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Tesis

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Analysis of the influence of solar cycles on meteorological variables in the central inter-Andean valley of Peru in the period 1986-2019

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Abstract

Solar activity transmitted in energy reaches the Earth, affecting atmospheric temperature and other global weather variables. This research aims to analyze the relationship between solar cycles and meteorological variables in the Central Inter-Andean Valley during the period 1986-2019. Sunspot data were obtained from the Royal Observatory of Belgium for solar cycles 22, 23 and 24, and the meteorological variables of the National Service of Meteorology and Hydrology of Peru from five stations that are distributed in the Valley. For the correlation of the variables, the nonparametric Spearman statistical test with a third-degree polynomial regression was applied. The results show that there is a decrease in the number of sunspots in cycle 24, and that the temperature varies by 3.85°C in the study period. Of the five stations analyzed, four of them show that there is no relation between the variables and only in the station Viques there is an inverse relation for $\alpha<0.05$ referring to the variables of maximum temperature and sunspots, obtaining a coefficient of determination of $R^2 = 0{,}619$. Therefore, solar activity does not influence the climate variability of the study valley, and this is due to climate change due to the effects of anthropogenic activities.

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Keywords: Solar activity; Solar cycles; Solar energy; Precipitation; Temperature

1. Introduction

The main source of energy for our planet is the Sun, due to its energetic emission and its magnetic field that vary over time. The radiant electromagnetic energy emitted by the sun at total wavelengths that fall every second in a square

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meter out of the Earth's atmosphere is referred to as total solar irradiation. Total solar irradiance means that the solar flux has been integrated into general wavelengths to include the contribution of ultraviolet, visible and infrared radiation [1]. Studies have shown that the number of sunspots correlates with solar radiation [2]. The energy of the sun depends on solar activity, which is affected by solar cycles, the most well-known manifestation of which is the number of sunspots caused by the Sun's magnetic fields [3].

Sunspots are concentrations of magnetic fields that occur on the solar surface (photosphere), with an extension of about 30 Mm and a lifetime of weeks, are characterized by being formed by the umbra a dark zone in the central part with a vertical magnetic field, and the surrounding penumbra with a flash of more than 75% solar granulation with a horizontal magnetic field [4]. Solar radiation is the determining element of Earth's temperature. Galileo in 1610 reported the existence of sunspots and the astronomer Henrich Schwabe in 1851 described the cycles of solar activity, by recording sunspots, showing that a cycle lasts about 11 years [5]. In the period 1645-1715 no sunspot was observed, being called Maunder Minimum or Small Ice Age, where there was a drop in global temperatures, since then there is a suspicion that the solar cycle has an influence on the Earth's climate [6]. On the other hand, since 99% of the energy of our planet comes from the Sun, it is a very logical idea that a very small variation of the energy emitted by the Sun should have a great influence on the Earth's climate [7]. The Intergovernmental Panel on Climate Change (IPCC) mentions that the cause of climate change may be due to external forces such as solar activity and anthropogenic actions [8]. What is under discussion in several scientific groups is the degree of impact in specific areas, and whether solar activity influences global warming or climate change, because today many investigations indicate that since the industrial era changes in climate patterns are driven by anthropogenic mechanisms [9]. Similar research on solar activity and climate change exists so far in different geographical areas, but not in Peru, which is one of the "particularly vulnerable" countries climate change according to the United Nations Framework Convention on Climate Change (UNFCCC) [10]. The effects of climate change in Peru are manifested through the retreat of glaciers, with a 51% loss of glacier surface, including the snowy mountains of the Central Inter-American Valley. [11].

To reduce the effects of climate change, the energy system must be decarbonized. Renewable energy sources should account for most of the technologies supplied. Decarbonization leads to the extraction of a significant amount of old energy based on fossil fuels. The massive integration of energies generated through variable natural sources poses new challenges that need to be assessed [12]. It is important to highlight that solar energy is a reliable source of energy for self-consumption, especially for the use of renewable energies, optimizing processes in the different productive sectors that each country has [13].

The comparison of the data in this study provides information for a better understanding of climate variations, solar activity and their relationship to climate change. The main objective of this study is to analyze the degree of relationship between solar activity and meteorological variables in the central Inter-Andean Valley of Peru during the period 1986 - 2019, using sunspots as an indicator of solar activity and climate variables such as minimum temperature, maximum temperature and precipitation.

