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Articles

Climate change and glacier retreat in the Huaytapallana Mountain Range, Peru

Cambio climático y retroceso glaciar en la Cordillera Huaytapallana, Perú

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Abstract

The objective has been to describe and determine the relationship between environmental temperature —as a manifestation of climate change— and the glacier mass retreat of Huaytapallana mountain range in Peru. The minimum temperature and glacier surface data were obtained from Senamhi and IGP official reports, they are expressed in °C and km^2 respectively. The temperature data belong to the Huancayo Observatory located at Latitude 12 ° 02 'S, Longitude 75 ° 19' W, Altitude 3 313 masl; in the Huachac district, Chupaca province, Junín department. The glacier surface data were taken from the mountain Huaytapallana's studies by the Instituto Geofísico del Perú. The variables' missing data estimation was performed with a linear regression model. Among the results we have found that between 1986 to 2016, an increase in the minimum annual temperature in the study area is evident, showing values between 3.435 to 5.227 °C; a value of 4.757 °C is estimated at 2016; likewise, the glacial mass surface of the Huaytapallana mountain shows a downward trend in this same period, estimated at 2016 in 11.86 km^2. In conclusion, the increase of minimum temperature of the period 1986 - 2016 affects the glacier mass surface retreat of the Huaytapallana mountain range; likewise, there is an inverse, moderate and significant relationship between the minimum temperature increase and the glacier mass retreat of the mountain which is our study object.

Keywords: Minimum temperature, glacier surface, Huaytapallana mountain range.

Resumen

El objetivo ha sido describir y determinar la relación de la temperatura ambiental —como manifestación del cambio climático— y el retroceso de la masa glaciar de la Cordillera Huaytapallana en Perú. Los datos de

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temperatura mínima y superficie glaciar se obtuvieron a partir de informes oficiales del Senamhi e IGP, y están expresadas en °C y km^2, respectivamente. Los datos de temperatura pertenecen al Observatorio de Huancayo, ubicado en latitud 12° 02' S, longitud 75° 19' W, altitud 3 313 msnm en el distrito de Huachac, provincia de Chupaca, departamento de Junín. Los datos de superficie glaciar fueron tomados de estudios de la Cordillera Huaytapallana por el Instituto Geofísico del Perú. La estimación de datos faltantes de las variables se realizó con un modelo de regresión lineal. Entre los resultados se tiene que, entre 1986 y 2016 es evidente un incremento de la temperatura mínima anual en la zona de estudio, mostrando valores entre 3.435 y 5.227 °C; se estima al 2016 un valor de 4.757 °C; asimismo, la superficie de masa glaciar de la Cordillera Huaytapallana muestra en este mismo periodo una tendencia de retroceso, estimado al 2016 en 11.86 km^2. En conclusión, el incremento de la temperatura mínima del periodo 1986-2016 incide en el retroceso de la superficie de masa glaciar de la Cordillera Huaytapallana; de igual forma, existe una relación inversa, moderada y significativa entre el incremento de la temperatura mínima y el retroceso de la masa glaciar de la cordillera objeto de estudio.

Palabras clave: temperatura mínima, superficie glaciar, Cordillera Huaytapallana.

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Introduction

Global climate change is the variation of the state of the climate, identifiable (for example, by statistical tests) in the variations of the average value or in the variability of its properties, that persists for long periods of time, usually for decades or longer periods. Climate change may be due to natural internal processes or external forcing such as modulations of solar cycles, volcanic eruptions or persistent anthropogenic changes in the composition of the atmosphere or land use (Panel Intergubernamental del Cambio Climático, 2014).

The United Nations Framework Convention on Climate Change (UNFCCC), in its article 1, define climate change as "climate change attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that adds to the natural variability of the climate observed for comparable periods of time". The UNFCCC differentiates, therefore, between climate change attributable to human activities that alter atmospheric composition and climate variability attributable to natural causes (Panel Intergubernamental del Cambio Climático, 2014).

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According to the Intergovernmental Panel on Climate Change (2014) warming in the climate system is unequivocal, and since the 1950 many of the changes observed have been unprecedented in recent decades to millennia. The atmosphere and the ocean have warmed, snow and ice volumes have decreased and sea level has risen. Each of the last three decades has been successively warmer on Earth's surface than any previous decade since 1850. It is likely that the period 1983-2012 has been the warmest 30-year period of the last 1 400 years in the northern hemisphere, where it is possible to carry out this evaluation (average confidence level). Temperature data of the land and ocean surface, combined and averaged globally, calculated from a linear trend, show a warming of 0.85 (0.65 to 1.06) °C, during the period 1880-2012, for which several data sets have been produced independently.

