Analysis and impact of meteorological droughts in the agriculture of Puno region, Peru

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Abstract. The research focuses on identifying and characterizing the occurrence of episodes of meteorological droughts in the Puno region in Perú, in order to determine the economic impact of this climatic phenomenon on agricultural activities in the region. From the use of the standardized rainfall index for 12 months (SPI-12) for the period 1981-2019, the occurrence, magnitude, persistence and spatial evolution of drought events in the area were determined, determining that the events that occurred in the years 1982/83, 1989/90 and 1991/92, escalated to levels of severe drought and extreme drought, mainly in the extreme south of the region, which corresponds to the provinces of El Collao, Yunguyo and Chucuito. For the determination of the impact of droughts on agriculture in the region, the records of losses of cultivated areas corresponding to the period 1997-2017 administered by the competent authority were used, finding the non-existence of a direct correlation between the presence of meteorological droughts and the economic losses in production, due to the fact that said information has a general character, not discriminating the different climatic phenomena that generate economic losses in the agriculture sector, therefore, they are not adequate to estimate the economic impact of droughts in the Puno region.

1 Introduction

Drought is a condition on the land caused by recurring water shortages that fall below the normal average [1,2] or defined threshold levels [3], being a very devastating natural hazard [4]. Droughts can develop in short periods (months) or long periods of time (years) [5] for different situations or causes, which depend on the climatic characteristics of each region, including water use, land use and the different economic activities that are developed [6]. Drought is perceived as one of the natural disasters with negative consequences on any type of climate [7]. Drought affects the level of precipitation, underground water storage, availability of soil moisture and water in rivers or reservoirs [8], Given the difficulty in defining its beginning and end, the onset of the drought may be delayed during its passage through the basin, causing a delay in the different types of droughts, prolonging the duration

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and attenuating the intensity of the anomalies [9]. Drought is a particular risk to agricultural production and productivity [10]. The impact of drought is governed by the magnitude, duration, frequency, and spatial extent of the precipitation deficit [11].

There are various indices of drought [12], in this study the standardized precipitation index (SPI) was used [13], this index uses a single hydrometeorological variable, which is mean precipitation; the method also allows us to describe droughts temporarily, that is, to evaluate in time and spatially to see the behavior in a given geographic space [1,6].

In the Altiplano region, in the year 1982/1983, there was a drought in the Titicaca-Desaguadero-Poopo-Salar de Coipasa (TDPS) system on the Peruvian side that led to significant agricultural losses of US $ 38.0 million at the Peruvian level and US $ 128.0 million for the entire TDPS system [14], mainly affecting the agricultural sector. It is the most serious drought that has been reported in agriculture and livestock, mainly for crops of grain barley, quinoa, potato, goose, mashua, broad bean, dry grain, forage barley, forage oats. Therefore, it is important to know the characteristics of droughts, so that they can be used as a management tool for proactive drought mitigation [15]. [16] analyzed the risk of droughts at the district level for the southern part of the country based on the risk estimate, obtaining that in the Puno region, 10 districts were classified as having a very high level of risk, as well as 52 districts with a level of risk high, which should be of special interest in the event of drought events in the southern part of the country, if actions to mitigate possible impacts are desired.