2. Materials and methods

The research design is the nonexperimental longitudinal one since it is sought to analyze the relation of the variables in a period of time, with a level of correlational and explanatory research because the study variables will be analyzed and related [14]. In addition, we seek to determine the effects of solar cycles (independent variable) on temperature and precipitation (dependent variables). An indicator of solar activity is the number of sunspots (SSN) which is the solar parameter with the longest record time, similarly for climate change the temperature is the most basic indicator [15].

2.1. Study area

The Mantaro Valley is an inter-Andean valley located in the Junín region, specifically in the heart of the Andes Mountain range, in the central highlands of Peru, is a geographical space between the provinces of Jauja, Concepción, Chupaca and Huancayo with an average altitude of 3300 masl, with a wide variety of plant, forest and animal species, among which are famous the Polylepis, the Retama sphaerocarpa and the Turdus chiguanco. The Mantaro Valley is surrounded by mountain ranges and is crossed by the river of the same name, the Mantaro River; the left bank being the flattest and extended, in addition in this are most of its tributaries and is the most developed in urban terms, The most important cities in this area are Huancayo, Concepción and Jauja, which occupy 90% of the population of the entire Mantaro Valley. On the right bank being the steepest and narrowest are small agricultural and livestock districts such as Sincos, Mito, Orcotuna and districts more populated like Chupaca [16].

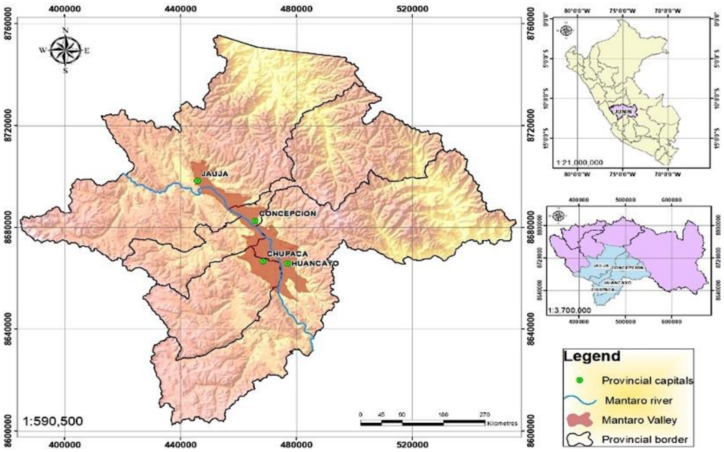

Fig. 1. Map of the Mantaro Valley.

2.2. Data collection areas

Table 1. Characteristics of meteorological stations used for research

Weather Station	Code	Altitude (masl)	Latitude S	Longitude W	Period
Jauja	111503	3370	11°47′11.9”	75°29′12.8”	1986-2019
Ingenio	111097	3373	11°52′30.8”	75°17′47.9”	1993-2019
Huayao	112056	3321	12°2′24.7”	75°19′13.8”	1986-2019
Santa Ana	112083	3293	12°0′34.4”	75°13′17.7”	1992-2019
Viques	112037	3186	12°9′21.7”	75°13′41.9”	1993-2019

2.3. Obtaining climatic variables and solar cycles

12 416 daily sunspot data were obtained from the Sunspot Index and Long-term Solar Observations (SILSO), public data belonging to the Royal Observatory of Belgium, Brussels. To obtain the solar cycles, a temporal space study was carried out, annual and monthly data of 33 years or 3 solar cycles were analysed in the period 1986-2019, with cycles 22 (1986-1997), 23 (1998-2008) and 24 (2009-2019).

For temperature and precipitation measurements, daily data were obtained from 5 meteorological stations that are distributed in the Mantaro Valley (Table 1) of the Historical Data Platform of the National Meteorology and Hydrology Service of Peru (SENAMHI), those for a period of 33 years were taken, as the World Meteorological Organisation mentions that a minimum period of 30 years should be assessed to reflect climate change [17].

2.4. Analysis statistic

For the processing of the historical behaviour of the meteorological variables and sunspots, the Excel software was applied, with which a statistical analysis was performed by which a third-degree polynomial regression was applied, obtaining the coefficient of determination (R^2) and dispersion graphs. Likewise, SPSS Statistics software was used, applying the Spearman correlation, to acquire the degree of relationship between the two variables, and a level of significance of α=0.05 was also used. The correlation of both variables was represented by the value of "r" and a coefficient of determination (R^2), while the significance in "p-value".

3. Results and discussions

About sunspots Fig. 2 and Fig. 3, there is a variation in the number of sunspots in any of the solar cycles. In the solar cycle 22 the maximum number of spots was 211 in the year 1989 and in the solar cycle 23 the maximum number of spots recorded was 174 in the year 2000. On the other hand, there is a decrease in the trend of the solar cycle 24, in the year 2014 the maximum amount of 113 sunspots is presented.

