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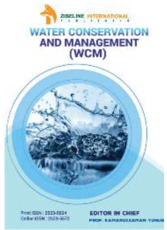

RESEARCH ARTICLE

WATER SCARCITY OR DROUGHT? THE CAUSE AND SOLUTION FOR THE LACK OF WATER IN LAGUNA DE ACULEO

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ABSTRACT

One of the most recurring discussions among people is the real impact of global warming and human activity on our natural resources. It is hard to identify and quantify the impact generated by each one. Laguna de Aculeo located in Paine city, Chile. It was one of the most attractive and beautiful places to visit in the summer. Today, It has been completely drying up. This research evaluates weather and hydrologic values registered by government weather and water levels stations. The purpose is to evaluate if there has been a change in precipitation, temperature, and water level trend. The analysis consists of the evaluation of the statistical parameters, and legal water withdrawals and fines imposed. The results of this study indicate that the cause of the drought of the lake is generated by climatic and anthropogenic factors. However, the changes in precipitation and temperature over the years are not significant for drying a lake. Therefore, it is possible to assume that human activities are arguably the greatest cause of impact on Laguna de Aculeo. Finally, we present tools, strategies, and practical solutions to prevent, control, and restore lake water level.

KEYWORDS

global warming, anthropogenic, natural resources, statistical

1. INTRODUCTION

1.1 Water scarcity and drought

Water scarcity and drought have become a significant problem in the entire world, affecting social and economic activities, and the environment (Liu et al., 2017). Water scarcity is defined as inadequate management of water resources in a long period causing that the water availability not satisfied the water demand. In other words, the deficient water duration, extent, and severity depends on the resources destined to decrease the negative impact of human activities, and the environmental system resiliency and ability to recover from human-caused or natural stress. On the contrary, drought is defined as abnormal variations of the water sources on a large scale caused by climate anomalies (Stahl, et al., 2018; Van Loon and Van Lanen, 2013). It may persist several seasons or years until to get precipitation values considered as expected or normal (Wilhite et al., 2013). As result, it is necessary to know the difference between these two concepts in order to identify the cause, potential impacts, and countermeasures.

1.2 Global water crisis

The lack of access to water has become a threat to human society with significant consequences. Mekonnen and Hoekstra estimated that two-thirds of the global population (4.0 billion people) have difficulty to get water at least 1 month of the year, and half a billion people in the world suffer it all year round (Mekonnen and Hoekstra, 2016). Several studies have analyzed the water deficiency impact on ecological integrity, concluded that it causes considerable damage to their prosperity (Corlett, 2016; Fabré et al., 2017; Li et al., 2019; Preece et al., 2019). In addition, the lack of water has significant repercussions on the performance of livestock, and agriculture activities, causing unsustainable food production, and price uncertainty (Hao et al., 2015; Rosegrant et al., 2009).

In this context, variations in the hydrological cycle can change the land-use and land cover in the catchment. More importantly, water is necessary for the well-being of people. Over the years several studies have been concluded that anthropic activities alter the water balance and water quality, helping us to improve our understanding of the hydrological cycle (Adler et al., 1989; Calijuri et al., 2015; Duan et al., 2018; Kokkonen et al., 2018). Under the correct weather conditions, it is possible to dry a large body of water such as a lake or river if the water balance or budget is negative.

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1.3 Drying lakes in the world

Lake Chad is located in central Africa. It has been decreasing its dimension since 1960. The lake had an area of 25000 km^2, and up to 175 fish species. At present, the surface and the number of fish species is 1350 km^2 and 80 types of fish, respectively. In other words, over recent decades, the lake has suffered a negative impact on water storage capacity by reducing the area by 95%, approximately, and deteriorate the aquatic system. The situation affects around 40 million people, who depend on the lake to obtain drinking water, fish, and cultivate the nearby lands. Although the amount of rainfall has progressively decreased since 1970, there is not a single cause for the shrunk of Lake Chad. Its size has declined because of unsustainable water management, prolonged drought, and climate change (Lauwaet, et al., 2012; Sarch and Birkkett, 2000; Zhu et al., 2019).

The Urmia Lake is one of the largest salt lakes in the world, located in north-western Iran. In 1975, UNESCO announced that the lake is a Biosphere Reserve to preserve the species that inhabit it. Every winter it is possible to see flocks of flamingos and pelicans. In addition, many migrant birds use the lake during their migrations. The lake is recharge by surface flow, direct precipitation, and groundwater flow. However, since 1995 the lake has reduced its area from 6100 km^2 to 610 km^2 (90%) and volume from 97.6·10^{10} m^3 to 19.52·10^{10} m^3 (80%), due to drought events, dam constructions, and inadequate management of the water resource. Furthermore, the concentration of salt has been increased by the variation in the volume of the lake, generating a negative impact on the natural habitat. Different investigations propose that the solution to this problem is to improve water management resources, increase water use efficiency in agriculture, reevaluate the discharge from the dam, and recharge the lake with water from adjacent basins (Asem et al., 2012; Fazel et al.,2018; Ghaheri et al., 1999; Hoseinpour et al., 2010).

A lake in South America that has experienced a dramatic situation is Poopó Lake, Bolivia. The lake had a maximum area of 2,492 km^2 in 1991. Nevertheless, its area was 669 km^2 in 2015. It is the second largest lake in Bolivia, and the local population does fishing activities in the area. It was recorded that temperature and anthropic activities have been increasing since the last decades, decreasing the lake water level. In other words, the lake to dry up is because of mining activity without environmental supervision, mismanaged of irrigation channels, the growth rates of quinoa production in the area, and climate change. Although Poopó Lake nearly had dried up in 2015, the last couple of years it has been recovering its storage capacity. However, it is still far below the critical water level threshold (Arsen et al., 2014; Ravilious, 2016; Zolá and Bengtsson, 2007). Research support that evapotranspiration has increased since 2000 due to the agricultural activities in the area, setting the lake at serious risk of drying up (Satge et al., 2017).