The research aims to characterize meteorological droughts using the Standardized Precipitation Index method in the Hydrographic Region of Lake Titicaca - Peruvian Zone and its economic impact on agriculture in the Puno region.
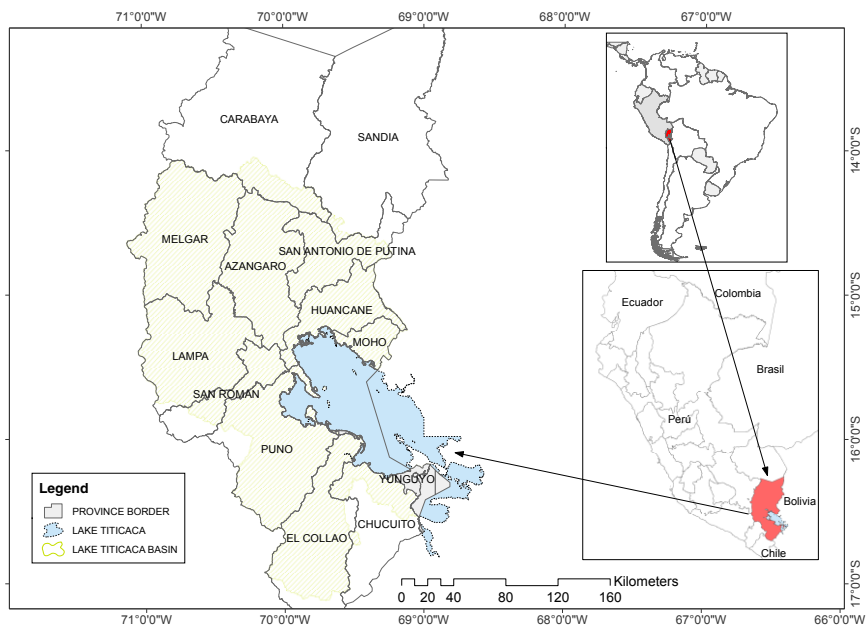
Fig. 1. Location of the Titicaca basin and provinces of the Puno region.

2 Study Area

The Puno region, is located in the south of Peru between 13° to 17° S and 69° to 71° W, includes the provinces: Azángaro, Carabaya, Chucuito, El Collao, Huancané, Lampa,

Melgar, Puno, San Antonio de Putina, San Pedro de Moho, Sandia, San Román and Yunguyo. It is located in the Lake Titicaca Hydrographic Region (Peruvian zone), and part of the Inambari basin towards the Atlantic Hydrographic Region. Figure 1 shows the location of the study area, where the political and hydrographic division differ. The Puno region occupies 71,999 km2, which represents 6% of the national territory, has 1,172,697 inhabitants, being 53.8% urban and 46.2% rural [17]. The economy of the rural population is based on the main agricultural products such as potato 22.9%, quinoa 13.4%, barley 9.1%, broad bean 3.9%, cañihua, oca, olluco, others. For the livestock field, forage oats 26.9% and alfalfa. The agricultural area of the Puno region is 406,267 ha, with only 3.27% of this area being irrigated, the rest is under rainfed [18].

3 Materials and methods

3.1 Data Source

The data of standardized 12-month precipitation indices (SPI-12 months) corresponding to the period 1981-2019 were obtained from the National Drought Observatory of Peru, which is administered by the National Water Authority [19] (http://snirh.ana.gob.pe/consultassnirh/oObservatorios.aspx).

Economic losses by type of crop and province were estimated from information on agricultural production from the Office of Agrarian Statistics [20] of the Puno Regional Agrarian Directorate (DRA).

Likewise, previous studies were reviewed on the determination of droughts in the area of the Lake Titicaca basin - Peruvian zone, by public entities such as the Local Water Administration, National Meteorology and Hydrology Service, Special Binational Lake Titicaca Project, institutions private and universities.

3.2 Drought indices

Meteorological droughts were determined using the Standardized Precipitation Index (SPI) method, being ideal for characterizing the severity of meteorological droughts. It is based on long-term monthly precipitation records that fit a gamma probability distribution. This distribution is then transformed into a normal distribution, with zero mean [21]. In Table 1, the classification of the values of the standardized precipitation index (SPI) and its corresponding category are presented [13].

Table 1. Classification of the SPI by Categories.

| SPI value	Category
2.00 or higher	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
0 to 0.99	Slightly wet
0 to -0.99	Slightly dry
-1.00 to -1.49	Moderately dry (moderate drought)
-1.50 to -1.99	Very dry (severe drought)
-2.00 or less	Extremely dry (extreme drought)

The SPI considers several time scales, which are analyzed together in order to form an overall judgment on droughts [22]. These time scales on which precipitation anomalies accumulate are very important and separate different types of droughts [23,24].

3.3 Economic Evaluation

The economic evaluation was carried out taking into account: population by province: urban and rural, crop production: potato and quinoa, crop yield, cost in farm of crops [20], Crop losses due to natural effects such as droughts, floods, frosts, hailstorms, other adverse climatic phenomena, with which economic losses were determined.