There is considerable similarity in the trends of the maximum temperature data for all stations Fig. 2 (a), in which Viques station records the highest average values since 2000. In 2001, Jauja station recorded the lowest average maximum temperature of 17.85ºC. The maximum temperature variation is up to 3.85°C throughout the period. A similar trend of maximum temperature with sunspots is not generally observed, although in certain years they increase or decrease at the same time. In 1991 the number of sunspots begins to decrease, but the maximum temperature still decreases two years later. For the year 2014 the number of spots reaches the top of that cycle, and the temperature reach a maximum top for the year 2016, where Viques station records the value of 21.7ºC.

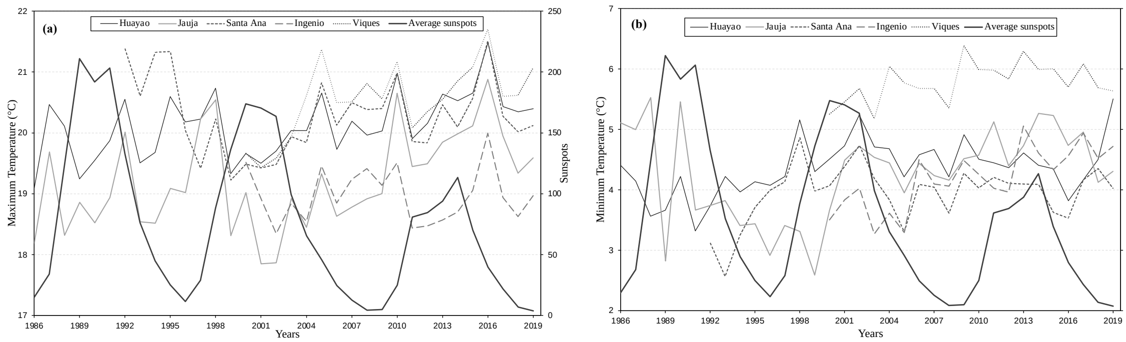

Fig. 2. (a) Average sunspot number and minimum temperature data; (b) Average sunspot number and maximum temperature data, for the Huayao, Jauja, Santa Ana, Ingenio and Viques stations, 1986-2019.

There is some similarity in the trends of the minimum temperature data for all stations Fig.2 (b). The minimum temperature variation is up to 3.82°C throughout the period, in the year 1999 the minimum temperature on average was 2.57ºC being the lowest value recorded by the Santa Ana station, In the following years the minimum temperature values are increasing mainly at the Viques station. There is no similar trend with sunspots, because in 1989 sunspots are at a maximum, but the temperature is low, while by 1990 the trend of minimum temperature increases and sunspots decrease, an inverse relationship is generally observed in the variables.

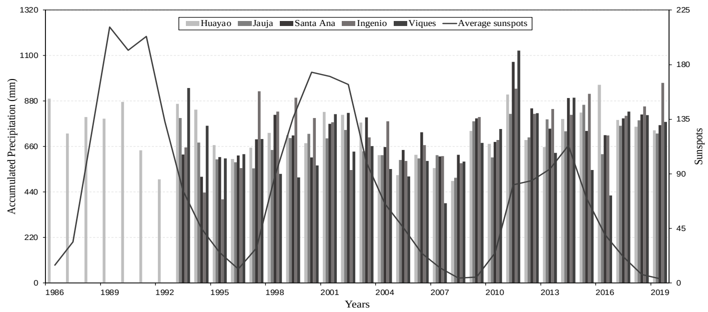

Fig. 3. Average sunspot number data and accumulated rainfall from the Huayao, Jauja, Santa Ana, Ingenio and Viques stations, period 1986-2019.

The Huayao station is the only one that has data since the beginning of cycle 22 which is the year 1986, rainfall values in all stations do not vary considerably Fig. 3, however, there are high peaks, as in 2011 that recorded the highest rainfall of 1124.2 mm, while the lowest peak was in 2007 with a value of 386 mm. There is no general similarity between precipitation and sunspot trends.