1.4 Laguna de Aculeo

1.4.1 Study área

Laguna de Aculeo is located in Estero Angostura Entre Estero Paine (II) y Río Maipo Sub-Basin, Paine city, Maipo Province, Metropolitan Region of Santiago, Chile (33º 50' 30'' S, 70º 54' 24'' W, 350 m a.s.l), one of the most attractive and beautiful places to visit in the summer has been completely drying up. However, it was not always like that. The lake had a surface of 11.5 km^2, average depth of 3.4 m, maximum depth of 7 m, average annual precipitation is 611 mm and water volume of 53.6 · 10^6 m^3. January is the warmest month and July is the coolest month, with an average temperature around 20.3 ºC and 7.6 ºC, respectively. The local climate is Mediterranean, and the primary source of water for lake recharge is shallow groundwater. The catchment had a surface of 264 km^2. The hydraulic conductivity is 15 m^3 · day^{-1}. The annual evaporation is approximately 1200 mm based on 27 years records from 1970 to 1997 (DGA-DCPRH, 2007, 2010; Garreaud et al., 2015; Merino Besoaín, 1967).

1.4.2 Anthropic activities data

In 2012 and 2017, the total number of habitants in Paine city was 50,028 (INE, 2012) and 72,759 (INE, 2017), respectively, increasing its population by 45% in 5 years. The economic activities developed in Paine city are diverse such as agriculture, livestock, manufacture, tourism, construction, and real estate. The Internal Revenue Service of Chile classifies all commercial sales and number of companies by economic activity (SII, 2018). The agriculture, livestock, hunting and forestry activity generated sales of 7,239,201.27 UF ($290M USD approximately) and the total number of the registered companies was 981 in 2012, and 10,236,583.81 UF ($409M USD approximately) and the total number of the registered companies was 975 in 2017, increasing by 41% in profits and decreasing by 0.61% in the creation of companies in 5 years.

The metal and non-metallic manufacturing industries activity generated sales of 484,332.89 UF ($19M USD approximately) and the total number of the registered companies was 115 in 2012, and 920,187.09 UF ($37M USD approximately) and the total number of the registered companies was 138 in 2017, increasing by 90% in profits and 20% in the creation of companies in 5 years. The construction activity generated sales of 336,551.13 UF ($13M USD approximately) and the total number of the registered companies was 133 in 2012, and 829,039.01 UF ($33M USD approximately) and the total number of the registered companies was 240 in 2017, increasing by 146% in profits and 80% in the creation of companies in 5 years.

The hotels and restaurants activity generated sales of 176,939.11 UF (4,423 dollars approximately) and the total number of the registered companies was 60 in 2012, and 140,257.95 UF (3,506 dollars approximately) and the total number of the registered companies was 89 in 2017, decreasing by 21% in profits and increasing by 48% in the creation of companies in 5 years. The real estate activity generated sales of 298,637.74 UF ($12M USD approximately) and the total number of the registered companies was 54 in 2012, and 575,592.32 UF ($23M USD approximately) and the total number of the registered companies was 168 in 2017, increasing by 93% in profits and 211% in the creation of companies in 5 years. Finally, all the activities of Paine city generated sales of 11,761,405.77 UF ($470M USD approximately) and the total number of the registered companies was 2853 in 2012, and 179,999,146.75 UF ($720M USD approximately) and the total number of the registered companies was 3491 in 2017, increasing by 53% in profits and 22% in the creation of companies in 5 years (SII, 2018).

1.4.3 Land use and land cover data

In 1999, CONAF & CONAMA performed a cadastre and evaluation of native vegetation resources in Metropolitan Region of Santiago, Chile. Then, (CONAF, 2014) had revised the data and added more parameters to assessment. The results state that the Paine city (67649.2 ha total area) increased the native forests area by 179% (10041.5 to 27990.5 ha), plantation area by 15% (68.1 to 78.2 ha), and mixed forest area in 2.1 ha (0 to 2.1 ha) from 1999 to 2014. Land use in Paine city is classified into nine different types: Urban and Industrial Area (4664.6 ha), Agricultural Land (18922.3 ha), Meadows and scrubland (14221.6 ha), Forests (28070.8 ha), Wetlands (109.5 ha), No Vegetation area (368.1 ha), Waterbody (1292.3 ha), Snow and Glaciers (0 ha), and Unrecognized Areas (0 ha) (CONAF, 2014). CIREN (2010) performed a soil erosion assessment on total area of Chile, identifying the degraded lands.
The methodology developed is based on the compilation and review information, fieldwork, and analytical evaluation. Erosion index has been classified into nine categories: no erosion, slightly erosion, moderate erosion, severe erosion, very severe erosion, and non-apparent. These classifications were defined according to the intrinsic soil properties, land use, soil cover, topography, and weather. The results indicate that approximately 40% of Paine city total area suffers erosion to some degree. In addition, the results indicate that approximately 43% of Paine city total area suffers some degree of erosion. Urbanization and agriculture areas near to Laguna de Aculeo has an erosion index of no erosion. In this context, the mountainous region has an erosion index from no-apparent to severe erosion (CIREN, 2010).