4 Results and discussion

The SPI-12 values (Figure 2) corresponding to the period 1981-2019 show the occurrence of droughts of moderate, severe and extreme intensity, thus, in the decade from 1981 to 1990 the occurrence of four drought events is evidenced whose values peaks correspond to the years 1982/83, 1983/84, 1988/89 and 1989/90, in the decade from 1991 to 2000 there is evidence of the occurrence of three drought events whose peak values were recorded in the years 1991/92, 1994/95 and 1995/96. In the decade from 2001 to 2010, the occurrence of three drought episodes was observed, the highest intensities of which were recorded in the years 2004/05, 2007/08 and 2008/09. In the decade from 2011 to 2019, the SPI-12 values indicate the occurrence of a single drought episode registered in the year 2010/2011.
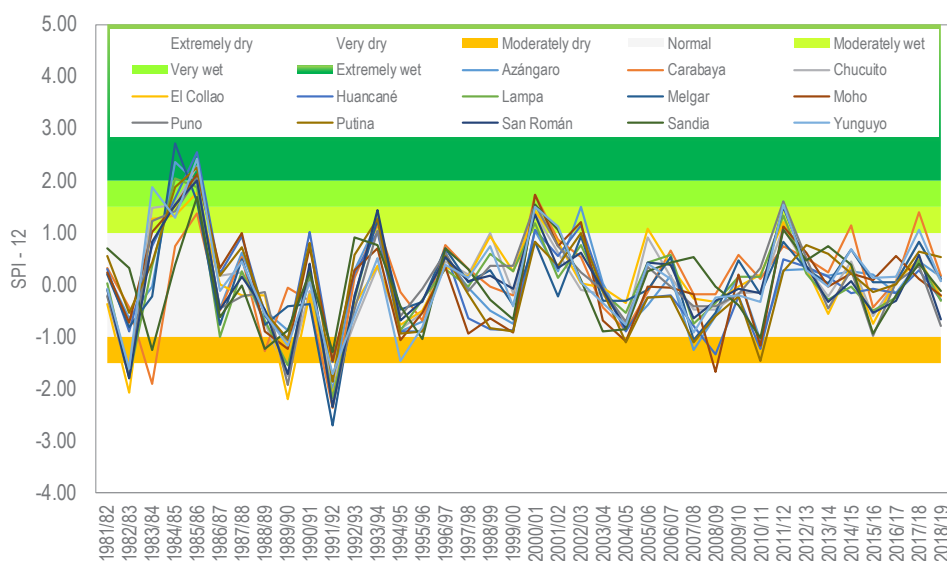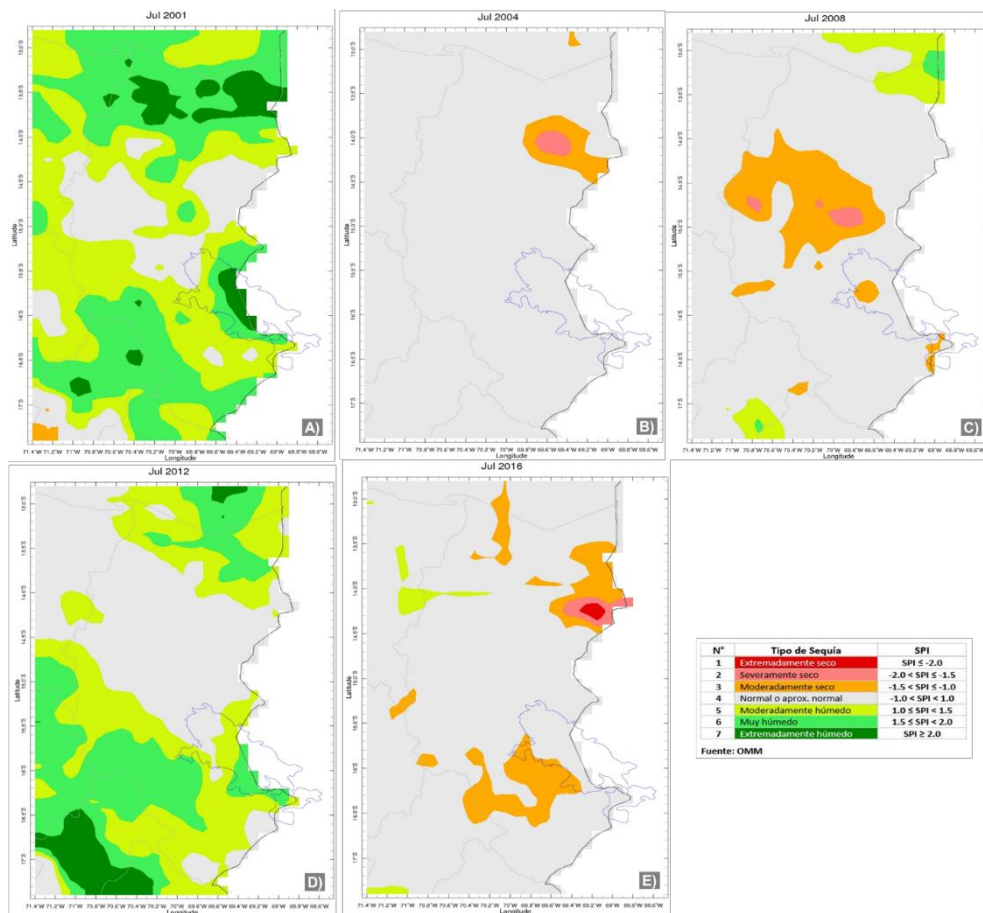

