# Climate Change Analysis

for

Resilient Puna

**Ecosystem based**

**Adaptation for sustainable high**

**Andean communities and**

**ecosystems in Peru**

*Updated November 2023, v.02*

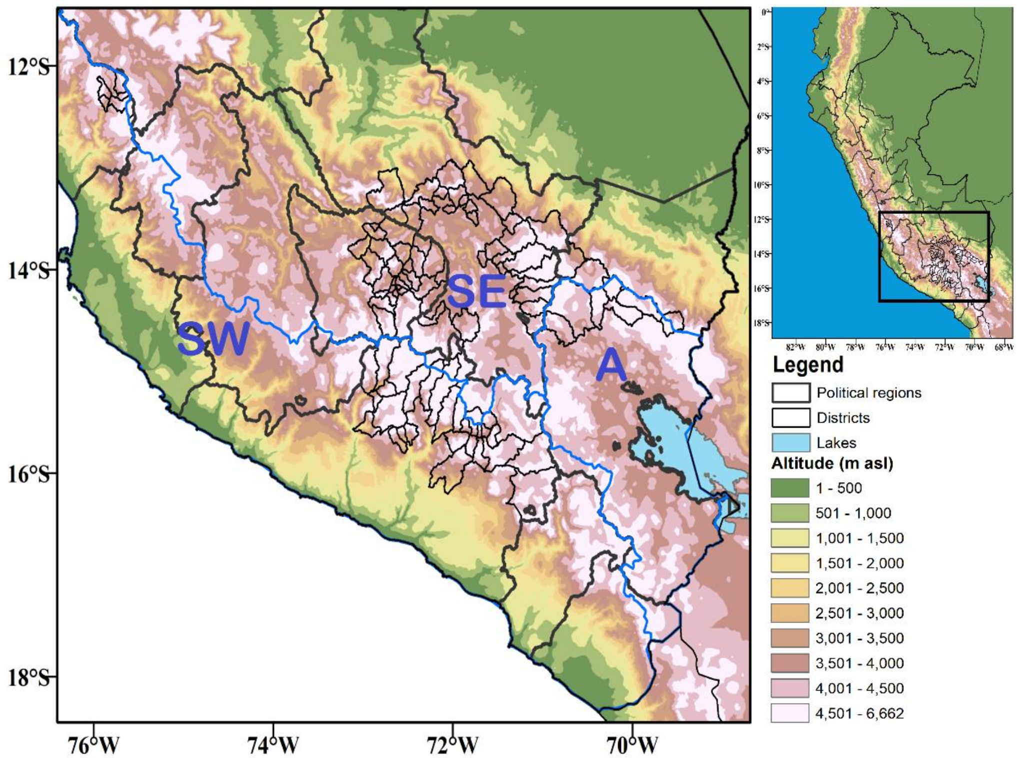
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

# Climate Profile – South High Andes of Peru

**SUMMARY**

## Introduction

This summary provides an overview of trends and projected climate parameters and related impacts in the Southern High Andes of Peru, (SHAP Region) completed in the full document.




*Topographical map of the SHAP region with the districts where the project is placed. Subregions are also shown and divided by blue lines: SW (southern west), SE (southern east) and A (Altiplano).*

In the project geographical location, the current climate trends are a result of the calculation of linear trends of observed meteorological variables in recent decades based on a 35-year analysis and covering the 1981-2016 period.

The future climate change Climate projections to 2050 (2036-2065) are obtained from the nationally validated regional model HadGEM2-ES-RCA4, adapted to Peru, under different climate change scenarios (called Representative Concentration Pathways, RCPs). RCP 4.5 represents an emissions scenario in line with the Paris Agreement; RCP8.5 represents a high emissions scenario. The Model projections do not account for effects of future socioeconomic impacts. Project changes are comparing to the 1981-2005 mean base period.

The meteorological variables analyzed are precipitation (Pr), maximum temperature (Tx) and minimum temperature (Tn). Analysis are made in annual averages and seasonal averages.

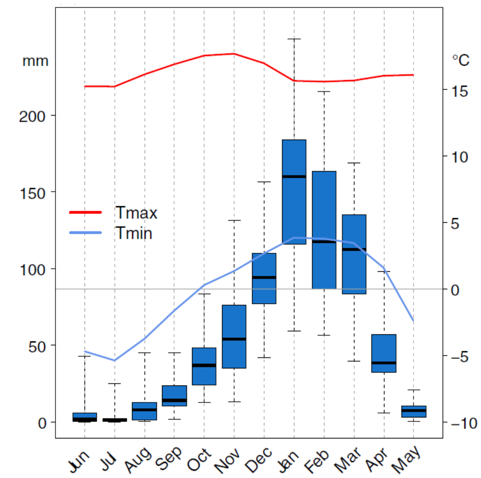
Seasons are referred to astronomical seasons for the southern hemisphere, in other words, austral seasons, which are summer (DJF), autumn (MAM), winter (JJA) and spring (SON).

Finally, as a result of a scientific bibliographic analysis the main impacts of climate change in the project area are summarized.

# Historical Climate Trends

## Climate Annual Profile

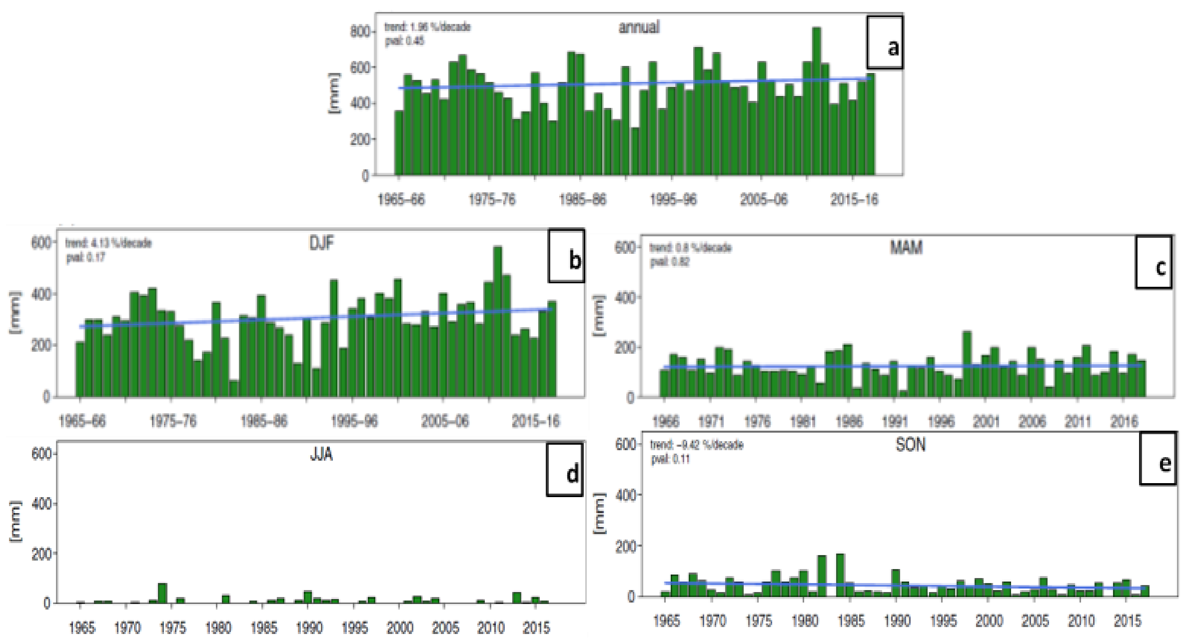
The mean annual cycle in the SHAP is characterized by a wet summer, a dry winter and two transitions seasons, which are spring and autumn. The maximum peak of Tx occurs in spring; the minimum, in winter. The maximum values of Tn happen in summer and the minimum, in winter. Precipitation exhibits a monomodal distribution during the year, with maximum values in summer and minimum values in winter.




*Mean annual cycle of precipitation and temperatures in the SHAP from 1981 to 2016. Source: Imfeld, et al. (2020).*

## Precipitation

Annual trends of precipitation are positive in the SHAP. However, **in spring, trends are mostly negative with the lowest values in the year**. In contrast, in summer, trends are mostly positive. In autumn, trends are slightly positive. In winter, precipitation values are pretty small, so, trends calculation can lead to misleading values.

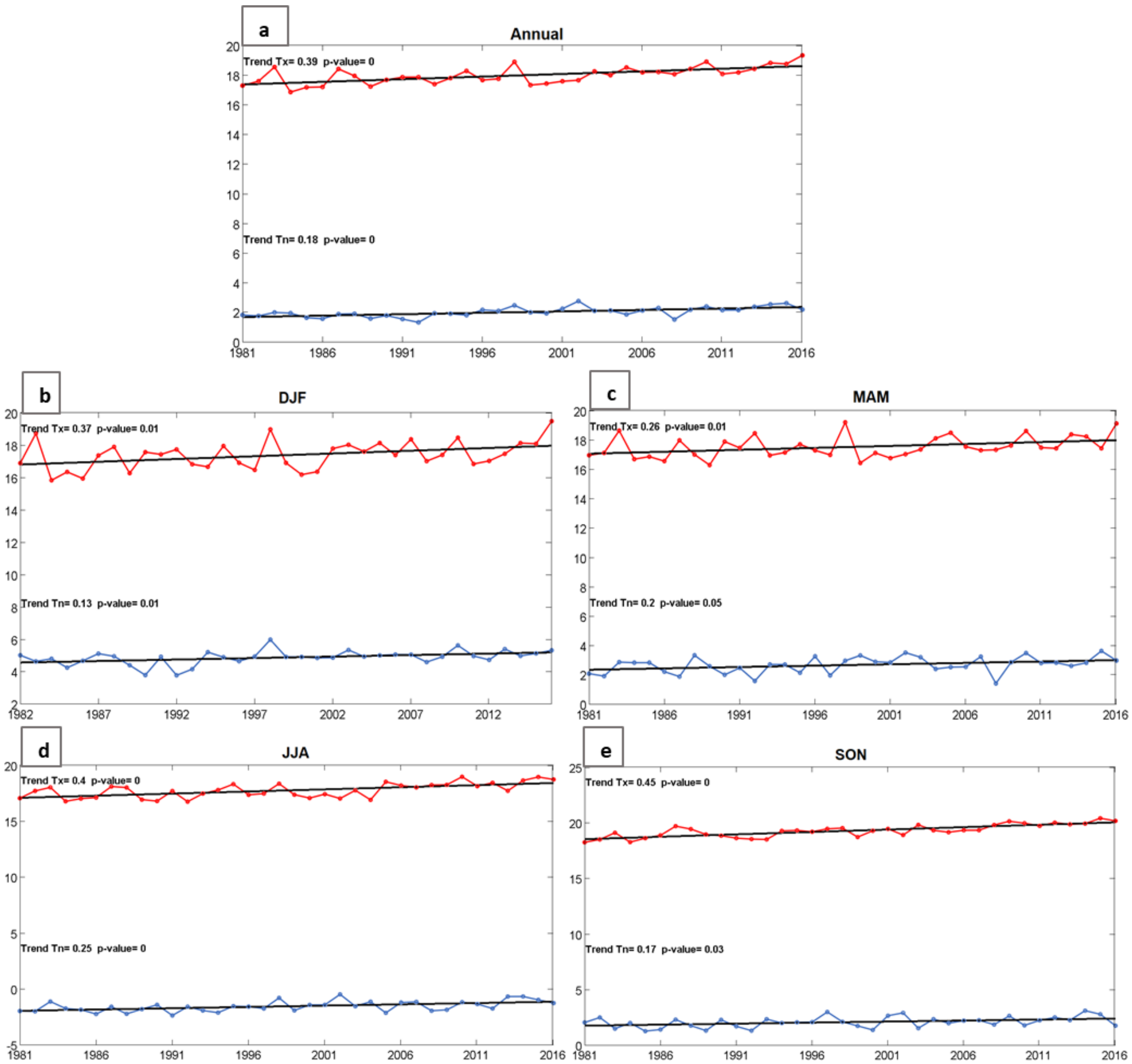



*Precipitation trends for the period 1965-2016. Annual trends (a) show a slightly increse of with no statistical significance. In austral summer (DJF), the trend increases more than the annual. In spring (SON) the trend is negative, showing a clearer decresing signal. For winter (JJA), no precipitation trends are shown. Source: Imfeld, et al. (2020)* [1]

[1] Imfeld, N, Sedlmeier, K, Gubler, S, et al. A combined view on precipitation and temperature climatology and trends in the southern Andes of Peru. *Int J Climatol*. 2021; 41: 679– 698. https://doi.org/10.1002/joc.6645

## Temperature

Temperature trends in the last three decades are certainly positive annually and in all the seasons. Larger trends are found at higher altitudes. Maximum temperature trends are larger than minimum temperature trends. The season when maximum temperature trends are larger, is spring (SON). However, maximum values of minimum temperature trends, happen in winter.




*Temperature trends for the period 1981-2016 for the annual mean (a), summer (b), autumn (c), winter (d) and spring (e). Red series represent Tx and blue series, Tn. Trends numeric values are also written along with the p-value, which shows statistical confidence.Tx trends are larger than Tn trends and larger trends occur in SON for Tx, and in JJA for Tn .*

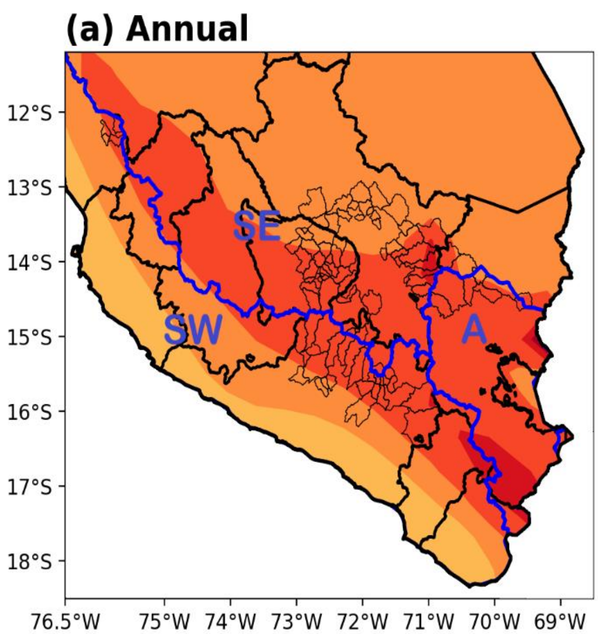
# Climate Change Projections to 2050

## Temperature

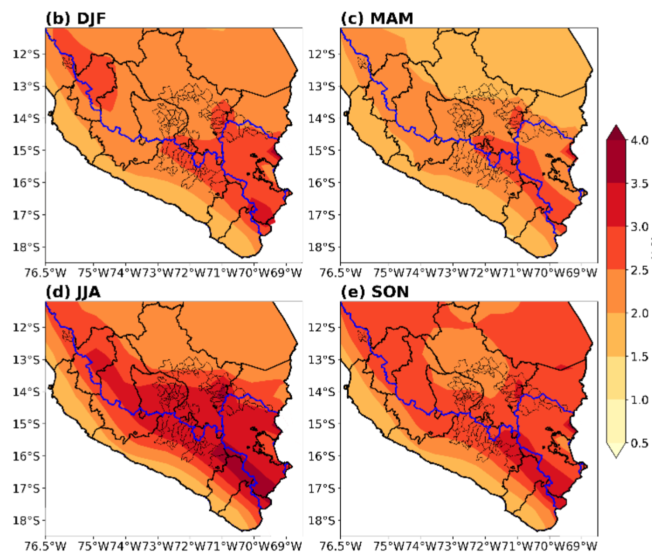
A robust trend towards increasing temperatures by 2050 is given for both scenarios and for the overall SHAP. Under the RCP4.5 emission scenario, changes in temperature are projected to rise by 2.1 to 3.8°C. Under the high emission scenario RCP 8.5, the mean climate model temperature exhibit increases by 1.3 to 4°C in reference to the 1981-2005 mean base period.

Spatially, the highest changes are projected in the high altitudes. which are mainly the northwest of the SW region and between the SE and A region.

Seasonally, increases of temperatures, compared with the base period (1981-2005), are expected. The major increase occurs during austral winter (JJA), when precipitations were also projected to decrease.




*Projected changes in maximum annual mean temperature towards 2050 under the RCP4.5 scenario for the annual mean. Subregions are also shown and divided by blue lines: SW (southern west), SE (southern east) and A (Altiplano). Areas that show higher increases in all season are the border of SE and A and the border of SW and SE in autumn (higher altitudes).*




*Projected changes in maximum temperature towards 2050 under the RCP4.5 scenario for summer (b), autumn (c), winter (d) and spring (e). Higher increases take place in winter.*

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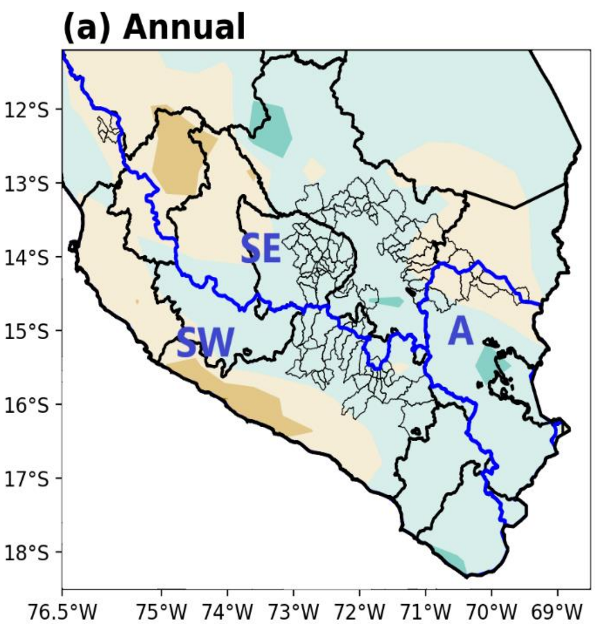
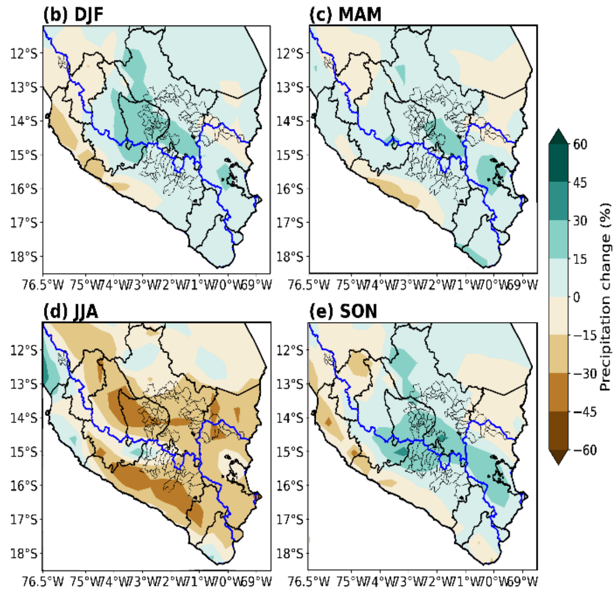
## Precipitation

With a significant variability, the general trend for the two-emission scenario RCP 4.5 and RCP 8.5 is an annual increase of precipitation simply explained by the increase of precipitations during the rainy season, especially in summer.

However, both scenarios present a clear trend of a **very negative impact during the dry season** – austral winter (JJA)- with losses between -60 and 0% in reference to the 1981-2005 mean base period.




*Total annual projected changes in precipitation towards 2050 under the RCP4.5 scenario for the total annual. Subregions are also shown and divided by blue lines: SW (southern west), SE (southern east) and A (Altiplano*




*Projected changes in precipitation towards 2050 under the RCP4.5 scenario for the total annual (a), summer (b), autumn (c), winter (d) and spring (e).). Higher decreases take place in winter. In general, areas that show higher increases in all season are located at the west of SE.*

## SUMMARY of TRENDS- Past and Future

| Climate variable | | Past trends | Future trends |
|---|---|---|---|
| | **Temperature** | Warming | Increased Warming |
| | **Dry days & length of consecutive dry days** | Increasing in spring, but decreasing in summer | Increased past tendency More droughts |
| | **Heavy precipitation intensity & frequency** | Increasing in summer | RCP4.5 and RCP8.5: Increasing summer total precipitation |
| | **Total precipitation** | Increasing in summer, but decreasing in spring | RCP4.5 and RCP8.5: Increasing in summer and spring, but decreasing in winter |

# Climate Change Impacts

| | |
|---|---|
| Increase Droughts<br> | The largest number of dry events in Peru take place in the SHAP.<br>Towards 2050, increase evapotranspiration rates and temperatures will result in more frequent meteorological droughts lasting between 1 to 2 months. during the dry season and rainy season onset[2], when water and pasture are already scarce. |
| Accelerated Glacier melting<br> | Tropical Andean glaciers are retreating at an alarming increasing rate since the late 1970s. The magnitude of glacier loss is directly related to glaciers size and elevation. So, glaciers that are above 5400 m asl lost glacier mass at a rate of -0.6 mw.e.(meter water equivalent) per year in recent decades; while those with lower altitudes contracted at a rate of -1.2 mw.e. by year[3]. So, this has an important effect on glaciers located in the SW subregion, which are the lowest glaciers in the SHAP[4].<br>During the period 2000-2013, the retreat rate in the southern SE subregion was $-1.3\ \%\ a^{-1}$, and in the SW subregion, it was $-2.3\ \%\ a^{-1}$, approximately[5]. |
| Reduced water availability<br> | Reductions in water availability are large in the SHAP, since evaporation and temperature have been decreasing. Projections of water availability towards the year 2050 indicate a reduction between 48% and 42% in the SW subregion, a decrease of 10% in the SE and a decrease in water availability of up to 28% in the A subregion[5]. |
| Decreased crop yield<br> | Climate change projections towards 2050 indicate a general decrease in crop yields in the SHAP. The onion yield in the SW may have physiological imbalances and phytosanitary problems. There are significant projections of a decrease in the wheat crop yield in Arequipa (SW subregion) [6]. A lower yield of the potato crop in the SE subregion is also expected. For tubers to keep their nutritional properties, they require cold temperatures. Many farmers of potato and oca in the high Andes are pushed upward. Reduced frost in the high Altiplano also threatens the production of Chuño (freeze-dried potatoes), a source of food security for centuries[7].<br>According to SENAMHI (2015), crop yields in the SE, SW and A subregions decrease in different magnitudes depending on the model and scenario. For potato, in the SE subregion for CanESM2 in the RCP4.5 scenario, the changes in yield crop is between -436.4 and -1750.3 kg/ha with statistical significance toward 2050. Similarly, for CNRM-CM5 in the RCP8.5 scenario, the yield crop is between |

[2] Zubieta, R., Molina-Carpio, J., Laqui, W., Sulca, J. & Ilbay, M. (2021). Comparative analysis of climate change impacts on meteorological, hydrological, and agricultural droughts in the lake Titicaca basin. *Water, 13* (2), 175. https://doi.org/10.3390/w13020175.

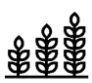
[3] Rabatel, A., Francou, B., Soruco, A., Gomez, J., Cáceres, B., Ceballos, J. L., Basantes, R., Vuille, M., Sicart, J.-E., Huggel, C., Scheel, M., Lejeune, Y., Arnaud, Y., Collet, M., Condom, T., Consoli, G., Favier, V., Jomelli, V., Galarraga, R., Ginot, P., Maisincho, L., Mendoza, J., Ménégoz, M., Ramirez, E., Ribstein, P., Suarez, W., Villacis, M., and Wagnon, P.: Current state of glaciers in the tropical Andes: a multi-century perspective on glacier evolution and climate change, The Cryosphere, 7, 81–102, https://doi.org/10.5194/tc-7-81-2013, 2013.

[4] Seehaus, T., Malz, P., Sommer, C., Lippl, S., Cochachin, A., Braun, M. (2019) Changes of the tropical glaciers throughout Peru between 2000 and 2016 – mass balance and area fluctuations. The Cryosphere, 13, 2537–2556. doi: https://doi.org/10.5194/tc-13-2537-2019.

[5] SENAMHI, 2015. Actualización de los escenarios de disponibilidad hídrica en el Perú en contexto de cambio climático". Lima. Abril 2015.

[6] SENAMHI, 2015. Evaluación de los impactos del cambio climático sobre el rendimiento de los cultivos en el Perú.

[7] Schoolmeester, T.; Saravia, M.; Andresen, M.; Postigo, J.; Valverde, A.; Jurek, M.; Alfthan, B. and Giada, S. 2016. Outlook on Climate Change Adaptation in the Tropical Andes mountains. Mountain Adaptation Outlook Series. United Nations Environment Programme, GRIDArendal and CONDESAN. Nairobi, Arendal, Vienna and Lima. www.unep.org, www.grida.no, www.condesan.org

| | |
|---|---|
| | -762.4 and -21.7 kg/ha with statistical significance toward 2050. Results obtained from MPI-ESM-MR for both scenarios, for CanESM2 for the RCP8.5 and CNRM-CM5 for the RCP4.5 are mostly negative but with no statistical significance. For wheat, in the SW and A subregions, the crop yield goes from -125.5 to 39.5 kg/ha with statistical confidence in the RCP4.5 scenario using the CanESM2 model. Likewise, the crop yield for the RCP8.5 scenario using the CNRM-CM5 model, goes from -56.6 to 18.2 kg/ha with statistical confidence. Other models and scenarios show a negative wheat yield in the SW subregion without statistical significance. Nevertheless, wheat yield for the A subregion are positive but without statistical significance.<br>In SENAMHI (2015), they also quantified the σ parameter, which is the proportion between the change in yield (Δyield = yield (2036-2065) – yield (1971-2010)) and the standard deviation (σ = Δyield (kg/ha)/standard deviation(kg/ha)) considering the average of 2036-2065 years as the future climate and the 1971-2010 average as the present climate. Results for potato crops showed that averaging all three models, σ goes from -0.17 to -0.82 for the RCP4.5 and from -0.28 to -0.69 for the RCP8.5. All models in both scenarios show a consistent decrease in potato yields. For wheat yield, the σ parameter goes from -0.84 to 0.56 in the RCP4.5 and from -0.71 to 0.35 in the RCP8.5. Positive σ is shown in the A region, while negative σ, in the SW region. |
| Shifting ecosystems – affecting grasslands<br> | Towards 2100, significant changes would be observed in several biomes[8]. If no action is taken, the area that nowadays is covered by grasslands, wetlands and shrub-lands, would reduce its area coverage from 77.6% to approximately 50%. Grasslands would reduce their extension from 15.4 to 4.6 million ha, while wetlands would go from 0.5 to 0.2 million ha. In turn, shrubs would substantially increase their extension over time, increasing from 2.8 to 7.1 million ha.<br>Water stress conditions might lead to the expansion of dry biomes (dry puna, seasonally dry forests and shrub-land)[9]. |
| Carrying capacity for Cattle and camelids disminished<br> | Most cattle, sheep, and camelids in Peru are located between 2 200 and 4 500 m asl, and they are fed by grasslands in the Puna ecoregion. However, since this ecoregion has a tendency to decrease (see previous point), the carrying capacity would reduce from 45 to 20 million of sheep units[10]. |
| Livelihoods impacted<br> | Peasants that live in the SHAP face and will face important impacts on their livelihoods. The chosen districts in the SHAP cover mostly rural areas, where the system of small agricultural producers dominate. This pattern of influence is articulated in an environment of high vulnerability.<br>Some highland communities use migration to anticipate or react to hazards. Sperling et al. (2008) in Bergmann, et al. (2021) [11]. noted the occurrence of outmigration due to drought, especially of young people, from the studied highland communities in Puno (Altiplano) study sites. Particularly for very high mountain communities (above 3 900 masl), migration is the second most important coping strategy when confronted with food scarcity. |

[8] BID y CEPAL. 2014. La economía del cambio climático en el Perú. C.E. Ludeña, L. Sánchez-Aragón, C. de Miguel, K. Martínez y M. Pereira, editores. Monografía BID No. 222 y CEPAL LC/W.640.

[9] Tovar C, Arnillas CA, Cuesta F, Buytaert W (2013) Diverging Responses of Tropical Andean Biomes under Future Climate Conditions. *PLOS ONE 8*(5): e63634. https://doi.org/10.1371/journal.pone.0063634

[10] Flores, E. (2016) Cambio climático: pastizales altoandinos y seguridad alimentaria. INAIGEM. https://doi.org/10.36580/rgem.i1.73-80

[11] Bergmann, J., K. Vinke, C.A. Fernández Palomino, C. Gornott, S. Gleixner, R. Laudien, A. Lobanova, J. Ludescher and H.J. Schellnhuber (2021). Assessing the Evidence: Climate Change and Migration in Peru. Potsdam Institute for Climate Impact Research (PIK), Potsdam, and International Organization for Migration (IOM), Geneva.

## Contents

## Introduction

This profile provides an overview of trends and projected climate parameters and related impacts in the Southern High Andes of Peru, (SHAP Region). Figure 01 shows the geographical location of the project. The project area is focused on 91 districts.