1.4.4 Current situation

The community and government entities have held meetings to find a solution to the lake water levels problem. However, the citizens believe that the cause of the lake dried up could be for the decrease in annual precipitation, increase in average temperatures, population growth, overexploitation of water resources by illegal wells, livestock and agricultural activities. The Chilean government issued Exempt Resolution No. 12/2018 on August 16, 2018 to officially state that Laguna de Aculeo is immersing in a growing decrease in water resources cause for natural and anthropic factors. Specifically, it indicates that agricultural water annual average consumption is 572 L/s and peak values of 1000 L/s, concluding that water demand is higher than water supply in the catchment area.

In addition, tourist activity has a significant influence on the floating population assessed in 4,000 people, and real estate activity caused an increment of wells constructions. Finally, the results stated that the creation of an integrated water resource management is required, and decides to restriction groundwater extraction (Dirección General de

Aguas, 2018). There is a lack of knowledge about the cause of the lake's drought and the best management practices for water efficiency. Moreover, there is no hydrologic analysis of the area. This research seeks to examine meteorological parameters, water extraction rights, anthropic activities and legal complaints. The results obtained will help the community to understand the situation from a scientific perspective.

2. MATERIALS AND METHODS

2.1 Climate data, level of groundwater, and water extraction rights

Monthly average temperature and monthly precipitation records were obtained from Laguna Acuelo meteorological station (33º 53' 09'' S, 70º 52' 39'' W, 360 m a.s.l; BNA code: 05716005-5). The amount of data totaled 23 years (1995 – 2018), 286 temperature and 277 precipitation reports. The water level records collected at San Francisco Aculeo monitoring well located 3 kilometers from Laguna de Aculeo (33º 53' 12'' S, 70º 52' 47'' W, 374 m a.s.l; BNA code: 05716006-3). The total water level data are 104 from 1999 to 2018. The time interval measurement is inconsistent. In-situ lake water level data derived from Laguna Aculeo Los Castaños limnimetric station during the period of 2006 to 2013 (33º 51' 00'' S, 70º 54' 00'' W, 354 m a.s.l; BNA code: 05716011-k).

The data set contains 94 records with a discontinuous time scale. Although, the database is limited one more data was added, corresponding to 0 meters in August 2018, when the lake was officially declared water shortage. The stations are part of national hydrometeorological gauge networks that are managed by the Dirección General de Aguas (DGA). Information on water extraction rights was collected from the DGA resources information center. Government agency that has the power to assess and provide water extraction rights. In addition, it was requested all the fines for pumping water illegally from 1988 to 2019. Although, the information received only comprise from 2012 to 2019. Figure 1 and 2 shows the study area.

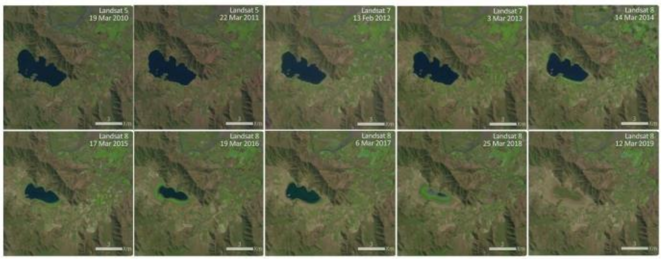

Figure 1: Landsat 5, 7 and 8 images over Laguna de Aculeo from 2010 to 2019.

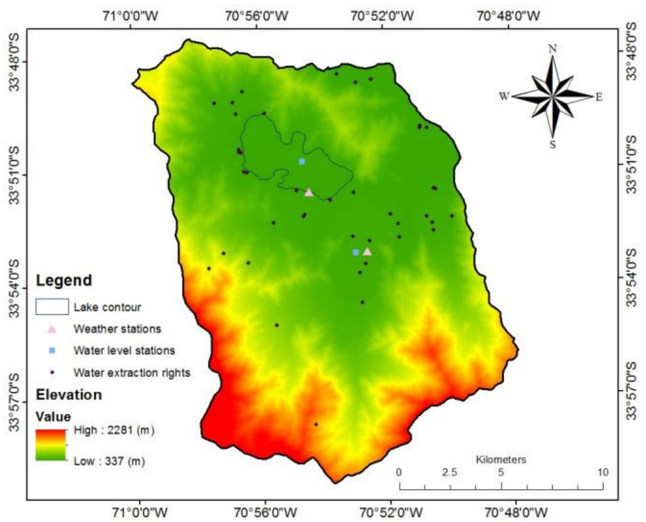

Figure 2: Spatial distribution of the water extraction rights, weather and water level stations at Estero Angostura Entre Estero Paine (II) y Río Maipo Sub-Basin.

2.2 Aridity index

The Aridity Index (IA), is a numerical indicator estimated by weather parameters to asset the disponibility of water of the study area (Stadler, 1998). In 1926, De Martonne developed an equation to determine the aridity index for a specific area. It wildly uses it in different research to evaluate the climate changes over the years (Nyamtseren et al., 2018; Quan et al., 2013; Tabari et al., 2014; Troyo Diéguez et al., 2014). It is computed using the following equation:

$$AI_{DM} = \frac{P}{T+10} \quad (1)$$

where AI_{DM} is the De Martonne aridity index (mm/ºC), P is the annual precipitation (mm), and T is the annual mean air temperature (ºC). Table 1 shows the climate type classification according to the aridity index.

Table 1: Climate type according the De Martonne aridity index.