In addition to recording a remarkable multi-decennial warming, the average global surface temperature shows considerable ten-year and interannual variability (Figure 1). Due to this natural variability, trends based on short registration periods are very sensitive to the start and end dates, and do not generally reflect long-term climate trends. For example, the heating rate during the last 15 years (0.05 [–0.05 to 0.15] °C for decade, between 1998 and 2012), which begins with a strong effect of the El Niño phenomenon, is lower than the rate recorded since 1951 (0.12 [0.08 to 0.14] °C for decade, between 1951 and 2012).

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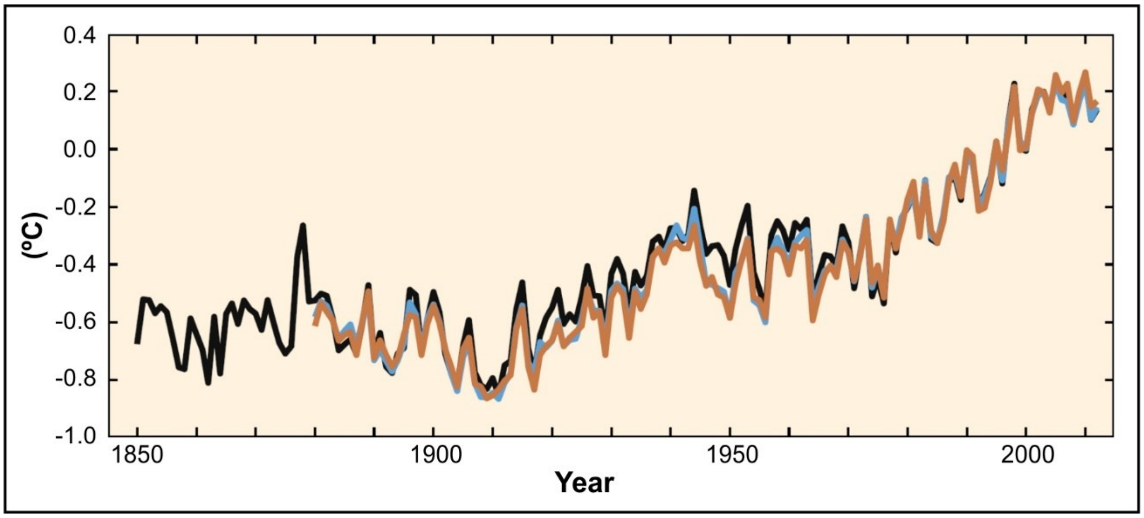

Figure 1. Abnormalities of the annual and global average of surface, terrestrial and ocean temperatures, combined with respect to the average for the period from 1986 to 2005. Source: Panel Intergubernamental del Cambio Climático (2014).

Ocean warming dominates the increase in energy stored in the climate system and represents more than 90% of the energy accumulated between 1971 and 2010 (high confidence level), only about 1% being the energy stored in the atmosphere. On a global scale, ocean warming is greater near the surface. The upper 75 m have warmed up 0.11 [0.09 to 0.13] °C per decade, during the period between 1971 and 2010.

In the period between 1992 and 2011, the ice sheets of Greenland and Antarctica have been losing mass (high level of confidence), and that loss is likely to have occurred at a faster rate between 2002 and 2011. Glaciers have continued to reduce almost everywhere (high level of confidence).

Causes of climate change

Cumulative anthropogenic emissions of Greenhouse Gases (GHG) since the pre-industrial era have experienced large increases in atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Between 1750 and 2011 the anthropogenic emissions of CO_2 to the accumulated atmosphere were of 2 040 ± 310 Gt CO_2 (Butze, 2004).

About 40% of those emissions have remained in the atmosphere (880 ± 35 Gt CO_2) and the rest were removed from the atmosphere and stored on land (in plants and soils) and in the ocean. The oceans have absorbed about 30% of the CO_2 emitted anthropogenic, causing its acidification. About half of these accumulated emissions between 1750 and 2011 have occurred in the last 40 years (high confidence level).

Total anthropogenic GHG emissions have continued to increase between 1970 and 2010 with greater absolute increases between 2000 and 2010, despite of the growing number of climate change mitigation policies. Anthropogenic GHG emissions in 2010 reached the figure of 49

± 4,5 Gt CO_2-eq/year. The emissions of CO_2 from the combustion of fossil fuels and industrial processes contributed around 78% of the total increase in GHG emissions from 1970 to 2010, with a similar percentage contribution to the increase experienced during the period from 2000 to 2010 (high confidence level). Globally, economic growth and demographic growth continued to be the most important drivers of increases in CO_2 emissions from the burning of fossil fuels.

