero-Puchuncaví zone. It shows queries by number, people served by age and gender, and queries by medical center.



Source: Cerda (2018).

Figure 6 shows an analysis of cases of poisoning where the main symptoms were:

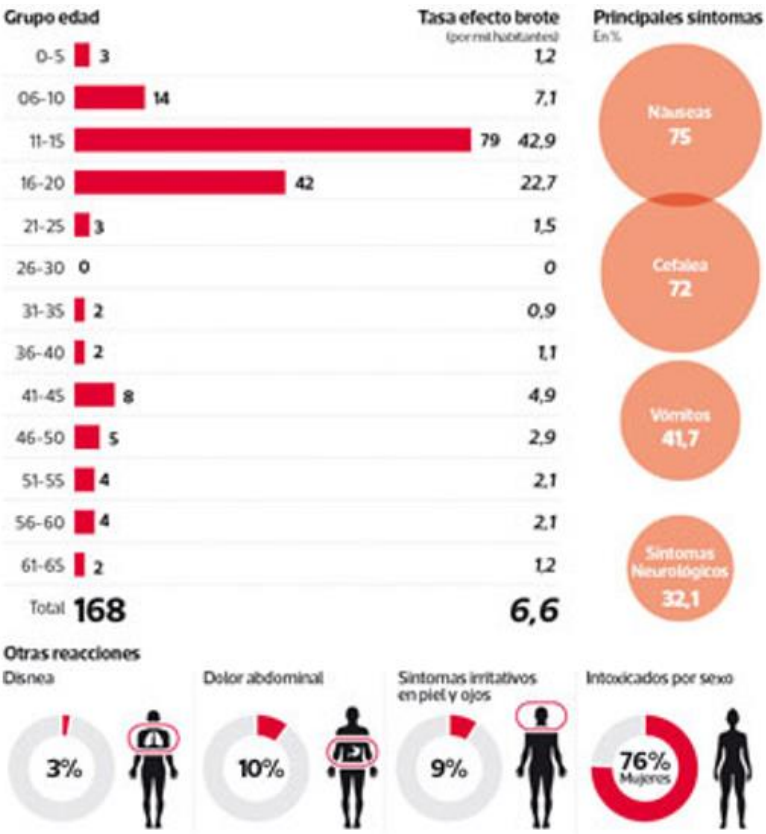
- Sickness: 75%
- Headache: 75%
- Vomiting: 42%
- Neurological systems: 32%

The age range with the most symptoms was 6-20 years, representing 80% of the total cases.

Other symptoms correspond to:

- Dyspnea: 3%
- Abdominal pain: 10%
- Skin and eye irritation: 9%

Figure 6. Analysis of cases of affected people, by age and gender.



Source: Solorio (2018).

Air quality is one of the environmental problems that most directly affects the population. There are pollutants like; SO_2, particulate matter (MP_{10}), Pb, As, Mo, V and Cd. Water quality is also great concern and discussion since it affects local industries such as preservation, fishing, research, tourism, and real estate. Contamination of Cu, As and Cd has been found in 100% of the species near the Ventanas smelter.