Climate type	AI_{DM} value
Arid	$AI_{DM} < 10$
Semi-arid	$10 \leq AI_{DM} < 20$
Mediterranean	$20 \leq AI_{DM} < 24$
Semi-humid	$24 \leq AI_{DM} < 28$
Humid	$28 \leq AI_{DM} < 35$
Very humid	$35 \leq AI_{DM} < 55$
Extremely humid	$AI_{DM} \geq 55$

2.3 The Mann-Kendall test.

The Mann-Kendall test is a non-parametric test based on the rank correlation that 229 allows evaluating if the data series has a monotonic trend (increasing or decreasing) 230 over time. In addition, the null hypothesis states that the data of a time series are 231 independent and identically distributed (Hamed, 2009; Mann, 1945; McLeod, 2005). It is calculated as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i) \quad (2)$$

$$sign(x_j - x_i) = \begin{cases} +1 & if(x_j - x_i) > 0 \\ 0 & if(x_j - x_i) = 0 \\ -1 & if(x_j - x_i) < 0 \end{cases} \quad (3)$$

where x_j and x_i are the observation data in chronological order. If the sample size is equal or less than 10 and the results of looking up S in a table of probability is less than the alpha value (α), we can conclude that exist a trend (Gilbert, 1987). On the contrary (n >10), the standard deviation presents an asymptotically normal distribution. In this context, mean is equal to 0 (Equation 4) and variance is computed as:

$$E[S] = 0 \quad (4)$$

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \quad (5)$$

where m is the number of tied groups, and t_i is the number of observations in the i^{th} group. Finally, the standard normal distribution (Z) is a normal distribution with a mean of 0 and a standard deviation of 1, it can be computed as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if\ S < 0 \end{cases} \quad (6)$$

The ascending tendencies are represented by a positive value of Z, while the descending ones are represented by a negative value of Z.

2.4 Sen's slope

Sen's slope estimator is a nonparametric procedure that estimates changes per unit of time in a series when a linear trend exists in it. It is used to estimate the slope in a univariate and nonparametric time series. In this context, when your trend analysis gives you a significant trend (positive or negative) Sen's slope is then to capture the magnitude of that trend (Kahya and Kalayci, 2004; Sen, 1968). For N data pairs, Sen's slope is estimated as follows:

$$Q_i = \frac{(x_j - x_k)}{(j-k)}\ for\ i = 1,2,3,\dots,N \quad (7)$$

where x_j and x_k are data at times j and k (j> k), respectively. Related hydrological and meteorological studies have been applying the Mann-Kendall test and Sen's slope to identify and assert the existence of a trend in a series of data (Amin et al., 2018; Gocic and Trajkovic, 2013; Kisi and Ay, 2014; Nyamtseren et al., 2018; Shrestha et al., 2019).

3. METHODOLOGY

The analysis consists of making a comparison between two groups of weather and hydrologic values. The first group is the data recorded from 1995 to 2006. The second group of data are the values of the dataset from 2007 to 2018. The time range of the second group was defined because the study conducted that indicated that the lake water level has been decreasing since 2007 (Eridanus, 2016). The purpose is to evaluate if there has been a change in the precipitation, temperature, and water level trend. The analysis consists of the evaluation of the statistical parameters, and legal water withdrawals and fines imposed.

4. RESULTS

4.1 Precipitation and temperature records

Figure 3 shows the precipitation (mm) and temperature (ºC) records from 1995 to 2018. It is appropriate to indicate the missing precipitation and temperature values of the dataset. The meteorological station did not record precipitation values from August to December 2017, and July to December 2018 (11 months). Likewise, there are no temperature records from November to December 2018 (2 months). In the catchment, there is only one meteorological station, and the nearest one is located 8.30 kilometers away from Laguna Acuelo meteorological station. The Río Angostura en Valdivia de Paine meteorological station (33º 48' 40'' S, 70º 53' 00'' W, 342 m a.s.l; BNA code: 05716001-2) has the same time range of lack of information. Thus, the missing information did not restore. Table 2 describes that highest rainfall records were recorded between 1995 and 2006 caused the average, standard deviation, and maximum values of group one are significantly higher than group two. On the contrary, temperature records do not show notable variations between the two groups. However, the second group (2007 to 2018) has the highest variability and maximum temperature values registered. Three of the top 10 highest total precipitation on monthly record have occurred since 2007. Additionally, seven of the top 10 highest and lowest average temperature on monthly record have occurred since 2007.

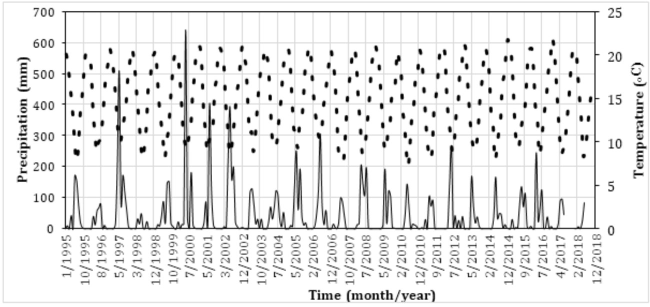

Figure 3: Monthly precipitation total (__), and average monthly temperature (···) from January 1995 to December 2018.

Table 2: Precipitation, average temperature, and water level statistic values.