Since the Fourth Evaluation Report (Panel Intergubernamental del Cambio Climático, 2007) the evidence of human influence on the climate system has increased. It is highly probable that more than half of the increase observed in the global average surface temperature in the period from 1951 to 2010 was caused by the combination of the increase in concentrations of greenhouse gases and other anthropogenic forcing.

According to the best estimates, the contribution of human activity to warming is similar to the warming observed during the mentioned period. It is likely that anthropogenic forcing have contributed significantly to the increase of surface temperature since the mid-twentieth century in all continental regions, except Antarctica.

It is likely that the anthropogenic influence has affected the global water cycle since 1960 and has contributed to the retreat of glaciers since the 1960s and increased melting of the Greenland ice sheet since 1993. It is very likely that the anthropogenic influence has contributed to the loss of sea ice in the Arctic since 1979 and that has contributed significantly to increases in the overall heat content in the upper ocean layer (0-700 m) as well as the elevation of the global average sea level observed since the 1970s (Panel Intergubernamental de Cambio Climático, 2014).

Temperature and glacier retreat

The glaciers go through a global thaw for over a hundred years. Michael Zemp, leader of the World Glacier Monitoring Service (WGMS), maintains that the glaciers observed today lose between half a meter and a meter of ice thickness every year, case that represents two or three times more than the average of the last century (Gubin, 2015). The snow cover in spring in the northern hemisphere continues to shrink. There is a high level of confidence that permafrost temperatures have increased in most regions since the early 1980s in response to the increase in surface temperature and the alteration of the snow cover.

In the Arctic, it is very likely that the average annual sea ice area has decreased during the period 1979-2012 in a range of 3.5% to 4.1% per decade. The extent of sea ice in the area has decreased in each season and in each successive decade since 1979, and it is in summer when the highest rate of decrease in the average ten-year extension has been recorded.

In Antarctica, it is very likely that the average annual sea ice extent has increased in a range between 1.2% and 1.8% per decade between 1979 and 2012; however, there is a high level of confidence that there are marked regional differences in this continent, with an increase in extension in some regions and a decrease in others. During the period 1901-2010, the average global sea level rose 0.19 m (de 0.17 to 0.21 m). Since the mid-nineteenth century, the pace of sea level rise has been higher than the average of the previous two millennia (Panel Intergubernamental de Cambio Climático, 2014).

The retreat of the glacier mass in the Chinese mountains, for example, are identified as very vulnerable to climate change, especially in western China. During the period 1961-2007, approximately 92% of glacier areas had a slight vulnerability, today 41.2% of such areas are at strong and very strong levels of vulnerability.

In general, the vulnerability of glaciers shows a decreasing trend between 2030 and 2050, but the glaciers in Altai, Tianshan, Kunlun, the central and western areas of the mountain Qilian, Central and eastern areas of the Himalayas, and the southeast of Tibet, they will continue to be classified at strong and very strong levels of vulnerability.

China's glaciers were relatively very vulnerable in the period 1961-2007, and it is considered that the topography and the high sensitivity of glaciers to climate change are the reasons for this situation. In addition to topographic factors, it is considered that variations in rainfall could become a crucial factor that affects the vulnerability of glaciers in the years 2030 and 2050 (Jian-Ping, Yong-Jian, Shi-Yin, & Chun-Ping, 2015).

In the morphology of high mountain ecosystems, negative impacts to tropical glaciers called glacial retreat are being recorded, and appearance of new lagoons in the concavities left by the ice mass. Changes in glacier and lagoon cover variations are evident in the 19 snow-capped mountain ranges of Peru divided into 3 sectors: North, Central and South showing a total of 2 669 glaciers with an area of 1 298.59 km^2.

The most extensive mountain ranges are: The Cordillera Blanca (Northern Andes), Vilcanota and Vilcabamba (Central Andes) with 755, 374 and 355 glaciers and surfaces of 527.62; 279.40 and 129.15 km^2 respectively. In general, the minimum altitude of the inventoried glaciers is over 4 000 m a.s.l. The snow-capped mountain ranges of Peru in the last 40 years have registered a surface loss of 42.64%, with respect to the results obtained in the inventory of the year 1970. Small glaciers are the most susceptible to surface changes; A total of 2 341 glaciers (87.38%) with surface area have been identified in the last inventory carried out ≤ 1 km^2 and 338 glaciers (12.62 %) with surface > 1 km^2. The results obtained from the inventory of lagoons of glacial origin total a total of 8 355 lagoons, which are located in the area of the 19 snowy mountain ranges of the country, and covers an area of 916.64 km^2 (Autoridad Nacional del Agua, 2014).