There has been a decrease in biodiversity due to the presence of heavy metals, as well as copper. Hg, Cu, Cd, Zn, Pb, Cr, As, suspended solids, oils, fats in marine life, and change water pH. This leads to changes in water temperatures as well. An important percentage of the soil is contaminated with Cd, Cu, Pb, Cr, As, Ni and Se as a result of particulate matter pollution. There is strong erosion of the soil and, consequently, a decrease in organic matter. Soil acidity also causes plants to have difficulties absorbing nutrients and increases the solubility of certain metals (Cu and Zn) causing a toxic effect on plants (Calisto, 2014). Based on the estimated concentrations of exchangeable Cu, 10, 15 and 75% of the study area exhibited a high, medium and low risk of phytotoxicity, respectively (Tapia-Gatica, et al., 2020). There are other toxic compounds present such as toluene, methichloroform (banned since 2015) and nitrobenzene. Different contaminants were found in analyzed soil samples at high concentrations, specifically Cu, Cd, As, Ni, Pb and Zn. The risk ratio values were higher for children than for adults both due to ingestion and dermal absorption. Pb was the most polluting based on all the studied contamination indexes, followed by Cu, As, Cd and Zn. (Tume, et al., 2019). Marine sediments from Quintero Bay were analyzed, the metal concentrations found suggest an anthropogenic origin related with Cu, Se, Mo, As, Sb and Pb. The heavy metal-bearing particles such as Cu, Zn, As and Pb are most likely associated with by the copper smelter (Parra, et al., 2015). The results of a study on the chemical composition of rainwater as an environmental pollution factor in the surroundings of the Puchuncaví-Ventanas industrial complex showed elements emitted by anthropogenic activities significantly polluted the rainwater of the area studied. The risk assessment showed that as content in rainwater is above the WHO guideline value for drinking water at some points in the study area (Cereceda-Balic, et al., 2020).

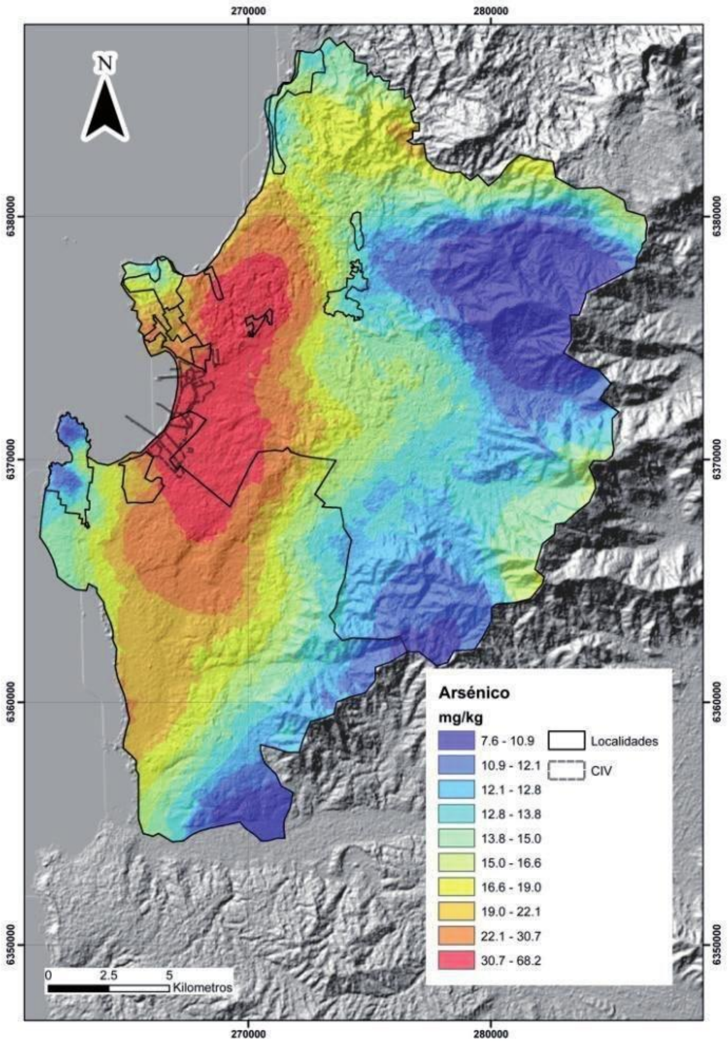
The aims of one research project were to assess the usefulness of a specific tree species as a biomonitor. The leaf samples were taken from five selected sites, located between 0.8 to 15 km away from the spelter. Leaf concentration of As, Ca, Cd, Cu, Dy, Er, Gd, K, Li, Mg, Mn, Mo, Na, Nd, P, Pb, Pr, S, Sb, Ti, Yb and Zn showed statistically significant differences between sampling sites. Increased concentrations of Cu, Sb, S, As, Cd and Pb were found depending on geographic closeness to the smelter. The high values of Cu and As were observed near the industrial area exceed phytotoxic levels. This provided the greatest variance the component related to industrial activity specific to copper smelters and refineries (Gorena, et al., 2020). The main results of atmospheric samples to evaluate pollution levels found long-term patterns of atmospheric deposition. The samples gave elements deposition values (Al, As, Ba, Cd, Co, Cu, Fe, K, Mn, Pb, Sb, Ti, V and Zn) in the insoluble fraction of the total atmospheric deposition. Results showed that again areas closer to the smelter were more polluted (Rueda-Holgado, et al., 2016).