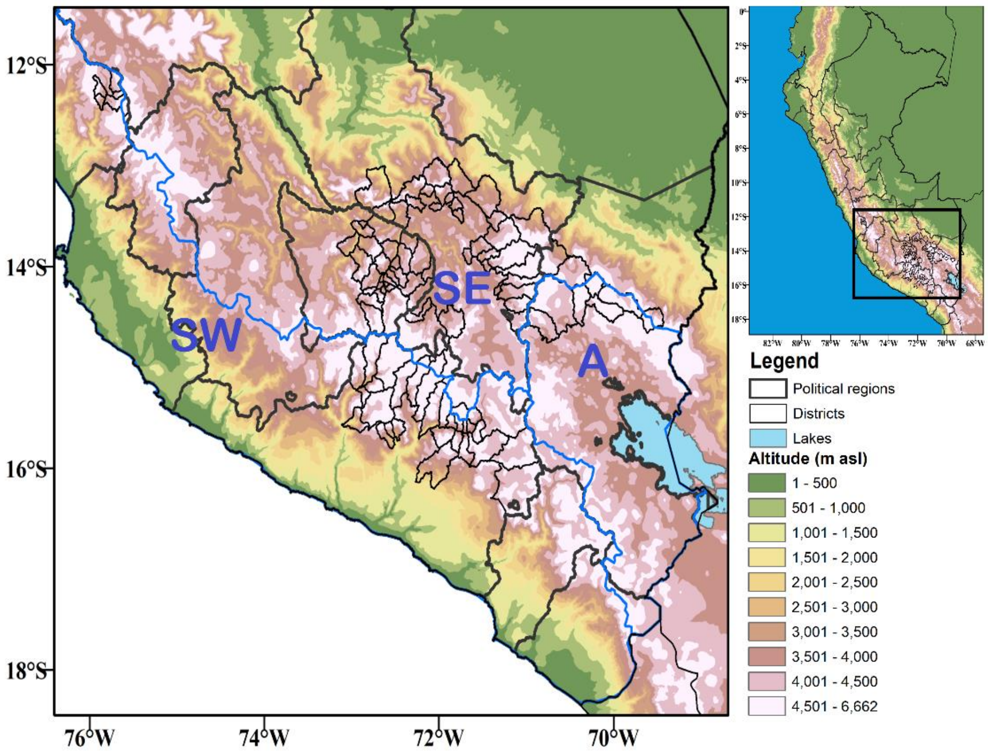



*Figure 1. Topographical map of the SHAP region with the districts where the project is placed. Subregions are also shown and divided by blue lines: SW (southern west), SE (southern east) and A (Altiplano).*

The current climate trends are a result of the calculation of linear trends of observed meteorological variables in recent decades based on a 35-year analysis and covering the 1981-2016 period.

The future climate change Climate projections to 2050 (2036-2065) are obtained from the nationally validated regional model HadGEM2-ES-RCA4, adapted to Peru, under different climate change scenarios (called Representative Concentration Pathways, RCPs). RCP 4.5 represents an emissions scenario in line with the Paris Agreement; RCP8.5 represents a high emissions scenario. The Model projections do not account for effects of future socioeconomic impacts. Project changes are comparing to the 1981-2005 mean base period.

On the present analysis, RCP4.5 climate projections results come from the validated regional model HadGEM2-ES-RCA4. However, RCP8.5 climate projections results come from the official scenarios in Peru, which is a multi-model regional ensemble made by SENAMHI. Nonetheless, the analysis regarding HadGEM2-ES-RCA4 RCP8.5 emission scenario, can be found on the Annexes.

The meteorological variables analyzed are precipitation (Pr), maximum temperature (Tx) and minimum temperature (Tn). Analysis are made in annual averages and seasonal averages.

Seasons are referred to astronomical seasons for the southern hemisphere, in other words, austral seasons, which are summer (DJF), autumn (MAM), winter (JJA) and spring (SON).

Finally, as a result of a scientific bibliographic[12] analysis the main impacts of climate change in the project area are summarized.

## 1. State of the climate in recent decades

### 1.1 Recent climate

The project area, which consists of 91 districts, covers 22 different climates according to the Thornthwaite classification (SENAMHI, 2020) [13]. Likewise, they are located in 14 different life zones (biomes). Most of this territory corresponds to headwaters of different basins and, therefore, have altitudes greater than 2000 m asl. These districts, which encompass four different political regions, will be classified into three subregions for a better climate analysis, which are: Southern west (SW), southern east (SE) and Altiplano (A) (Figure 02).

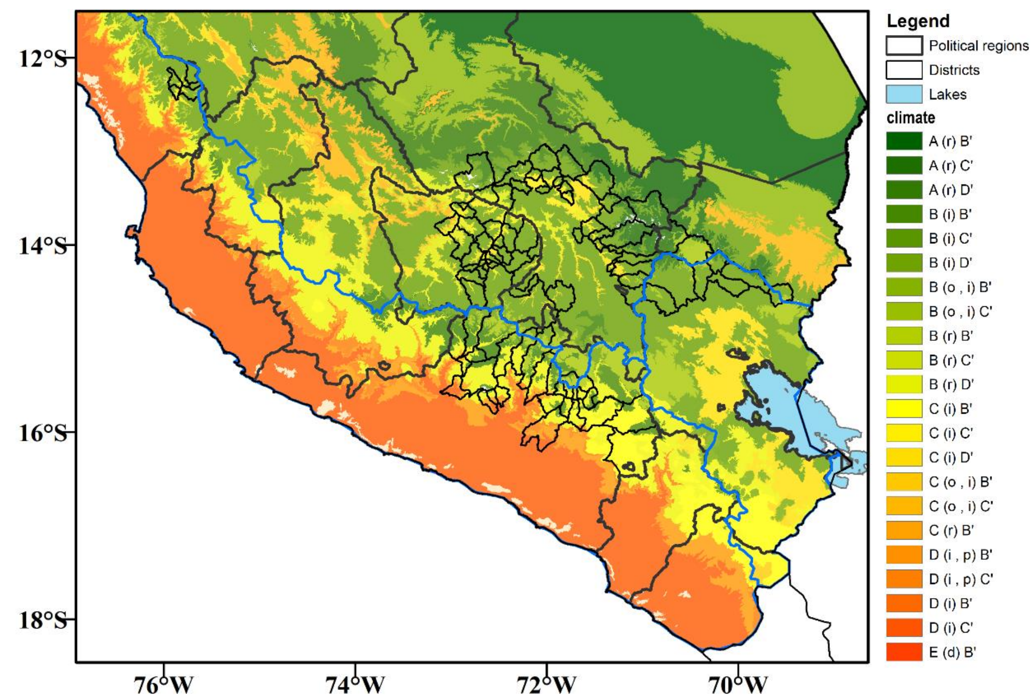



*Figure 2. Climate classification in the SHAP. Chosen districts where the project is placed are delimited in black. Subregions are also shown and divided by blue lines: SW (southern west), SE (southern east) and A (Altiplano). Source: SENAMHI 2020.*

[12] Note that for this study the most updated list of scientific literature was used due to the gap of recent information in Peru. The most relevant for are the Llosa (2009) article which collects and assembles information about the impacts of climate change. It is not a scientific article, however, it contains valuable information from previous studies and interviews to experts from different areas impacted by climate change, such as agriculture, economy and society. The affirmation quoted from this article refers to the impact of a specific drought event that occurred in 2009. This information is useful, as it tells how large the impacts of extreme events are, such as droughts, on yields. Yet, no future scenario was used in this affirmation and in this article overall. In addition, the quoted (Aragón, Oteiza, & Rud, 2018) study also refers to the present situation and not to any future scenario. Also, this study used the SENAMHI (2015) article where the RCP4.5 and RCP8.5 scenarios were considered. The climate data included temperature and precipitation from two scenarios and three models independently: CanESM2, CNRM-CM5 y MPI-ESM-MR. The RCP4.5 and RCP8.5 scenarios are considered the most likely scenarios used for the present project, as well. It is important to emphasize that the projections used in SENAMHI (2015) are towards 2050, and not towards 2100.

[13] SENAMHI, 2020. CLIMAS DEL PERÚ. Mapa de clasificación climática.

Throughout the SHAP, there is a marked difference between the summer (DJF) and winter (JJA), both in precipitation and temperature, with summer typically being rainy (wet period) and winter, very dry (dry period). In the austral summer, 57% of the annual precipitation occurs; while, in the winter, only 3% is produced (Lavado-Casimiro et al., 2012) [14].

Annual precipitation ranges from 47.1 to 1128 mm. The districts where Pr values are less than 100 mm are those in the SW and are closer to the southern coast of Peru. On the other hand, the districts with the highest rainfall (over 900 mm per year) are those of SE and A that are closer to the transition zone to the Amazon. The annual Tx mean ranges from 13 to 24.9 ° C. The districts that show lower values of this variable are at a higher altitude. The Tn shows a range that goes from -3.1 to 12 ° C and, similarly to Tx, at higher altitude, lower Tn.

The wettest season of the year is spring in the SE and A districts; however, for the SW districts, the wettest season is autumn (MAM). In contrast, the driest season is winter (SENAMHI, 2015). Seasons when the highest values of Tx occur are spring (SON) in A and SE; however, in SE, it is summer. On the other hand, the coldest season is in winter in most of the districts of the intervention zone, except in several districts located in SW, where the season with the lowest Tx is autumn. The Tn shows higher values in summer in most districts, except in some SW districts, where the highest values are in MAM. The lowest Tn in all districts occur in winter. The annual cycle of precipitation and temperatures averaged per month throughout the SHAP, is shown in Figure 03.

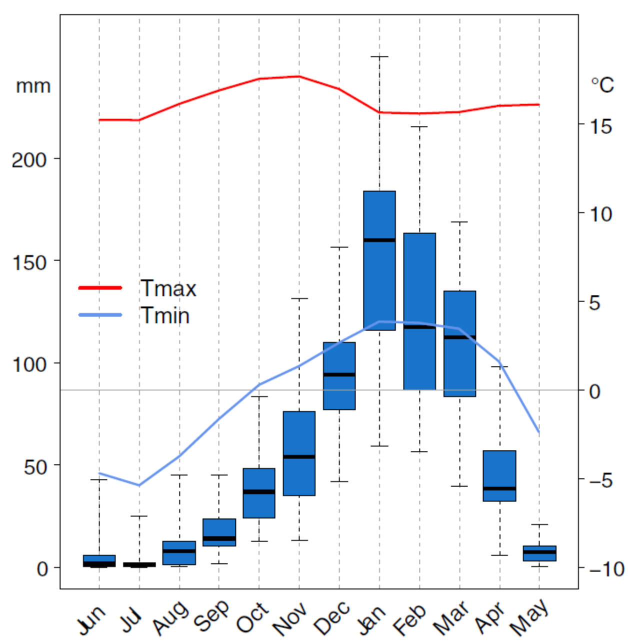



*Figure 3. Mean annual cycle of precipitation and temperatures in the SHAP from 1981 to 2016. The maximum peak of Tx occurs in spring; the minimum, in winter. The maximum values of Tn happen in summer and the minimum, in winter.*

[14] Lavado, C.W.S., J. Ronchail, D. Labat, J.C. Espinoza, and J.L. Guyot, 2012: Basin-scale analysis of rainfall and runoff in Peru (1969-2004): Pacific, Titicaca and Amazonas drainages. Hydrological Sciences Journal-Journal Des Sciences Hydrologiques, 57(4), 625-642.

*Precipitation exhibits a monomodal distribution during the year, with maximum values in summer and minimum values in winter. Source: Imfeld, et al. (2020)* [15]

### 1.2 Historical climate trends

Due to high seasonal and interannual variability in the Andes, precipitation trends are small and usually do not show statistical significance. In general, the SHAP regions show increases of Pr on the total annual, in DJF and MAM; however, in SON, trends are negative (Figure 04).

Annual Pr trends range from -14.1 to 55.4%. The annual trend of this variable is positive throughout SHAP, except in ten districts located in SE and A, where the trends are slightly negative (Figure 05). In the DJF season, a clear pattern of increase is shown, because all the districts present positive trends ranging from 3.7 to 50.9% and a greater number of districts show statistical significance. In MAM, the trends range from -28.6 to 65.4%, eastern SE and A show mostly negative trends; in contrast, the west of SE and SW have positive trends. In JJA, the trends are not significant, but the difference in trends again between the east of SE and A (showing decreases) and the west of SE and SW (showing increases), is noticeable. In SON, there is a clear trend of decreasing rainfall, ranging from -45.7 to 45.7%. All districts show decreases, except for a few located northwest of the SE. These decreases in SON are related to the tendency to delay the onset of rainfall that typically begins in this season, thus confirming the results obtained by Giraldez, et al. (2020) [16].


[15] Imfeld, N, Sedlmeier, K, Gubler, S, et al. A combined view on precipitation and temperature climatology and trends in the southern Andes of Peru. *Int J Climatol*. 2021; 41: 679– 698. https://doi.org/10.1002/joc.6645

[16] Giráldez, L., Silva, Y., Zubieta, R., & Sulca, J. (2020). Change of the rainfall seasonality over Central Peruvian Andes: onset, end, duration and its relationship with large-scale atmospheric circulation. Climate, 8 (2), 23. https://doi.org/10.3390/cli8020023

*Figure 4. Precipitation trends for the period 1965-2016 in the SHAP. Annual trends (a) show a slightly increse of with no statistical significance. In austral summer (DJF), the trend increases more than the annual. In spring (SON) the trend is negative, showing a clearer decresing signal. For winter (JJA), no precipitation trends are shown. Source: Imfeld, et al. (2020)*

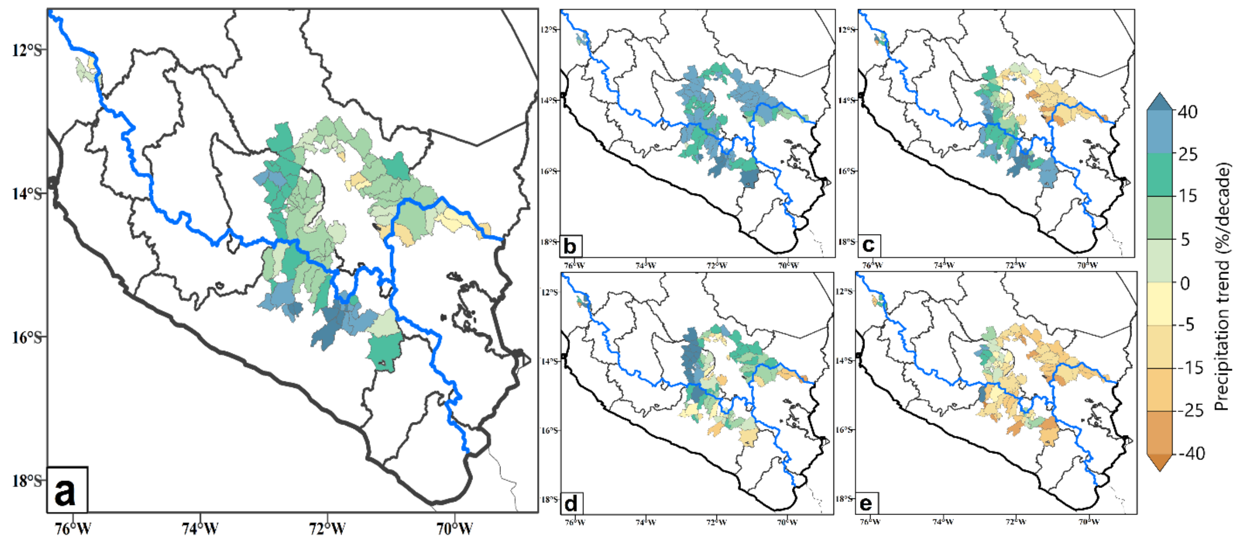



*Figure 5. Spatial distribution of precipitation trends (%/ decade) from 1981 to 2016 in the SHAP chosen districts. Annual trends (a) indicate an increase in most districts, with an emphasis in the northwest of SE and SW subregions. In summer (b), the signal of increase is pretty clear in all the districts. In autumn (c), winter (d) and spring (e), a higher increase occurs in the nothwest of SE and SW than in the eastern part of SE and A. In spring, negative trends are dominant.*

Tx trends are positive in the SHAP. In general, the largest increases occur in spring. On the other hand, lighter increases occur in autumn (Figure 06).

The annual trends of Tx show an evident and statistically significant increase in temperature in all the districts, especially in the ones at higher altitudes (Figure 07). Its values range from 0.3 to 0.45°C/decade and the districts with the greatest trends are approximately 4600 masl. In DJF, trends range from 0.17 to 0.48°C/decade and greater trends are observed at higher altitudes. MAM is the season that shows the lowest trends, ranging from 0.17 to 0.38°C/decade. In this period, a greater trend is observed in the districts located further south, in SW and A. JJA shows trends ranging from 0.33 to 0.44 °C/decade. In this season, the warming is almost unanimous in all districts. SON shows the greatest trends in Tx, ranging from 0.35 to 0.55 °C/decade.

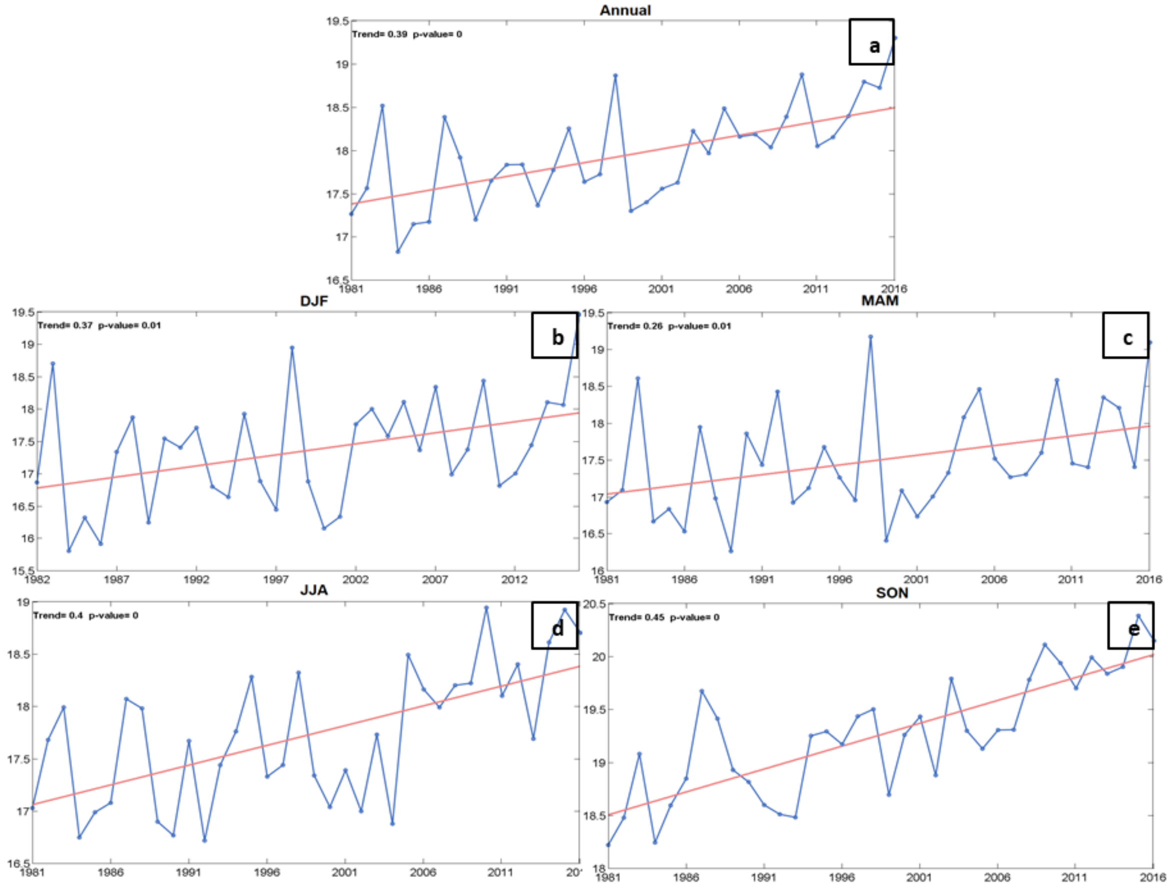



*Figure 6. Tx trends for the period 1981-2016 in the project intervention area for the a) annual mean (b), summer (DJF), c), autumn (MAM), d), winter (JJA), and e) spring (SON). All periods show steep increases. In spring we see the steepest trend.*

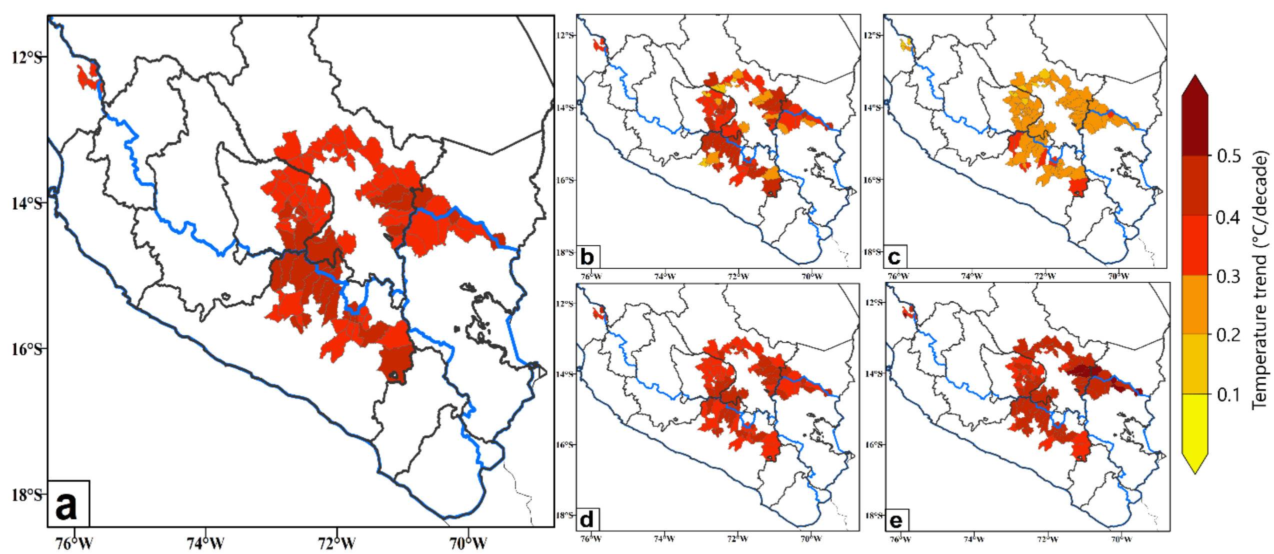



*Figure 7. Spatial trends of Tx (°C/decade) from 1981 to 2016 in the SHAP chosen districts. Annual trends (a) indicate a dominant increase, with an emphasis in high altitudes. In summer (b), the signal of increase is also clear. The lowest*

*increases of the year happen in autumn (c). In winter (d), trends are also positive, especially over high altitudes. The largest trends occur in spring (e), especially in the border of SE and A.*

Tn trends are positive in the SHAP. In general, the largest increases in the year occur in winter. On the other hand, lighter increases occur in summer (Figure 08). Compared to trends in Tx, Tn trends are smaller.

Annual Tn trends range from 0.16 to 0.23 °C/decade and all districts show statistical significance and the trend is slightly higher at high altitudes where there are currently glaciers. In DJF, the trends range from 0.1 to 0.2 °C/decade and the greatest trends are over SE. In MAM, the trends range from 0.09 to 0.2 °C/decade and the trends are similar in SE and SW; however, in A, they are slightly smaller. In JJA, the trends range from 0.16 to 0.33 °C/decade. This is the season when the greatest tendency to increase occurs. In SON, the trends range from 0.11 to 0.23 °C/decade and here a spatially even warming is shown throughout the SHAP.

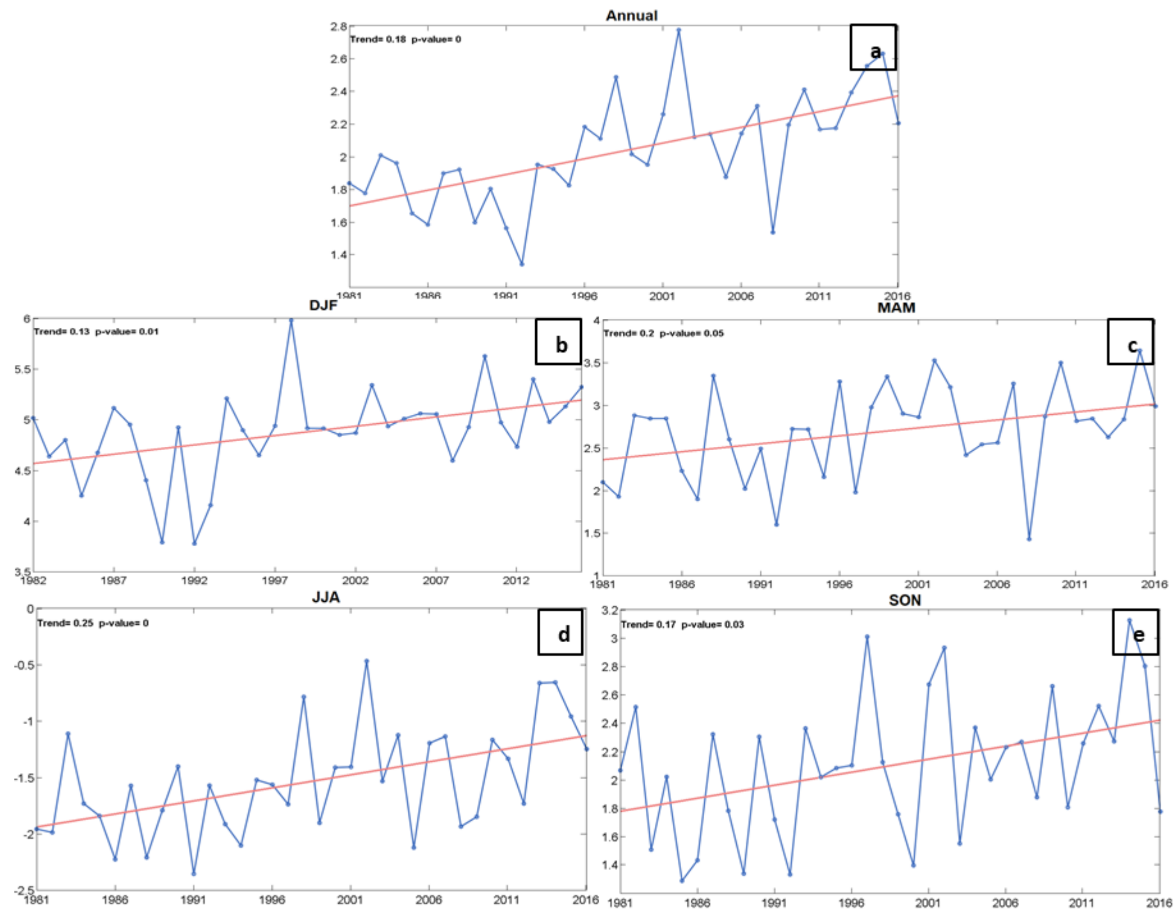



*Figure 8. Tn trends for the period 1981-2016 in the project intervention area for the a) annual mean (b), summer (DJF), c), autumn (MAM), d), winter (JJA), and e) spring (SON). All periods show steep increases. In winter we see the steepest trend.*

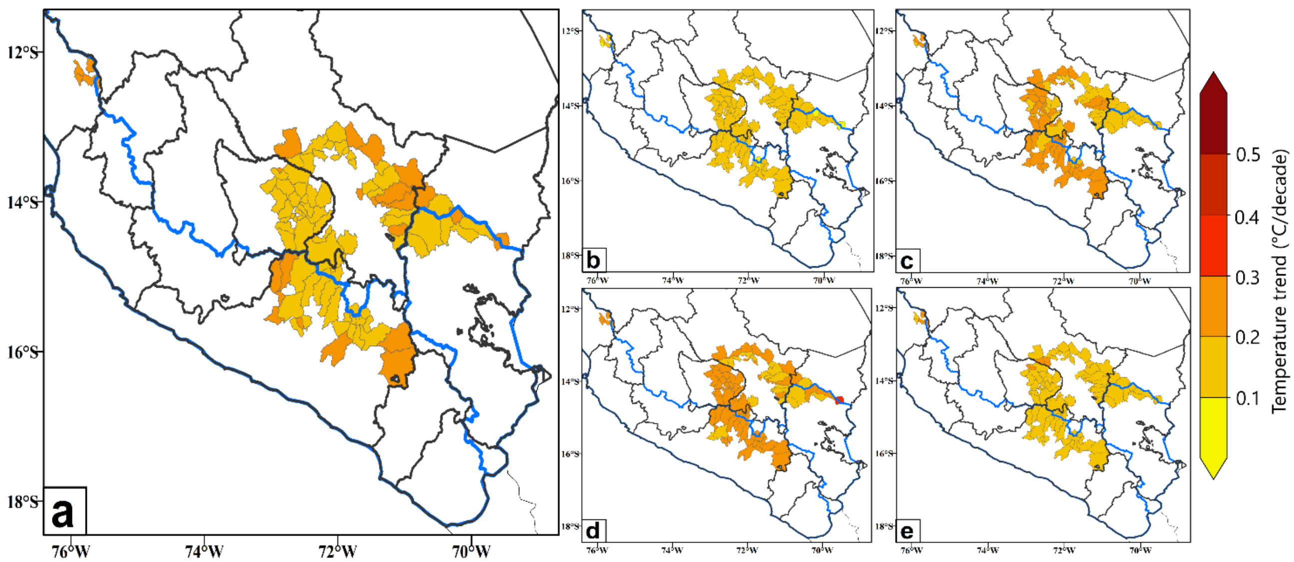



*Figure 9. Spatial trends of Tn (°C/decade) from 1981 to 2016 in the SHAP chosen districts. Annual trends (a) indicate an increase, with an emphasis in high altitudes where glaciers exist. In summer (b), the lowest increases in the year occur and trends show almost the same values in all the districts. In autumn (c). The highest increases in the year occur winter (d), and trends are higher over high altitudes. In spring (e), trends are similar to summer.*

Recently, some studies analyzed climatic indices related to precipitation[17]. They found that the index "maximum in a month of the sum of precipitation of five consecutive days of precipitation" (Rx5) and "number of days with precipitation greater than 10 mm" (R10mm) are increasing in summer. Meanwhile, the index of dry days ("number of days with precipitation less than 1 mm in a year", DD) is higher in winter and has a tendency to decrease in summer, to increase in spring, but to slightly decrease in winter. Likewise, although there is a high uncertainty, the trend in the number of consecutive dry days or dry periods (length of consecutive dry days: CDD) is increasing in Puno, Cusco and Apurímac, especially in spring[18] [19]. This behavior of increasing trends of extreme rainfall events in summer and increases of dry periods and their durations in winter and spring, would be understood as more intense and frequent rains that have been occurring in apparently shorter rainy periods.[20] [21]. Likewise, Lang's pluviometric index was analyzed, which indicates arid conditions. The changes in their values between a recent period (1990-2020) with respect to a reference period (1981-2010) were compared. Results showed high aridity conditions in the last decades on SHAP[22].