Between 2003 and 2011 mass balance measurements made on glaciers Yanamarey and Artesonraju in the Cordillera Blanca, in Huaraz, showed in the case of Yanamarey loss of area in the front, and at the lateral edges to the top of the glacier. Despite the slowdown in temperature rise and an increase in precipitation, the retreat of the glaciers has continued at a high rate in the last thirty years.

Precipitation and temperature can affect the accumulation process. The increase in precipitation observed during the wet seasons would lead to an increase in solid precipitation in the accumulation area and, therefore, a more positive annual mass balance in case of precipitation that falls in the form of snow (Vuille, Kaser, & Juen, 2008); for example, it was found that on interannual time scales, Precipitation variability seems to be the main driver of fluctuations in the glacier mass in the Cordillera Blanca. On the other hand, the increase in air temperatures during episodes of precipitation also leads to an increase in the snow line. However, the increase in air temperature in the last thirty years is particularly dominant in the season from June to November, relatively dry, in which rainfall is rather scarce.

Rainfall in the Cordillera Blanca has increased significantly between 1980 and 2012, which would lead to a more positive mass balance if precipitation falls in the form of snow, a condition that shows that glaciers have continued to recede since the 1980s. The decrease in glacier surface is particularly high for low altitude glaciers and isolated glaciers such as Yanamarey y Pastoruri.

There are studies that report the different retreat scenarios for small glaciers with maximum elevations below 5 400 m a.s.l. and the great glaciers with the maximum elevation above such altitude. Changes in temperature and precipitation since the 1980s probably do not fully explain the strong retreat of glaciers during the past 30 years.

Therefore it is possible that the recent retreat of glaciers can still occur in response to the sharp rise in temperature of more than 0.3 °C for the decade before 1980, especially in the 1970s.

In general, glaciers with low ice thickness on the equilibrium line and large annual ablation on the tongue of the glacier have shorter response times to climatic disturbances than large glaciers. There are measurements and estimates of ice thickness and annual ablation rates for some glaciers in the Cordillera Blanca (for example, Artesonraju) and allow to estimate a response time of the order of ten to forty years.

The strong retreat of glaciers observed during the last three decades may include a sign of the rise in temperature before the 1980s, depending on the glacier. The moderate temperature rise during the last thirty years may have induced additional forcing.

However, interpreting the responses of climate forcing glaciers is a challenge, since some climatic fluctuations occur on shorter time scales than reaction times and, consequently, the observed response of a glacier may be a reaction to a large number of overlapping causes (Schauwecker *et al*., 2014).

The glacier retreat in the Huaytapallana Mountain Range

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In the case of the Huaytapallana Mountain Range, Arroyo (2013), and Arroyo, Gurmendi and Machuca (2015) communicate "it is reported in the studies of Zubieta and Lagos (15), that there was a net loss of more than 50% compared to 1956. Negative anomalies caused by the phenomenon of the drought accelerate the decrease of glaciers and that results in the cooling of the system that causes positive anomalies and generates an increase in the temporary glacier mass"; likewise, Zubieta and Lagos (2010) mentions that "Between 1976 and 2006, the glacial surface of the Cordillera Huaytapallana was reduced from 35.6 to 14.5 km^2, this represents a loss of 59.4%, in turn the spatial dynamics of glacier retreat - occurred in the circuses of Huaytapallana - it is also subject to the morphology and direction of its glacial masses, therefore, the marked difference in the distribution of the retreat in the circus glaciers" (IGP, 2012, p. 85).

The tendency to decrease the glacier surface is also mentioned by López-Moreno *et al*. (2014) when pointing out that the glacier retreat would be 55% in the last 28 years and that its impacts could be significant with respect to water resources and ecology of the area.

The National Water Authority (Autoridad Nacional del Agua, 2014, p. 17) reports that the Cordillera Huaytapallana —whose maximum elevation is the snow of the same name—it has lost 58.4% of its glacier mass, according to the Inventory of Glaciers and Lagoons presented in the same year, at the same time, the 19 snow-capped mountain ranges of Peru identified in the mentioned report have jointly lost 42.6% of its

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glacier surface, the case of the Lasuntay lagoon would be an example of this trend in the Huaytapallana Mountain Range. In the absence of other relevant studies with annual measurements, the media have also disseminated information from the aforementioned sources, this is the case of La República (2014) that mentions data from the report of the National Water Authority of Peru.

