Impacts of the Major Drought in Chile and Mitigation Measures

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Abstract. Since 2010, Chile has experienced a megadrought. It is the most persistent and severe climatic issue of the last millennium, affecting not only precipitation and temperature but also lakes and glaciers. This article aims to summarize the specific impacts caused by the drought in Chile and give some advice to alleviate these effects. To begin with, the study will focus on analyzing the increase in temperature, decrease in rainfall, and decline in water surface area of particular lakes. Additionally, it will delve into the effects of climate change on plant and animal species as well as human activities, including a decrease in vegetation coverage, disruption of the food chain, a substantial reduction in biodiversity, and a decline in gross domestic product (GDP). Finally, the study will also propose a range of measures to minimize these impacts from both biological and political perspectives. There are two main ways: (i) change the genes of plants to make them more adaptable to the environment; (ii) transport sea water from the Pacific Ocean and build water management plants. In the future, scientists and governments will be required to find more ways to mitigate the impacts of the megadrought and promote some measures to protect the environment. This article could provide some new ideas for improving the climate in Chile in the future.

1 Introduction

The megadrought in Chile has been occurring since 2010. It is the most longstanding and severe climatic problem in the last millennium and has impacted not only precipitation and temperature but also lakes and glaciers. In 2021, the temperatures encountered in central Chile are 1-2°C above the established normal range for the period 1981–2010. These values are 0.36°C higher than the average temperature increase for the continent. In the same year, most of Chile also experienced below-normal rainfall, a trend that has been maintained for 13 years. Different regions of the country encountered precipitation deficits ranging from 20% to 60%. In addition, between 2010 and 2020, the mountain lakes of central Chile, the primary source of pure water, dried up. To be more specific, the surface area of twelve lakes declines by 7% to 25% [1]. As a result of these changes in environmental factors, plants, animals and human activities have been affected to varying degrees. This drought has resulted in water scarcity, food insecurity, decrease in crop yield, disrupted food cycle and significantly affected biodiversity. Moreover, human activities have also been affected; for example, the average income has been dropped and physical health of citizens has been threatened. Despite receiving considerable notice on a worldwide scale, impacts of the megadrought in Chile have not been alleviated and have even grown worse. So, studying the specific impacts of the megadrought in Chile and finding solutions to mitigate those impacts will be extremely important in the next few years.

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There have been many research articles discussing the effects of Chilean megadrought. However, only a small amount of dissertation mentions mitigation methods for the effects. In this article, both impacts and ways to alleviate them will be discussed. Firstly, specific changes in temperature as well as rainfall and the reduced water surface area of particular lakes will be studied and summarized. Secondly, impacts on plants, animals, and human activities due to climate change will be listed and discussed in detail. Thirdly, several measures to mitigate these effects will be given from a biological and political point of view.