Neaman et al. (2009) analyzed soils exposed to emissions from the Ventanas copper smelter. Using perforated plastic bottles in the soil and testing based on how often it rained, they studied soil pH, free $Cu2^{+}$ activity, and total dissolved copper. Topsoil (up to 30 cm) had lower pH and higher copper concentrations compared to soil lower in the ground of up to 10 times more copper concentration and 2.6 lower pH.

Salmanighabeshi, et al (2015) also investigated soil pollution by elemental contaminants and compared ecological risk indexes related to industrial activities for the case study of Puchuncaví-Ventanas. Selected elements (As, Pb, Cd, Ni, Hg, V, Mn, Zn, Sr, Sb, Cr, Co, Cu, K, and Ba) were analyzed during a long-term period (2007–2011). The results suggested that a copper smelter and a coal-fired power plant complex were major pollution sources. According to Codelco itself, the pollutants related to Ventanas smelter are SO_2, particulate matter and As, but Pb, Zn, Ni and others may also be involved.

When we specifically look at arsenic in Figure 7, again concentrations of this toxic element increase as get closer to the industrial complex with ranges between 30 and 68 mg/kg. The scope of the significant concentrations is approximately 20 km from industrial complex in every direction.

Figure 7. Arsenic (As) spatial distribution, in milligrams per kilogram of sample.



Source: Poblete, et al. (2018).

1.5 SOME ASPECTS OF ECONOMIC COSTS

Environmental pollution causes damage to the economy that can be quantified from health and environmental remediation expenses. Costs could be due to say heavy metals leaching during food waste composting or the treatment and lost wages costs of arsenic contamination of drinking water. It is possible to estimate expenses resulting from environmental pollution based on concentrations of specific pollutants.

1.5.1 Environmental costs

Heavy metals in leachate during food waste composting may produce different degrees of pollution hazards and further induce environment costs when the concentrations of heavy metals exceed the dis-charging quality standards. Chu et al (2019) estimates the heavy metal environmental costs from food waste composting in Minhang food waste treatment plant located in northern Shanghai. Major findings of this study are the pollution hazard rate of Cd amounts to 94.03%, and the environmental costs caused by heavy metals in leachate during food waste composting amount to US$ 0.52 per ton. This magnitude of environmental costs is meaningful and significant, considering that it is equivalent to 2.97% of Shanghai's food waste treatment charges.

Understanding the potential for reducing air pollution emissions and the associated costs is a prerequisite for designing cost-effective control policies. In one study, a model was updated to estimate the abatement potential and the marginal cost of multiple pollutants in China. The associated control cost of such reductions was estimated at CNY 92.5 and CNY 469.7 million for SO_2 and NO_x respectively. Notably it also found that regions with high GDP tend to have higher total abatement costs. End-of-pipeline technologies tended to be a cost-effective way to control pollution in industry processes, while such technologies were less cost effective in fossil fuel related sectors compared to renewable energy. The marginal reduction cost curves developed in this study can be used as a crucial component in an integrated model to design optimized and cost-effective control policies (Zhang, et al., 2020).

The negative health effects of mercury poisoning have been documented for both chronic and acute exposure. Today, exposure to Hg is largely diet or occupationally dependent. Hylander, et al. (2006) puts a tentative monetary value on Hg polluted food sources in the Arctic, where local, significant pollution sources are limited, and relates this to costs for strategies to avoid Hg pollution and to remediation costs of contaminated sites in Sweden and Japan. The cases studied are relevant for point pollution sources globally and their remediation costs ranged between 2,500 and 1.1 million US dollars per kilogram of Hg isolated from the biosphere.