[17] Imfeld, N, Sedlmeier, K, Gubler, S, et al. A combined view on precipitation and temperature climatology and trends in the southern Andes of Peru. *Int J Climatol*. 2021; 41: 679– 698. https://doi.org/10.1002/joc.6645

[18] Huerta, A, Lavado-Casimiro, W. Trends and variability of precipitation extremes in the Peruvian Altiplano (1971–2013). Int J Climatol. 2021; 41: 513– 528. https://doi.org/10.1002/joc.6635

[19] SENAMHI (2013) Evaluación de los modelos CMIP5 del IPCC en el Perú: Proyecciones al año 2030 en la Región Puno.

[20] SENAMHI (2009). Escenarios de cambio climático en la Cuenca del rio Urubamba para el año 2100.

[21] SENAMHI (2012). "Escenarios de cambio climático al 2030 y 2050 de las regiones Apurímac y Cusco". Serie de investigación regional # 2. Programa de Adaptación al Cambio Climático PACC – Perú

[22] MINAM (2020). PLAN NACIONAL DE ADAPTACIÓN AL CAMBIO CLIMÁTICO (NAP). Manuscrito en revisión.

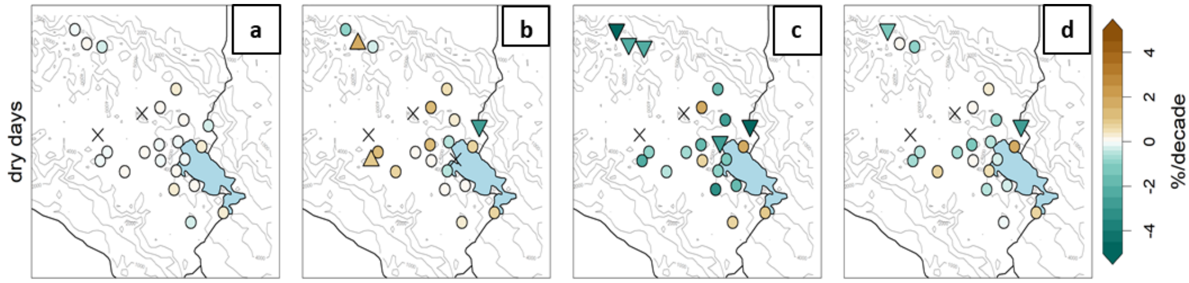



*Figure 10. Trends of total dry days in winter (a), spring (b), summer (c) and autumn (d) from 1965 to 2018. Stations with trends significant at the 0.1 level are marked with an upward or downward triangle to denote positive and negative trends, respectively. Circles denote no significance based on a significance level of 0.1 (10%). Black crosses denote stations where no mean has been calculated because more than 20% of daily values were missing. Spatial trends are low and disperse in winter. In spring, an increasing trend of DD is noticed in the SW subregion and a decreasing trend in A. In summer, most stations indicate a notorious decrease in the number of DD. In autumn, a decrease is also seen. Source: Imfeld, et al. (2020).*

On inter-annual time scales, The El Niño Southern Oscillation (ENSO) is known as the dominant feature leading to dry or wet years at the northern Peruvian coast (Takahashi, 2004; Lagos et al., 2008; Bazo et al., 2013 in Imfeld, et al., 2020), which also has an (typically opposite) impact on the SHAP. During El Niño, precipitation is reduced in the southern Andes (Vuille, 1999; Lavado Casimiro et al., 2012 in Imfel, et al., 2020) and dry spells are significantly more likely to occur (Sulca et al., 2015; Huerta and Lavado-Casimiro, 2020 in Imfeld, et al., 2020), though the effect is not pronounced.

Temperature variability is strongly modulated by ENSO (Vuille et al., 2000 in Imfeld, et al., 2020). Segura, et al. (2016) [23] showed that on decadal to interdecadal timescales, hydrological deficits occur. Imfeld, et al (2020) calculated temperature and precipitation trends from 1965 to 2018 and trends removing an ENSO-related part in the regional mean-time series. They compared the results and found out that temperatures trends are weaker (up to 0.16°C/decade) when removing the ENSO-related part compared to regular trends, but they remain positive with statistical significance in all the SHAP. The strongest reductions occur on winter and spring for Tx. ENSO leads to larger maximum temperature, but has less impact on minimum temperatures. Nevertheless, for precipitation, no consistent effect can be observed when removing the ENSO-related signal.

Although temperature increases still occur in a non-ENSO scenario, ENSO still and will still modulate the interannual variability in the future. Therefore, it is important to take into account that recent studies of projections of ENSO events indicate that, in a warmer climate in the future, ENSO events over the eastern Pacific will increase in frequency as end of the 21st century by approximately 15%. Additionally, extreme El Niño and La Niña events (ENSO in their cold phase) will increase their frequency by the double.

**Conclusions:**

- The mean annual cycle in the SHAP is characterized by a wet summer, a dry winter and two transitions seasons, which are spring and autumn. The maximum values of maximum temperature in the year occur in spring, while the maximum values of minimum temperature, take place in summer.
- Precipitation trends (considering the 1981-2016 period), are generally small. Annual trends of precipitation are positive in the SHAP. However, in spring, trends are mostly negative with the lowest values in the year. In contrast, in summer, trends are mostly positive. Trends are

[23]Segura, H., Espinoza, J.C., Junquas, C. and Takahashi, K. (2016) Evidencing decadal and interdecadal hydroclimatic variability over the Central Andes. Environmental Research Letters, 11(9), 094016. https://doi.org/10.1088/1748-9326/11/9/094016.

also higher over the SW subregion and western of SE, but lower in A and eastern of SE. In general, the annual cycle has a tendency to increase its intensity.

- Temperature trends (considering the 1981-2016 period) are certainly positive annually and in all the seasons. Large trends are found at higher altitudes. Maximum temperature trends are larger than minimum temperature trends. The season when maximum temperature trends are largest, is spring. However, maximum values of minimum temperature trends, happen in winter.
- Climate indices suggest an increase of the number of dry days (DD) in spring and winter. The length of dry days (CDD) also tend to increase in the SHAP region. The annual cycle has a tendency to get stronger. A decreasing tendency in the duration of the rainy season[24] is also known.

## 2. Climate projections towards 2050

### 2.1 Changes under the RCP4.5 emission scenario

The annual precipitation changes in this scenario range from -7.4 to 15.5% (Figure 11). Most districts expect positive changes (increases); however, the few districts that show negative changes (decreases) are located in the A subregion. Seasonally, the greatest changes in Pr in all districts is winter, which exhibits negative changes with high values (between -30 to -20%). The greatest positive changes occur in spring in most districts. In summer and autumn, there is a positive change in most districts. Spatially, areas that show higher increases in most seasons are located at the west of SE. On the contrary, areas with decreases or smaller increases are located in the A subregion.

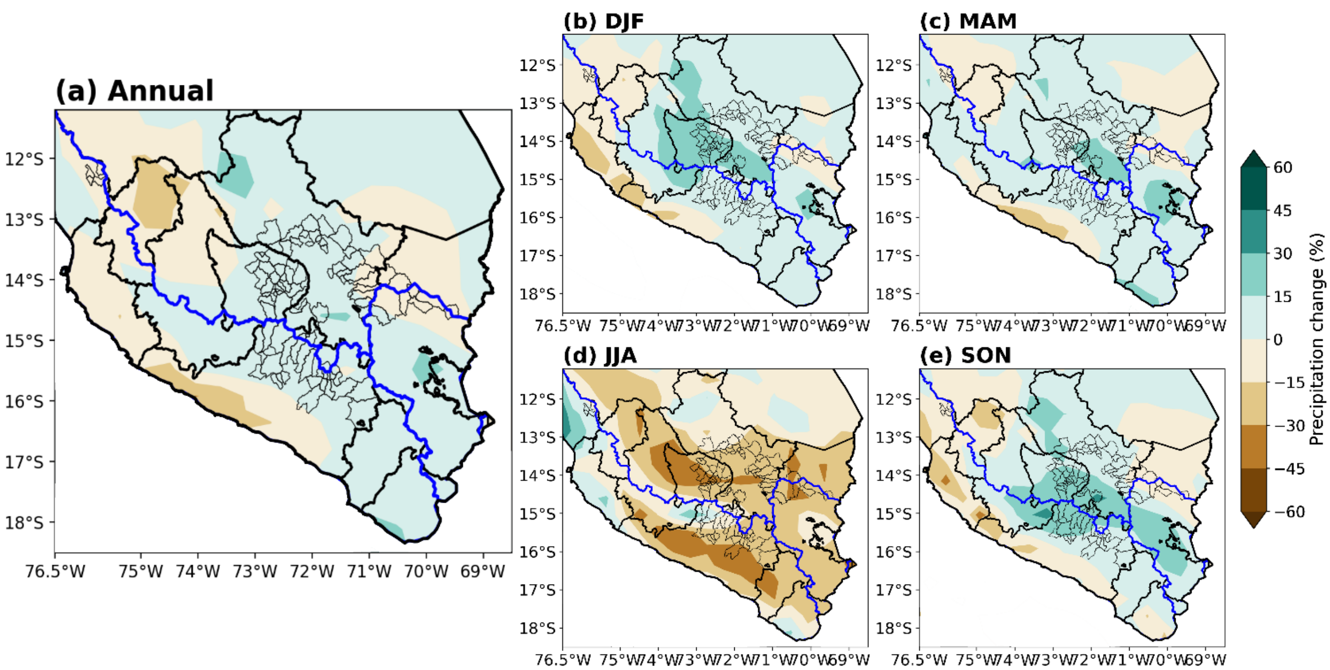



*Figure 11. Projected changes in precipitation towards 2050 under the RCP4.5 emission scenario for the total annual (a), summer (b), autumn (c), winter (d) and spring (e). Subregions are also shown divided by blue lines. Higher decreases take*

[24] Giráldez, L., Silva, Y., Zubieta, R., & Sulca, J. (2020). Change of the rainfall seasonality over Central Peruvian Andes: onset, end, duration and its relationship with large-scale atmospheric circulation. *Climate, 8* (2), 23. https://doi.org/10.3390/cli8020023

*place in winter. In general, areas that show higher increases in all seasons are located at the west of SE. On the contrary, areas with decreases or smaller increases are located in the A subregion.*

The projected annual mean changes of Tx range from 2.1 to 3.2 °C (Figure 12). Seasonally, winter shows the greatest changes, ranging from 2.4 to 3.8 °C. Instead, autumn is the season when the smallest changes occur. Areas that show higher increases in most seasons are located at the border of SE and A and in the border of SW and SE (high altitudes). This changes show consistency with previous studies; for example, SENAMHI (2009) [25] analyzed changes in the Urubamba river basin. According to this document, the greatest changes in Tx occur between winter and spring.

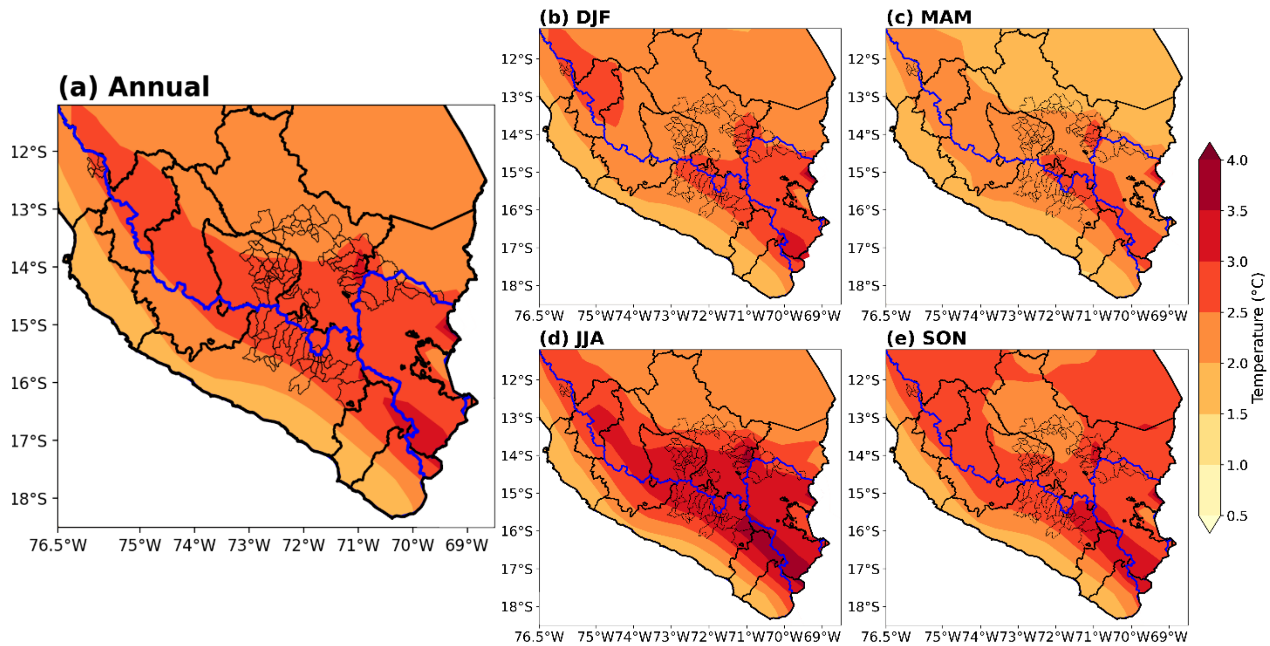



*Figure 12. Projected changes in maximum temperature towards 2050 under the RCP4.5 scenario for the annual mean (a), summer (b), autumn (c), winter (d) and spring (e). Subregions are shown divided by blue lines. Higher increases take place in winter. Areas that show higher increases in all season are the border of SE and A and the border of SW and SE in autumn (higher altitudes).*

Changes in Tn range from 1.3 to 3.4 °C (Figure 13). Seasonally, the largest changes occur in spring in most districts, except in few of them (which are located in SE). Instead, the lowest values take place in JJA. It is important to note that, in this season, six districts show a very large warming, which is above 4 °C. Areas that show higher increases in most seasons are the ones located at the border of SE and A, similar to Tx changes. In accordance to SENAMHI (2009), it can be seen that changes in Tn are more uniform throughout the year (in comparison to Tx).

[25] SENAMHI, 2009. Escenarios de cambio climático en la cuenca del río Urubamba para el año 2100 (Climate change scenarios in the Urubamba river basin for the year 2100).

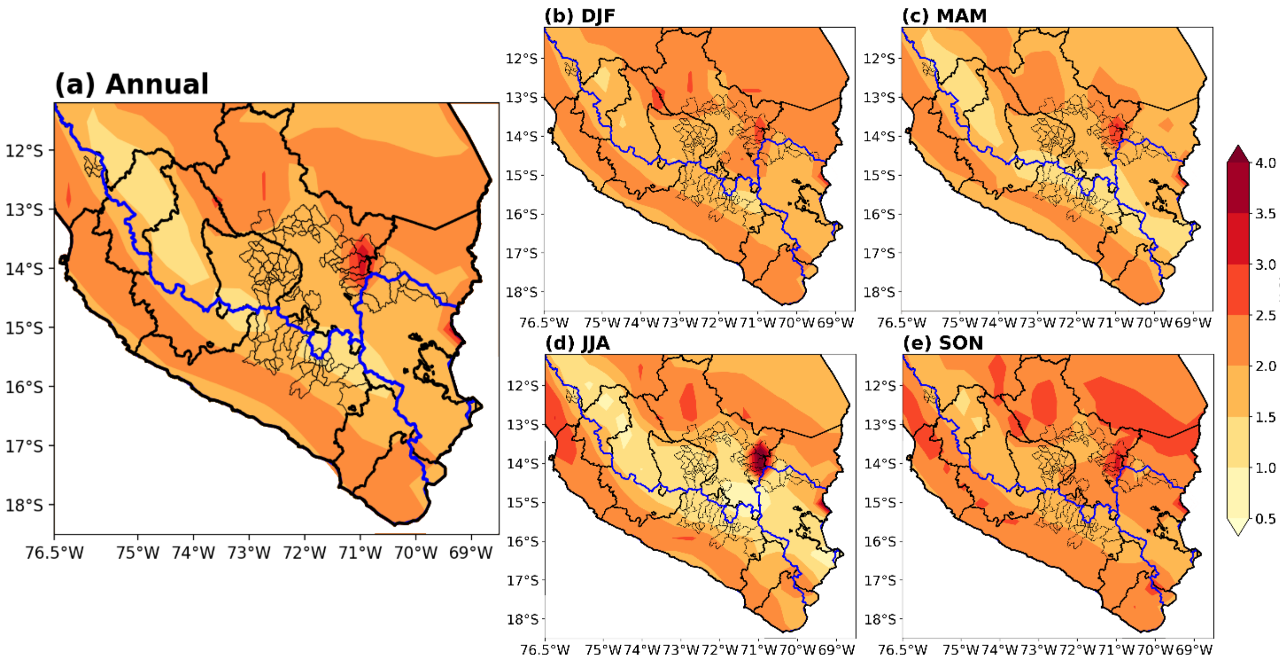



*Figure 13. Projected changes in minimum temperature towards 2050 under the RCP4.5 scenario for the annual mean (a), summer (b), autumn (c), winter (d) and spring (e). Subregions are also shown and divided by blue lines. The area that shows the highest increases in all season is the border of SE and A (higher altitudes, where glaciers exist).*

### 2.2 Changes under the RCP8.5 emission scenario

The annual precipitation changes in this scenario range from -30 to 30% (Figure 14). The season that shows the greatest changes in most districts is JJA, which shows strong negative changes (between -60 to 0%). On the other hand, the greatest positive changes are observed in spring, ranging from 0 to 30% in the entire SHAP. The districts located in the SE and A subregions are the ones that show slightly larger increases, but those that are located in SW show decreases or smaller increases.

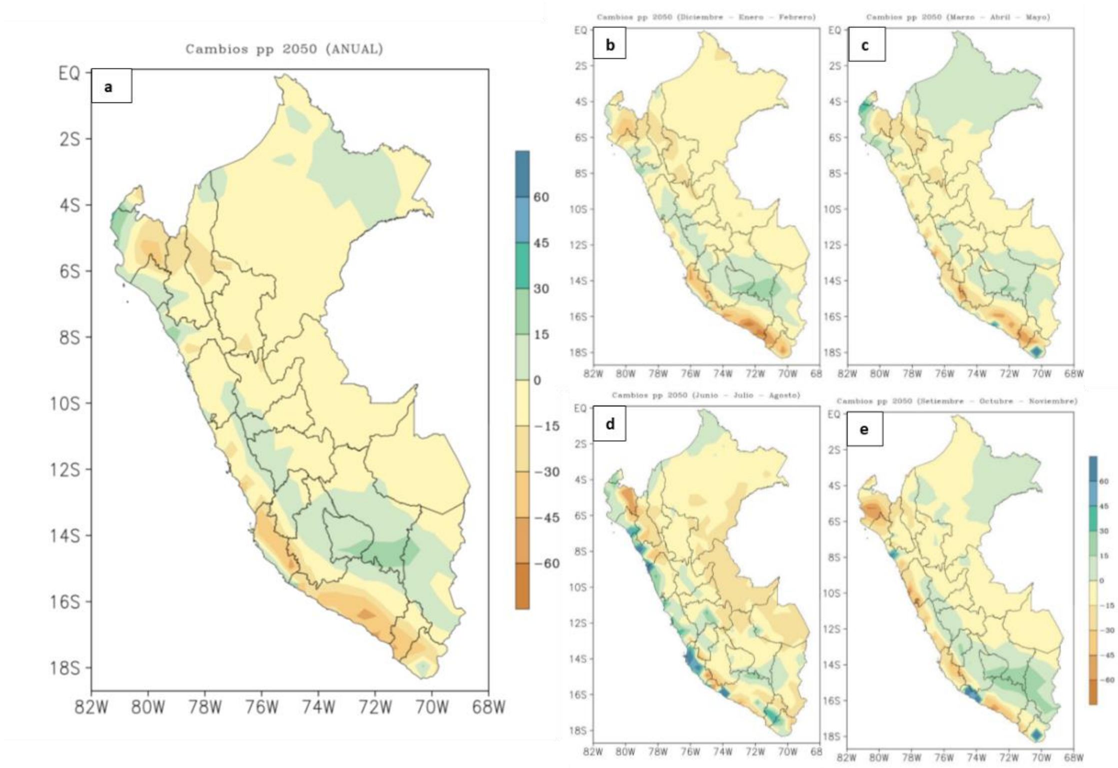



*Figure 14. Projected changes in precipitation (%) towards 2050 under the RCP8.5 scenario for the annual mean (a), summer (b), autumn (c), winter (d) and spring (e). Annual changes are positive. The SE and A regions show mostly positive changes; however, the SW region show mostly negative changes. The largest negative changes happen in winter. However, spring is the season when the largest positive changes. Source: SENAMHI 2020.*

Changes in the annual Tx range from 2.5 to 3.5 °C (Figure 15). Seasonally, in JJA the greatest changes take place, ranging from 2.5 to 4 °C. However, the smallest changes occur in summer (DJF). Spatially, in most seasons, the region with the greatest changes is the northwest of SW and between SE and A. Both areas are headwaters of basins where also glaciers exist.

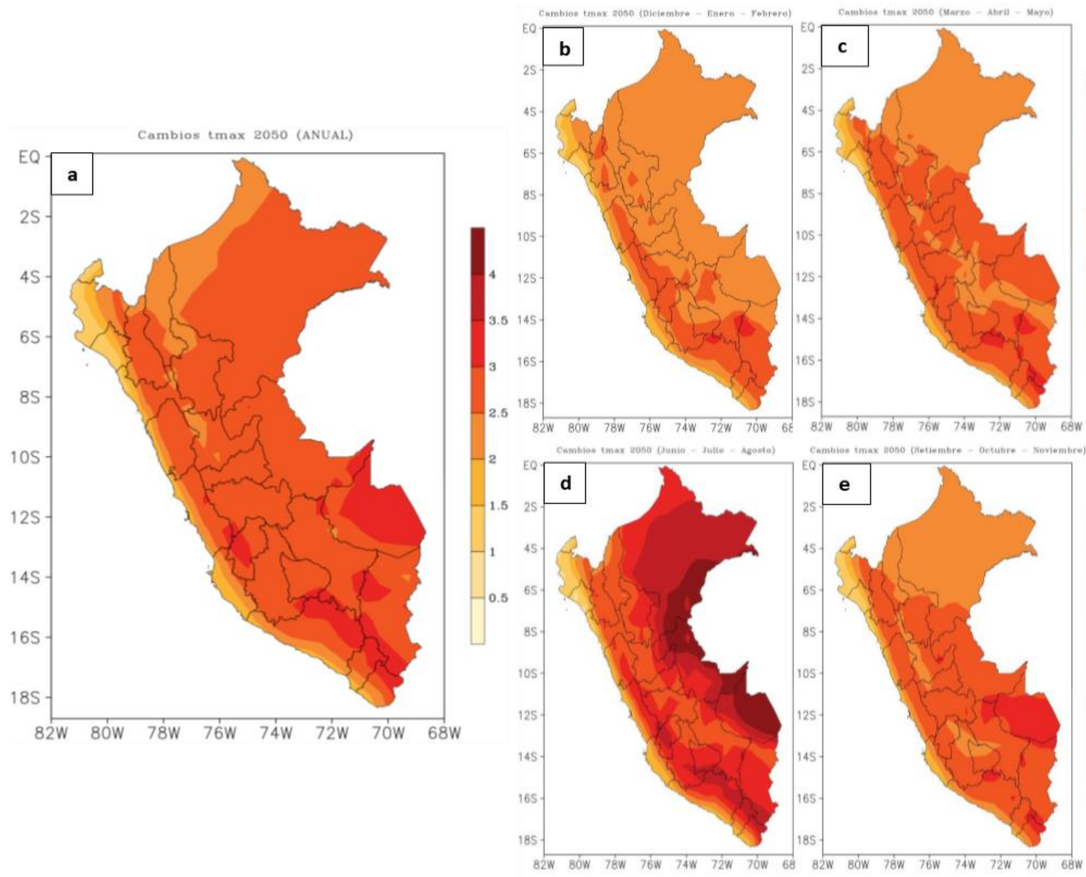



*Figure 15. Projected changes in maximum temperature (°C) towards 2050 under the RCP8.5 scenario for the annual mean (a), summer (b), autumn (c), winter (d) and spring (e). Winter is when larger changes take place. Similar to RCP4.5, areas that show higher increases in all season are the border of SE and A and the border of SW and SE.*

Changes in Tn range from 2.5 to 3.5 °C, but in most part of the SHAP, less warming than Tx is clearly seen. The largest changes in Tn occur in winter, followed by spring. In JJA the changes are between 2 and 4 °C. Smaller changes happen in summer. In general, the changes of this variable are spatially homogeneous, but there are two zones that present two hotspots of greater heating. These are found, as in Tx, over northwest SW and between SE and A.

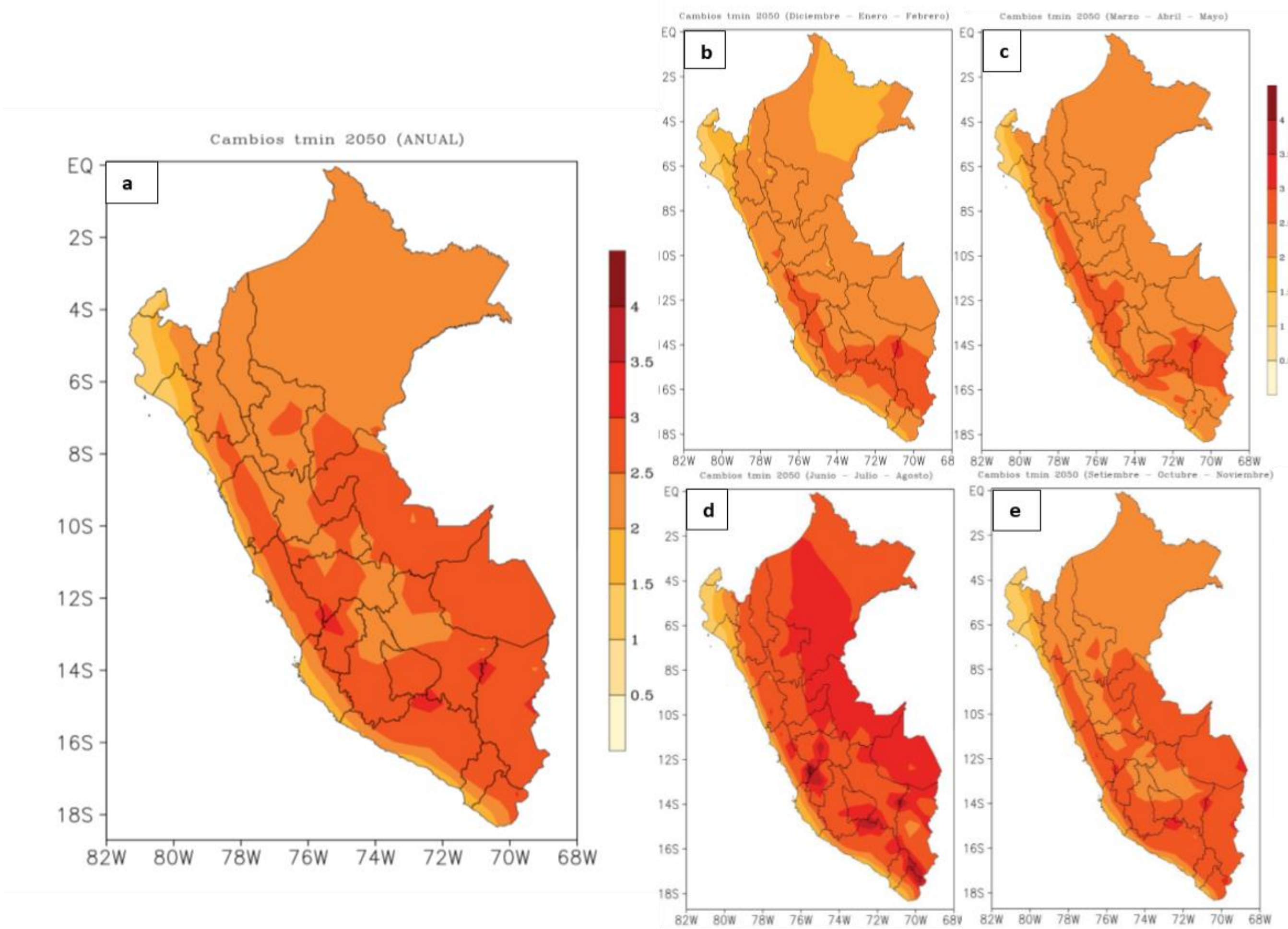



*Figure 16. Projected changes minimum temperature (°C) towards 2050 under the RCP8.5 scenario for the annual mean (a), summer (b), autumn (c), winter (d) and spring (e). Winter is when larger changes take place. Similar to maximum temperature, changes are largest in two specific zones placed over high altitudes, which are the northwest of the SW region and between the SE and A region.*

**Conclusions:**

- Under the RCP4.5 emission scenario, annual changes go from -5 to 20%. In winter, changes are negative in most part of the SHAP. On the other hand, the largest positive changes occur in summer, specially over the northwestern of the SE region.
- Under the RCP8.5 emission scenario, annual changes go from -30 to 30%. The largest negative changes happen in winter. However, spring is the season when the largest positive changes occur. The SE and A regions show positive changes; however, the SW region show mostly negative changes.
- Temperature changes are always positive, in any season or scenario; however, they are larger in the RCP8.5 emission scenario than in the RCP4.5. Maximum temperature shows larger changes than minimum temperature. Spatially, minimum temperatures exhibit a more regular distribution.
- According to the RCP4.5 scenario, changes in maximum temperature go from 2.1 to 3.8°C, and winter is when the largest changes take place. Minimum temperature shows changes

that go from 1.3 to 4°C. Spatially, these changes are especially large in one specific zone placed over high altitudes between the SE and A region.