Fig. 2. Standardized 12-month precipitation index (SPI-12), areal average at the provincial level of the Puno region.

The SPI time series for a 12-month time scale (SPI-12) estimated as of July of each year of the analysis period (1981-2019), for the 13 provinces of the Puno region (Figure 2) suggests the existence of a common pattern in the behavior of SPI values in the 13 provinces, evidencing the presence of SPI-12 values lower than -1.0, in the years 1982/83, 1983/84, 1989/90, 1991/92, 1994/95, 2004/05, 2007/08, 2008/09 and 2010/11, being the episodes of greatest severity of the drought those that occurred in the years 1982/83, 1989/90 and 1991/92, climbing to severe to extraordinarily dry conditions. The most severe drought events occur in the extreme south of the Puno region, mainly in the provinces of El Collao, Yunguyo and Chucuito. Likewise, there is no marked recurrence of the occurrence (frequency) of drought episodes in the Puno region. The occurrence of drought episodes in the Puno region, located in the Titicaca Hydrographic Region, as a consequence of (negative) rainfall

anomalies, could be attributed in part to the occurrence of the El Niño Phenomenon, as referred to [25–27]. However, the causes of the drought are not yet precisely known [28].

Figure 3 presents the spatial variation of the SPI-12 values, for the years 2000/01, 2003/04, 2007/08, 2011/12 and 2015/16, which represent the years with the highest economic losses recorded by the Puno Regional Agrarian Directorate, from which it can be inferred that, only in the years 2003/04, 2007/08 and 2015/16 the presence of moderate and severe intensity drought episodes was perceived in isolated areas of the Puno region. While in the years 2000/01 and 2011/12, years with records of greater economic losses (Figure 4), the presence of droughts is not observed, on the contrary, humidity conditions between moderate to extremely humid and with greater extension in the Puno region compared to the years with the presence of droughts.

N°	Tipo de Sequía	SPI
1	Extremadamente seco	SPI ≤ -2.0
2	Severamente seco	-2.0 < SPI ≤ -1.5
3	Moderadamente seco	-1.5 < SPI ≤ -1.0
4	Normal o aprox. normal	-1.0 < SPI < 1.0
5	Moderadamente húmedo	1.0 ≤ SPI < 1.5
6	Muy húmedo	1.5 ≤ SPI < 2.0
7	Extremadamente húmedo	SPI ≥ 2.0