On the correlation analysis, the third-degree polynomial adjustment was the most optimal for meteorological variables and solar cycles at the 5 stations in the Mantaro Valley because the coefficient of determination approached one. The Spearman correlation shows that there is a relationship between the variable of solar cycles and the maximum temperature at the Viques station presenting a high coefficient of determination with an inverse ratio (r=-0.787; R^2=0.619) y p-value=0.013 which is less than our confidence level (α=0.05). For the remaining four stations in the Mantaro valley, no significant relationship between solar cycles and the maximum temperature variable is observed because the p-value is higher than the confidence level (p-value>α) accepting the null hypothesis where no correlation is mentioned. Even in the four stations, low coefficients of determination in maximum temperature are shown in the Ingenio station (r=-0.620; R^2=0.385; p-value=0.14) with a period of 19 years, and the Huayao station (r=-0.510; R^2=0.265; p-value=0.06) with a period of 33 years. In the variables of precipitation and minimum temperature there is no correlation with solar cycles in the 5 stations at a confidence level α= 0.05, presenting in the precipitation variable a low coefficient of determination and a direct relationship, with an average of R^2=0,136 and r=0,353, while for minimum temperature an indirect mean determination coefficient with an average of R^2=0,154 and r=-0,392 is presented.

It follows that the variation of temperature and precipitation data, in the five stations located in the Mantaro Valley is due to certain factors such as latitude, distance from the site to large water bodies, ocean currents, direction and types of prevailing winds, altitude, local topography and cloudiness [18]. A study in Peru analyzed temperature and precipitation data from 10 meteorological stations, observed negative trends, and events of El Niño – Southern Oscillation that generate less precipitation and temperature increase in the high Andean zone [19].

Bonfili et al. (2018) modeled rainfall series with annual data in the city of Río Gallegos (Argentina) and Punta Arenas (Chile), using additive models, variograms, identified a very weak correlation between precipitation and sunspots with a confidence of 95% [20]. Gonzales (2017) found correlation between the series and its annual rainfall lags and the number of sunspots in three stations in Colombia with a confidence of 99%, except at the Miguel Valencia station, which was barely correlated with 95% confidence and has 59 years of less information than the other stations, they mention that the affectation of significance is not due to the number of years [21].

Research at the global level has confirmed that there is a relationship between solar variations and climate variables, with changes in the emission of solar radiation related to changes in climate. Useros (2013) mentions that solar radiation is the determining element of Earth’s temperature, but the general warming of the atmosphere and the melting of ice sheets is probably not due to natural factors, but to anthropogenic forcing [5]. On the other hand, there is evidence that in some parts of the planet the number of sunspots from certain solar cycles affects precipitation, while in other regions this behavior is not confirmed. Thus, in a study carried out in Mexico, they show that between 2005 and 2011, there were considerable variations in the climate causing high rainfall and floods, due to solar activity, confirming that this influences climate variations [22]. The results of maximum annual temperature show that there is a correlation with sunspots in Viques station with a significant indirect correlation (p-value=0.013), over a 19-year period, unlike the other stations. Hanson (2021) in his scientific study in the wetland area of West Africa found that the variables of surface air temperature and precipitation were not affected by the amount of sunspot numbers in solar cycles 22-24, because the ratio is less than 1% causing a minimal effect and attributing that it is not possible to be driven by solar activity, but for anthropogenic factors [9]. It should be noted that temperature data are important as they influence the performance and operation of different new renewable energy systems. A study in Turkey evaluated a case of electricity production using natural gas at a defined temperature [23]. In fact, in Peru natural gas concentrates 80% of the country’s energy production and only 20% covers electricity production [24]. In the field of energy, Peru is considered an ideal country to initiate renewable energy projects, due to its great abundance of resources and green energy sources. In addition, Peru has a unique and diverse natural wealth, which is necessary to combat climate change and preserve biodiversity worldwide. [25].

4. Conclusion

Analyzing the meteorological variables as minimum and maximum temperature showed an increase in the 5 stations of 3.85°C throughout the period, and in the precipitation analysis a similar behavior of the trends of each year was found. On the other hand, solar cycles showed a decrease of sunspots in the solar cycle 24. In the correlation analysis there is no relationship between the average number of annual sunspots on precipitation and the minimum temperature in the 5 stations, since the coefficients of determination are low, and the p-values obtained are higher than the confidence level. Except for the Viques station where an inverse ratio for α0.05 was found between the sunspots and the maximum temperature, which came to obtain a coefficient of determination (r=-0.787; R^2=0.619). The results at the Viques station vary due to the fact that in the last 20 years the highest temperatures have been recorded throughout the Mantaro Valley. Because there is an indirect influence of solar activity on meteorological variables in stations, variations may manifest due to climate change resulting from anthropogenic activities. One way to reduce this impact of climate change is to decarbonize and apply renewable technologies in Peru's economic sectors.

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