- According to the RCP8.5 scenario, changes in maximum temperature go from 2.5 to 4°C, and winter is when the largest changes take place. Minimum temperature shows changes that go from 2 to 4°C. Spatially, these changes are especially large in two specific zones placed over high altitudes, which are the northwest of the SW region and between the SE and A region.

## 3. Impacts on water security, agriculture, ecosystems and on society

### 3.1 Droughts

Droughts are one of the main threats in Peru, especially in the SHAP region. According to the Risk Management and Adaptation Plan to Climate Change in the Agricultural Sector Period 2012-2021 - PLANGRACC-A (“Plan de Gestión de Riesgos y Adaptación al Cambio Climático en el Sector Agrario Período 2012-2021 - PLANGRACC-A”)[26] potential drought hazard zones were identified within the SHAP. SENAMHI (2016)[27] quantified hazard, vulnerability and risk to droughts in every district of the southern Andes of Peru. As seen in Figure 17 a, most districts located in the SHAP, show middle, high and very high drought hazard, especially in districts located in the A and SE regions. Vulnerability is also high, but especially in the SW and A region (Figure 17 b). The risk quantified is higher mostly in the A and part of SE region (Figure 17 c).

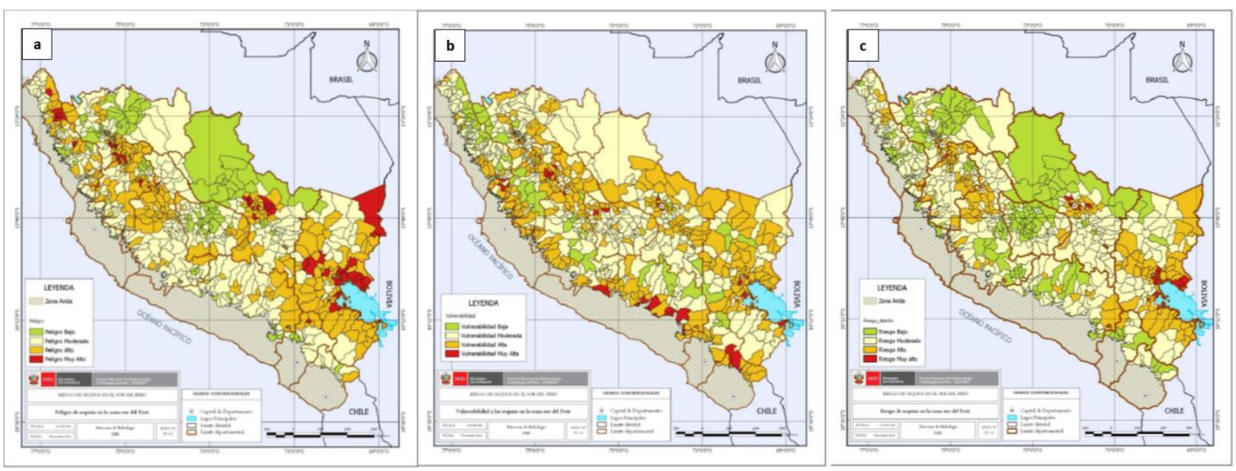



*Figure 17. Drought hazards (a), drought vulnerability (b) and dought risks in all districts in the SHAP. SE, SW and A subregions show high values in at least one of the three components.*

Droughts characterization in Peru exhibit different patterns related to frequency, length and intensity in each region that may affect different socioeconomic activities in different ways (see section 3). In the study of drought characterization (SENAMHI, 2015)[28], they found out that the largest numbers of dry events between 1970 and 2014 in Peru, are placed in the SHAP and surrounding areas (Figure 18 a). However, these events have shorter lengths, especially in the Altiplano (A subregion; Figure

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[26] MINAGRI (2012). According to the Risk Management and Adaptation Plan to Climate Change in the Agricultural Sector Period 2012-2021 - PLANGRACC-A.

[27] SENAMHI (2016). Drought risk analysis in southern Peru.

[28] SENAMHI (2015). Regionalization and characterization of droughts in Peru.

18 b). On the other hand, the maximum intensity of dry events take place over the high areas of the Arequipa (SW subregion; Figure 18 c). Between Cusco and Apurimac (SE subregion), dry events show greater intensity and number of events at the same time (Figure 18 b-c).

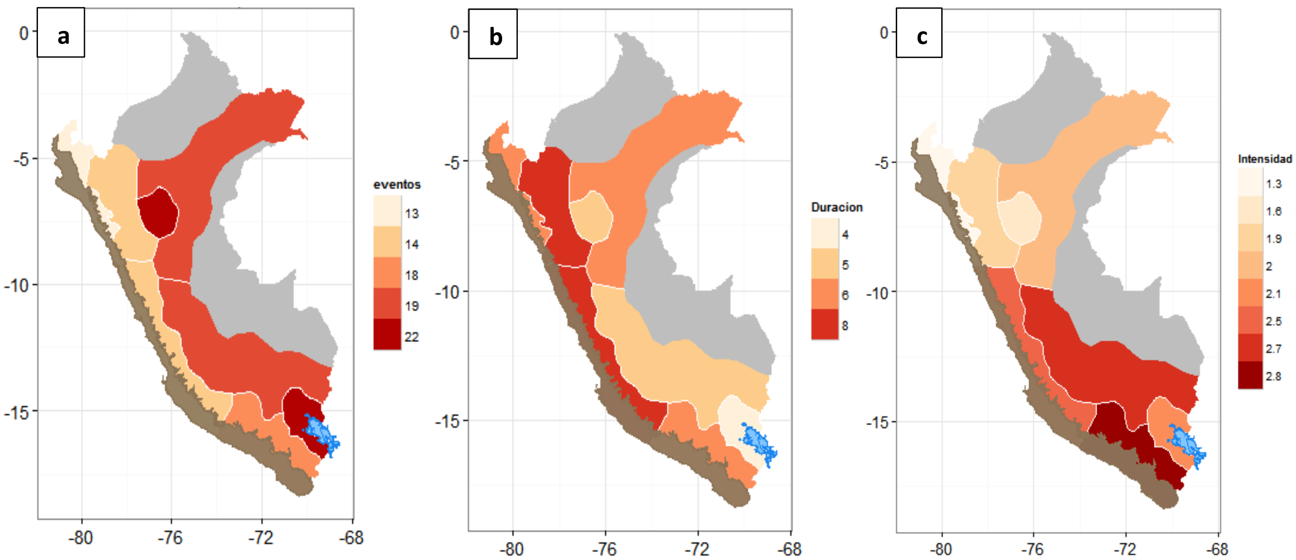


*Figure 18. Drought characterization in Peru regarding number of events (a), length (b) and intensity (c) in 1970-2014. The SE subregion registered a high number of events, lengths of 5 months and high intensity. The SW subregion registered a high number of events, 6-months lengths in average and a very high intensity. The A subregion denotes a very high number of events, 4-month lengths and high intensity Source: SENAMHI, 2015.*

Trends of short-term droughts (that last three months) were also calculated, and results show positive trends of drought occurrence in all the seasons, except in winter (JJA) in the SE subregion. The SW subregion shows similar results as the SE subregion, and in winter, negative trends of droughts are strongly negative. However, in the A subregion, negative trends happen in spring and winter, with an emphasis of the latter.

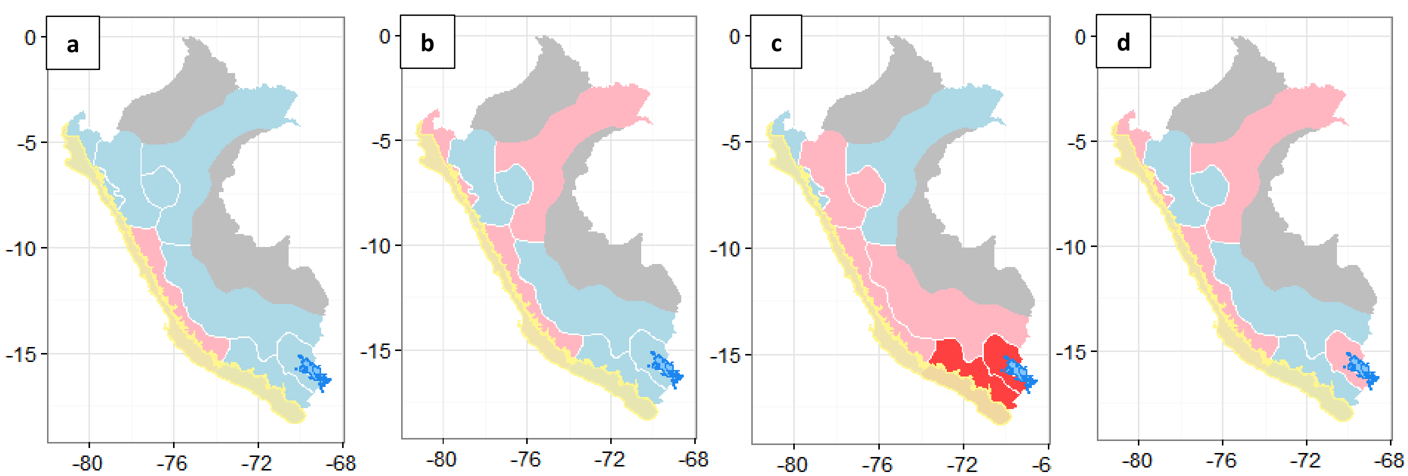


*Figure 19. Seasonal trends of droughts in DJF (a), MAM (b), JJA (c) and SON (d) from 1970 to 2014. Blue means significant positive trend; light blue, positive trends; red, negative significant trends and pink, negative trends. Source: SENAMHI, 2015.*

In recent decades, the Cusco, Puno and Arequipa regions (SHAP), were the most affected by major meteorological droughts, especially in 1983, 1987, 1990, 1992, 2005 and 2016. The El Niño phenomenon (ENSO - El Niño Southern Oscillation in its warm phase) has teleconnections on the behavior of the climate of the Altiplano and its surroundings, causing a decrease in rainfall during El Niño episodes[29]. ENSO explains a good percentage, although not totally, of the deficiencies of rainfall in the Andes, mainly in the central and southern western highlands [30]. Therefore, it is important to take into account that recent studies of projections of ENSO events indicate that, in a warmer climate in the future, they imply an increase in ENSO events (see section 1.2).

Projections under the RCP8.5 scenario in the Peruvian-Bolivian Altiplano (A region)[31], indicate that increases in evapotranspiration and temperature are expected in 2050. The frequency of meteorological droughts lasting between three to four months would remain mostly the same. However, a significant rise in the frequency of meteorological droughts between one to two months-length is expected, and they would develop between the dry season and the rainy season onset. Furthermore, a nonlinear propagation from meteorological droughts to agricultural and hydrological systems results in drought frequency and duration being amplified from meteorological to hydrological and agricultural droughts.

**Conclusions:**

- Droughts characterization in Peru exhibit different patterns related to frequency, length and intensity in each region that may affect different socioeconomic activities in different ways. Considering the analysis of recent decades, the largest number of dry events take place at the south of the country, in the SHAP and surrounding areas. However, these events have shorter lengths, especially in the A subregion. On the other hand, the maximum intensity of dry events take place over the high areas of the SW subregion. In the SW subregion, a larger number of dry events occur with larger intensity, at the same time.
- Under the RCP8.5 scenario, evapotranspiration will also (apart from temperatures) increase towards 2050. The frequency of meteorological droughts lasting between one to two months is expected, and they would develop between the dry season and the rainy season onset (in the transition between the wet to the dry season).
- A nonlinear propagation from meteorological droughts to agricultural and hydrological systems results in drought frequency and duration being amplified from meteorological to hydrological and agricultural droughts.

### 3.2 Glacier retreat

Since the end of the 1970s, Andean tropical glaciers have been shrinking at an increasing rate [32]. The main factor that explains this retreat is the warming of the atmosphere, given that precipitation does not show significant changes. Rabatel, et al (2013) concluded that the magnitude of glacier loss

[29] Lavado, W.; Espinoza, J.C. Impact of El Niño and La Niña events on Rainfall in Peru. Rev. Bras. Meteorol. 2014, 29, 171–182.

[30] SENAMHI, 2019. Caracterización espacio-temporal de la sequía en los departamentos altoandinos del Perú (Temporal and spatial characterization of the drought in the high Andean regions of Peru).

[31] Zubieta, R., Molina-Carpio, J., Laqui, W., Sulca, J. & Ilbay, M. (2021). Comparative analysis of climate change impacts on meteorological, hydrological, and agricultural droughts in the lake Titicaca basin. Water, 13 (2), 175.https://doi.org/10.3390/w13020175.

[32] Rabatel, A., Francou, B., Soruco, A., Gomez, J., Cáceres, B., Ceballos, J. L., Basantes, R., Vuille, M., Sicart, J.-E., Huggel, C., Scheel, M., Lejeune, Y., Arnaud, Y., Collet, M., Condom, T., Consoli, G., Favier, V., Jomelli, V., Galarraga, R., Ginot, P., Maisincho, L., Mendoza, J., Ménégoz, M., Ramirez, E., Ribstein, P., Suarez, W., Villacis, M., and Wagnon, P.: Current state of glaciers in the tropical Andes: a multi-century perspective on glacier evolution and climate change, The Cryosphere, 7, 81–102, https://doi.org/10.5194/tc-7-81-2013, 2013.

is directly related to glaciers size and elevation, so, glaciers that are above 5400 masl lost glacier mass at a rate of -0.6 mw.e. (meter water equivalent) every year in the last decades. Meanwhile, those with lower altitudes contracted at a rate of -1.2 mw.e. by year (the double). This way, a higher vulnerability in the smaller glaciers is evidenced.

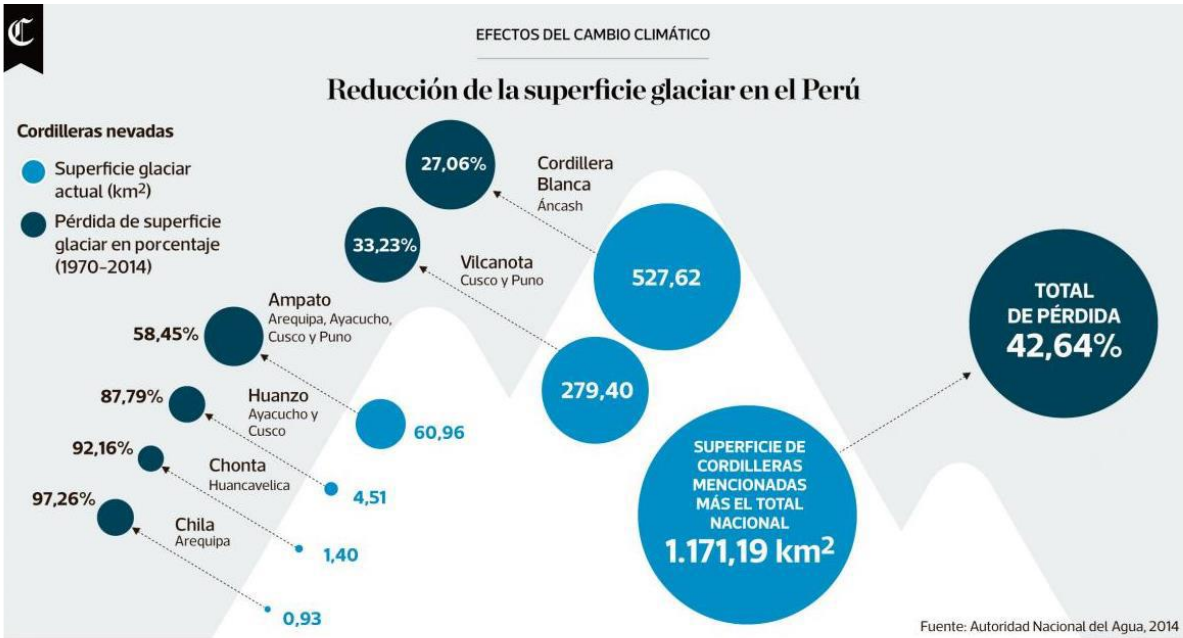


*Figure 20. Summary of glacier retreat in the SHAP from 1970 to 2014. Percentage of surface lost are shown in dark blue circles and the total area (in km2), in soft blue circles. Glaciers located over lowest altitudes have been suffering the greatest losses and the total glacier loss during this period is 42.64%. Source: National Water Authority of Peru (ANA), 2014. Retrieved from: https://elcomercio.pe/peru/infografia-del-dia-reduccion-superficie-glaciar-peru-noticia-448054-noticia/*

Tropical glacier melting happens because of temperature increases, high solar radiation and tropical humidity dynamics. Furthermore, the fact that precipitation falls as rain and not as snow, reduces the albedo of the surface[33]. Additionally, Francou, et al. (2013) [34], explained that one of the main factors that influence the deglaciation on the external tropics of Peru (corresponding to the SHAP region) is the onset of the wet season. So, the crucial factor for accumulation is the early generation (from November-December) of snow, so that it may block the melt. Moreover, ENSO events are also associated with the reduction of the glacier mass due to the increase in temperature and the reduction of precipitation, with often (but not always) significant mass loss during warm episodes associated with El Niño events, while cold phases (La Niña) tend to lead to less negative or in some cases even

[33] Vuille, Mathias (2013). El cambio climático y los recursos hídricos en los Andes tropicales. p. cm. (IDB Technical Note; 517) Incluye referencias bibliográficas. 1. Water resources development—Andes Region. 2. Water use—Andes Region. 3. Climatic changes—Andes Region. I. Banco Interamericano de Desarrollo. Unidad de Salvaguardias Ambientales. II. Title. III. Series.

[34] Francou, B., Rabatel, A., Soruco, A., Sicart, J.E., Silvestre, E.E.,Ginot, P., Cáceres, B., Condom, T., Villacís, M., Ceballos, J.L., Lehmann, B., Anthelme, F., Dangles, O., Gomez, J., Favier, V., Maisincho, L., Jomelli, V., Vuille, M., Wagnon, P., Lejeune, Y., Ramallo, C., & Mendoza, J. (14) (PDF) Glaciares de los Andes Tropicales víctimas del Cambio Climático. Available from: https://www.researchgate.net/publication/259235400_Glaciares_de_los_Andes_Tropicales_victimas_del_Cambio_Clim atico

balanced or slightly positive mass balance[35] (see section 1.2 for further information about ENSO and climate change).

Recent analysis of glacier melting in the last decades in the SHAP[36], show considerable glacier losses. During the period 2000-2013, the retreat rate in the southern SE subregion was −1.3 % by year, and in the SW subregion, it was −2.3 % by year, approximately. Faster losses are found in the SW subregion, because of the dominant low-altitude and small glaciers in this area. These losses may lead to the increasing GLOF (glacial lake outburst flow) risk, because of the gain and formation of glacial lakes, and might also impact on water availability.

Glaciers play an important role in the hydrology of the Andes by storing water in the rainy season and releasing it throughout the year[37]. The proportion of glacial meltwater in rivers is substantially higher in the dry season and in dry years (Buytaert et al., 2018 in Schoolmeester et al., 2016). This happens because of the lack of rain in the dry season. Glaciers have a particularly significant effect downstream in rivers that move into arid areas towards the Pacific, Atlantic or Titicaca lower basins after leaving the mountains. On average, the contribution of glacial water in this river is between 4 and 8 %. However, in years with little precipitation the contribution can be as high as 80 % in the dry season. The compensation effect of glaciers is particularly important in Peru and Bolivia, where, the highest difference in seasonal precipitation and annual precipitation totals are low. In the short term in the Tropical Andes, diminishing glaciers cause increased water flow, but in the long term there will be reduced dry season compensation (Vuille 2013), which is mainly important for local ecosystems and mountain communities.

**Conclusions:**

- Tropical Andean glaciers are retreating at an increasing rate since the late 1970s. The main factor that explains this is the warming of the atmosphere. The magnitude of glacier loss is directly related to glaciers size and elevation. So, glaciers that are above 5400 m asl lost glacier mass at a rate of -0.6 mw.e.(meter water equivalent) per year in recent decades; while those with lower altitudes contracted at a rate of -1.2 mw.e. by year.
- During the period 2000-2013, the retreat rate in the southern SE subregion was −1.3 % $a^{-1}$, and in the SW subregion, it was −2.3 % $a^{-1}$, approximately. Faster losses are found in the SW subregion, because of the dominant low-altitude and small glaciers.
- Glaciers are important components of the hydrology in the SHAP, because they storage water in the rainy season and release it in the rest of the year. So, glacier melting in the SHAP, in the short term, might cause increased water flow, but in the long term there will be reduced dry season compensation.

[35] Mathias Vuille, Mark Carey, Christian Huggel, Wouter Buytaert, Antoine Rabatel, Dean Jacobsen, Alvaro Soruco, Marcos Villacis, Christian Yarleque, Oliver Elison Timm, Thomas Condom, Nadine Salzmann, Jean-Emmanuel Sicart , Rapid decline of snow and ice in the tropical Andes – Impacts, uncertainties and challenges ahead. Earth(2017), doi:10.1016/j.earscirev.2017.09.019

[36] Seehaus, T., Malz, P., Sommer, C., Lippl, S., Cochachin, A., Braun, M. (2019) Changes of the tropical glaciers throughout Peru between 2000 and 2016 – mass balance and area fluctuations. The Cryosphere, 13, 2537–2556. doi: https://doi.org/10.5194/tc-13-2537-2019.

[37] Schoolmeester, T.; Saravia, M.; Andresen, M.; Postigo, J.; Valverde, A.; Jurek, M.; Alfthan, B. and Giada, S. 2016. Outlook on Climate Change Adaptation in the Tropical Andes mountains. Mountain Adaptation Outlook Series. United Nations Environment Programme, GRIDArendal and CONDESAN. Nairobi, Arendal, Vienna and Lima. www.unep.org, www.grida.no, www.condesan.org.

### 3.3 Impacts on water availability

According to recent researches[38], the results of climate change projections show a trend towards greater seasonality in rainfall and a strong reduction in available water during the driest months, which is linked to the fact that global models project more intense dry and wet seasons, with a direct effect on the intensification of the water cycle.

Projections of water availability towards the year 2050[39] indicate a reduction between 48% and 42% near the SW subregion, approximately. Over the SE subregion, there is a projected decrease of 10%. In the hydrographic region of Titicaca, which corresponds to the A subregion, a decrease in water availability of up to 28% is estimated. On the other hand, other studies took into account the results of seven climate models analyzed towards 2100[26]. Their results showed that some models announce a significant decrease in water availability. The driest projections of the seven models consider a decrease of more than 50% in water availability. Despite the high uncertainty in the projections of changes in water availability, the results of the study allowed us to observe consistent trends for the management of water resources in the future.

An additional issue for water availability is water quality. The melting of tropical glaciers has additional effects on the reduction of fresh water supplies, which are related to the quality of the water, which could become a threat to humans and ecosystems[40]. Thus, these authors evaluated the hydrogeochemistry of the glacial melt current in a hydrographic basin in the tropical Andes during the dry season of 2008. They found that the water had a Ph of 4, which is acidic. Furthermore, the trace element concentration was comparable to acid mine drainage. Thus, the poor water quality observed at the headwaters of the Cordillera Blanca, coupled with the likely exposure of additional sulfide-rich outcrops due to ongoing glacier retreat, can pose challenges to water quality.

**Conclusions:**

- Projections of water availability towards 2050, indicate a reduction between 48% and 42% in the SW subregion, a decrease of 10% in the SE and a decrease in water availability of up to 28% in the A subregion.
- Towards 2100, some models announce a significant decrease in water availability. The driest projections of the seven models consider a decrease of more than 50% in water availability.

### 3.4 Impacts on ecosystems

In recent decades, ecosystems have been undergoing changes as a direct consequence of increases in temperatures, changes in precipitation, deglaciation and increases of droughts. So, one of the important consequences of droughts is the impact on various ecosystems. In a study carried out by SENAMHI (2019) [41],they found that the vegetation covers associated with more arid regions (dry mountain forest, Cardonal and shrubby scrub) are more sensitive to the variability of droughts. In addition, the alterations in the maximum vegetative activity occur during the months of April and May.

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[38] BID and CEPAL. 2014. La economía del cambio climático en el Perú. C.E. Ludeña, L. Sánchez-Aragón, C. de Miguel, K. Martínez y M. Pereira, editores. Monografía BID No. 222 y CEPAL LC/W.640.

[39] SENAMHI, 2015. Actualización de los escenarios de disponibilidad hídrica en el Perú en contexto de cambio climático". Lima. Abril 2015.

[40] Sarah K. Fortner, Bryan G. Mark, Jeffrey M. McKenzie, Jeffrey Bury, Annette Trierweiler, Michel Baraer, Patrick J. Burns, LeeAnn Munk. Elevated stream trace and minor element concentrations in the foreland of receding tropical glaciers. Applied Geochemistry. Volume 26, Issue 11, 2011, Pages 1792-1801, ISSN 0883-2927, https://doi.org/10.1016/j.apgeochem.2011.06.003.

[41] Vega, F. Respuesta de la vegetación a diferentes escalas temporales de sequía en los Andes Peruanos. Servicio Nacional de Meteorología e Hidrología del Perú –SENAMHI. Dirección de Hidrología –DHI. Diciembre, 2019.

Impacts of increasing temperatures on ecosystems have been behaving in different ways, depending on the population species. For instance, Seimon, et al (2007) [42] identified a clear retreat of glaciers that, at the same time, has opened a suitable territory for the settlement of some species. Specifically, the glacial retreat in the Vilcanota mountain range (SE subregion) has opened an ecological corridor in recent decades that already has impacts on species distributions. In the mountains of South America, an expansion of plants and animals to higher altitudes was found. At the same time, the thawing of glaciers also constitutes a source of water that serves for vegetative growth, aquatic microorganisms, insects, and mammals. Many of the woody and herbaceous species in the Andes (e.g. Ericaceae, Bromeliaceae) depend on interactions with animals for seed dispersal and pollination; the effects of CC in these organisms could cause spatial, temporal or physiological asynchronies between mutualistic species, producing changes in the composition and structure of communities[43].

On the other hand, Feeley, et al. (2011)[44] studied the recent behavior of Andean trees in the tropical Andes on an elevational gradient from 950 to 3400 m a.s.l. They demonstrated that, due to the increase of temperature in the last decades, trees tend to migrate upslope. In fact, most tropical trees genera ascend at a mean rate of 2.5 to 3.5 m/year (up to 20.6 m/year in some specific genera). The observed mean rate of change is less than predicted from the temperature increases for the region, possibly due to the influence of changes in moisture, lags in tree community response, etc. Whatever the cause(s), continued slower-than-expected migration of tropical Andean trees would indicate a limited capacity to respond to increasing temperatures, which may lead to increased extinction risks in the future.

In recent years, response of biomes was studied considering climate change scenarios[26]. In a CMIP3 A2 emission scenario (equivalent to a RCP 8.5 emission scenario regarding temperature rise), significant changes were observed in various biomes. For example, an increase in shrub surface were found in extensive areas of the puna. This trend is consistent between the different climate models. The same occurs with the paramos, and the seasonal and xerophytic montane forest. On the other hand, glaciers, the suprandina area (which occupies the area between the glaciers and the puna), the puna and the yungas forest showed large and consistent reductions in extension. In general, a climb was observed in the vegetation bands that characterize the Andes, but the puna was replaced by shrubs and not by the yungas forests. The projected advance of desert and xeric areas would impact local water availability and, in the lower parts of these areas, the capacity to provide environmental services would be reduced. So, this suggests a greater risk of water stress in some inter-Andean valleys.

Flores (2016)[45] analyzed the behavior of grasslands, wetlands and shrubs in a climate change intermediate scenario. His findings showed that the three types of ecosystems will change their surface due to the retreat of the glacier and the increase in temperature. This way, the area that is constituted by grasslands, wetlands and shrub-lands, which in 2010 represented 77.6% of the total extension of the puna, would be reduced to approximately 50% by the end of the century. In the case of the grasslands, these would reduce their extension, going from 15.4 to 4.6 million ha, while the

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[42] SEIMON, T.A., SEIMON, A., DASZAK, P., HALLOY, S.R., SCHLOEGEL, L.M., AGUILAR, C.A., SOWELL, P., HYATT, A.D., KONECKY, B. and E SIMMONS, J. (2007), Upward range extension of Andean anurans and chytridiomycosis to extreme elevations in response to tropical deglaciation. Global Change Biology, 13: 288-299. https://doi.org/10.1111/j.1365-2486.2006.01278.x

[43] Cuesta F., P. Muriel, S. Beck, R. I. Meneses, S. Halloy, S. Salgado, E. Ortiz y M.T. Becerra (Eds.). 2012. Biodiversidad y Cambio Climático en los Andes Tropicales - Conformación de una red de investigación para monitorear sus impactos y delinear acciones de adaptación. Red Gloria Andes. Lima-Quito. Pp 180.

[44] Feeley, K.J., Silman, M.R., Bush, M.B., Farfan, W., Cabrera, K.G., Malhi, Y., Meir, P., Revilla, N.S., Quisiyupanqui, M.N.R. and Saatchi, S. (2011), Upslope migration of Andean trees. Journal of Biogeography, 38: 783-791. https://doi.org/10.1111/j.1365-2699.2010.02444.x

[45] Flores, E. (2016) Cambio climático: pastizales altoandinos y seguridad alimentaria. INAIGEM. https://doi.org/10.36580/rgem.i1.73-80

wetlands would go from 0.5 to 0.2 million ha. In turn, the shrubs would substantially increase their extension over time, increasing from 2.8 to 7.1 million ha (Figure 21).