Variable	Time series	Period	Sample	Mean	Standard Deviation	Max.	Min.
Precipitation	Monthly	1995 to 2018	277	43.14	80.220	641.5	0
		1995 to 2006	144	51.65	96.892	641.5	0
		2007 to 2018	133	33.99	56.076	266	0
Temperature	Monthly	1995 to 2018	286	14.87	4.209	21.94	7.04
		1995 to 2006	144	14.98	4.071	21.05	7.65
		2007 to 2018	142	14.76	4.356	21.94	7.04
Water level	Discontinue	1999 to 2018	105	7.21	3.161	23.63	1.80
		1999 to 2006	42	6.40	2.776	13.70	1.80
		2007 to 2018	63	7.75	3.304	23.63	2.12

Different ranges of precipitation and temperature were arbitrarily defined to asset the magnitude value recorded over time. Figure 4 reveals that precipitation values with the greatest magnitudes were recorded between 1995 and 2006, concluding that in recent years no significant events have been recorded. Only in three ranges of precipitation (0-20, 80-100, and 100-120 mm), group two has major quantities of events than group one. It is greater occurrence (64% of the total recorded events, approximately) to have less than 20 mm month^{-1} of rainfall. Similarly, Figure 5 shows that in recent years (2007 to 2018) maximum and minimum temperatures (≤ 8, 10-12, and ≥ 22 ºC) are more recurrent. If we compare the number of events among the whole temperature ranges between group one and two, the 12-14 ºC range has the higher percentage change (56%).

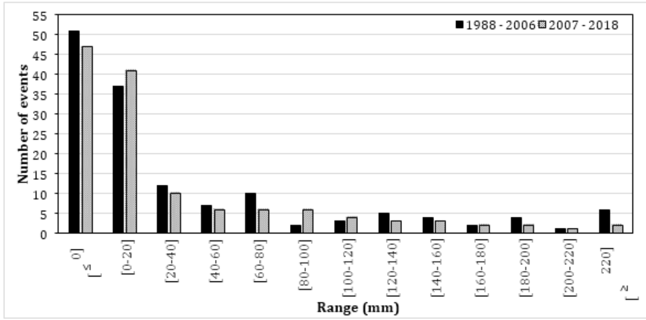

Figure 4: The number of events per different precipitation ranges, from 1995 to 2018.

In addition, The Central Limit Theorem is a statistical theory states that the distribution of independent random large samples (≥ 30) approximates a normal distribution (Chang et al., 2006). In this context, the two-sample t-test was performed on the data to determine if two population means are equal. The results supported that the average of the precipitation and temperature first group (1995 to 2006) is considered to be equal to the precipitation and temperature of the second group (2007 to 2018) with a significant level of 0.05. The p-value was 0.067 in precipitation analysis, and 0.659 in temperature analysis. In other words, the difference between the average of the first and second group is not big enough to be statistically significant.

On the contrary, the water level of the first group (1999 to 2006) is considered to be not equal to the second group (2007 to 2018) with a significant level of 0.05. The p-value was 0.031. In the same order, the f-test was used to evaluate the variation of the variance. The results supported that the variance in the precipitation analysis is statistically different (p-value < 0.00001), temperature analysis is statistically equal (p-value = 0.421), and water level analysis is statistically equal (p-value = 0.238) with a significant level of 0.05.

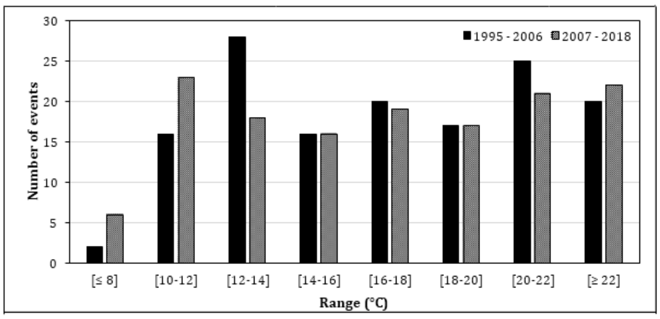

Figure 5: The number of events per different temperature ranges, from 1995 to 2018.

Figure 6 illustrates the correlation between monthly precipitation total vs average monthly temperature over the 23 year period from 1995 to 2018.

Negative precipitation-temperature correlations were observed, which means that higher magnitude precipitation events tend to start at low temperatures. However, the linear plot has an insignificant correlation coefficient ($r^2 = 0.266$). In addition, low magnitudes of precipitation (< 100 mm) occur over a wide temperature range (5 - 25 ºC). Oppositely, extreme precipitation events (> 100 mm) only happen in a narrower temperature range (< 15 ºC).

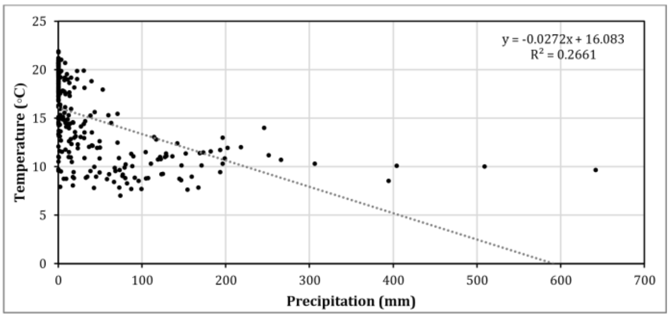

Figure 6: Correlation between monthly precipitation total vs average monthly temperature from January 1995 to December 2018.

4.2 Aridity index

De Martonne aridity index was used as a drought quantifier to evaluate the variation of the climate type over the years at Laguna de Aculeo (Figure 7). The results stated that the study area was classified as a very humid zone in 1997, 2000 and 2002. Nevertheless, it is classified as an arid zone in 1998 and 2018. In fact, the climate indices had a drastic change (very humid zone to arid zone) from one year to another (1997 to 1998). Finally, it can be concluded that the aridity index value shows a decreasing tendency indicating the degree of dryness in the area.