Study approach

The study was developed based on the research question ¿How the change in environmental temperature influences as a manifestation of climate change in the glacial retreat of the Huaytapallana Mountain Range - Peru?, It has been proposed as objectives to describe the effect of the environmental temperature in the last 30 years and its relationship with the retreat of the glacial surface of the Huaytapallana.

This study is justified in response to the commitments made by the signatory countries of the Kyoto Protocol established in the Framework Convention on Climate Change and which among others raises the need to cooperate in research to reduce uncertainties related to climate change; as well as facilitating knowledge and public access to information on climate change (ONU, 1997). In this context, our country ratified the Kyoto Protocol in 2002, and duly submitted its offer

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for global mitigation through its “Expected and Determined Contribution at National Level” (iNDC, for its acronym in English) in September 2015 and participated in the efforts to reach the Paris agreement in December 2015 (Ministerio del Ambiente del Perú, 2016).

Materials and methods

Description of the area of study

The department of Junín has a population of 1 331 253 people; the province of Huancayo is the capital with a population of 499 432 people, has 28 districts, and the district of Huancayo has an estimated population of 116 930 inhabitants as of 2013 (INEI, 2015; Banco Central de Reserva del Perú, 2011). Also the surface of the province is of 3 558.1 km^2, is located at 11° south latitude and 77° west longitude, at a height of 3 194 masl (Wikipedia, 2016).

The measurements of the glacier surface were made in the Huaytapallana Mountain Range located in the province of Huancayo, between the coordinates 11° 35’-11° 58’ south latitude and 74° 48’ -

75° 17’ west longitude; this presents 105 glaciers and an area of 14.3 km^2 on the year 2011 (IGP, 2012).

Methodological aspects

The type of research is basic because it generates knowledge; quantitative approach to have hypothesized, made measurements and quantitatively analyzed the study variables (Hernández-Sampieri, Fernández-Collado, & Baptista-Lucio, 2014) The general research method was analytical-synthetic; of descriptive scope - correlational, with a non-experimental design because no variable was manipulated; and transversal for having collected data in a single moment (Hernández-Sampieri *et al*., 2014)

The minimum temperature data - as a manifestation of climate change - and glacier surface were obtained from official reports of the National Meteorology and Hydrology Service (Senamhi, 2016) and Observatory of Huancayo belonging to the Instituto Geofísico del Perú (2016). The minimum temperature data are expressed in °C and glacier surface data in km^2. The temperature data belong to the Huancayo Observatory located in Latitude 12° 02' S, Longitude 75° 19' W, Altitude 3,313 m a.s.l.; in the district of Huachac, province of

Chupaca, department of Junín, Peru. Glacier surface data were taken from the studies of the Huaytapallana Mountain Range - because it is the closest of the glaciers to the study area.

For the estimation of the missing data of the study variables in certain years, the dispersion of the data of the minimum temperature and glacier surface variables considered as dependent variables with respect to the year as an independent variable was explored; then regression models were selected based on the significance of the parameters and the coefficient of determination (R^2); The linear model was selected for the variables minimum temperature and glacier surface.

The applied mathematical model is formulated as: $Y = \beta_0 + \beta_1 X + \varepsilon$. Wherein Y is the dependent variable (glacier surface); X it is the independent variable (minimum temperature); β_0 is the intercept, β_1 is the slope of the regression, and ε It is the error or residue.

Data not available between 1986-2016 were interpolated based on linear regression models. To determine the normality of the dependent variables, the test of Shapiro-Wilk, then the relationship of independent and dependent variables was performed with Pearson's *r* test. For the validation of linear regression models, the analysis of variance and Durbin Watson test were used.

Results

Climate change is evident in the city of Huancayo based on the increase in the minimum temperature indicator for the period 1986-2016 (30 years). The annual values are the average of the minimum monthly values recorded by the GIP Huancayo Observatory; also the behavior of the glaciers of the Huaytapallana Mountain Range that in the same period has been showing a retreat of the glacier mass.

Between 1986 and 2016 there is an increase for the minimum and average annual temperatures in the study area; this increase is higher for the minimum temperature, showing values between 3.435 to 5.227 °C; a value of 4.757 is estimated to 2016 °C (Figure 2); also the surface of the glacier mass shows in this same period a tendency of retreat, estimated to 2016 at 11.86 km^2 of extension (Figure 2).