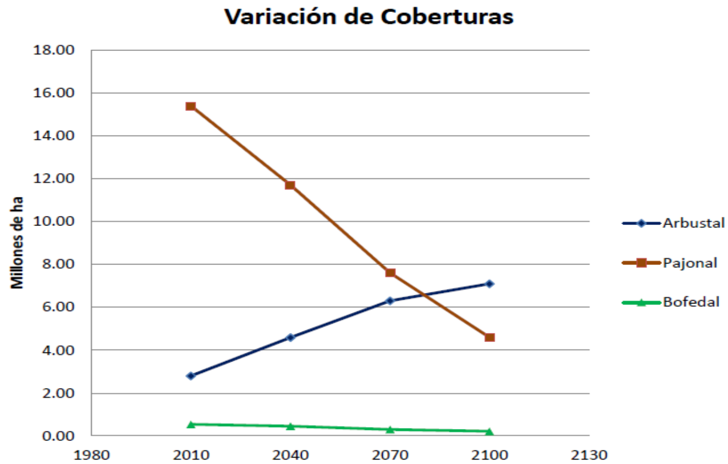


*Figure 21. Land cover extension from 2010 to projections towards the years 2040, 2070 and 2100 under a medium emission scenario, considering shrub-lands (blue line), pajonal areas (red line) and wetlands (green line). A clear decrease of pajonal areas is shown, while shrub-lands increase their extension. Wetlands show a slight decrease. Source: Flores, et. al (2016)*

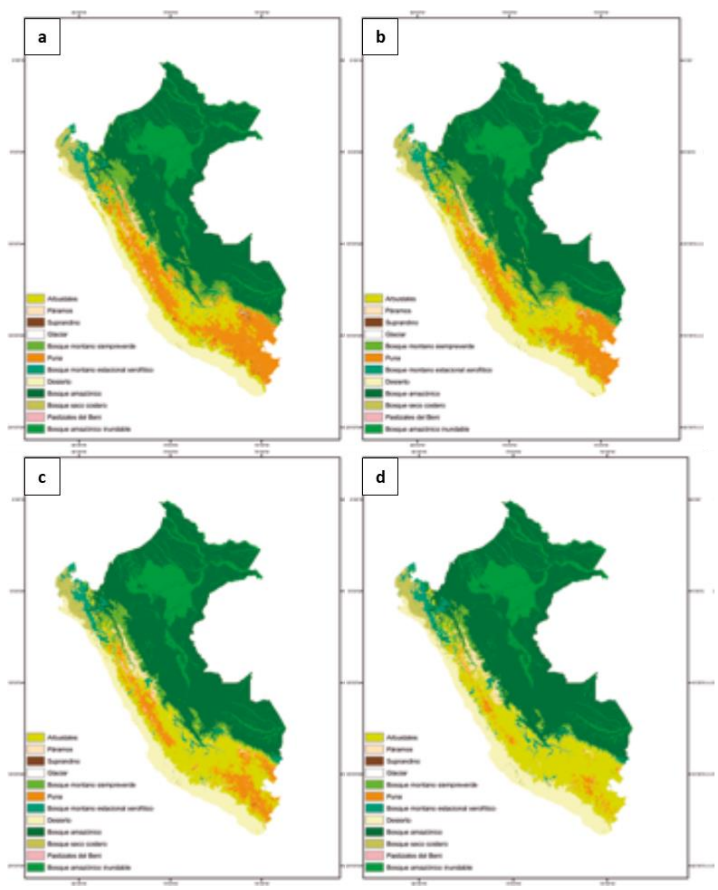


*Figure 22**.** Current (a) and Projected changes in biome extension under the A2 emission scenario (equivalent to RCP 8.5 regarding temperature increases) towards 2010-2039 (b), 2040-2069 (c) and 2070-2099 (d). Puna areas are the biomes that show large shrinkages; however, shrub-lands areas show increases, especially in the SHAP. Source: BID and CEPAL, 2014*

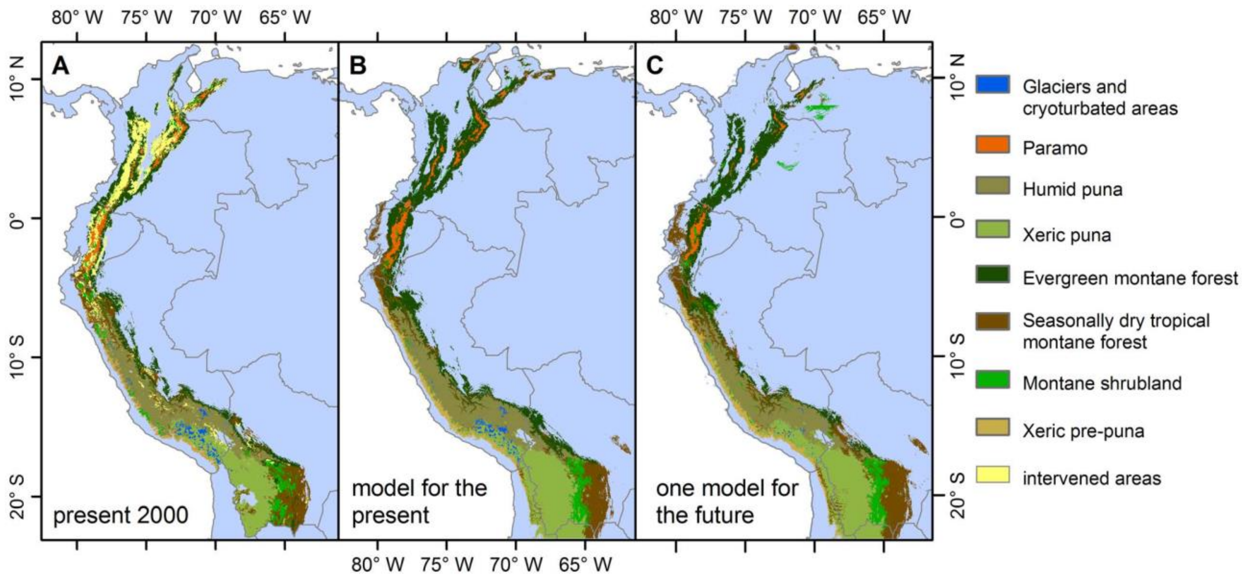


*Figure 23. Biome maps. Current (observed) biome map (A), modelled potential biome map for the present 2000 (B) and an example of future biome map (C) using climatic variables of model gfdl_cm2_0 for A1B 2040–2069 scenario. In the future biome distribution in the SHAP, glacier areas show an alarming decrease, while xeric puna and xeric pre-puna show increases in their extension. Source: Tovar et. al, 2013*

Other studies[25 34] predict a potential change of 25% in ecosystem distribution in the Andes by 2050. Glaciers, cloud forests and paramos are most vulnerable to climate change (Young et al., 2011 in Schoolmeester et al., 2016), with the highest relative loss of area being predicted for these ecosystems and tropical mountain forests such as Yungas. These losses can be explained by the direct impact of climate change on hydrology, and also by the high altitude of these ecosystems. Their altitude implies difficulty for species to migrate, a high rise in temperature and other factors resulting in fragility. However, this prediction does not take into account land-use change, which is the most damaging stressor on regional ecosystems (Magrin et al., 2014 in Schoolmeester et al., 2016).

The aforementioned predictions also indicate a reduction of evergreen forests, in favor of more seasonally dry forests. Additionally, other dry biomes (dry puna and shrub-land) are the ones whose lower limits are predicted to expand downward in response to climate change and increased water stress[46]. Variance in ability to migrate partly determines the implications of climate change on species and ecosystems. Features of species themselves and their environment can limit migration. For instance, peaks and steep valleys represent migration borders. Studies show faster upward migration in protected than in non-protected areas (Lutz et al., 2013 in Schoolmeester et al., 2016). However, authors indicate that the rate of migration is still too slow to match the predicted changes in climate.

Carbon stocks in Andean ecosystems are comparable with those in tropical lowland forests, especially when organic carbon stocks in the soil are considered (Spracklen and Righelato, 2014 in Schoolmeester et al., 2016). However, for Andean forest biomes, the limited carbon assimilation rates at higher elevations due to low night time temperatures might be overcome by a temperature increase induced by climate change. In the case of a reduction of up-slope or down-slope migration of plant populations, aboveground carbon storage will be reduced. Nevertheless, non-forested biomes such as the paramo, which have a simpler vertical structure, tend to have a larger belowground and soil carbon stock. So, impacts on carbon storage may differ[34].

[46] Tovar C, Arnillas CA, Cuesta F, Buytaert W (2013) Diverging Responses of Tropical Andean Biomes under Future Climate Conditions. *PLOS ONE 8*(5): e63634. https://doi.org/10.1371/journal.pone.0063634

**Conclusions:**

- Towards 2100, significant changes would be observed in several biomes. If no action is taken, the area that nowadays is covered by grasslands, wetlands and shrub-lands, would reduce its area coverage from 77.6% to approximately 50%. Grasslands would reduce their extension from 15.4 to 4.6 million ha, while wetlands would go from 0.5 to 0.2 million ha. In turn, shrubs would substantially increase their extension over time, increasing from 2.8 to 7.1 million ha.
- Forests species will either up-slope migrate at a rapid rate or disappear, if they do not have the capacity to keep up with the temperature increasing rates or if they face other barriers, such as peaks or steep valleys.
- Water stress conditions might lead to the expansion of dry biomes (dry puna, seasonally dry forests and shrub-land).
- Carbon storage will also change in different ways. Aboveground carbon storage will reduce for plants that tend to vertically migrate, but belowground storage may increase for non-forest biomes, which do not tend to vertically migrate.

### 3.5 Impacts on agriculture and livestock

**Agriculture**

According to BID and CEPAL (2014)[26], in Peru, agricultural activity is a sector vulnerable to climatic variations caused by anomalous events (such as floods, droughts, and ENSO events, which affect crop yield). 34% of the agricultural area is under irrigation and is concentrated on the coast, with more infrastructure than in the rest of the country. However, 66% of agriculture is developed under rainfed conditions, and is located mainly in the mountains. The Andean highlands have a deficit of water storage and irrigation infrastructure, despite having a higher volume of rainfall. Furthermore, they do not have a high potential for new soils for cultivation, due to its uneven territory. That is why droughts have especially negative effects in this area. The current state of agriculture in the Andes is shown in Figure 24 (a), which shows the main cultivated products and agriculture intensity.

A study of corn farmers in Peru found that in the last two decades, crops had been extended by 200-300 m up-wards (Skarbø and Lambrou, 2015 in Schoolmeester, et al., 2016)[25]. The crops adapted to the higher altitudes, however, are likely to suffer due to natural limitations to upward relocation. Potato and oca are examples of crops particularly threatened by climate change. For tubers to keep their nutritional properties, they require cold temperatures (Ortiz, 2015 in Schoolmeester, et al., 2016). Many farmers in the high Andes are pushed upward to maintain favourable temperatures for their crops. One study shows that potato farmers in the region have moved their crops upward by about 150 m in the last 30 years (Shaw and Kristjanson, 2013 in Schoolmeester, et al., 2016). Reduced frost in the high Altiplano also threatens the production of Chuño, freeze-dried potatoes, which for centuries have been a source of food security (Valdivia et al., 2013 in Schoolmeester, et al., 2016). Chuño is still an important food component for many in the region. Investment is needed to preserve the genetic resources of the Andean potatoes as well as to find substitutes capable of coping with the changing climate.

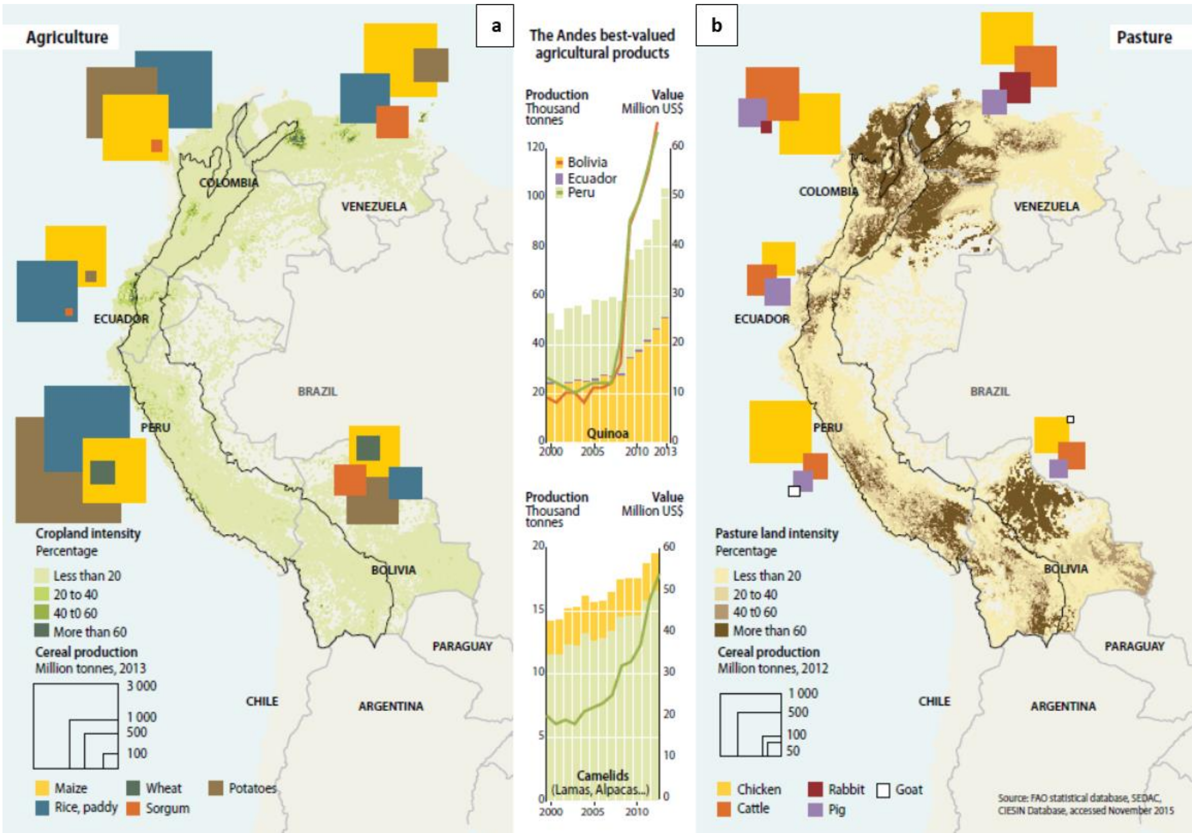


*Figure 24. Current state of the agriculture (a) and pasture (b) in the Andes. In the SHAP, potatoes and maize are the main cultivated products and the cropland intensity is less than 20% and one of the best-valuated products is quinoa. On the other hand, pasture production is mainly chicken, catlle, pig and goat, with a land intensity of more than 60% and one of the best-valuated products are camelids. Source: Schoolmeester et al., 2016.*

Agricultural vulnerability for each district in Peru were evaluated for the 2003-2010 period, taking in consideration twelve main crops were identified: potato, rice, hard yellow corn, cassava, coffee, cocoa, wheat, banana, starchy corn, barley grain, broad bean and bean grain; three main species of grasses and forages: alfalfa, forage oats and brachiaria. To estimate agricultural vulnerability, the main crops at the national level were taken into account, as well as vulnerability indices to the social system (IVSS), the productive system (IVSP) and the economic system (IVSE)[14]. Results for the SHAP indicate high and very high vulnerability.

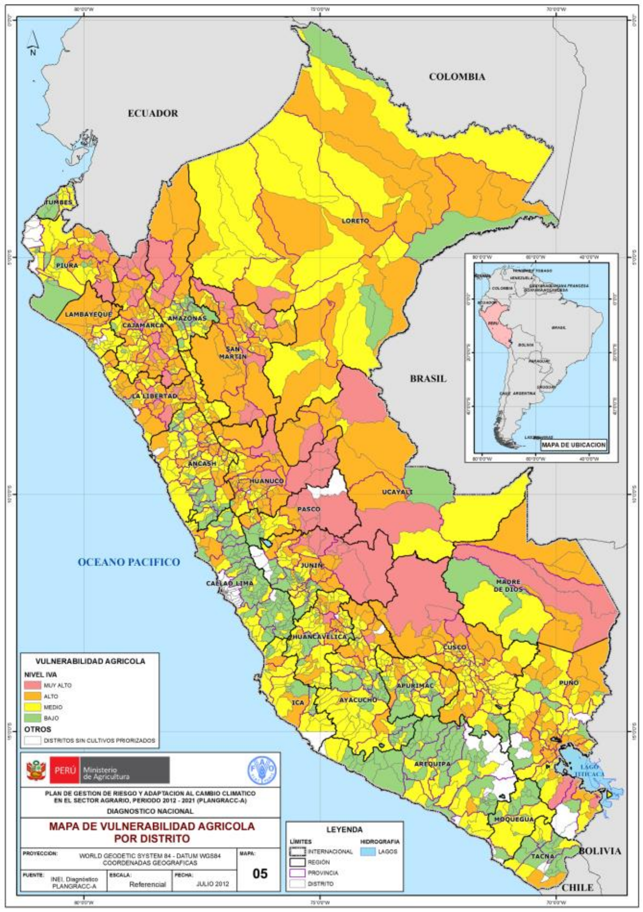


*Figure 25. Agricultural vulnerability for each district of Peru between 2003-2010. For the SHAP, high and very high vulnerability is shown. Source: MINAGRI, 2012.*

Sanabria, et al (2014) [47] examined the potential implications of the 2030 climate change scenarios for potato, corn, wheat, barley and broad bean crops in Cusco and Apurímac (SE subregion). The scenarios evaluated to 2030, which by the time indicated an increase close to 1 °C and a moderate increase in precipitation. The results obtained show advances in the harvest period, shorter growing seasons and, in some cases, a slightly higher risk of sowing failure. SENAMHI (2015) [48], evaluated crop yields according to projections of regionalized models towards 2050, according to which increases in maximum temperature (2 °C to 3 °C), minimum temperature (4 °C to 6 °C), and higher rainfall (10% to 20%) nationwide. Although in some places climate change will have positive impacts, there are negative impacts on SHAP. The obtained results show a lower yield of the potato crop in Apurímac and Cusco (SE subregion). Likewise, the onion yield in Arequipa (SW subregion) may have physiological imbalances and phytosanitary problems greater than those that are present now. With respect to the wheat crop, there are significant projections of a decrease in the wheat crop yield in two models in both emission scenarios for the Arequipa region. They also indicate that these changes in precipitation and temperature will change the behavior of pests and diseases in potato and onion crops, among others. Therefore, they recommend finding varieties that adapt to future climate change, and indicate that this challenge should be planned using the abundant germplasm that is available (more than 3,000 potato varieties), use of new phytosanitary technologies (efficient

[47] Sanabria J. & J. P. Lhomme. 2013. Climate change and potato cropping in the Peruvian Altiplano. Theor Appl Climatol 112:683–695.

[48] SENAMHI (2015). EVALUACIÓN DE LOS IMPACTOS DEL CAMBIO CLIMÁTICO SOBRE EL RENDIMIENTO DE LOS CULTIVOS EN EL PERÚ.

microorganisms, etc.), so as not to create tension in the food security and poverty of small families in rural areas.

**Livestock**

The raising of camelids and sheep is mainly carried out under extensive systems, highly dependent on climatic conditions for the generation of forage that feeds them and for the health of the animals[26]. Most cattle, sheep, and camelids in Peru are located between 2 200 and 4 500 masl, and are in charge of peasant communities, who use grasslands as a basic resource for feeding their animals. The current state of livestock in the Andes is shown in Figure 24 (b), which shows the main breeding animals and livestock intensity.The Puna ecoregion, where most of the extensive cattle ranching takes place, covers an area of more than 21 million ha of grasslands, wetlands, glaciers, bodies of water and protection areas, and is a key ecosystem for the national economy, for the environmental products and services it provides to society (Brown and MacLeod, 2011 in BID and CEPAL, 2014).

Similar to agricultural vulnerability, livestock vulnerability was also calculated. For this, the three main breeds have been taken into account: cattle, sheep and camelids. To estimate agricultural vulnerability, the main crops at the national level were taken into account, as well as vulnerability indices to the social system (IVSS), the productive system (IVSP) and the economic system (IVSE)[14]. Results for the SHAP indicate a very high vulnerability. Table 1 shows the value of loss of animals due to climatic hazards by political region between 2003 and 2010.

giz

**Valor de pérdida de animales, por peligros climatológicos, según región. 2003-2010**

Fuente:
MINAG/FAO, Plan de Gestión del Riesgo y Adaptación a los Efectos del Cambio Climático en el Sector Agrario para el periodo 2012 – 2021 PLANGRACC

| Región | Vacuno (soles) | Ovino (soles) | Camélidos (soles) |
|---|---|---|---|
| **Nacional** | **47 151 300** | **28 171 400** | **62 902 320** |
| Puno | 17 011 750 | 9 827 600 | 3 9 408 720 |
| Piura | 14 186 900 | 2 781 200 | - |
| Huancavelica | 4 331 250 | 6 023 200 | 5 704 320 |
| Apurímac | 2 918 300 | 1 393 950 | 5 179 200 |
| Cusco | 557 900 | 3 096 400 | 3 927 480 |
| Ayacucho | 4 415 950 | 869 500 | 1 848 840 |
| Arequipa | 1 668 100 | 1 345 000 | 3 303 360 |
| Pasco | 204 400 | 2 146 600 | 1 257 720 |
| Moquegua | 25 900 | 122 450 | 1 060 920 |
| Tacna | 7 700 | 11 800 | 1 061 880 |
| San Martín | 878 500 | - | - |

*Table 1. Value (in local currency) of loss of animals due to climatic hazards by political region between 2003 and 2010. In Cusco, Apurimac, Puno and Arequipa (SHAP), total losses are very high, especially in Puno, whose losses constitute more than 60% of the national total. Source: MINAGRI, 2012.*

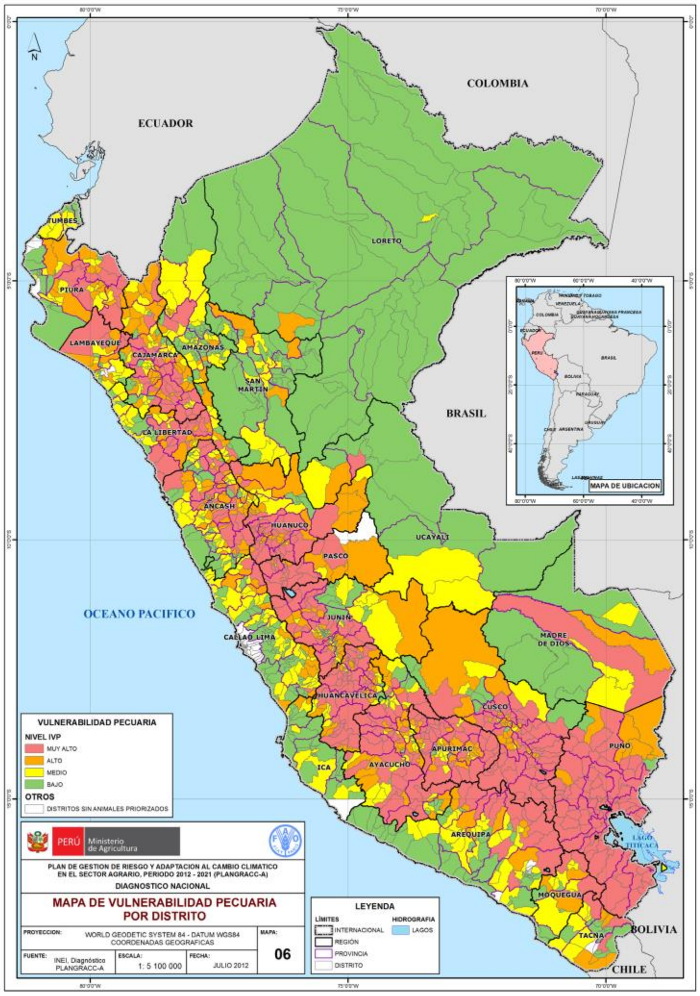


*Figure 26. Livestock vulnerability for each district of Peru between 2003-2010. For the SHAP, a generalized very high vulnerability is shown. Source: MINAGRI, 2012.*

To analyze the effect of climate change on livestock, it is essential to first analyze the effects on biomes (see section 3.4), especially grasslands. Flores (2016) calculated found a significant reduction in the extension of the grasslands, together with the lower relative productivity of the shrub vegetation and the expansion of agriculture. This would reduce the carrying capacity and the relative contribution of livestock to GDP (gross domestic product). Added to this, the reduction in wetlands, would hinder the development of livestock. This is particularly true in arid areas where these spaces are the main source of water supply in critical periods or in the absence of rain, such as in the dry puna.

To analyze of the impact of climate change on high Andean livestock, authors transformed all livestock species (sheep, cattle, camelids, equines, goats) that make use of the puna ecosystem into sheep units (SU) to, determine the variation in meat production[26]. Results for the three climate change scenarios (Figure 28) suggest a progressive reduction in the carrying capacity of ecosystems and a decrease in the available area of grazing land. The greatest impact would be for scenario A2 (similar to RCP 8.5), where sheep units would go from 45 million in 2010 to 19 million by the end of the century. The A1B scenario would follow, with reductions ranging from 45 million to 21 million for the same period. Finally, with fewer impacts, there would be scenario B1 (similar to RCP 4.5).

The reduction in the extension of the grasslands, together with the lower relative productivity of the shrub vegetation and the expansion of agriculture, would reduce the carrying capacity and the relative contribution of livestock to GDP. Added to this, the reduction in wetlands - a strategic resource, since they constitute an important source of forage during periods of drought - would hinder the development of livestock. This is particularly true in arid areas where these spaces are the main source of water supply in critical periods or in the absence of rain, such as in the dry puna[26].

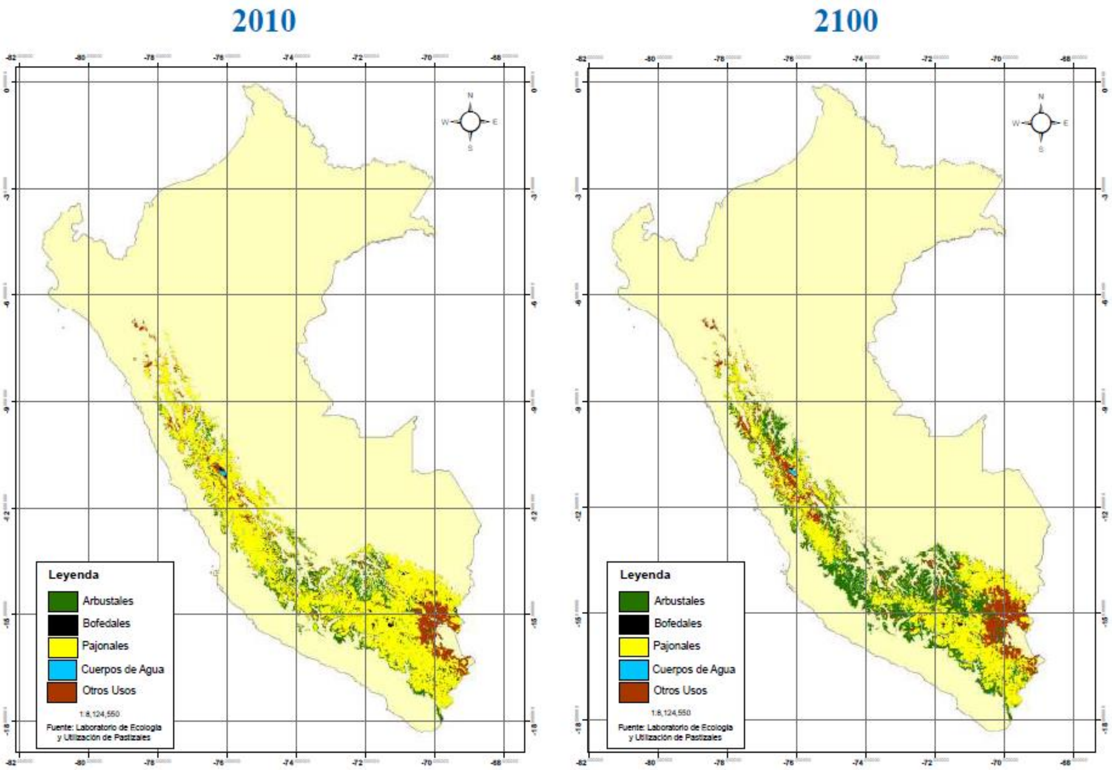


*Figure 27. Temporal variation in vegetation cover and land uses of the Puna for current (2010) and future (2100) extension. Wetlands and pajonal areas show a tendency to reduce their area coverage; while shrublands would increase, as well as other uses. Source: Flores (2019).*

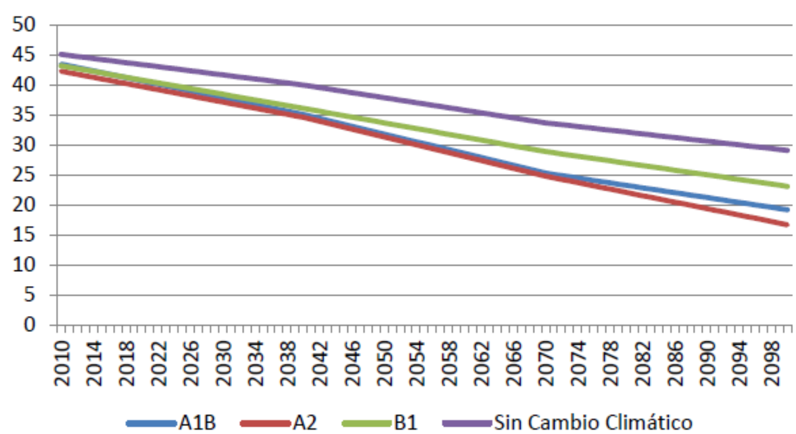


*Figure 28. Impact of climate change on the total animal load for the Puna in different CMIP3 emissions scenarios towards 2100, x axis show the year and y axis shows millions of sheep units. In all emission scenarios, a decrease is obvious. Higher decreases take place in higher emission scenarios. Source: Bid and CEPAL (2014).*

According to Schoolmeester et al. (2016), Climate change is also threatening high mountain grasslands important to pastoral communities. The southern Tropical Andes are also home to two wild species of camelids, vicuñas and guanacos. Both provide significant income for local farmers through their fine wool, which is the most expensive in the world. The animals are caught, sheared and then released back to the wild. However, sustainable ecosystem management is required to prevent pastoralism of domesticated animals from pushing these wild animals out of their grazing areas or infecting them with diseases.