Holland (2019) reviews the environmental risks to human health associated with the primary and secondary production of copper, rare earth elements, and cobalt. The environmental cost range of air pollution in Europe is from 3.7 to 40.2, 12.3 to 124.3 and 14.2 to 88.4 thousand euros per ton of NO_x, PM_{10} and SO_2, respectively. In the worst case, the estimate of the costs of air pollution for a ton produced of primary and secondary copper is a total of 53,870 euros.

1.5.2 Health costs

Mahanta et al. (2016) estimates the health costs of arsenic contamination of drinking water in Assam, India, where nearly one million people were affected. Using data collected through a primary survey of 355 households in 2013, it estimates health costs due to arsenic contamination. The estimates show that the average annual health cost of a 1 microgram increase in arsenic concentration per liter of drinking water is about INR 4 per household. Furthermore, if the average level of arsenic concentration was reduced to the safe limit of 50 microgram per liter, the average annual welfare gain for a household is estimated to be INR 862 (USD 14). Projecting these figures to the entire arsenic-affected population of Assam, the annual health costs of a 1 microgram increase in arsenic concentration per liter are estimated to be about INR 0.76 million (USD 0.01 million), and the welfare gains from reducing the level of arsenic concentration to the safe limit are estimated to be INR 153 million (USD 2.49 million). The results also indicate that these health costs and welfare gains vary significantly across different levels of arsenic concentration and across districts.

Another study estimates the health damages due to arsenicosis among people residing in two districts of Bihar, India. Arsenic field test kits were used to test the arsenic level in drinking water. The water test results indicate that 18.3% of the sample contained 50 ppb of arsenic, and 5.12% of the sample had levels between 300 and 500 ppb. Water source pollution, doctor visits, work loss, and arsenic concentration levels are all found to significant and positively related to arsenicosis, and awareness is significant but negatively related to arsenicosis. Per-capita income, sanitation, awareness, and depth of water sources are significant and positively related to defensive activities, i.e., water purification. The annual wage loss, cost of treatment, and cost of illness for sample households are estimated as INR 2437.92 ($45.83), INR 5942.40 ($111.72), and INR

8380.32 ($157.55), respectively. The annual cost of illness for the society is estimated as INR 265.97 million ($5 million) (Thakur, et al., 2019).

1.6 CONCLUSION

From the reviewed information it is found that the main local pollutants are Copper, Sulphur Dioxide, Nitrogen Oxides, Lead, Arsenic, Cadmium, Mercury, Zinc and Selenium. Those elements have effects on people's health, from respiratory illnesses to cancer. Also, on the environment, the presence of heavy materials in the vicinity of smelters, generates air pollution, with both particulate matter and greenhouse gases; water pollution; and reduction of biodiversity.

In the case of Chile, there are a total of 7 smelters, 3 of which are also refiners, and 2 of which are sulfuric acid plants. In 2018, they produced a total of 1,246 thousand tons of molten copper and 2,461 thousand tons of refined copper in 2018. They are concentrated in the center of Chile, and in the Atacama and Antofagasta Regions in the north. Especially, in the area of the Ventanas smelter, there have been a high number of environmental and health problems with the ecosystem has been affected by gases and polluting elements. to the extreme of being declared a slaughter area.

Any public policy that involves increasing copper refining and smelting in Chile must consider these aspects: the environmental impact and the health of the population. Regarding cost valuation, international research gives some suggestions regarding environmental and health costs. It is important to bear in mind that this has been presented in the form of "some aspects," given the complex and specific locality of this valuation process; the objective has been to shed insights on this issue. This does not mean that these processes cannot be developed to add more value to copper and reduce global GHG emissions, however, any such development should be located in accordance with a land use policy considering the health and local environmental impacts described here along with their costs.

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