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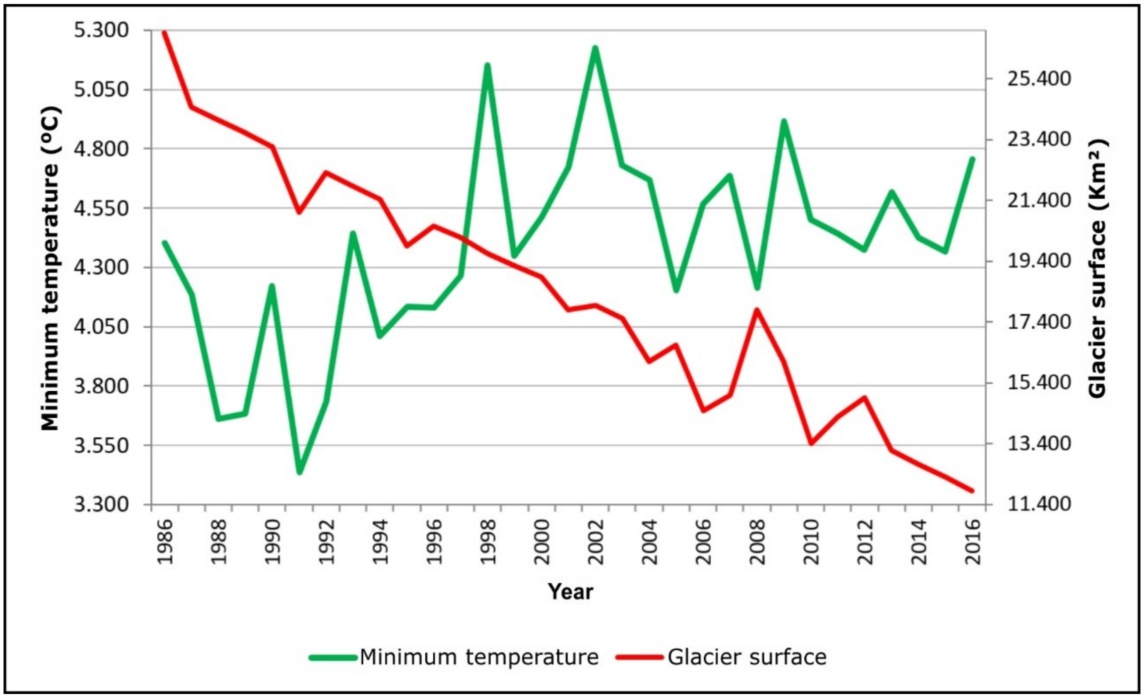

Figure 2. Data observed and estimates of minimum temperature and glacier surface of the Cordillera de Huaytapallana 1986 to 2016, Huancayo, Peru. Senamhi and IGP data Source: Self elaboration.

For the verification of statistical hypotheses, the following were raised:

H_0: There is no relationship between temperature and glacier surface as dimensions of climate change in Huancayo to 2016 (H_0: $\rho = 0$).

H_1: There is a significant relationship between temperature and glacier surface as dimensions of climate change in Huancayo to 2016 (H_1: $\rho \neq 0$).

Table 1 shows the results of the application of the Shapiro-Wilk statistical test to the glacier surface variable; whose significance indicates that the samples have a normal distribution (0.641 is greater than α =0.05).

Table 1. Glacier Surface Normality Test.

	Shapiro-Wilk		
	Statistical	**gl**	**Sig.**
Glacier surface	0.974	31	0.641

Source: Self elaboration.

In Figure 3, it is observed that the sample of scores is normally distributed, since the points of the normal Q-Q diagram fit the diagonal line.