Fuente: OMM

Fig. 3. SPI-12 Spatial Distribution at the level of the provinces analyzed (a) July 2001 (b) July 2004 (c) July 2008 (d) July 2012 (e) July 2016.
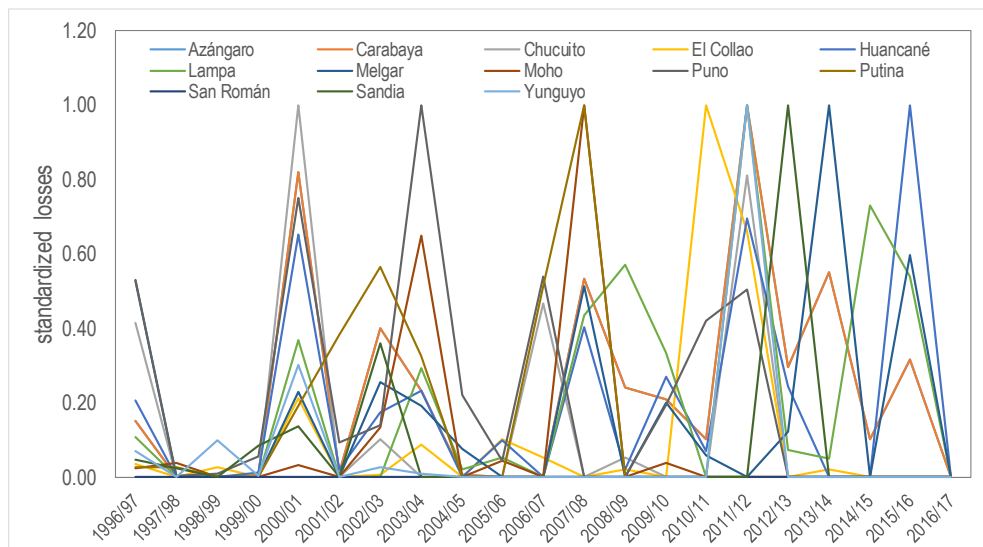
Fig. 4. Standardized losses in the provinces of the Puno region, in the period 1996/1997 to 2016/2017.

The quantification of the occurrence of drought episodes in the Puno region in the period 1981 to 2019 at the level of decades shows the decrease in the occurrence of droughts and their intensity, mainly in the decades 2001-2010 and 2011-2019, as well as reports it [29]. Likewise, the absence of a marked pattern in the recurrence of drought events in the 13 provinces of the Puno region is observed, thus the episodes of droughts of greater intensity (03 events) recorded in the area occurred in a age 12 (1982-1993) which represents 25% of the total for the period. In addition, it should be mentioned that in this same period an event classified as extremely humid was recorded (1985/86), which suggests that in the Puno region there is great variability in the behavior of rainfall in relatively short periods, making it a region highly exposed to the occurrence of extreme climatic phenomena, which would be aggravated when considering the effects of global warming and the increase in climate variability, which would generate an increase in drought events in many basins around the world as indicated [30,31], added to the changes in land use and the increase in water demands that are catalysts for worsening drought events and existing water scarcity processes [32,33].

The levels and zoning of drought hazard determined by [34], suggest that in the Puno region, there are predominantly levels between very high and high, which makes this region highly exposed to the occurrence of drought events, generated by the deficit of precipitation or by the increase in evapotranspiration [35], the latter being the one that reaches higher values compared to precipitation, as indicated by [36]. Likewise, the levels and zoning of vulnerability to the occurrence of a drought suggest that the high and medium levels are those that occur in the Puno region. However, there are also very high and low levels of vulnerability in the districts of Juliaca and Umachiri, respectively. Therefore, the Puno region is mostly at a very high-risk level due to the occurrence of droughts. The very high-risk areas are located mainly in the extreme south, center and northeast of the region, with 46 districts with more than 266,523 people exposed, where 56% of the population is in extreme poverty.

When graphing jointly the SPI-12 values and the standardized economic losses for potato cultivation in the province of Azángaro (Figure 5a), it can be seen that the years with the highest levels of economic losses are not related to the occurrence of episodes. of droughts ($R^2 = 0.1321$), but on the contrary, there is a coincidence between the levels of economic losses and the years with a moderate to extremely humid condition (rainy years), which is corroborated with the relationship of economic losses and SPI -12 of Figure 6b. Likewise,