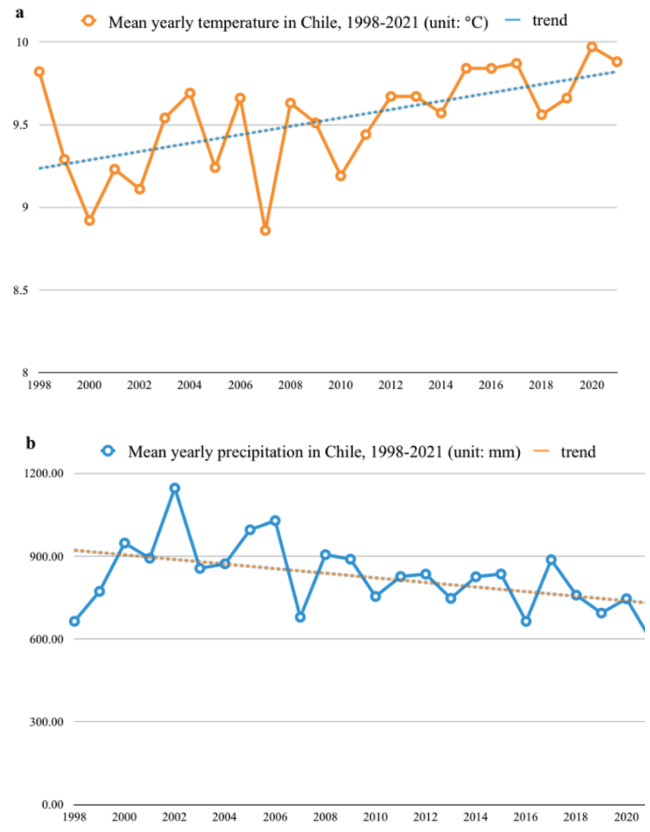

Fig. 1 (a) Mean yearly temperature in Chile from 1998 to 2021 [2] (Picture credit: Original);
(b) Mean yearly precipitation in Chile from 1998 to 2021 [3] (Picture credit: Original).

2 Impacts of Chilean Megadrought

2.1 Climate

The megadrought in Chile has affected the climate in local area significantly and progressively, including a decrease in mean yearly precipitation and an increase in mean yearly temperature. Fig. 1 shows an increasing trend in the mean yearly temperature between 1998 and 2021, growing from approximately 9.25 ℃ to 9.88 ℃, and a decreasing trend in the mean yearly temperature in the same period of time, dropping from about 921.4 mm/yr to 750.0 mm/yr.

In addition, the increase in temperature causes an increase in water evaporation, which worsened the water crises in Chile. Table 1 represents the loss of surface water area in twelve Chilean lakes during two periods (1984–2009 and 2010–2020). The findings indicate a significant decline over the last decade (2010–2020) in the surface area of several lakes, particularly in Aguas Calientes which decreased from approximately 0.60 km^2 between 1984–2009 to 0.45 km^2 between 2010–2020, corresponding to a surface loss of 25.48%. Cari Launa also experienced a surface loss of 23.01%, decreasing from 2.50 km^2 to 1.93 km^2 during the same periods. Yeso and Caracol showed fluctuations from 0.44 km^2 and 0.67 km^2 respectively in the first period to 0.34 km^2 and 0.53 km^2 in the second period, with a total surface reduction of 21.89% and 20.97% respectively. Meanwhile, Chepical, Embalse El Yeso, Laguna del Inca and Mollera lakes exhibited surface area declines from 0.47 km^2, 8.17 km^2, 1.59 km^2 and 0.59 km^2 respectively to 0.37 km^2, 6.86 km^2, 1.35 km^2 and 0.51 km^2. The study period resulted in a percentage loss of total lacustrine surface area of 20.97%, 19.92%, 14.84% and 13.19% for Chepical, Embalse El Yeso, Laguna del Inca and Mollera lakes respectively. On the other hand, Laguna del Maule, Teno and Laguna Negra had smaller decreases in surface area of 9.95%, 6.96% and 5.27% respectively.

Table 1. Comparison of lake surface area changes in 12 Chilean lakes for two periods, 1984-2009 and 2010-2020 [1].

Lake	Average (km2)	Surface lost (km2)	Surface loss (%)
Chepical	0.47 (1984–2009)	0.09	19.92
	0.37 (2010–2020)		
Laguna del Inca	1.59 (1984–2009)	0.24	14.84
	1.35 (2010–2020)		
Laguna Negra	5.45 (1984–2009)	0.30	5.46
	5.15 (2010–2020)		
Embalse El Yeso	8.17 (1984–2009)	1.31	15.99
	6.86 (2010–2020)		
Yeso	0.44 (1984–2009)	0.10	21.89
	0.34 (2010–2020)		
Caracol	0.68 (1984–2009)	0.14	21.17
	0.53 (2010–2020)		
Teno	7.92 (1984–2009)	0.55	6.96
	7.37 (2010–2020)		
Mollera	0.61 (1984–2009)	0.09	15.26
	0.51 (2010–2020)		
Aguas Calientes	0.62 (1984–2009)	0.18	28.34
	0.45 (2010–2020)		
Cari Launa	2.50 (1984–2009)	0.58	23.01
	1.93 (2010–2020)		
Laguna del Maule	52.34 (1984–2009)	5.21	9.95
	47.14 (2010–2020)		
Dial Lake	6.54 (1984–2009)	0.019	0.29
	6.52 (2010–2020)		