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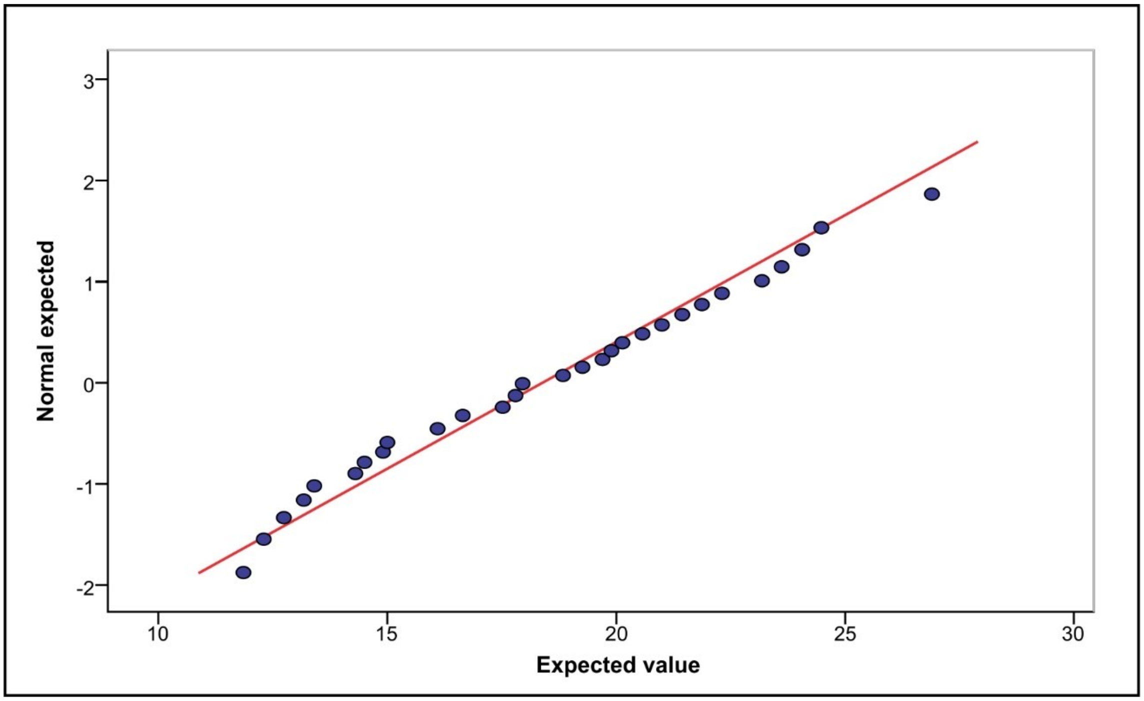

Figure 3. Normal Q-Q chart of glacier surface. Source: Self elaboration.

Table 2 and Figure 4 show that the correlation between the minimum temperature and glacier surface is negative and moderate (-0.493**) highly significant (0.002 is less than 0.05).

Table 2. Temperature correlation and glacier surface.

		Glacier surface
Minimum temperature	Pearson correlation	-0.493**
	Sig. (unilateral)	0.002

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	N	31

** The correlation is significant at the 0.01 level (unilateral)

Source: self Made

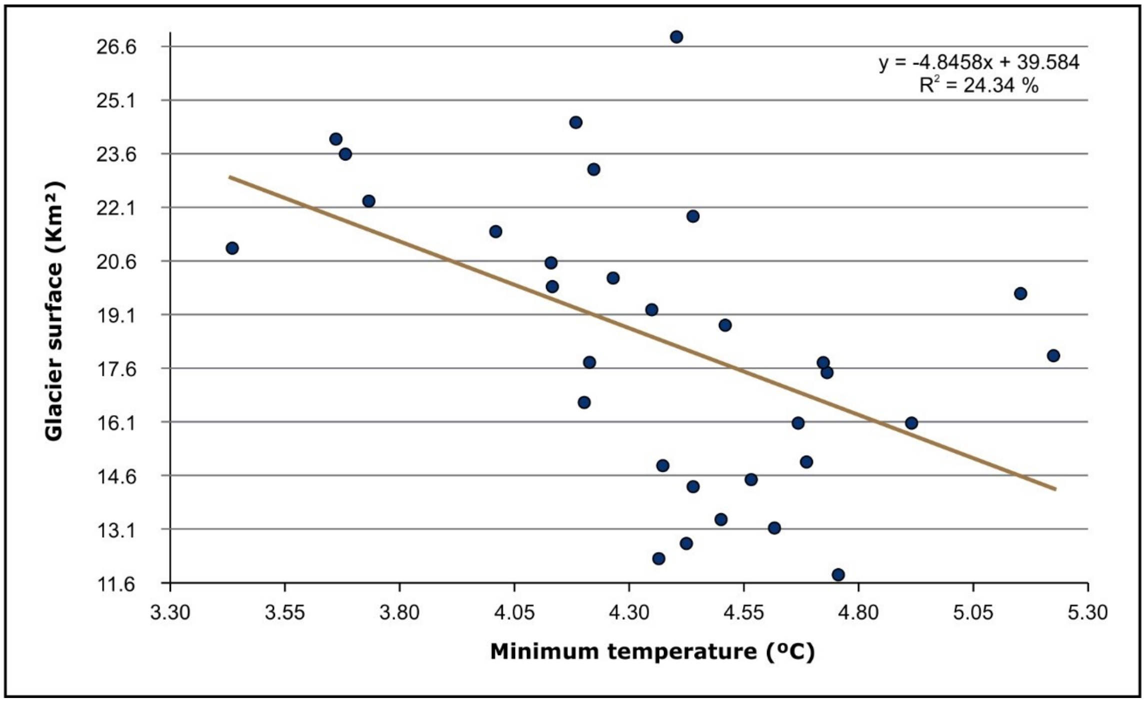

Figure 4. Minimum temperature and glacier surface ratio. Source: Self Elaboration.