**Conclusions:**

- Climate change projections towards 2050 indicate a general decrease in crop yields in the SHAP. The onion yield in the SW may have physiological imbalances and phytosanitary problems. There are significant projections of a decrease in the wheat crop yield in Arequipa (SW subregion). A lower yield of the potato crop in the SE subregion is also expected. For tubers to keep their nutritional properties, they require cold temperatures.
- Many farmers of potato and oca in the high Andes are pushed upward. Reduced frost in the high Altiplano also threatens the production of Chuño (freeze-dried potatoes), a source of food security for centuries.
- Agricultural vulnerability is high and very high in dictricts of the SHAP.
- Livestock vulnerability is very high in the SHAP districts. Recent losses calculations due to climatic hazards evidence an alarming monetary total loss.
- Most cattle, sheep, and camelids in Peru are located between 2 200 and 4 500 m asl, and they are fed by grasslands in the Puna ecoregion. However, reduction in the extension of the grasslands, together with the lower relative productivity of the shrub vegetation and the expansion of agriculture, would reduce the carrying capacity from 45 to 20 million of sheep units towards the year 2100.

### 3.6 Socioeconomic impacts

The interdependence of nature and society, at multiple levels, is changing in the high Andean territory, which is inhabited mainly by peasant farmers. The displacement of the ecological layer, the ecological processes that have not been studied and the change in the water level are some of the manifestations of this transformation.

In low-income countries, the sectors most sensitive to climate change, the percentage of GDP is more important because in these countries agriculture plays a fundamental role in creating jobs and producing value. In these countries, due to reduced availability of public services, reduced institutional development, and slower development of financial markets, the vulnerability of the population may be greater. Furthermore, due to the little development of solid institutions, the capacity to adapt to change is less in these countries (Amat and León, 2008) [49].

Despite everything, Peru has made rapid progress in human development in recent years, thus reducing its vulnerability to climate impacts. Careful observation reveals that certain groups of people are still excluded from this progress and that, in the future, climatic influences may make people more vulnerable than before. Given that approximately one in five Peruvians are poor, high incidence rates in rural areas, the urban poor, and significant inequalities between ethnic groups and genders, there are some segments of society that will be particularly vulnerable to climate impacts, as who are deprived of assets, skills, voice and access to services (Bergmann et al., 2021) [50].

[49] Amat y Leon, Carlos. (2008). El Cambio Climático no tiene Fronteras. Secretaría general de la comunidad Andina. https://hdl.handle.net/20.500.12543/4600

[50] Bergmann, J., Vinke. & Fernández. (2021). Assessing the Evidence: Climate Change and Migration in Peru. Geneva, SWI: International Organization for Migration

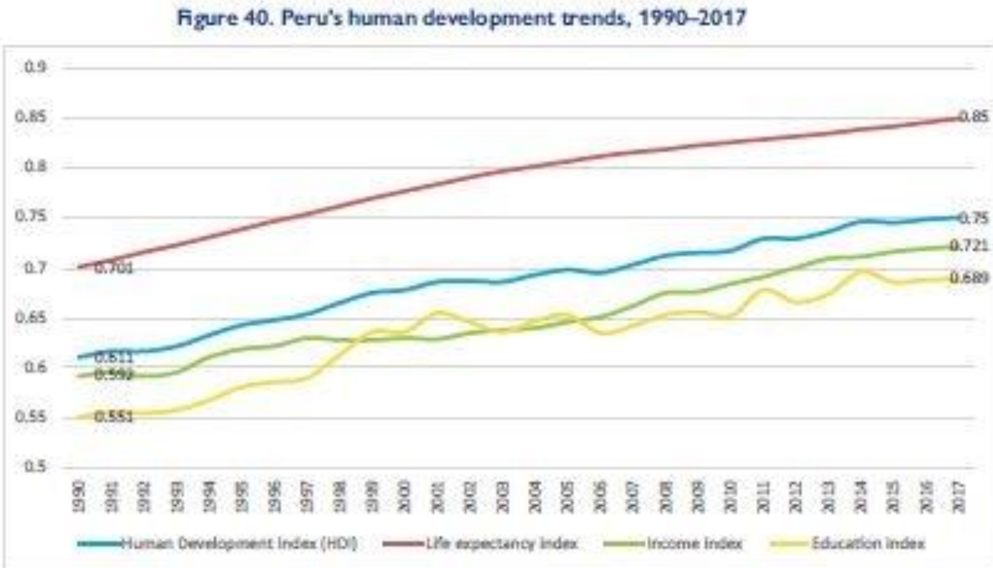


*Figure 29. Trends in human development in Peru. Reproduced by Jonas Bergman and based on data from UNDP (2018, p.2)* [51].

One of the main concerns is that climate change may undo much of Peru's recent progress and plunge many people into new vulnerabilities. For instance, the COVID-19 pandemic showed that external shocks can undermine previous development achievements, with immigrants and displaced persons being the groups most at risk due to lack of basic services and information asymmetry (UNDP, 2020) [52].

**Vulnerability in the Andes**

Vulnerabilities are often related to people's socio-economic status. In many mountainous areas, poverty, insufficient property rights and resources, poor soil quality, poor infrastructure and basic services, and a lack of quality education generate vulnerabilities (Oliver-Smith, 2014) [53] observe an incidence of poverty 55% in their large-scale survey of more than 46,000 farm households in the Peruvian highlands. In a study carried out in Puno by Cavagnoud (2018) [54], almost two thirds of the surveyed families had irregular income. Only a third could cover the food expenses of all their children and only a third could cover their education costs. Virtually all households live in simple adobe houses, and one-third lack access to water (Sperling et al., 2008) [55].

[51] United Nations Development Programme (UNDP). Human development indices and indicators: 2018 statistical update. Briefing note for countries on the 2018 statistical update – Peru. New York

[52] United Nations Development Programme (UNDP). Covid-19 and external shock: Economic impacts and policy options in Peru. Report. New York. Available at www.latinamerica.undp.org/content/rblac/en/home/library/crisis_prevention_and_recovery/covid-19-y-el-schock-externo--impactos-economicos-yopciones- de-.html.

[53] Oliver-Smith, A. (2014) Climate change adaptation and disaster risk reduction in highland Peru. In: Adapting to Climate Change: Lessons from Natural Hazards Planning (B.C. Glavovic and G.P. Smith, eds.). Springer, Dordrecht, Netherlands, pp. 77–100.

[54] Cavagnoud, R.T.F. (2018) Vulnerabilidades medioambientales y migraciones juveniles desde las comunidades altoandinas cercanas al Lago Titicaca (Perú) (Environmental vulnerabilities and youth migrations from the high Andean communities near.

[55] Sperling, F., C. Validivia, R. Quiroz, R. Valdivia, L. Angulo, A. Seimon and I. Noble (2008) Tran-sitioning to climate resilient development: Perspectives from communities in Peru. Climate Change Series Environment Department Papers No. 115. World Bank, Washington, D.C.

Specifically among the Andean population in Peru, in rural areas where the system of small agricultural producers dominates, this pattern of influence is articulated in an environment of high vulnerability. These systems face difficult conditions related to environmental processes that degrade the resource base (such as soil erosion) and socioeconomic processes that affect the well-being of rural residents (Carrasco et al, 2011) [56]. A significant percentage of its economy and workforce depends on climate-sensitive primary activities, such as agriculture and fishing, and on its natural resources. According to surveys carried out in Apurimac, the loss of production due to drought caused by potato production was 69% and corn 65%. Most of the products from this region will be used for self-consumption (Llosa, 2009) [57].

**Climatic migrations**

Changes in the rainfall pattern (along with other reported impacts, such droughts) can also induce changes in the livelihood sector, as shown by a study in Cusco, where farmers move to economies. based on livestock to survive, with long-term consequences for ecosystem governance and future vulnerabilities (Lennox and Gowdy, 2014) [58].

A considerable proportion of family members of migrants indicate that "environmental problems" play some role in the migration decision. In addition to permanent migration, circular movements are also common. Sperling et al. (2008)[43] describe the habitual migration of young people in search of work in Puno. Given the disadvantages of the small farmer's market, entire families sometimes leave to improve their income. Some households close enough to cities travel daily, constantly or sporadically. According to a survey carried out in the Apurimac region, in the last five years, 50% of the relatives of the inhabitants of that region have emigrated due to the drought, being the provinces of Grau (76%) and Aymaraes (75%) the provinces with the highest immigration according to the proportion of cases (Llosa, 2009)[45].

Some migrate across the border, but the majority (37% of migrants), especially young people, migrate to Lima temporarily. Some women move to Argentina, while others go to Lima. Crespeigne et al. (2009) [59] distinguish two common migration seasons from Huancavelica, mainly the school break from December to April and, to a lesser extent, that from July to August. Demographic stress and landlessness have contributed to emigration. A study of five indigenous communities from the highlands in Cusco describes transhumance as an inherent characteristic of their lifestyles (Cometti, 2018) [60].

Some highland communities use migration to anticipate or react to hazards. In terms of temperature-related hazards, Sperling et al. (2008)[43] mention the emigration of communities from the highlands of Puno, especially of young people, and frosts and droughts drive migration in the six communities.

[56] Carrasco, Jorge & Casassa, Gino & Pizarro, Roberto & Saravia Lopez de Castilla, Miguel. (2011). Impactos del Cambio Climático, Adaptación y Desarrollo en las Regiones Montañosas de América Latina. 10.13140/RG.2.1.2926.6804.

[57] Llosa, Jaime (2009). Los andes altiplánicos frente al cambio climático global. Potenciales escenarios de conflictos socioambientales y "soluciones" que el norte nos impone que llevan inexorablemente al ecocidio. DESCO, Centro de Estudios y Promoción del Desarrollo. http://bibliotecavirtual.clacso.org.ar/Peru/desco/20100312095043/05_Llosa.pdf

[58] Lennox, E.; J. Gowdy (2014) Ecosystem governance in a highland village in Peru: Facing the chal-lenges of globalization and climate change. Ecosystem Services, 10:155–163

[59] Crespeigne, E., E. Olivera, R. Ccanto and M. Scurrah (2009) Exploración de las estrategias y prácticas de una comunidad campesina de los Andes Centrales frente a los riesgos extremos aso-ciados al cambio climático (Exploring the strategies and practices of a Central Andes mountain community facing extreme risks associated with climate change). In: Perú : el problema agrario en debate (Peru: The Agrarian Problem in Debate) : Seminario SEPIA XIII (P. Ames and V. Caba-llero, eds.). Tarea Asociación Gráfica Educativa, Lima, pp. 260–290.

[60] Cometti, G (2018) Changement climatique et crise des relations de réciprocité dans les Andes pé-ruviennes: Les Q'eros et l'Anthropocène (Climate change and the crisis of reciprocal relationships in the Peruvian Andes: The Qeros and the Anthropocene). In: Penser l'Anthropocène (Thinking about the Anthropocene) (R. Beau and C. Larrère, eds.). Presses de Sciences Po, Paris, pp. 235–247.

Crespeigne et al. (2009) state that after an episode of rainfall deficiencies investigated in a community in Puno in 2007, 31 percent of those surveyed migrated or looked for work as vendors, waiters and shoe-shiners to smooth out income losses in places like Lima and other cities, or by working in mines and in agribusiness. In more regular times, temporary migration was also among the main diversification strategies of subsistence farmers in the highlands: 54% of households had at least one member who was a temporary migrant. The use and duration of such migration increased when harvests were unsatisfactory. The authors suggest that temporary migration is often an option of last resort (Bergmann et al., 2021).

Climate change is a second main reason, after education, behind the movement of those who have already left. Permanent migrants maintain a network with their areas of origin and visit them frequently. Five of the eleven potential migrants interviewed cite climate change as their migration motivation. Migration also triggers change: with people leaving, there is a shortage of labor in agriculture and traditional planting practices, rituals and knowledge are lost, all of which could ultimately increase vulnerability in the future (Lennox, 2015).

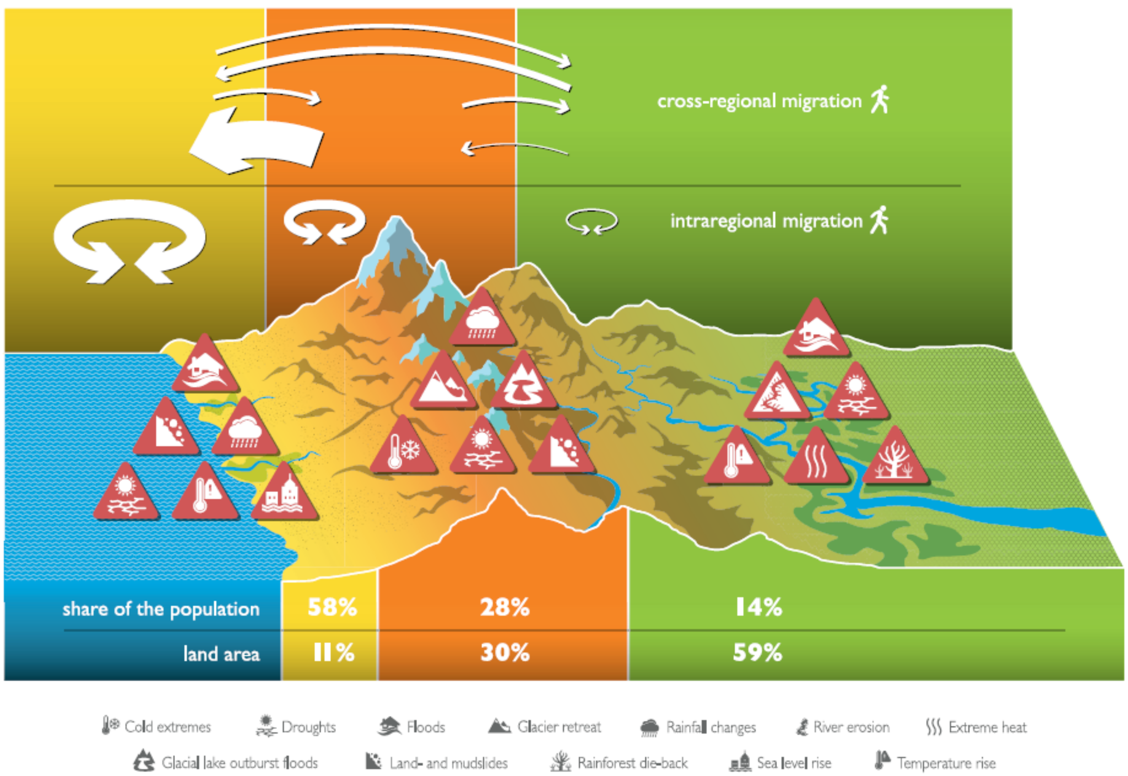


*Figure 30. Conceptual model of climate migration across geographical regions in Peru. In the SHAP, which corresponds to high altitudes, the main factors that produce migration are rainfall changes, glacier retreats, glacial lakes outbursts floods, cold extremes, droughts and land and mud slides. Source: Jonas Bergmann, 2021.*

**The gender gap**

In rural areas, the relationship between final energy access and consumption and gender roles is very evident. Rural areas have very limited access to electrification services, with biomass being the main source for power generation. The energy poverty of many rural households in Peru has exacerbated the gender gap because it is women and girls who are in charge of collecting firewood and bagasse, which requires time and energy to allocate other activities such as education, production and recreation. In addition, they tend to be at higher risk, because the collection location is usually far from home. Women in rural areas cook an average of 19 hours and 41 minutes a week. If we consider that 68.5% of rural households use firewood and dung for cooking, and 16% of households use excrement for cooking, we can understand the important role that women play in protecting the environment and public health, as well as in the use of technologies that pollute less (MIMP, 2012) [61].

In energy management, forest management activities are generally differentiated by gender. Men are often interested in forests through the timber trade, while women are engaged in the use and management of forest products to maintain livelihoods, food, small-scale agriculture and health (fuelwood, medicines, natural fertilizers). Women generally know well about forests in terms of species diversity, management and use for various purposes, and have a good understanding of conservation practices (FAO, n.d.) [62]. For men, studies have shown that, in general, when they receive economic income from logging activities, their motivation to participate in conservation actions weakens (Aguilar et al., 2011) [63]. These differences make it possible to determine the degree of vulnerability and the capacity of men and women to respond to the effects of climate change (FAO, 2013) [64].

Due to the fact that many homes in rural areas do not have drinking water and electricity services, there is a greater dependence on natural resources that are threatened by climate change. In this context, the situation of women in rural areas, who are the main responsible for feeding their families, worsens. This problem is also recurrent in peripheral urban areas, such as settlements, where the persistence of limited access to basic services of drinking water and electricity is confirmed. (IUCN, 2016).

In the communities studied, there is evidence that gender inequality aggravates the vulnerability of women to the impacts of climate change: restricted access to productive economic resources; dependence on water, firewood, crops and other natural resources to support their families; less access to credit, financing and job opportunities; high illiteracy rate (which is especially high among women), low level of education, information and training; low degree of autonomy, inability to participate in decision-making in community life. Furthermore, a gender diagnosis carried out in five departments in Peru showed that women have little access to education, live in rural areas, and do not have access to public services (USAID, 2013) [65]. In that sense, despite the fact that indigenous women depend to a greater extent on forest resources and wildlife, they do not participate in the decision-making space and community leaders often do not pay attention to their concerns. (IUCN, 2016).

**Conclusions**

- The chosen districts in the SHAP cover mostly rural areas, where the system of small agricultural producers dominates. This pattern of influence is articulated in an environment of high vulnerability.
- Some highland communities use migration to anticipate or react to hazards. The occurrence of outmigration due to climate extremes, such as frosts or rainfall deficits, especially of young

[61] MIMP. (2012). Plan Nacional de Igualdad de Género 2012-2017. Recuperado de http://www.mimp.gob.pe/files/planes/planig_2012_2017.pdf

[62] FAO. (n.d.). La FAO, los bosques y el cambio climático. Recuperado de http://www.fao.org/docrep/017/i2906s/i2906s00.pdf.

[63] Aguilar, L., Quesada-Aguilar, A. And Shaw, D.M.P. (eds) (2011). Forests and Gender. Gland, Switzerland: IUCN and New York, NY: WEDO.

[64] FAO. (2013). Los bosques, la seguridad alimentaria y el género: vínculos, disparidades prioridades para la acción. Recuperado de http://www.fao.org/docrep/018/mg488s/mg488s.pdf

[65] USAID. (2013a). Diagnóstico de género en la Amazonía. Amazonas, Loreto, Madre de Dios, San Martín y Ucayali. Recuperado de http://www.unfpa.org.pe/WebEspeciales/2013/Nov2013/25NOV/USAID-PRODES-Diagnostico-Genero-Amazonia.pdf

people from highland communities is a common practice. This happens particularly for very high mountain communities (above 3 900 masl), where migration is the second most important coping strategy when confronted with food scarcity.

- Women have fewer opportunities to develop mitigation strategies to adapt to the adverse effects of climate change. The energy poverty of many rural households in Peru has exacerbated the gender gap because it is women and girls who are in charge of collecting firewood and bagasse, which requires time and energy, so they cannot perform other activities such as education, production and recreation. In addition, they tend to be at higher risk, because the collection location is usually far from home.

# 4. Annexes

## 4.1 Methodology

### 4.1.1 Data

Tables and maps were created in order to characterize the recent climate (of the last decades) of the intervention area, as well as the future climate based on the RCP 4.5 and RCP 8.5 scenarios. The period that was analyzed for the recent climate was from 1981 to 2016 and for the future climate, from 2036 to 2065. The variables that were used were maximum temperature (Tx), minimum temperature (Tn) and precipitation (Pr).

To characterize the current climate and that of recent years, data from the PISCO product (Peruvian Interpolated data of the SENAMHI's Climatological and hydrological Observations) (Aybar, et al., 2018; Huerta, et al., 2018) [66] [67] were used. This is a gridded product (in grids) that provides data on maximum temperature, minimum temperature and precipitation at a spatial resolution of 10 km and daily and monthly temporal resolution from 1981 to 2016. SENAMHI Peru was developed based on meteorological stations from long records and satellite images CHIRPS, TRMM and MODIS.

The precipitation and temperature variables of PISCO were developed in a different, although similar way. In the case of PISCO precipitation, bias corrections and calibrations were made on the products CHIRPm, CHIRPd (CHIRPS monthly and daily, respectively) and TRMM (Aybar, et al., 2018). After this, a union of these products was made with the observations of meteorological stations that were used through the Residual Ordinary Kriging (ROK) method and finally, the monthly data were statistically corrected (Aybar, et al. 2018). It is important to highlight that this product will have greater confidence in areas where there are direct meteorological observations; that is to say, weather stations. On the contrary, confidence will be lower where there are not many weather stations. In the specific case of the southern highlands of Peru, several meteorological observation points are observed, but most of them are below 3500 meters above sea level.

PISCO temperature was developed using daily and monthly data from weather stations and MODIS satellite images. The Geographic Weighted Regression Kriging (GWRK) and Regression Splines (RSPLINES) methods were used and the results were evaluated through cross validation (Huerta, et al., 2018). Thus, a good reduction in general was demonstrated, although the same authors indicated that it cannot be safely assumed if this product is reliable in areas far from the points of meteorological stations, due to the limited information and topographic complexity.

[66] Aybar, C.; Fernández, C.; Huerta, A.; Lavado-Casimiro, W.; Vega, F.; Felipe-Obando, O. (2019). Construction of a high-resolution gridded 1 rainfall dataset for Peru from 1981 to the present day. Hydrological Sciences Journal.

[67] Huerta, A.; Aybar, C.; Lavado-Casimiro, W. PISCO temperatura v.1.1. SENAMHI - DHI-2018, Lima-Perú.

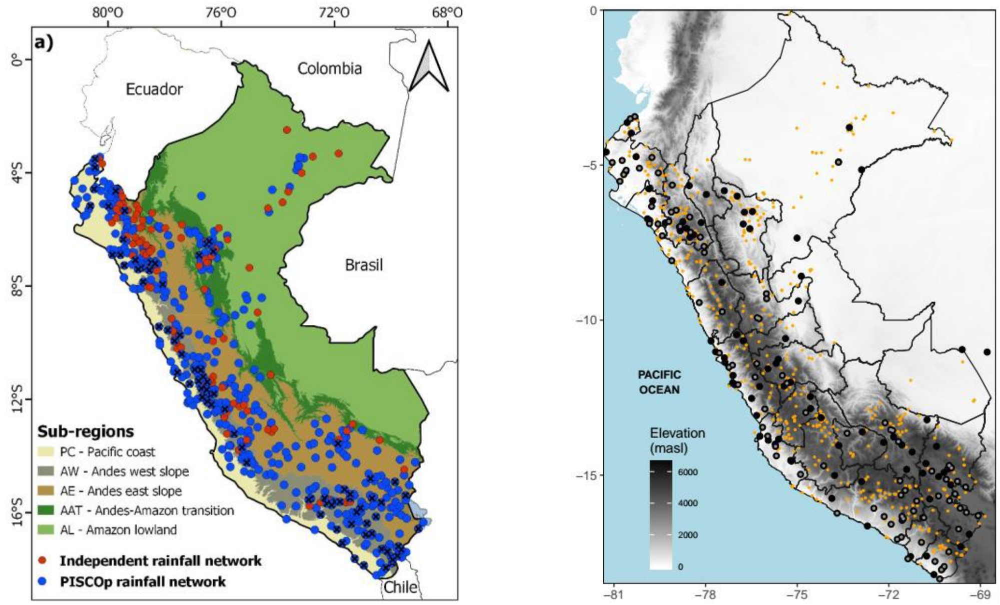


*Figure 31. a) Points of meteorological stations that were used for the development of PISCO precipitation (Source: Aybar, et al., 2018) and b) points of meteorological stations that were used for the development of PISCO temperature in black. Source: Huerta, et al. (2018).*

To characterize the climate in the RCP4.5 and RCP8.5 scenarios, the HadGEM2-ES RCA4 model was used. Previously, the information of the dynamically regionalized CMIP5 models of the CORDEX project (Coordinated Regional Climate Downscaling Experiment, https://cordex.org/), which has several regionalized models for South America and is freely accessible, was reviewed. Within these models, it was decided to choose the HadGEM2-ES-RCA4 model (Strandberg et al., 2014) [68], which contains the HISTORICAL, RCP4.5 and RCP8.5 experiments with a spatial resolution of approximately 50 km and a spatial resolution daily and monthly. This model was chosen for three main reasons. First, because it uses the HadGem2-ES model as a global model. Previously done analyzes for the choice of global climate models for Peru, HadGEM2-ES is one of the models that best represents the southern Andes of Peru (e.g., Barreto Schuler, 2016) [69]. Second, because studies carried out by SENAMHI that compare the CORDEX project models, which are still under review, also indicate that this is one of the best models of this project for the Peruvian Andes. Third, because this model contains simulations for the RCP4.5 and RCP8.5 scenarios.

### 4.1.2 Methods

#### Historical climate

The climatology (interannual averages of 30 years or more) of maximum temperature, minimum temperature and precipitation from 1981 to 2016 was calculated. In the case of temperatures, seasonaly and annual averages were calculated first and then interannual averages were calculated. In the case of precipitation, the seasonaly and annual accumulated were first calculated and then the interannual averages were calculated. Spatial averages were then made for each district and for each region.

[68] Gustav Strandberg, Lars Bärring, Ulf Hansson, Christer Jansson, Colin Jones, Erik Kjellström, Michael Kolax, Marco Kupiainen, Grigory Nikulin, Patrick Samuelsson, Anders Ullerstig and Shiyu Wang.(2014). CORDEX scenarios for Europe from the Rossby Centre regional climate model RCA4.

[69] Barreto Schuler, CW. 2016. COMPORTAMIENTO DE LA ALTA DE BOLIVIA HACIA FINALES DEL SIGLO XXI BAJO EL ESCENARIO DE EMISIÓN RCP8.5. s.l., Universidad Nacional Agraria La Molina. 105 p.

Subsequently, the trends of these variables were calculated for each region and district of intervention. The trends were calculated by estimating the slope Sen (Sen, 1968) [70], which is a robust non-parametric method of linear regression that allows to quantify the trend as change per unit of time in a series. Additionally, its statistical significance was calculated with the non-parametric Mann-Kendall method (Kendall & Stuart, 1967; Mann, 1945) [71] [72]. These calculations will be described in the next section together with the equations used.

To estimate trends for districts, the coordinates of their centroids were first calculated and trends for those midpoints were obtained. This methodology was chosen because the districts occupy relatively small areas and their trends do not change much from one point to another within the same area.

**Climate projections toward 2050**

Annual and seasonal climatologies of Tx, Tn and Pr were calculated for the HISTORICAL experiment (from 1981 to 2005), RCP4.5 and RCP8.5 (from 2036 to 2065 in both scenarios). Both climatologies were compared to generate the changes that would occur in the variables analyzed through a subtraction of their annual and seasonaly climatologies; that is, Equations 1 and 2 were used. Subsequently, the trends of these climatic variables were calculated in the RCP4.5 and RCP8.5 scenarios using the same method indicated in section 2.2.1.

$$\Delta T_i = \overline{T}_{i(2036\text{-}2065)} - \overline{T}_{i(1981\text{-}2005)} \quad \text{.................................(Equation 1)}$$

Where,

***ΔTi*** = Average annual temperature change to 2050 (2036-2065) compared to 1981-2005 in the temporal aggregation ***i*** (monthly, annual, seasonal, semi-annual, etc.) in ° C.

$\overline{T_i}_{(2036\text{-}2065)}$ = Multi-year average temperature in the years 2036-2065 in the temporal aggregation ***i*** (monthly, annual, seasonal, semi-annual, etc.) in °C.

$\overline{T_i}_{(1981\text{-}2005)}$ = Multi-year average temperature in the years 1981-2005 in the temporal aggregation ***i*** (monthly, annual, seasonal, semi-annual, etc.) in °C.

$$\Delta P_i = \frac{\overline{P_i}(2036-2065) - \overline{P_i}(1981-2005)}{\overline{P_i}(1981-2005)} * 100\% \quad \text{.................. (Equation 2)}$$

Where,

***ΔPi*** = Change in multiannual average rainfall to 2050 (2036-2065) compared to 1981-2005 in ***i*** (monthly, annual, seasonal, semi-annual, etc) en %.

$\overline{P_i}_{(2036\text{-}2065)}$ = Multi-year average of precipitation in the years 2036-2065 in ***i*** (monthly, annual, seasonal, semi-annual, etc) en mm.

$\overline{P_i}_{(1981\text{-}2005)}$ = Multi-year average of precipitation in the years 1981-2005 in ***i*** (monthly, annual, seasonal, semi-annual, etc) en mm.

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[70] Sen, P.K. 1968. Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association, 63:1379-1389.

[71] Kendall, M. A.; Stuart, A. The advanced theory of statistics. 2nd ed. Londres: Charles Griffin, 1967.

[72] Mann, H. B. Non-parametric tests against trend. Econometrica, v. 13, n. 3, p. 245-259, 1945.

**Equations used to calculate trends and their significance**

a) The Sen slope

If there is a linear trend in a time series, then the “correct” slope can be estimated using a non-parametric procedure developed by Sen (1968), (Drápela & Drápelová, 2011) [73]. The linear model is written as follows:

$$f(t) = Qt + B$$ …………………(Equation 3)

Where, Q is the slope and B is the constant. To estimate the slope Q, the slopes of all pairs are calculated with the following equation:

$$Q_i = \frac{x_j - x_k}{j - k}, i = 1, 2, \ldots N, j > k$$ …………(Equation 4)

The slope estimator Sen is the median of these N values of Qi; that is, as follows:

$$Q = \begin{cases} Q_{\frac{N+1}{2}} & \text{If } N \text{ is odd} \\ \frac{1}{2}\left(Q_{\frac{N}{2}} + Q_{\frac{N+2}{2}}\right) & \text{If } N \text{ is even} \end{cases}$$ ……….. (Equation 5)

Then, a 100 (1-α) % confidence interval is obtained around the slope with a non-parametric technique based on normal distribution. This method is valid if N is small, unless there are many bindings. To obtain the value of B (Equation 3), the original equation is solved from the equation of the original model of the slope of Sen, with which it remains to calculate xi - Qti. The median of the values obtained would be the estimated B. Estimates for the constant B at 99% and 95% confidence intervals are calculated in a similar way. (Drápela & Drápelová, 2011).

b) The Mann-Kendall Test

The computational procedure for this test is as follows: the data values are considered as an ordered time series. Each value is compared with all the subsequent data values. If a data value from a later time period is greater than the data value from a previous time series, the S statistic increases by 1. However, if the data value from a later time period is less than the previous data, S decreases by 1 (Drápela & Drápelová, 2011). The net result of all these provides the final value of the statistic S. Thus, the calculation is shown with the following equation and function:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k)$$

$$sgn(x_j - x_k) = \begin{cases} +1 & if \quad x_j - x_k > 0 \\ 0 & if \quad x_j - x_k = 0 \\ -1 & if \quad x_j - x_k > 0 \end{cases}$$

[73] Drápela, K., & Drápelová, I. (2011). Application of Mann-Kendall test and the Sen’s slope estimates for trend detection in deposition data from Bílý Kříž (Beskydy Mts., the Czech Republic) 1997–2010. Beskydy, 133-146..