2.2 Plants

Water deficiency is a common problem induced by drought that typically influence plant growth and development profoundly. When plants lack water, certain symptoms, such as rolling and yellowing leaves, flower dropping and closure, wilting, and premature aging, will all appear. More seriously, branch dieback, necrosis, and stunted growth may also be displayed [4, 5]. Moreover, a low water potential gradient in air could reduce the rate of transpiration which is not only critical to uptake of water by plants, but also extremely important for diffusion of carbon dioxide into plants. As a result, plants do not absorb sufficient carbon dioxide which is the raw material of production of starch that reserve energy in plants. Eventually, many plants are died, and there is a total drop in final yield.

In addition, drought has a significant impact on water quality, which then deeply affects plant species. According to Peña-Guerrero et al., drought with high temperatures promotes the evaporation of water, causing low-flow conditions [6]. Under low-flow conditions, water quality, such as salinity, dissolved oxygen, and pH value, is affected. Firstly, it is known that there is an inverse relationship between low-inflow and high salinity periods. Soil salinization results in low soil productivity and reduces the transport of water to the top by plants [7]. Secondly, because of the lower oxygen saturation during drought conditions, the higher decomposition rate of microbial organic matter, and the lower reaeration rate, the value of dissolved oxygen will be reduced [6]. This will result in hypoxia in the roots of plants, which will lead to poor growth and low yield. Thirdly, since it is easier for ocean water to intrude into freshwater systems under low-flow conditions, the irrigated water becomes more basic, which negatively affects photosynthesis and inhibits enzyme activity [8].

In Chile, many plants are suffering from devastating effects of the megadrought. For example, grass is becoming a rare luxury, pollination is badly affected and disrupted, and the "browning" of vegetation is common and irreversible [9, 10].

2.3 Animals

During the drought period, the population of several animal species, including condors, hummingbirds (birds), frogs (amphibians), catfish, mackerel (fish), nutria, guanacos, foxes, rabbits, degúes, hares (mammals), has decreased in Chile [11]. According to Chilean agriculture ministry, more than 10,000 animals have died and another 50,000 are at risk in 2019 due to lack of water and fodder, mostly goats, cattle and sheep. In addition, wild carnivores have shifted their prey from wild to domestic due to the drought, so that number of domesticated livestock may continue to decline [12]. Furthermore, amphibian chytridiomycosis, which is caused by the fungus

Batrachochytrium dendrobatidis (Bd), has broken out in Chile, and the spreading rate has been accelerated by the megadrought [13]. This disease is so catastrophic that it has caused several extinctions of amphibian species world-wide and greatly reduced the population of some species [14]. Regarding fish, they are affected and killed by harmful algal blooms (HAB). The Chilean megadrought causes a rise in concentration of salt and nutrients in the water system, which is conducive to the growth of HAB [15]. According to Zohdi and Abbaspour [16], there are two types of HAB-causing microorganisms that will negatively affect the fish: (i) non-toxin-producing species that generate an exponential rise in microalgal cell density, reducing dissolved oxygen in water dramatically, resulting in significant fish mortality rates; (ii) species that physically harm fish by blocking their gills or by producing ichthyotoxic chemicals. In the last several years, it has been noticed that the paralytic shellfish poisoning (PSP) outbreak, which was one kind of HAB, has strengthened and spread northward. These tendencies have had a significant effect on both shellfish and salmon aquaculture [17].

2.4 Human Activities

Drought limits human activities to a large extent. In Chile, agriculture and tourism, the predominant sectors of industry chains, have been severely impacted by the megadrought. Regarding agriculture, the decline in the quality and quantity of crops, the reduction in irrigated land, the shrinkage in the size of agricultural products, and the inability to sow on traditional dates have resulted in decreased income and increased irrigation costs for Chilean farmers. In addition, it has been discovered that the decreasing demand for agricultural labor made it harder to pay employees during customary seasons, leading to a drop in seasonal employment. This decline in revenue impacted both large-scale farmers and owners of small pieces of land or livestock, who were forced to alter their operations in certain instances [11]. Megadrought has also harmed tourism in Chile. As temperatures rise and snowfall decreases, some tourist areas have to produce artificial snowfall, which has significantly increased the cost for operators. Moreover, the famed Chilean wine sector has been threatened by severe water shortages for several years. Nonetheless, many visitors visit Chile because of its wine, and the fall of the wine industry would have a devastating effect on the Chilean tourism economy [18].