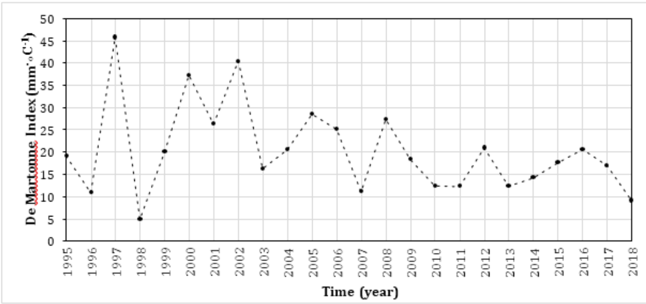

Figure 7: De Martonne aridity index (mm·ºC^{-1}) for Laguna de Aculeo from 1995 to 2018 per year.

4.3 Water level

San Francisco Aculeo station measures the distance between the surface to the groundwater level. Thus, when the value increase means that water table decrease, making access to water more difficult. The present dataset contains 105 records, covering the period from February 1999 to March 2018, and the time series is discontinuous (Figure 8). Over the years, the water level records seem to have a positive trend. Consequently, the greatest magnitude values were recorded after 2007, 15.5 meters in October 2008 and 23.63 meters in April 2015. On the contrary, the value with the greatest magnitude recorded in the period from 1999 to 2006 is 13.70 meters. The average and standard deviation are lower in group one (1999 to 2006) than in group two (2007 to 2018), revealing major records of high values and greater dispersion of data in recent years. The minimum value registered in both groups is similar (1.80 meters group one and 2.12 meters group two) giving support to the idea that there is a positive trend.

Table 1 shows all the statistical analyses performed. The lake water level records o shows two significant negative trends (Figure 7). The first starts in February 2006 until March 2008. Then, it seems a recovery period begins until October 2008. Finally, the second negative trend occurs from October 2008 to August 2018. The maximum lake water level value was 8.2 meters in August 2006.

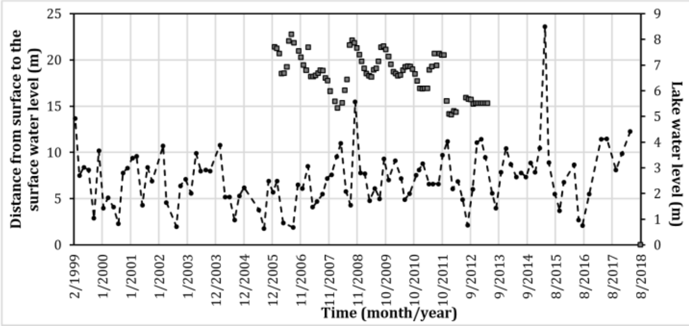

Figure 8: San Francisco Aculeo monitoring well recorded the distance (m) from surface to the surface water level from February 1999 to March 2018 (▬ • ▬), and Laguna Aculeo Los Castañosstation recorded Laguna de Aculeo water level (m) from January 2006 to August 2018 (▪).

4.4 Monotonic trend analysis

The non-parametric test of Mann-Kendall and Sen's slope were applied at 95% significant level to all the dataset in annual, monthly, and discontinue time series. The results are presented in Table 3. When p-value is lower than the significance level alpha (0.05), one can conclude that there is a monotonic trend. Subsequently, a positive Kendall's tau value indicates an increasing trend. On the contrary, a negative value indicates a decreasing trend. Sen's slope shows the degree of change over time. Thus, Mann-Kendall analyzes the tendency of the dataset, and Sen's slope quantified the variation. The rainfall and temperature data for 23 years from 1995 to 2018 at the annual and monthly scale has examined, revealing that p-value is significantly higher than the alpha value meaning one cannot reject the hypothesis of no trend. Correspondingly, water level data for 19 years from 1999 to 2018 at discontinue scale has the same result. Mann-Kendall test shows that there is no increasing or decreasing trend over the years. Consequently, the values obtained by performing the Sen's slope test are inconclusive. In other words, the results state that independent of the variable and time series, no monotonic 394 trend cannot be detected. Because the trend in the dataset is not statistically significant using Mann-Kendall and Sen's slope test. However, the results stated that lake water levels database 396 from 2006 to 2013 (94 records) shows a negative monotonic trend.

Table 3: Mann-Kendall and Sen's slope trend test for Laguna de Aculeo from 1995 to 2018.

Variable	Time series	Period	n	Mann-Kendall test			Sen's slope
				alpha	p-value (Two-tailed)	Kendall's tau	
Precipitation	Monthly	1995 to 2018	277	0.05	0.832	-0.009	0.000
Temperature	Monthly	1995 to 2018	286	0.05	0.891	-0.005	0.000
Precipitation	Annual	1995 to 2018	23	0.05	0.154	-0.217	-1.189
Temperature	Annual	1995 to 2018	23	0.05	0.958	-0.012	0.000
Groundwater level	Discontinue	1999 to 2018	104	0.05	0.089	0.113	0.000
Lake water level	Discontinue	2006 to 2013	94	0.05	<0.0001	-0.339	-0.001

4.5 Water extraction rights and fines

DGA's database has a cadastre of all water extraction rights given over the years, and receive a monthly update. This research used the information dated on April 4, 2019. One of the information that the database has is the name of the owner, water consumption, and geolocation. The data were

merged with Estero Angostura Entre Estero Paine (II) y Río Maipo Sub-Basin. The results reveal that there are 41 water extraction points, and all water consumption is 10,218,386 $m^3 \cdot year^{-1}$. The maximum value in the basin is 50 liters per second (1,576,800 $m^3 \cdot year^{-1}$), and it is located 100 meters from the lake. In this context, the lake has 5 (2,702,635 $m^3 \cdot year^{-1}$), 5 (318,514 $m^3 \cdot year^{-1}$), and 6 (1,280,188 $m^3 \cdot year^{-1}$) water extraction points within 100 (1 km^2), 1000 (6 km^2), and 2000 (13 km^2) meters from the lakeshore, respectively. Furthermore, all the fines for pumping water illegally from 1988 to 2019 was requested to DGA. Although, the information received only cover the period from 2012 to 2019, revealing 16 infringements process. In fact, DGA did not impose penalties or investigations in 2014 and 2015. Legal investigations during 2012, 2013, 2016, 2017, 2018, and 2019 were one, one, two, three, two, and seven, respectively. However, only nine infringements process were penalized with a total payment of 9,208 UF ($0.37M USD approximately), corresponding to all the information remitted for the period 2018 and 2019. In other words, there are no fines information provided from 2012 to 2017.