the relationship between the levels of economic losses of the quinoa crop and the SPI-12 (Figures 6a and 6b), also shows a behavior similar to that of the potato crop, not finding a relationship between the level of economic losses and the occurrence of drought episodes ($R2 = 0.0032$). This behavior described for the province of Azángaro, is repetitive in the other 12 provinces of the Puno region, which suggests that the records of economic losses made by the Regional Agrarian Directorate Puno have a general nature, not discriminating the different climatic phenomena that generate Losses in the agriculture sector are therefore not adequate to estimate the economic impact of droughts on agriculture.
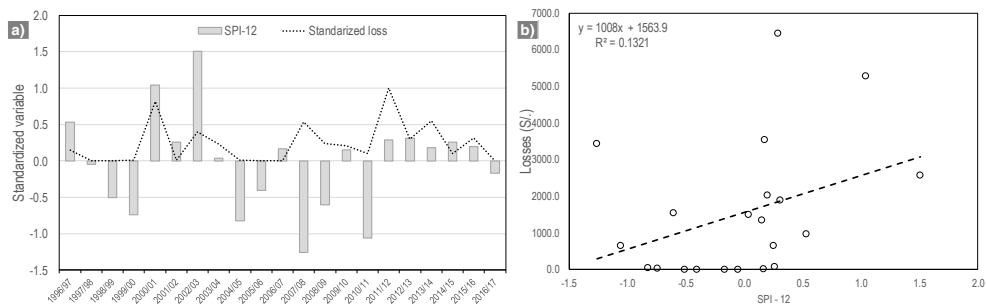
Fig. 5. a) Variation of SPI-12 and standardized losses of Potato, b) Correlation between losses in Soles and SPI-12 for Papa, Azángaro station.
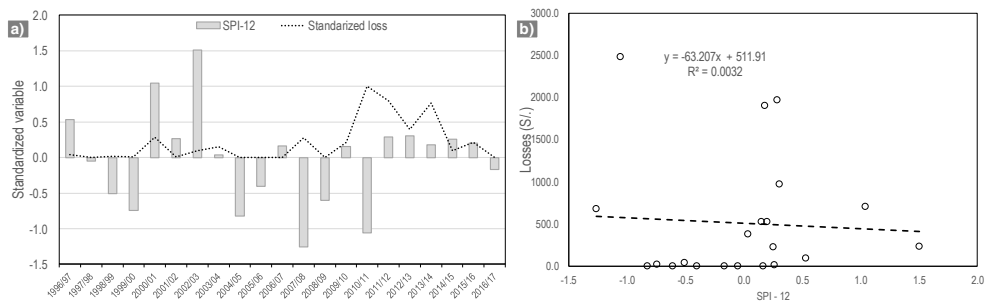
Fig. 6. a) Variation of SPI-12 and standardized losses of Quinoa b) Correlation between losses in Soles and SPI-12 for Quinoa, Azángaro station.

The effects of the 1982/1983 and 1989/1990 droughts caused more than US $ 128 and US$ 89 million in damages, respectively, in the Lake Titicaca Water System complex, Desaguadero River, Lake Poopó and Lake Salar de Coipasa (TDPS), where the study area of this research is located, with which it is demonstrated that droughts are one of the extreme events that has the most impact in the area of the TDPS Water System [14,27]. Likewise, it was estimated that the probability of occurrence (in the next 50 years, starting in 1993) of droughts equal to or greater than the episodes of 1982/1983 and 1989/1990 is 10 and 15%, respectively, which shows that this phenomenon could occur and could generate damages similar to those described above, if the necessary measures are not taken to counteract its effects.

5 Conclusions

This study addresses the impact of meteorological droughts in the Puno region, evaluated by the SPI on a 12-month time scale. From the characterization of meteorological droughts in the Puno region, for the period from 1981 to 2019, there were moderate to extreme droughts in the years 1982/83, 1983/84, 1989/90, 1991/92, 1994/95, 2004/05, 2007/08, 2008/09 and

2010/11; spreading spatially throughout the Puno region. Therefore, the Puno region is mostly at a very high-risk level due to the occurrence of droughts, mainly in the extreme south, center and northeast of the region.

From the results, it can be said that it is undeniable to affirm that the droughts generated economic losses in the 13 provinces of Puno, however, the loss statistics registered by the Puno Regional Agrarian Directorate, on the contrary, indicate that the greatest economic losses were recorded in years where there were no episodes of droughts, but very humid and extremely humid conditions, which we consider may be due to the fact that the loss statistics group together damages caused by different types of climatic phenomena (droughts, floods, frosts, hailstorms and others), and in extreme case, it would be because these statistics are not representative and would not contribute to the research pursued, therefore, they are not adequate for quantifying the economic impact of droughts in the Puno region.

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