*Functions used in the Mann-Kendall test when there are less than 10 data points. xj and xk are the annual values in years j and k (j is greater than k)*

For series of less than 10 data, the S test is used and for time series with 10 or more data, a normal approximation given by the calculation of Z is used. The variance in this case, is calculated as shown in Equation 6, where q is the number of linked groups and tp is the number of data in the p-th group.

$$VAR(S)=\frac{1}{18}\left[n(n-1)(2n+5)-\sum_{p=1}^{q}t_p(t_p-1)(2t_p+5)\right] \quad \text{.............(Equation 6)}$$

$$Z=\begin{cases}\frac{S-1}{\sqrt{VAR(S)}} & if\ S>0\\ 0 & if\ S=0\\ \frac{S+1}{\sqrt{VAR(S)}} & if\ S<0\end{cases} \quad \text{.............(Equation 7)}$$

Where, xj and xk are the annual values in years j and k (j is greater than k).

A positive value of Z indicates a positive trend; while a negative value will indicate a negative trend. The Z statistic has a normal distribution. To find out or test whether it has a positive or negative monotonic trend at a significance level α, Ho is rejected if:

$$|Z| > Z_{1-\alpha/2}$$

Where, Z1-α / 2 is obtained from cumulative normal distribution tables.

### 4.2 Results of climatologies, climate trends and climate change projections

### 4.2.2 Historical means in political regions

| Region | Historical climatologies | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pr annual | Pr DJF | Pr MAM | Pr JJA | Pr SON | Tx annual | Tx DJF | Tx MAM | Tx JJA | Tx SON | Tn annual | Tn DJF | Tn MAM | Tn JJA | Tn SON |
| **Apurimac** | 789.7 | 203.8 | 189.3 | 17.6 | 114.6 | 18.9 | 20.2 | 18.3 | 18.8 | 20.4 | 4.9 | 5.9 | 5.1 | 2.5 | 5.2 |
| **Arequipa** | 210.7 | 36.8 | 57.6 | 3.4 | 15.4 | 21.5 | 22.0 | 21.8 | 20.1 | 21.9 | 6.2 | 6.4 | 7.2 | 3.6 | 5.3 |
| **Cusco** | 1429.2 | 472.9 | 373.1 | 77.7 | 327.2 | 22.2 | 23.0 | 21.9 | 21.7 | 23.2 | 8.3 | 9.5 | 8.9 | 5.2 | 8.4 |
| **Puno** | 1217.4 | 391.0 | 265.8 | 70.7 | 236.4 | 18.4 | 19.3 | 18.0 | 18.0 | 19.5 | 3.0 | 4.5 | 3.7 | -1.0 | 3.1 |

### 4.2.3 Climate trends in the SHAP project districts by alphabetical order

| Climate trends | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Annual Pr (%) | DJF Pr (%) | MAM Pr (%) | JJA Pr (%) | SON Pr (%) | Annual Tx (°C/déc) | DJF Tx (°C/déc) | MAM Tx (°C/déc) | JJA Tx (°C/déc) | SON Tx (°C/déc) | Annual Tn (°C/déc) | DJF Tn (°C/déc) | MAM Tn (°C/déc) | JJA Tn (°C/déc) | SON Tn (°C/déc) |
| 22.2 | 28.0 | 9.1 | 78.7 | 26.6 | 0.31 | 0.19 | 0.17 | 0.39 | 0.40 | 0.20 | 0.19 | 0.22 | 0.23 | 0.21 |
| 39.9 | 38.4 | 49.8 | 17.8 | 1.1 | 0.40 | 0.42 | 0.29 | 0.40 | 0.46 | 0.19 | 0.12 | 0.21 | 0.30 | 0.16 |
| -3.8 | 22.5 | -22.4 | -7.9 | -30.5 | 0.37 | 0.41 | 0.25 | 0.38 | 0.45 | 0.21 | 0.15 | 0.21 | 0.29 | 0.19 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.4 | 25.4 | -16.7 | 3.8 | -16.8 | 0.43 | 0.46 | 0.31 | 0.44 | 0.55 | 0.21 | 0.09 | 0.17 | 0.27 | 0.19 |
| 16.9 | 27.2 | 41.2 | 58.7 | -9.4 | 0.42 | 0.46 | 0.30 | 0.41 | 0.44 | 0.19 | 0.14 | 0.21 | 0.24 | 0.17 |
| 2.8 | 22.3 | -6.6 | 5.4 | -13.3 | 0.38 | 0.38 | 0.25 | 0.40 | 0.46 | 0.17 | 0.11 | 0.15 | 0.21 | 0.18 |
| 48.4 | 45.5 | 60.0 | 0.1 | -22.5 | 0.38 | 0.34 | 0.27 | 0.41 | 0.42 | 0.20 | 0.14 | 0.21 | 0.25 | 0.17 |
| 4.2 | 25.4 | -3.1 | -1.9 | -19.9 | 0.36 | 0.32 | 0.21 | 0.40 | 0.49 | 0.20 | 0.17 | 0.20 | 0.19 | 0.19 |
| 4.2 | 9.7 | 4.6 | -36.3 | 5.7 | 0.32 | 0.35 | 0.2 | 0.4 | 0.26 | 0.23 | 0.19 | 0.27 | 0.24 | 0.29 |
| 14.7 | 22.4 | 15.2 | 16.1 | -12.3 | 0.43 | 0.41 | 0.29 | 0.44 | 0.49 | 0.18 | 0.14 | 0.22 | 0.24 | 0.16 |
| 7.7 | 32.9 | -3.3 | 17.8 | -19.7 | 0.37 | 0.31 | 0.23 | 0.41 | 0.47 | 0.18 | 0.15 | 0.16 | 0.17 | 0.18 |
| 11.0 | 26.3 | 15.6 | 8.9 | -18.1 | 0.42 | 0.41 | 0.29 | 0.43 | 0.49 | 0.19 | 0.15 | 0.23 | 0.23 | 0.17 |
| 7.5 | 20.9 | 2.4 | 34.8 | -23.8 | 0.36 | 0.38 | 0.21 | 0.37 | 0.44 | 0.21 | 0.17 | 0.21 | 0.28 | 0.19 |
| 7.1 | 23.8 | 5.8 | 4.5 | -5.8 | 0.39 | 0.37 | 0.26 | 0.41 | 0.49 | 0.18 | 0.17 | 0.21 | 0.23 | 0.18 |
| 13.9 | 36.9 | -7.4 | 19.1 | -9.4 | 0.42 | 0.44 | 0.29 | 0.44 | 0.52 | 0.21 | 0.14 | 0.21 | 0.23 | 0.19 |
| 25.4 | 21.6 | 39.4 | 0.0 | -5.8 | 0.30 | 0.17 | 0.25 | 0.33 | 0.35 | 0.22 | 0.18 | 0.26 | 0.20 | 0.19 |
| 6.0 | 6.7 | -7.7 | -5.4 | -8.7 | 0.32 | 0.22 | 0.2 | 0.36 | 0.4 | 0.15 | 0.16 | 0.18 | 0.13 | 0.20 |
| 33.9 | 32.0 | 42.3 | 4.0 | -3.6 | 0.40 | 0.41 | 0.30 | 0.40 | 0.46 | 0.20 | 0.11 | 0.21 | 0.29 | 0.16 |
| 22.9 | 31.4 | 30.8 | -4.8 | -10.4 | 0.43 | 0.46 | 0.33 | 0.40 | 0.48 | 0.19 | 0.11 | 0.23 | 0.26 | 0.17 |
| 15.3 | 19.2 | 28.9 | 51.2 | 4.7 | 0.41 | 0.39 | 0.27 | 0.39 | 0.46 | 0.19 | 0.16 | 0.22 | 0.25 | 0.17 |
| 22.5 | 25.3 | 35.7 | 66.0 | 19.9 | 0.36 | 0.40 | 0.25 | 0.33 | 0.37 | 0.19 | 0.14 | 0.18 | 0.29 | 0.20 |
| 34.6 | 37.4 | 44.5 | 5.6 | -10.9 | 0.40 | 0.41 | 0.30 | 0.40 | 0.47 | 0.19 | 0.11 | 0.23 | 0.29 | 0.16 |
| 6.8 | 30.2 | -14.0 | 14.0 | -17.5 | 0.43 | 0.45 | 0.30 | 0.43 | 0.54 | 0.22 | 0.11 | 0.20 | 0.25 | 0.19 |
| 18.6 | 3.7 | 19.0 | 8.4 | -45.7 | 0.39 | 0.44 | 0.38 | 0.40 | 0.40 | 0.21 | 0.16 | 0.23 | 0.26 | 0.13 |
| 11.7 | 28.2 | 0.8 | 14.3 | 0.4 | 0.36 | 0.42 | 0.24 | 0.35 | 0.39 | 0.19 | 0.13 | 0.20 | 0.27 | 0.18 |
| -1.0 | 12.2 | -16.3 | -17.5 | -15.6 | 0.39 | 0.37 | 0.26 | 0.40 | 0.47 | 0.17 | 0.11 | 0.13 | 0.24 | 0.18 |
| 24.1 | 35.9 | 19.1 | 58.0 | 2.1 | 0.36 | 0.37 | 0.23 | 0.36 | 0.40 | 0.20 | 0.17 | 0.21 | 0.26 | 0.19 |
| 11.8 | 24.0 | 13.7 | 30.5 | -0.1 | 0.41 | 0.41 | 0.28 | 0.39 | 0.44 | 0.19 | 0.15 | 0.21 | 0.27 | 0.17 |
| 16.5 | 24.0 | 14.6 | 53.6 | 8.3 | 0.37 | 0.40 | 0.25 | 0.35 | 0.39 | 0.19 | 0.15 | 0.21 | 0.27 | 0.19 |
| -3.7 | 26.9 | -25.0 | 15.6 | -24.6 | 0.37 | 0.26 | 0.23 | 0.42 | 0.44 | 0.17 | 0.16 | 0.18 | 0.19 | 0.18 |
| -10.1 | 8.2 | -23.3 | -39.1 | -20.1 | 0.44 | 0.48 | 0.29 | 0.41 | 0.54 | 0.22 | 0.10 | 0.16 | 0.33 | 0.19 |
| 19.0 | 29.2 | 10.6 | 47.7 | -1.7 | 0.35 | 0.28 | 0.20 | 0.40 | 0.44 | 0.19 | 0.18 | 0.21 | 0.22 | 0.19 |
| 0.8 | 19.4 | 2.8 | -3.4 | -12.1 | 0.38 | 0.32 | 0.22 | 0.41 | 0.48 | 0.18 | 0.17 | 0.19 | 0.21 | 0.18 |
| 17.2 | 22.9 | 39.3 | 54.4 | 7.2 | 0.39 | 0.42 | 0.26 | 0.37 | 0.40 | 0.18 | 0.12 | 0.21 | 0.26 | 0.19 |
| 2.4 | 23.9 | -15.2 | -7.6 | -16.1 | 0.34 | 0.25 | 0.19 | 0.40 | 0.44 | 0.18 | 0.17 | 0.21 | 0.18 | 0.19 |
| 13.3 | 25.7 | 4.8 | 21.3 | 4.4 | 0.37 | 0.35 | 0.23 | 0.39 | 0.46 | 0.19 | 0.18 | 0.21 | 0.23 | 0.18 |
| 4.6 | 5.5 | 13.7 | 9.4 | 2.0 | 0.44 | 0.47 | 0.33 | 0.44 | 0.48 | 0.21 | 0.16 | 0.23 | 0.29 | 0.19 |
| 40.2 | 44.1 | 57.7 | -2.7 | -1.3 | 0.43 | 0.46 | 0.35 | 0.39 | 0.47 | 0.19 | 0.10 | 0.22 | 0.29 | 0.17 |
| 3.3 | 22.4 | -5.9 | -5.5 | -26.7 | 0.36 | 0.31 | 0.22 | 0.41 | 0.47 | 0.18 | 0.18 | 0.20 | 0.20 | 0.18 |
| 28.6 | 31.7 | 21.4 | 75.7 | 15.5 | 0.40 | 0.39 | 0.25 | 0.39 | 0.44 | 0.20 | 0.16 | 0.23 | 0.25 | 0.18 |
| 0.6 | 5.7 | 1.3 | -17.5 | 1.5 | 0.31 | 0.32 | 0.21 | 0.35 | 0.34 | 0.24 | 0.15 | 0.25 | 0.28 | 0.26 |
| 12.0 | 21.4 | 2.8 | 24.6 | -10.0 | 0.34 | 0.30 | 0.18 | 0.40 | 0.45 | 0.19 | 0.18 | 0.21 | 0.21 | 0.20 |
| 28.9 | 37.7 | 47.6 | 2.0 | 5.2 | 0.43 | 0.48 | 0.31 | 0.40 | 0.46 | 0.19 | 0.09 | 0.20 | 0.28 | 0.17 |
| -10.1 | 14.5 | -27.8 | 5.3 | -25.8 | 0.37 | 0.33 | 0.25 | 0.41 | 0.44 | 0.18 | 0.13 | 0.18 | 0.18 | 0.19 |
| 11.7 | 30.6 | -3.7 | 23.8 | -8.2 | 0.36 | 0.20 | 0.23 | 0.42 | 0.43 | 0.18 | 0.18 | 0.20 | 0.17 | 0.21 |
| 3.1 | 22.4 | -1.3 | -5.3 | -13.2 | 0.43 | 0.43 | 0.30 | 0.41 | 0.49 | 0.19 | 0.15 | 0.21 | 0.25 | 0.17 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 47.3 | 50.9 | 58.1 | -19.2 | -27.1 | 0.36 | 0.32 | 0.26 | 0.38 | 0.40 | 0.21 | 0.13 | 0.22 | 0.26 | 0.16 |
| 49.5 | 41.3 | 64.1 | 2.8 | -5.2 | 0.39 | 0.39 | 0.29 | 0.41 | 0.44 | 0.20 | 0.13 | 0.21 | 0.29 | 0.17 |
| 55.4 | 42.0 | 45.8 | -5.3 | -11.7 | 0.44 | 0.48 | 0.36 | 0.43 | 0.48 | 0.19 | 0.11 | 0.22 | 0.27 | 0.15 |
| 8.2 | 32.2 | -13.5 | 19.0 | -14.7 | 0.40 | 0.38 | 0.26 | 0.40 | 0.50 | 0.17 | 0.11 | 0.14 | 0.18 | 0.20 |
| 41.1 | 49.0 | 65.4 | -2.0 | -6.1 | 0.42 | 0.45 | 0.36 | 0.39 | 0.48 | 0.19 | 0.11 | 0.21 | 0.29 | 0.16 |
| 10.2 | 21.8 | 19.3 | 26.3 | -1.8 | 0.39 | 0.38 | 0.26 | 0.41 | 0.48 | 0.18 | 0.17 | 0.20 | 0.23 | 0.18 |
| 3.6 | 21.6 | -14.4 | 15.5 | -20.2 | 0.44 | 0.45 | 0.28 | 0.40 | 0.50 | 0.21 | 0.11 | 0.20 | 0.27 | 0.18 |
| 16.0 | 36.5 | -6.5 | 22.3 | -19.5 | 0.40 | 0.41 | 0.25 | 0.39 | 0.49 | 0.21 | 0.16 | 0.19 | 0.28 | 0.18 |
| 11.8 | 24.0 | 13.7 | 30.5 | -0.1 | 0.41 | 0.41 | 0.28 | 0.39 | 0.44 | 0.19 | 0.15 | 0.21 | 0.27 | 0.17 |
| 4.9 | 4.9 | 4.2 | -27.1 | -1.4 | 0.33 | 0.35 | 0.18 | 0.38 | 0.36 | 0.24 | 0.16 | 0.26 | 0.26 | 0.28 |
| 18.3 | 31.6 | 11.8 | 55.5 | 1.4 | 0.33 | 0.21 | 0.20 | 0.40 | 0.43 | 0.18 | 0.17 | 0.21 | 0.20 | 0.21 |
| 6.7 | 27.1 | -13.6 | 8.1 | -7.9 | 0.37 | 0.34 | 0.24 | 0.39 | 0.46 | 0.17 | 0.12 | 0.16 | 0.18 | 0.19 |
| 7.7 | 39.0 | -7.0 | 16.8 | -10.9 | 0.40 | 0.26 | 0.25 | 0.43 | 0.49 | 0.18 | 0.15 | 0.19 | 0.16 | 0.20 |
| 4.7 | 24.0 | -11.4 | 12.5 | -7.7 | 0.35 | 0.34 | 0.21 | 0.39 | 0.44 | 0.20 | 0.18 | 0.21 | 0.25 | 0.19 |
| 12.2 | 25.8 | 13.8 | 13.0 | -23.0 | 0.43 | 0.42 | 0.30 | 0.43 | 0.50 | 0.19 | 0.14 | 0.22 | 0.24 | 0.16 |
| 14.5 | 31.2 | 22.5 | 39.6 | 2.6 | 0.41 | 0.38 | 0.27 | 0.43 | 0.50 | 0.19 | 0.16 | 0.21 | 0.22 | 0.18 |
| 38.8 | 20.6 | 24.1 | 16.0 | -25.1 | 0.43 | 0.44 | 0.36 | 0.43 | 0.49 | 0.19 | 0.12 | 0.21 | 0.26 | 0.13 |
| 8.4 | 3.1 | 11.2 | 16.7 | -2.2 | 0.41 | 0.42 | 0.32 | 0.39 | 0.42 | 0.22 | 0.14 | 0.23 | 0.31 | 0.17 |
| 16.1 | 22.0 | 37.7 | 52.1 | 5.0 | 0.36 | 0.40 | 0.24 | 0.34 | 0.37 | 0.19 | 0.13 | 0.19 | 0.28 | 0.19 |
| 7.6 | 31.2 | -3.8 | 15.7 | -17.5 | 0.37 | 0.39 | 0.23 | 0.38 | 0.47 | 0.21 | 0.17 | 0.20 | 0.28 | 0.19 |
| 29.4 | 32.3 | 23.3 | 89.5 | 35.5 | 0.36 | 0.37 | 0.24 | 0.38 | 0.39 | 0.20 | 0.16 | 0.22 | 0.26 | 0.19 |
| 3.3 | 22.4 | -5.9 | -5.5 | -26.7 | 0.36 | 0.31 | 0.22 | 0.41 | 0.47 | 0.18 | 0.18 | 0.20 | 0.20 | 0.18 |
| 10.3 | 36.7 | -9.2 | 6.1 | -13.7 | 0.42 | 0.44 | 0.28 | 0.43 | 0.54 | 0.21 | 0.12 | 0.21 | 0.20 | 0.18 |
| -3.2 | 9.5 | -12.3 | -23.5 | -20.9 | 0.37 | 0.29 | 0.26 | 0.41 | 0.51 | 0.16 | 0.13 | 0.12 | 0.19 | 0.17 |
| 9.9 | 25.0 | 7.0 | 15.4 | -1.9 | 0.39 | 0.42 | 0.25 | 0.36 | 0.39 | 0.19 | 0.14 | 0.20 | 0.28 | 0.19 |
| 17.7 | 20.1 | 23.6 | 44.7 | -0.1 | 0.41 | 0.47 | 0.30 | 0.39 | 0.43 | 0.19 | 0.12 | 0.20 | 0.27 | 0.18 |
| -7.1 | 25.2 | -28.6 | 17.5 | -28.9 | 0.34 | 0.24 | 0.21 | 0.39 | 0.40 | 0.17 | 0.17 | 0.19 | 0.17 | 0.17 |
| 39.8 | 20.2 | 40.0 | -3.2 | -12.2 | 0.38 | 0.26 | 0.28 | 0.39 | 0.43 | 0.20 | 0.14 | 0.24 | 0.19 | 0.20 |
| 4.7 | 7.6 | 0.4 | -1.6 | -1.5 | 0.36 | 0.27 | 0.29 | 0.42 | 0.43 | 0.25 | 0.18 | 0.29 | 0.25 | 0.24 |
| 20.2 | 9.5 | 2.1 | 0.0 | -9.7 | 0.45 | 0.47 | 0.35 | 0.44 | 0.48 | 0.23 | 0.15 | 0.24 | 0.34 | 0.19 |
| 10.1 | 34.1 | -12.4 | 13.6 | -17.4 | 0.40 | 0.38 | 0.25 | 0.43 | 0.49 | 0.19 | 0.13 | 0.17 | 0.20 | 0.17 |
| -5.7 | 20.1 | -16.2 | -3.4 | -31.1 | 0.37 | 0.37 | 0.22 | 0.39 | 0.46 | 0.20 | 0.18 | 0.21 | 0.25 | 0.19 |
| -14.1 | 11.1 | -27.0 | -12.0 | -29.2 | 0.37 | 0.24 | 0.28 | 0.44 | 0.47 | 0.18 | 0.14 | 0.19 | 0.19 | 0.18 |
| 16.8 | 28.9 | 15.6 | 63.3 | 9.1 | 0.39 | 0.41 | 0.23 | 0.40 | 0.45 | 0.21 | 0.16 | 0.23 | 0.24 | 0.20 |
| 8.3 | 27.4 | 8.3 | 4.3 | -13.1 | 0.41 | 0.39 | 0.27 | 0.42 | 0.48 | 0.18 | 0.16 | 0.20 | 0.23 | 0.16 |
| 3.6 | 25.1 | -24.7 | 9.2 | -23.9 | 0.37 | 0.26 | 0.24 | 0.41 | 0.44 | 0.18 | 0.15 | 0.18 | 0.18 | 0.19 |
| 12.1 | 30.2 | -3.7 | 3.6 | -4.8 | 0.36 | 0.41 | 0.25 | 0.35 | 0.39 | 0.20 | 0.14 | 0.20 | 0.28 | 0.18 |
| 24.9 | 30.3 | 12.8 | 75.1 | 24.8 | 0.34 | 0.32 | 0.21 | 0.39 | 0.42 | 0.21 | 0.20 | 0.26 | 0.24 | 0.19 |
| -1.6 | -0.5 | -0.6 | -28.3 | -4.0 | 0.32 | 0.36 | 0.18 | 0.42 | 0.31 | 0.25 | 0.19 | 0.27 | 0.24 | 0.29 |
| 14.0 | 21.5 | 28.7 | 40.1 | 2.1 | 0.40 | 0.41 | 0.28 | 0.38 | 0.45 | 0.19 | 0.14 | 0.21 | 0.26 | 0.17 |
| 17.3 | 30.3 | 14.1 | 8.1 | -11.9 | 0.40 | 0.40 | 0.30 | 0.43 | 0.45 | 0.19 | 0.14 | 0.20 | 0.24 | 0.18 |
| 6.0 | 24.1 | -12.4 | -5.1 | -8.8 | 0.34 | 0.20 | 0.21 | 0.42 | 0.42 | 0.17 | 0.17 | 0.20 | 0.17 | 0.20 |
| 4.0 | 24.2 | -12.6 | -23.5 | -14.9 | 0.37 | 0.27 | 0.24 | 0.43 | 0.43 | 0.18 | 0.17 | 0.21 | 0.19 | 0.19 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 43.2 | 28.5 | 33.5 | 11.4 | -20.5 | 0.39 | 0.33 | 0.28 | 0.41 | 0.43 | 0.22 | 0.16 | 0.22 | 0.26 | 0.15 |
| 25.9 | 18.5 | 24.8 | 7.1 | 7.8 | 0.42 | 0.41 | 0.29 | 0.42 | 0.46 | 0.20 | 0.13 | 0.21 | 0.27 | 0.17 |

### 4.2.4 Projected changes in temperature and precipitation under the RCP 4.5 scenario in the SHAP project districts by alphabetical order.