5. DISCUSSION

5.1 Results

The results of the statistical analysis presented in Table 2 states that the first group has a higher magnitude of monthly precipitation compared to the second group. The standard deviation indicates that the decrease in rainfall volume is not due to a higher dispersion of data. On the contrary, the first group has a sizable data dispersion than the historical precipitation data, showing the high fluctuation of magnitudes. Furthermore, if the data is considered normally distributed, it is correct to assert that the mean of group one and two are statistically equal. Nevertheless, the variance has changed over time. In other words, the total volume of water during a storm has remained with no significant variation over the years, but in recent years there have been no recorded high rainfall events compared to the first group (1995 to 2006). On the contrary, temperature value seems not to have significant variation over time.

However, the highest and lowest events had recorded since 2007, concluding that the data dispersion has increased over time. In addition, the analysis of precipitation and temperature at different ranges suggested it seems more probably has a lower magnitude rainfall events and higher temperatures in recent years, showing fluctuation in compare with the first group. The analysis of correlation coefficients between precipitation and temperature has shown that there is an insignificant negative linear relationship. Through the years, De Martonne aridity index reveals a decreasing trend. It conceivably because of reducing annual precipitation values and rising average annual temperature. Although the decrease in the aridity index value probably due to the missing precipitation data in 2017 and 2018. Likewise, the absent months have a significant impact on the average yearly rainfall. A particular situation occurred in 1998; the measurement of rainfall was 123 mm. As a consequent, the evaluation of these results should be conducted in a precise manner.

San Francisco Aculeo monitoring well recorded the distance in meters from surface to the surface water level, and Laguna Aculeo Los Castaños station recorded Laguna de Aculeo water level in meters. The results stated that both measurements exhibit a negative impact on water reserves. The ongoing decrease in the groundwater level is correlated with the lake drying up until August 2018. It is necessary to clarify that the value registered in August 2018 was incorporated because on that date the lake was officially declared dried. However, it is possible that the lake dried up before. Because there are unofficial sources and satellite images that support the lake experienced water scarcity.

This study examined different climate variables concluding the trend existence. However, the Mann-Kendall and Sen's slope test do not support this idea. Although this should relate to alpha value was conservative (95%), the amount of data, or that the trend is not statistically significant. This result is remarkable because it indicates that no variables have a significant change in its values over time. It seems that there is not a strong correlation between the lake dryness and climate variables. In contrast, lake water level registered a negative monotonic trend, evidencing the accuracy of the statistical analysis in view of the fact that the lake is currently dry. If Mann-Kendall and Sen's slope test had been done in 2013, perhaps actions for mitigation drought and water scarcity would have been done years ago; or at least public authorities and citizens would have been aware of a possible water deficit scenario.

The results of the water extraction points reveal that approximately 15 percent (1,576,800 $m^3 \cdot year^{-1}$) of the total water consumption (10,218,386 $m^3 \cdot year^{-1}$) is generated by only one well. It is also located within 100 meters from the lakeshore. Even more important, approximately 26 percent (2,702,635 $m^3 \cdot year^{-1}$) and 42 percent (4,301,238 $m^3 \cdot year^{-1}$) of the total consumption is generated within 100 and 2000 meters from the lakeshore, respectively. It is important to note that 42 percent of the total water consumption is distributed over a surface area of 13 km^2 that corresponds to 5 percent of the catchment's total area (264 km^2). Finally, it should be emphasized that the yearly water consumption corresponds to the fifth part of the volume of water in the lake ($53.6 \cdot 10^6$ m^3), approximately. In other words, if there are meaningful changes in the water balance, it is possible that the water extraction points could dry the lake in five years. Everything already stated shows that wells locations and use of water should be reevaluated to minimize potential impacts on the lake. Another aspect, illegal wells investigations and fines imposed have been increasing over the years, revealing human behavior and government actions in a period of water shortages, causing people to take action without the permission of the authorities.

5.2 Solutions

Practical solutions to water shortage have been studying in several scientific articles. First, it is essential to develop and test a water balance model to analyze the amount of water and its availability in the catchment. This study will provide detailed information about water change perturbations by climate change and anthropic activities. Furthermore, water balance estimation has been proved to help to manage the optimal use of water resources (Kokkonen et al., 2018; Mello et al., 2019; Thompson et al., 2017). Currently, it is no longer create or acquire water rights under legislation due to the complex scenario in Laguna de Aculeo. In addition, the DGA has the power to expropriate the water rights. Thus, it is advisable to expropriate all water rights that generate a prominent negative impact on the catchment. Additionally, water educational strategies have demonstrated to improve the knowledge of the water cycle, water consumption, water quality, water treatment, regulation, and water sustainability.