Drought affects not only the economy but also the health of the people in Chile. The decrease in moisture in the air in Chile may cause an increase in cases of respiratory diseases because of the increase in airborne particles. Mental health is also affected. Those who lack adequate water have experienced unpleasant feelings such as anxiety, rage, agony, annoyance, and distress [19]. These factors contribute to the low quality of life of Chileans. Some Chileans choose to emigrate due to the unlivable conditions, which can be disadvantageous for the future development of the country.

3 Measures to Mitigate the Impacts of Chilean Megadrought

Currently, people can only mitigate the impacts of the Chilean megadrought by making plants more drought-tolerant and improving water quality.

There are two measures to increase the ability of plants to survive in drought conditions. The first one is the induction of drought-tolerant traits in plants that could allow them to be more adaptable to the permanent water deficiency. Scientists commonly first identify some favorable features, such as deep and extensive roots and rolled leaves covering hairs with sunken stoma, which help plants to absorb water from soil as much as possible and reduce the loss of water vapor through their stoma in leaves. Then those desired features are induced into some individual plants or crops of different species. After a period of time of about one month or more, plants are observed and selected so that only those that show drought tolerance are allowed to reproduce. These steps are repeated. Eventually, most plants will be drought tolerant. The second one is associated with arbuscular mycorrhizal (AM) fungi, which live in symbiosis with plants. AM fungi could protect host plants in four ways: (i) the direct uptake and transfer of water and nutrients; (ii) increased osmotic adjustment; (iii) improved gas exchange and water use efficiency; and (iv) improved protection against

oxidative damage [20]. In addition, under conditions of water deficiency, proline builds up in the roots of various species of plants due to the accumulation of AM fungi. High endogenous proline levels will regulate osmotic adjustment, contribute to gas exchange parameters, and attenuate the harmful effects of drought-induced oxidative stress via the large-scale production of ascorbate peroxidase and superoxide dismutase [21].

Water quality can be improved by increasing the flow rate. Governments could set rules that allow the release of water from reservoirs with a fixed volume of water (such as 5 Mm^3/month) at regular intervals [22]. Nevertheless, altering the flow can cause future difficulties in satisfying water demand owing to the loss of hyper-annual storage capacity. This potential problem is highly likely to develop into a permanent deficit [23]. In addition, take the Red Sea-Dead Sea Water Conveyance Project in Jordan as an example: the government in Jordan built a pipe from the Red Sea to the Dead Sea in order to meet the demand for water in local areas [24]; the governments in Chile could also build a pipe from the Pacific Ocean to inland areas. Then that seawater can be desalinated to produce fresh water for drinking and irrigation.

In the future, the Chilean megadrought may disappear because of climate change. However, a new drought may occur. In the unpredictable natural environment, the most effective and practical way to protect ourselves from drought is to save and recycle fresh water. In addition, scientists could predict natural disasters by using remote sensing, geothermal temperature-measuring instruments, and so forth, in order to plan for calamities in advance.

4 Conclusion

Chile has been experiencing a devastating megadrought since 2010. It has resulted in a significant decrease in mean yearly precipitation and an increase in mean yearly temperature, leading to an increase in water evaporation and exacerbating the water crisis in Chile. The impact of the drought has been far-reaching, affecting agriculture, wildlife, and human activities. Crop yields have been drastically reduced, and some species of animals have suffered due to a lack of food and an increased incidence of disease. Meanwhile, human activities have been severely disrupted as a result of water scarcity. In order to alleviate those severe impacts, this article gave some biological and government-related advice, including the induction of AM fungi, genetic engineering, and an improvement in the provision of water. However, all measures are based on the availability of sufficient economic reserves. It is recommended that the funding can be provided by international foundations. In addition, major news websites should do more promotion to raise awareness about the impact of the megadrought on Chile, not only in terms of the natural aspect but also the human aspect, in order to encourage more people to donate to the region.

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