Table 3 shows the summary of the simple linear regression model applied, where the variable included (minimum temperature) in the analysis explains 24.3% of the variance of the dependent variable (glacier surface) (R^2 = 24.3 %). The typical error of the residues is 3.546, the Durbin Watson statistic (0.473) indicates that there is a positive self-correlation between the residues.

Table 3. Simple linear regression model between minimum temperature and glacier surface.

Model	R	R square	Standard error of the estimate	Durbin-Watson
1	0.493[a]	24.3 %	3.54854	0.473
Predictors: (Constant), minimum temperature. Dependent variable: Glacier surface.				

Source: Self elaboration

Table 4 shows the result of the analysis of variance of the simple regression applied with the F level test. (α =0.05); where the significance of the F statistic (0.005) indicates that there is a highly significant linear relationship between the variables.

Table 4. Analysis of variance for simple linear regression between minimum temperature and glacier surface.

Model		Sum of squares	Gl	Quadratic mean	F	Sig.
1	Regression	117.464	1	117.464	9.328	0.005[b]
	Residue	365.171	29	12.592		
	Total	482.635	30			

[a] = Dependent Variable: glaciar Surface.
[b] = Predictors: (Constant), minimum temperature.

Source: Self elaboration

Table 5 shows the coefficients of the adjusted simple linear regression model, described as: Glacier Surface (Y) = 39.587 – 4.846 * temperature.

Table 5. Coefficients and statistical significance of the glacier surface variable.

		Non-standardized coefficients		**Standardized Coefficients**		
Model		**B**	**Standard error**	**Beta**	**t**	**Sig.**
1	(Constant)	39.587	6.977		5.674	0.000
	Temperature	-4.846	1.587	-0.493	-3.054	0.002
[a] = Dependent Variable: Glacier surface.						

Source: Self elaboration.

The estimated coefficients of the model (b_0 = 39.587 and b_1 = -4.846) they are highly significant (Sig < 0.01), which states that it is statistically valid. The coefficient 39,587 means that, if the temperature rises by 1 °C, the glacier surface decreases by 4.846 km^2.

In conclusion, at 99% statistical confidence, it is concluded that there is a highly significant linear relationship between temperature and glacier surface at 2016; also the coefficient of determination (R^2) is low (0.2 a 0.4).

Discussion

The temperature in Huancayo in recent years shows an increasing trend (Baltazar-Castañeda, 2014). The estimated minimum temperature in Huancayo in 2016 (4.757 °C) better evidence of climate change; factor that contributes to the retreat of the glacier mass of the Cordillera Huaytapallana and, according to the measurements made between 1986-2016 and estimates based on linear regression models, the glacier surface is estimated at 11.860 km^2 on 2016; the relationship between these variables is linear, inverse and moderate; it is evident that the increase in temperature affects the retreat of the glaciers of the Cordillera Huaytapallana, coinciding with this phenomenon with the case of the Cordillera Blanca in Ancash reported by the Autoridad Nacional del Agua (2014).

In this regard Gonzales (2013) states that the high concentrations of CO_2 and other GHGs in the atmosphere generate the increase in the average surface temperature on the planet. This would also be one of the main factors of the glacial retreat.

The Intergovernmental Panel on Climate Change (2014) regarding glaciers at the Earth's poles, The Arctic case reports that it is very likely that the average annual sea ice area has decreased during the period 1979-2012 in a range of 3.5% to 4.1% per decade. The extent of sea ice in the area has decreased in each season and in each successive decade since 1979, and it is in summer when the highest rate of decline in the average ten-year extension has been recorded.

The results are also consistent with those reported by Schauwecker *et al*. (2014) that a strong glacial retreat observed during the last three decades may include a sign of the temperature rise before the 1980s, depending on the glacier. The moderate temperature rise during the last thirty years may have induced additional forcing.

In the future —in terms of sustainability of natural resources—, water resources will be insufficient due to the demand for human consumption and various socio-economic activities of the city of Huancayo.

Conclusions

The minimum estimated temperature for 2016 at 4.757 °C it is affecting the reduction of the glacier surface of the Huaytapallana Mountain Range, estimated at 11.86 km² for the same year. There is an inverse, moderate and significant relationship between the increase in temperature and the retreat of the glacier mass of the Huaytapallana Mountain Range.

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