It only encourages people to find solutions to our current water problems or being more conscious of them (Atkinson, 2017; Brandl et al., 2019; Lien, 2005). Another practice to promote water efficiently is to implement economic incentives. It is complex to change the amount of personal water use because of water rights. Due, they are a legal authorization on the permitted use of a specified amount of water without breaking the law. In this context, control the cost of water or define economic incentives as a policy instrument is more practical (Huffaker and Whittlesey, 2003; Pezzey, 1992). Broadview Water District (California, United States) has implemented an economic incentive program to reduce water consumption in agriculture, raising the price of water by 150% (US$13 to US$32.45 per 1000 m^3). This measure generated an average irrigation reduction of 25% (1000 to 749 mm) on cotton fields. The results indicate that the water efficiency increase due to economic incentives in practical cases (Wichelns et al., 1996).

Similarly, another proposal is to waterproof of specific areas of significant inflows of lake River. Impervious surfaces not only increase flow velocity, achieving that the volume of water reaches the body of water faster. Also, water losses through infiltration decrease. Several studies have reported that runoff can increases by 30-500% in impervious area, revealing the correlation between land cover and overflow (Lee and Brody, 2018). This could help to maximize the lake recharge if the higher infiltration rate areas are identified and managed. In the same way, another method to recharge the lake is to perform artificial recharges to recover the lake water level. The recharge methods consist in increasing the natural infiltration rates. There are multiple experiences of artificial recharge that demonstrate improvement in the quality of groundwater reserves. The artificial water recharge of groundwater by controlling the water level of the aquifers is a promising solution for managing the lack of water.

The artificial recharge of groundwater is a promising methodology to solve water problems; some researchers have evaluated its efficiency. Al-Assa'd and Abdulla are independent researchers. They have experienced in water management projects. They wrote an article points out the idea of doing an artificial recharge of groundwater by using predictive models in the

Mujib aquifer. Their work provided the aquifer's response data to different groundwater recharge rates. The results obtained by collecting physical parameters, understanding the complexity of the hydrology and geology process, and using the MODFLOW software were encouraging (Al-Assa'd and Abdulla, 2010). In other words, if you perform an artificial recharge of groundwater correctly, you can recover the groundwater table. However, the uncertain part of the investigation is that all the results are theoretical. In this context, Igboekwe & Ruth are professors at the Department of Physics at the Michael Okpara University of Agriculture, Nigeria. They had written an article focuses on the benefits to accomplish artificial recharge groundwater in Umudike, Southeastern Nigeria.

The methodology used in Umudike consisted of the construction of a well 50 meters deep. The water used to perform an artificial recharge was a combination between rainwater and river water. As a result, the whole area of study had a positive impact on the water resources, raising the water table by 10 meters on average (Igboekwe and Ruth, 2011). The research demonstrates promises results of the application of artificial recharge. In addition to the other practices, it is necessary to asset and improves land use planning decision focused on manage water supply. It will generate economic, social and environmental benefits, increasing the availability of water supplies (Carter et al., 2005). A theoretical approach in Yanhe watershed in the Loess Plateau by using SWAT software indicated that water yield and soil erosion decrease in the simulation scenarios by reducing the farm's areas and increasing the vegetation biomass on grasslands (Yang et al., 2019). On the other hand, it had demonstrated that land use planning on native forest protection in East Maui in Hawaii preserve the natural water storage, promoting social and environmental benefits (Bremer et al., 2019). Finally, the last measure should be to increase well inspections in Laguna de Aculeo to identify illegal activities and improve the regulation system in order to obtain the sentence expeditiously and efficiently.

6. CONCLUSIONS

In this study, the changes in water level at Laguna de Aculeo were analyzed to identify the root causes of this problem. The events of rainfall, temperature, and groundwater level records were divided into two time series. The first group is composed of data recorded from 1995 to 2006 (water level from 1999 to 2006), and the second group from 2007 to 2018. The statistical analysis reveals that there is a change in magnitudes between the two groups. In other words, in recent years (second group) the values of precipitation and groundwater level have decreased. More precisely, higher rainfall events and groundwater levels have recorded from 1999 to 2006. On the contrary, the temperature variation has increased, recording the highest values registered in recent years. However, the coefficient of linear correlation between precipitation and temperature is low ($r^2 = 0.266$), making it difficult to estimate values. De Martonne aridity index shows that the climate has changed over time, from very humid to arid zone.

Likewise, the distance between the surface and the level of groundwater has been increasing. At the same time, the water level of the lagoon has been decreasing. The results indicate that the hydrological and climatic variables have experienced a change in their magnitudes between the first group and the second group. However, the variations are not significantly drastic to generate a water loss of water volume of $53.6 \cdot 10^6$ m^3 in 11 years (2007 to 2018). It is important to note that approximately 46% of the water extraction points are located within two kilometers from the lakeshore. In addition, the annual volume of legal water extraction corresponds to the fifth part of the volume of water in the lake. Moreover, the creation of illegal wells and anthropogenic activities have increased year by year. As it was mentioned previously that the population has increased by 45% in 5 years. The creation and profit of commercial activities have increased by 22% and 53%, respectively, in 5 years.

Land use and land cover data have varied significantly in 5 years. The results of this study indicate that the cause of the drought of the lake is generated by climatic and anthropogenic factors. However, the changes in precipitation and temperature over the years are not significant for drying a lake. Therefore, it is possible to assume that human activities are arguably the greatest cause of impact on Laguna de Aculeo. Future studies should focus on the anthropogenic impact on water resources because there has been a considerable increase in human activities over the years. Finally, The potential solutions are (1) conduct a water balance; (2) evaluate and remove water rights; (3) implement environmental education; (4) execute economy incentives; (5) increase the inflow into lake; (6) perform artificial recharge; (7) change land use planning; (8) increment well inspections.

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