| Region | Province | District | Changes under the RCP4.5 scenario | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | PR annual (%) | PR DJF (%) | PR MAM (%) | PR JJA (%) | PR SON (%) | TX annual (°C) | TX DJF (°C) | TX MAM (°C) | TX JJA (°C) | TX SON (°C) | TN annual (°C) | TN DJF (°C) | TN MAM (°C) | TN JJA (°C) | TN SON (°C) |
| APURIMAC | ABANCAY | ABANCAY | 4.2 | 15.8 | 11.6 | -26.8 | 14.7 | 2.4 | 2.2 | 2.2 | 2.9 | 2.4 | 1.7 | 1.9 | 1.7 | 1.3 | 1.9 |
| AREQUIPA | CAYLLOMA | ACHOMA | 4.8 | 9.2 | 8 | -32.8 | 9.8 | 2.5 | 2.4 | 2.2 | 3.1 | 2.7 | 1.8 | 1.8 | 1.9 | 1.6 | 2 |
| CUSCO | ACOMAYO | ACOMAYO | 4.1 | 9 | 11.6 | -23.3 | 7.2 | 2.4 | 2.3 | 2.2 | 2.9 | 2.4 | 1.7 | 1.8 | 1.7 | 1.5 | 1.8 |
| PUNO | CARABAYA | AJOYANI | -5.2 | 0.7 | -1 | -26.2 | -2.5 | 2.4 | 2.4 | 2.1 | 2.7 | 2.6 | 1.8 | 2 | 1.7 | 1.5 | 2 |
| APURIMAC | ANTABAMBA | ANTABAMBA | 6 | 14.9 | 12 | -16.3 | 21.2 | 2.8 | 2.5 | 2.5 | 3.4 | 2.8 | 1.5 | 1.5 | 1.4 | 1.4 | 1.9 |
| PUNO | MELGAR | ANTAUTA | -5.9 | -1.7 | -1.7 | -30.6 | -3.4 | 2.5 | 2.4 | 2.2 | 2.9 | 2.6 | 1.5 | 1.7 | 1.6 | 1.2 | 1.8 |
| AREQUIPA | CAYLLOMA | CABANACONDE | 1.3 | 7.2 | 7 | -19.6 | 12.8 | 2.8 | 2.7 | 2.5 | 3.4 | 3 | 1.4 | 1.4 | 1.4 | 1.3 | 1.7 |
| CUSCO | CALCA | CALCA | 2.4 | 6.4 | 9 | -18.1 | 4.5 | 2.2 | 2.2 | 1.9 | 2.5 | 2.3 | 1.8 | 2 | 1.9 | 1.4 | 1.9 |
| LIMA | YAUYOS | CARANIA | -7.0 | -2.9 | -4.3 | 6.9 | -0.3 | 2.5 | 2.5 | 2.2 | 2.8 | 2.8 | 1.7 | 1.7 | 1.6 | 1.5 | 2.8 |
| AREQUIPA | CONDESUYOS | CAYARANI | 0.9 | 7.6 | 5.8 | -1.6 | 17.5 | 2.8 | 2.7 | 2.5 | 3.3 | 3 | 1.6 | 1.6 | 1.4 | 1.5 | 2 |
| CUSCO | QUISPICANCHI | CCARHUAYO | 2.6 | 7.7 | 7.7 | -26.4 | 6.1 | 2.4 | 2.4 | 2.2 | 2.8 | 2.5 | 1.8 | 1.9 | 1.9 | 1.4 | 1.9 |
| AREQUIPA | CASTILLA | CHACHAS | 0.9 | 7.6 | 5.8 | -1.6 | 17.5 | 2.8 | 2.7 | 2.5 | 3.3 | 3 | 1.6 | 1.6 | 1.4 | 1.5 | 2 |
| CUSCO | PAUCARTAMBO | CHALLABAMBA | 2.4 | 6.4 | 9 | -18.1 | 4.5 | 2.2 | 2.2 | 1.9 | 2.5 | 2.3 | 1.8 | 2 | 1.9 | 1.4 | 1.9 |
| APURIMAC | COTABAMBAS | CHALLHUAHUACHO | 7.9 | 20.4 | 17.6 | -30.5 | 23.5 | 2.6 | 2.3 | 2.4 | 3.3 | 2.6 | 1.7 | 1.9 | 1.8 | 1.5 | 2.1 |
| CUSCO | CANCHIS | CHECACUPE | -6.8 | -3.6 | -3.8 | -26.7 | -3.8 | 3.2 | 3.1 | 2.8 | 3.8 | 3.2 | 3.1 | 2.6 | 2.8 | 4.3 | 3.2 |
| AREQUIPA | CONDESUYOS | CHICHAS | 9.5 | 14.9 | 11.5 | -20.8 | 20.4 | 2.5 | 2.3 | 2.2 | 3 | 2.6 | 1.7 | 1.8 | 1.8 | 1.5 | 1.9 |
| CUSCO | URUBAMBA | CHINCHERO | 2.4 | 2.4 | 9 | -18.1 | 4.5 | 2.2 | 2.2 | 2 | 2.5 | 2.3 | 1.8 | 2 | 1.9 | 1.4 | 2.3 |
| AREQUIPA | CAYLLOMA | CHIVAY | -1.1 | 5.5 | 7.2 | -23.3 | 11.8 | 3 | 2.8 | 2.6 | 3.5 | 3.1 | 1.3 | 1.4 | 1.2 | 1.1 | 1.7 |
| AREQUIPA | CASTILLA | CHOCO | 6 | 12.2 | 9.6 | -17.5 | 17.8 | 2.7 | 2.5 | 2.3 | 3.2 | 2.8 | 1.5 | 1.6 | 1.6 | 1.4 | 1.7 |
| APURIMAC | GRAU | CHUQUIBAMBILLA | 5.7 | 19.7 | 13.5 | -33.1 | 20.8 | 2.7 | 2.3 | 2.4 | 3.4 | 2.6 | 1.6 | 1.8 | 1.6 | 1.3 | 1.9 |
| APURIMAC | ABANCAY | CIRCA | 5.7 | 19.7 | 13.5 | -33.1 | 20.8 | 2.7 | 2.3 | 2.4 | 3.4 | 2.6 | 1.6 | 1.8 | 1.6 | 1.3 | 1.9 |
| AREQUIPA | CAYLLOMA | COPORAQUE | 1.3 | 7.2 | 7 | -19.6 | 12.8 | 2.8 | 2.7 | 2.5 | 3.4 | 3 | 1.4 | 1.4 | 1.4 | 1.3 | 1.7 |
| PUNO | CARABAYA | CORANI | -4.8 | 0.6 | 1.3 | -32.2 | -4.5 | 2.3 | 2.3 | 1.9 | 2.6 | 2.7 | 1.9 | 2.1 | 1.9 | 1.6 | 2.1 |
| AREQUIPA | LA UNION | COTAHUASI | 9.5 | 14.9 | 11.5 | -20.8 | 20.4 | 2.5 | 2.3 | 2.2 | 3 | 2.6 | 1.7 | 1.8 | 1.8 | 1.5 | 1.9 |
| APURIMAC | COTABAMBAS | COYLLURQUI | 3.4 | 10.8 | 10.3 | -23.5 | 10.2 | 2.4 | 2.2 | 2.2 | 2.9 | 2.4 | 1.7 | 1.8 | 1.7 | 1.5 | 1.8 |
| PUNO | CARABAYA | CRUCERO | -5.2 | 0.7 | -1 | -26.2 | -2.5 | 2.4 | 2.4 | 2.1 | 2.7 | 2.6 | 1.8 | 2 | 1.7 | 1.5 | 2 |
| APURIMAC | ABANCAY | CURAHUASI | 4.2 | 15.8 | 11.6 | -26.8 | 14.7 | 2.4 | 2.2 | 2.2 | 2.9 | 2.4 | 1.7 | 1.9 | 1.7 | 1.3 | 1.9 |
| APURIMAC | GRAU | CURASCO | 5.7 | 19.7 | 13.5 | -33.1 | 20.8 | 2.7 | 2.3 | 2.4 | 3.4 | 2.6 | 1.6 | 1.8 | 1.6 | 1.3 | 1.9 |
| APURIMAC | GRAU | CURPAHUASI | 5.7 | 19.7 | 13.5 | -33.1 | 20.8 | 2.7 | 2.3 | 2.4 | 3.4 | 2.6 | 1.6 | 1.8 | 1.6 | 1.3 | 1.9 |
| CUSCO | QUISPICANCHI | CUSIPATA | 2.6 | 7.7 | 7.7 | -26.4 | 6.1 | 2.4 | 2.4 | 2.2 | 2.8 | 2.5 | 1.8 | 1.9 | 1.9 | 1.4 | 1.9 |
| PUNO | SANDIA | CUYOCUYO | -7.3 | -6.5 | -4.3 | -24.8 | -6.3 | 2.6 | 2.6 | 2.2 | 3 | 2.7 | 1.8 | 1.9 | 1.6 | 1.8 | 2 |
| APURIMAC | GRAU | GAMARRA | 4.2 | 15.8 | 11.6 | -26.8 | 14.7 | 2.4 | 2.2 | 2.2 | 2.9 | 2.4 | 1.7 | 1.9 | 1.7 | 1.3 | 1.9 |
| APURIMAC | COTABAMBAS | HAQUIRA | 7.9 | 20.4 | 17.6 | -30.5 | 23.5 | 2.6 | 2.3 | 2.4 | 3.3 | 2.6 | 1.7 | 1.9 | 1.8 | 1.5 | 2.1 |
| APURIMAC | ANTABAMBA | HUAQUIRCA | 5.7 | 19.7 | 13.5 | -33.1 | 20.8 | 2.7 | 2.3 | 2.4 | 3.4 | 2.6 | 1.6 | 1.8 | 1.6 | 1.3 | 1.9 |
| CUSCO | ANTA | HUAROCONDO | 4 | 8.9 | 8.7 | -14.3 | 9.1 | 2.1 | 2.1 | 2 | 2.4 | 2.2 | 1.9 | 2.1 | 2 | 1.5 | 2.1 |
| APURIMAC | GRAU | HUAYLLATI | 7.9 | 20.4 | 17.6 | -30.5 | 23.5 | 2.6 | 2.3 | 2.4 | 3.3 | 2.6 | 1.7 | 1.9 | 1.8 | 1.5 | 2.1 |
| AREQUIPA | LA UNION | HUAYNACOTAS | 6.3 | 12.5 | 6.8 | 14.4 | 25.2 | 2.7 | 2.6 | 2.4 | 3.2 | 2.8 | 1.5 | 1.5 | 1.3 | 1.4 | 2.8 |
| AREQUIPA | CAYLLOMA | ICHUPAMPA | 1.3 | 7.2 | 7 | -19.6 | 12.8 | 2.8 | 2.7 | 2.5 | 3.4 | 3 | 1.4 | 1.4 | 1.4 | 1.3 | 1.7 |
| CUSCO | CALCA | LAMAY | 2.4 | 6.4 | 9 | -18.1 | 4.5 | 2.2 | 2.2 | 1.9 | 2.5 | 2.3 | 1.8 | 2 | 1.9 | 1.4 | 1.9 |
| APURIMAC | ABANCAY | LAMBRAMA | 4.2 | 15.8 | 11.6 | -26.8 | 14.7 | 2.4 | 2.2 | 2.2 | 2.9 | 2.4 | 1.7 | 1.9 | 1.7 | 1.3 | 1.9 |
| LIMA | YAUYOS | LARAOS | -7.0 | -2.9 | -4.3 | 6.9 | -0.3 | 2.5 | 2.5 | 2.2 | 2.8 | 2.8 | 1.7 | 1.7 | 1.6 | 1.5 | 2.8 |
| CUSCO | CALCA | LARES | 2.4 | 6.4 | 9 | -18.1 | 4.5 | 2.2 | 2.2 | 1.9 | 2.5 | 2.3 | 1.8 | 2 | 1.9 | 1.4 | 1.9 |
| AREQUIPA | CAYLLOMA | LARI | 1.3 | 7.2 | 7 | -19.6 | 12.8 | 2.8 | 2.7 | 2.5 | 3.4 | 3 | 1.4 | 1.4 | 1.4 | 1.3 | 1.7 |
| CUSCO | CANAS | LAYO | 6.4 | 10.6 | 11.6 | -24.6 | 11 | 2.7 | 2.6 | 2.4 | 3.1 | 2.7 | 1.6 | 2.1 | 1.5 | 0.9 | 2.3 |
| CUSCO | ANTA | LIMATAMBO | 4 | 8.9 | 8.7 | -14.3 | 9.1 | 2.1 | 2.1 | 2 | 2.4 | 2.2 | 1.9 | 2.1 | 2 | 1.5 | 2.1 |
| CUSCO | CHUMBIVILCAS | LLUSCO | 6 | 16.3 | 13.9 | -18.7 | 23.3 | 2.8 | 2.6 | 2.5 | 3.3 | 2.8 | 1.6 | 1.7 | 1.5 | 1.4 | 2.1 |
| AREQUIPA | CAYLLOMA | LLUTA | 4.8 | 9.2 | 8 | -32.8 | 9.8 | 2.5 | 2.4 | 2.2 | 3.1 | 2.7 | 1.8 | 1.8 | 1.9 | 1.6 | 2 |
| AREQUIPA | CAYLLOMA | MACA | 4.8 | 9.2 | 8 | -32.8 | 9.8 | 2.5 | 2.4 | 2.2 | 3.1 | 2.7 | 1.8 | 1.8 | 1.9 | 1.6 | 2 |
| AREQUIPA | CASTILLA | MACHAGUAY | 6 | 12.2 | 9.6 | -17.5 | 17.8 | 2.7 | 2.5 | 2.3 | 3.2 | 2.8 | 1.5 | 1.6 | 1.6 | 1.4 | 1.7 |
| PUNO | CARABAYA | MACUSANI | -5.9 | -1.7 | -1.7 | -30.6 | -3.4 | 2.5 | 2.4 | 2.2 | 2.9 | 2.6 | 1.5 | 1.7 | 1.6 | 1.2 | 1.8 |
| AREQUIPA | CAYLLOMA | MADRIGAL | 1.3 | 7.2 | 7 | -19.6 | 12.8 | 2.8 | 2.7 | 2.5 | 3.4 | 3 | 1.4 | 1.4 | 1.4 | 1.3 | 1.7 |
| APURIMAC | GRAU | MAMARA | 5.7 | 19.7 | 13.5 | -33.1 | 20.8 | 2.7 | 2.3 | 2.4 | 3.4 | 2.6 | 1.6 | 1.8 | 1.6 | 1.3 | 1.9 |
| CUSCO | CANCHIS | MARANGANI | -6.8 | -3.6 | -3.8 | -26.7 | -3.8 | 3.2 | 3.1 | 2.8 | 3.8 | 3.2 | 3.1 | 2.6 | 2.8 | 4.3 | 3.2 |
| CUSCO | QUISPICANCHI | MARCAPATA | -2.5 | 2.1 | 0.9 | -23.4 | 0.1 | 3.1 | 3 | 2.7 | 3.5 | 3.1 | 3.4 | 2.8 | 3.1 | 4.7 | 3.1 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| APURIMAC | GRAU | MICAELA BASTIDAS | 5.7 | 19.7 | 13.5 | -33.1 | 20.8 | 2.7 | 2.3 | 2.4 | 3.4 | 2.6 | 1.6 | 1.8 | 1.6 | 1.3 | 1.9 |
| LIMA | YAUYOS | MIRAFLORES | -6.7 | -2.9 | -4.3 | 6.9 | -0.3 | 2.5 | 2.5 | 2.2 | 2.8 | 2.8 | 1.7 | 1.7 | 1.6 | 1.5 | 2.8 |
| CUSCO | ANTA | MOLLEPATA | 7.6 | 16.2 | 13.7 | -12 | 17.5 | 2.1 | 2.1 | 1.9 | 2.4 | 2.2 | 2.1 | 2.2 | 2.1 | 1.8 | 2.3 |
| PUNO | MELGAR | NUÑOA | -5.9 | -1.7 | -1.7 | -30.6 | -3.4 | 2.5 | 2.4 | 2.2 | 2.9 | 2.6 | 1.5 | 1.7 | 1.6 | 1.2 | 1.8 |
| CUSCO | QUISPICANCHI | OCONGATE | 2.6 | 7.7 | 7.7 | -26.4 | 6.1 | 2.4 | 2.4 | 2.2 | 2.8 | 2.5 | 1.8 | 1.9 | 1.9 | 1.4 | 1.9 |
| CUSCO | URUBAMBA | OLLANTAYTAMBO | 4 | 8.9 | 8.7 | -14.3 | 9.1 | 2.1 | 2.1 | 2 | 2.4 | 2.2 | 1.9 | 2.1 | 2 | 1.5 | 2.1 |
| AREQUIPA | CASTILLA | ORCOPAMPA | 0.9 | 7.6 | 5.8 | -1.6 | 17.5 | 2.8 | 2.7 | 2.5 | 3.3 | 3 | 1.6 | 1.6 | 1.4 | 1.5 | 2 |
| APURIMAC | ANTABAMBA | OROPESA | 6 | 14.9 | 12 | -16.3 | 21.2 | 2.8 | 2.5 | 2.5 | 3.4 | 2.8 | 1.5 | 1.5 | 1.4 | 1.4 | 1.9 |
| AREQUIPA | CASTILLA | PAMPACOLCA | 9.5 | 14.9 | 11.5 | -20.8 | 20.4 | 2.5 | 2.3 | 2.2 | 3 | 2.6 | 1.7 | 1.8 | 1.8 | 1.5 | 1.9 |
| AREQUIPA | LA UNION | PAMPAMARCA | 6.3 | 12.5 | 6.8 | 14.4 | 25.2 | 2.7 | 2.6 | 2.4 | 3.2 | 2.8 | 1.5 | 1.5 | 1.3 | 1.4 | 2.8 |
| APURIMAC | GRAU | PATAYPAMPA | 5.7 | 19.7 | 13.5 | -33.1 | 20.8 | 2.7 | 2.3 | 2.4 | 3.4 | 2.6 | 1.6 | 1.8 | 1.6 | 1.3 | 1.9 |
| CUSCO | PAUCARTAMBO | PAUCARTAMBO | 2.2 | 7.4 | 9.3 | -24.1 | 4.8 | 2.2 | 2.2 | 1.9 | 2.4 | 2.4 | 2.1 | 2.3 | 2.1 | 1.8 | 2.2 |
| APURIMAC | ABANCAY | PICHIRHUA | 1.6 | 17.7 | 11.3 | -34.3 | 13.1 | 2.5 | 2.2 | 2.2 | 3 | 2.4 | 1.7 | 1.9 | 1.7 | 1.3 | 1.9 |
| CUSCO | CALCA | PISAC | 2.4 | 6.4 | 9 | -18.1 | 4.5 | 2.2 | 2.2 | 1.9 | 2.5 | 2.3 | 1.8 | 2 | 1.9 | 1.4 | 1.9 |
| CUSCO | CANCHIS | PITUMARCA | -2.5 | 2.1 | 0.9 | -23.4 | 0.1 | 3.1 | 3 | 2.7 | 3.5 | 3.1 | 3.4 | 2.8 | 3.1 | 4.7 | 3.1 |
| PUNO | AZANGARO | POTONI | -7.4 | -6.5 | -6.9 | -30.4 | -5.5 | 2.7 | 2.7 | 2.3 | 3.2 | 2.8 | 1.8 | 1.9 | 1.6 | 1.8 | 2.3 |
| APURIMAC | GRAU | PROGRESO | 7.9 | 20.4 | 17.6 | -30.5 | 23.5 | 2.6 | 2.3 | 2.4 | 3.3 | 2.6 | 1.7 | 1.9 | 1.8 | 1.5 | 2.1 |
| AREQUIPA | LA UNION | PUYCA | 6.3 | 12.5 | 6.8 | 14.4 | 25.2 | 2.7 | 2.6 | 2.4 | 3.2 | 2.8 | 1.5 | 1.5 | 1.3 | 1.4 | 1.9 |
| CUSCO | QUISPICANCHI | QUIQUIJANA | 2.6 | 7.7 | 7.7 | -26.4 | 6.1 | 2.4 | 2.4 | 2.2 | 2.8 | 2.5 | 1.8 | 1.9 | 1.9 | 1.4 | 1.9 |
| AREQUIPA | CONDESUYOS | SALAMANCA | 9.5 | 14.9 | 11.5 | -20.8 | 20.4 | 2.5 | 2.3 | 2.2 | 3 | 2.6 | 1.7 | 1.8 | 1.8 | 1.5 | 1.9 |
| AREQUIPA | CAYLLOMA | SAN ANTONIO DE CHUCA | 0.3 | 5.4 | 7.4 | -25.6 | 9.3 | 3 | 2.9 | 2.6 | 3.6 | 3.2 | 1.4 | 1.5 | 1.3 | 1.5 | 3.2 |
| AREQUIPA | AREQUIPA | SAN JUAN DE TARUCANI | 4.8 | 8.4 | 8.8 | -26.7 | 9.3 | 2.8 | 2.6 | 2.4 | 3.4 | 3 | 1.6 | 1.6 | 1.6 | 1.5 | 3 |
| CUSCO | CANCHIS | SAN PABLO | -6.8 | -3.6 | -3.8 | -26.7 | -3.8 | 3.2 | 3.1 | 2.8 | 3.8 | 3.2 | 3.1 | 2.6 | 2.8 | 4.3 | 3.2 |
| CUSCO | CALCA | SAN SALVADOR | 2.4 | 6.4 | 9 | -18.1 | 4.5 | 2.2 | 2.2 | 1.9 | 2.5 | 2.3 | 1.8 | 2 | 1.9 | 1.4 | 1.9 |
| PUNO | MELGAR | SANTA ROSA | 6.4 | 10.6 | 11.6 | -24.6 | 11 | 2.7 | 2.6 | 2.4 | 3.1 | 2.7 | 1.6 | 2.1 | 1.5 | 0.9 | 2.3 |
| CUSCO | LA CONVENCION | SANTA TERESA | 7.6 | 16.2 | 13.7 | -12 | 17.5 | 2.1 | 2.1 | 1.9 | 2.4 | 2.2 | 2.1 | 2.2 | 2.1 | 1.8 | 2.3 |
| CUSCO | CHUMBIVILCAS | SANTO TOMAS | 6 | 16.3 | 13.9 | -18.7 | 23.3 | 2.8 | 2.6 | 2.5 | 3.3 | 2.8 | 1.6 | 1.7 | 1.5 | 1.4 | 2.1 |
| CUSCO | CANCHIS | SICUANI | -6.8 | -3.6 | -3.8 | -26.7 | -3.8 | 3.2 | 3.1 | 2.8 | 3.8 | 3.2 | 3.1 | 2.6 | 2.8 | 4.3 | 3.2 |
| APURIMAC | COTABAMBAS | TAMBOBAMBA | 3.4 | 10.8 | 10.3 | -23.5 | 10.2 | 2.4 | 2.2 | 2.2 | 2.9 | 2.4 | 1.7 | 1.8 | 1.7 | 1.5 | 1.8 |
| APURIMAC | ABANCAY | TAMBURCO | 4.2 | 15.8 | 11.6 | -26.8 | 14.7 | 2.4 | 2.2 | 2.2 | 2.9 | 2.4 | 1.7 | 1.9 | 1.7 | 1.3 | 1.9 |
| LIMA | YAUYOS | TOMAS | -10.2 | -4.1 | -8.4 | -5.6 | -0.4 | 2.6 | 2.6 | 2.3 | 2.9 | 2.9 | 1.5 | 1.6 | 1.4 | 1.2 | 2.9 |
| APURIMAC | GRAU | TURPAY | 5.7 | 19.7 | 13.5 | -33.1 | 20.8 | 2.7 | 2.3 | 2.4 | 3.4 | 2.6 | 1.6 | 1.8 | 1.6 | 1.3 | 1.9 |
| AREQUIPA | CAYLLOMA | TUTI | -1.1 | 5.5 | 7.2 | -23.3 | 11.8 | 3 | 2.8 | 2.6 | 3.5 | 3.1 | 1.3 | 1.4 | 1.2 | 1.1 | 1.7 |
| CUSCO | URUBAMBA | URUBAMBA | 4 | 8.9 | 8.7 | -14.3 | 9.1 | 2.1 | 2.1 | 2 | 2.4 | 2.2 | 1.9 | 2.1 | 2 | 1.5 | 2.1 |
| CUSCO | CHUMBIVILCAS | VELILLE | 15.5 | 27.8 | 26.9 | -16.9 | 34.2 | 2.7 | 2.5 | 2.5 | 3.2 | 2.7 | 1.7 | 2.2 | 1.6 | 0.8 | 2.3 |
| AREQUIPA | CASTILLA | VIRACO | 9.5 | 14.9 | 11.5 | -20.8 | 20.4 | 2.5 | 2.3 | 2.2 | 3 | 2.6 | 1.7 | 1.8 | 1.8 | 1.5 | 1.9 |
| AREQUIPA | CAYLLOMA | YANQUE | 3 | 8.1 | 7.8 | -26.9 | 11 | 2.8 | 2.7 | 2.4 | 3.5 | 3 | 1.6 | 1.5 | 1.5 | 1.6 | 1.7 |

### 4.2.4 Projected changes in temperature and precipitation under the RCP 8.5 scenario in the SHAP project districts

| Region | Province | District | Changes under the RCP8.5 scenario | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | PR annual (%) | PR DJF (%) | PR MAM (%) | PR JJA (%) | PR SON (%) | TX annual (°C) | TX DJF (°C) | TX MAM (°C) | TX JJA (°C) | TX SON (°C) | TN annual (°C) | TN DJF (°C) | TN MAM (°C) | TN JJA (°C) | TN SON (°C) |
| APURIMAC | ABANCAY | ABANCAY | 11.1 | 17.6 | 18.5 | -23.8 | 15.5 | 3.3 | 3 | 3.1 | 4 | 3.2 | 2.4 | 2.6 | 2.6 | 1.9 | 2.5 |
| AREQUIPA | CAYLLOMA | ACHOMA | 0.6 | 4.7 | 3.7 | -41.7 | 2 | 3.4 | 3.1 | 3 | 4.2 | 3.5 | 2.2 | 2.3 | 2.4 | 2 | 2.4 |
| CUSCO | ACOMAYO | ACOMAYO | 9.4 | 10 | 15.6 | -20.7 | 8.2 | 3.3 | 3 | 3.2 | 4 | 3.2 | 2.4 | 2.4 | 2.4 | 2.2 | 2.4 |
| PUNO | CARABAYA | AJOYANI | -2.1 | 3.1 | 0.9 | -31.4 | -2.2 | 3.3 | 3.1 | 3 | 3.7 | 3.4 | 2.4 | 2.5 | 2.4 | 2 | 2.5 |
| PUNO | SAN ANTONIO DE PUTINA | ANANEA | -7.6 | -7.7 | -4.3 | -31 | - 11.4 | 3.5 | 3.3 | 3.1 | 4.1 | 3.5 | 2.4 | 2.5 | 2.3 | 2.3 | 2.5 |
| APURIMAC | ANTABAMBA | ANTABAMBA | 4.2 | 15.8 | 8.5 | -13.7 | 19.2 | 3.8 | 3.3 | 3.5 | 4.7 | 3.8 | 2 | 2 | 2 | 1.8 | 2.3 |
| PUNO | MELGAR | ANTAUTA | -4.6 | -1.8 | -1.7 | -34.8 | -5.8 | 3.4 | 3.2 | 3.1 | 4 | 3.4 | 2.1 | 2.3 | 2.2 | 1.6 | 2.3 |
| AREQUIPA | CASTILLA | AYO | 2.7 | 12.4 | 6.5 | -20 | 14 | 3.6 | 3.3 | 3.2 | 4.3 | 3.7 | 1.9 | 1.9 | 2 | 1.7 | 2.1 |
| AREQUIPA | CAYLLOMA | CABANACONDE | -3.3 | 7.8 | -1.4 | -23.1 | 11 | 3.8 | 3.5 | 3.4 | 4.6 | 3.9 | 1.7 | 1.8 | 1.7 | 1.6 | 2 |
| CUSCO | CALCA | CALCA | 9.6 | 10.8 | 15.1 | -17.4 | 9.3 | 3 | 2.8 | 2.8 | 3.3 | 3 | 2.6 | 2.6 | 2.8 | 2.2 | 2.6 |
| LIMA | YAUYOS | CARANIA | -7.6 | -2.5 | -9.2 | 7.5 | 3.2 | 3.4 | 3.2 | 3.1 | 3.8 | 3.5 | 2.2 | 2.2 | 2.3 | 2 | 2.4 |
| AREQUIPA | CONDESUYOS | CAYARANI | -3.1 | 7.8 | -1.8 | 1.8 | 16.3 | 3.8 | 3.5 | 3.5 | 4.5 | 3.9 | 1.9 | 2 | 1.9 | 1.9 | 2.3 |
| CUSCO | QUISPICANCHI | CCARHUAYO | 7 | 9.9 | 10.8 | -26.6 | 7.9 | 3.3 | 3.1 | 3.1 | 3.9 | 3.2 | 2.5 | 2.5 | 2.7 | 2 | 2.5 |
| AREQUIPA | CASTILLA | CHACHAS | -3.1 | 7.8 | -1.8 | 1.8 | 16.3 | 3.8 | 3.5 | 3.5 | 4.5 | 3.9 | 1.9 | 2 | 1.9 | 1.9 | 2.3 |
| CUSCO | PAUCARTAMBO | CHALLABAMBA | 9.6 | 10.8 | 15.1 | -17.4 | 9.3 | 3 | 2.8 | 2.8 | 3.3 | 3 | 2.6 | 2.6 | 2.8 | 2.2 | 2.6 |
| APURIMAC | COTABAMBAS | CHALLHUAHUACHO | 9.4 | 16.1 | 15.6 | -27.1 | 18.1 | 3.6 | 3.1 | 3.4 | 4.6 | 3.4 | 2.4 | 2.5 | 2.5 | 2.2 | 2.6 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CUSCO | CANCHIS | CHECACUPE | -8.4 | -6.4 | -7.6 | -28.2 | -8.5 | 4.4 | 4 | 4.1 | 5.1 | 4.2 | 3.9 | 3.3 | 3.7 | 5.2 | 3.8 |
| AREQUIPA | CONDESUYOS | CHICHAS | 6.8 | 13 | 11.1 | -22.8 | 15.2 | 3.4 | 3.1 | 3 | 4 | 3.4 | 2.2 | 2.3 | 2.4 | 1.9 | 2.4 |
| CUSCO | URUBAMBA | CHINCHERO | 9.6 | 10.8 | 15.1 | -17.4 | 9.3 | 3 | 2.8 | 2.8 | 3.3 | 3 | 2.6 | 2.6 | 2.8 | 2.1 | 2.6 |
| AREQUIPA | CAYLLOMA | CHIVAY | -5.3 | 5.7 | -3.5 | -27.4 | 12.4 | 4 | 3.6 | 3.6 | 4.8 | 4.1 | 1.6 | 1.8 | 1.5 | 1.3 | 2 |
| AREQUIPA | CASTILLA | CHOCO | 2.7 | 12.4 | 6.5 | -20 | 14 | 3.6 | 3.3 | 3.2 | 4.3 | 3.7 | 1.9 | 1.9 | 2 | 1.7 | 2.1 |
| AREQUIPA | CONDESUYOS | CHUQUIBAMBA | -14.4 | -8.5 | -11.7 | -41 | -8.6 | 2.9 | 2.7 | 2.8 | 3.3 | 2.9 | 2.9 | 2.9 | 2.8 | 3.3 | 3.1 |
| APURIMAC | GRAU | CHUQUIBAMBILLA | 6.9 | 17.7 | 11.7 | -31.5 | 17.5 | 3.7 | 3.1 | 3.5 | 4.6 | 3.5 | 2.3 | 2.4 | 2.4 | 1.9 | 2.4 |
| APURIMAC | ABANCAY | CIRCA | 6.9 | 17.7 | 11.7 | -31.5 | 17.5 | 3.7 | 3.1 | 3.5 | 4.6 | 3.5 | 2.3 | 2.4 | 2.4 | 1.9 | 2.4 |
| AREQUIPA | CAYLLOMA | COPORAQUE | -3.3 | 7.8 | -1.4 | -23.1 | 11 | 3.8 | 3.5 | 3.4 | 4.6 | 3.9 | 1.7 | 1.8 | 1.7 | 1.6 | 2 |
| PUNO | CARABAYA | CORANI | -1.5 | 2.6 | 3.8 | -38.6 | -4.1 | 3.1 | 3 | 2.8 | 3.5 | 3.4 | 2.6 | 2.8 | 2.8 | 2.3 | 2.7 |
| AREQUIPA | LA UNION | COTAHUASI | 6.8 | 13 | 11.1 | -22.8 | 15.2 | 3.4 | 3.1 | 3 | 4 | 3.4 | 2.2 | 2.3 | 2.4 | 1.9 | 2.4 |
| APURIMAC | COTABAMBAS | COYLLURQUI | 8.9 | 10.7 | 15.7 | -20.1 | 9.2 | 3.4 | 3 | 3.2 | 4 | 3.2 | 2.5 | 2.5 | 2.5 | 2.3 | 2.4 |
| PUNO | CARABAYA | CRUCERO | -2.1 | 3.1 | 0.9 | -31.4 | -2.2 | 3.3 | 3.1 | 3 | 3.7 | 3.4 | 2.4 | 2.5 | 2.4 | 2 | 2.5 |
| APURIMAC | ABANCAY | CURAHUASI | 11.1 | 17.6 | 18.5 | -23.8 | 15.5 | 3.3 | 3 | 3.1 | 4 | 3.2 | 2.4 | 2.6 | 2.6 | 1.9 | 2.5 |
| APURIMAC | GRAU | CURASCO | 6.9 | 17.7 | 11.7 | -31.5 | 17.5 | 3.7 | 3.1 | 3.5 | 4.6 | 3.5 | 2.3 | 2.4 | 2.4 | 1.9 | 2.4 |
| APURIMAC | GRAU | CURPAHUASI | 6.9 | 17.7 | 11.7 | -31.5 | 17.5 | 3.7 | 3.1 | 3.5 | 4.6 | 3.5 | 2.3 | 2.4 | 2.4 | 1.9 | 2.4 |
| CUSCO | QUISPICANCHI | CUSIPATA | 7 | 9.9 | 10.8 | -26.6 | 7.9 | 3.3 | 3.1 | 3.1 | 3.9 | 3.2 | 2.5 | 2.5 | 2.7 | 2 | 2.5 |
| PUNO | SANDIA | CUYOCUYO | -7.6 | -7.7 | -4.3 | -31 | -11.4 | 3.5 | 3.3 | 3.1 | 4.1 | 3.5 | 2.4 | 2.5 | 2.3 | 2.3 | 2.5 |
| APURIMAC | GRAU | GAMARRA | 11.1 | 17.6 | 18.5 | -23.8 | 15.5 | 3.3 | 3 | 3.1 | 4 | 3.2 | 2.4 | 2.6 | 2.6 | 1.9 | 2.5 |
| APURIMAC | COTABAMBAS | HAQUIRA | 9.4 | 16.1 | 15.6 | -27.1 | 18.1 | 3.6 | 3.1 | 3.4 | 4.6 | 3.4 | 2.4 | 2.5 | 2.5 | 2.2 | 2.6 |
| APURIMAC | ABANCAY | HUANIPACA | 17.2 | 25.5 | 25.1 | -17.5 | 21.3 | 3 | 2.8 | 2.8 | 3.3 | 2.9 | 2.9 | 2.9 | 3.1 | 2.8 | 2.9 |
| APURIMAC | ANTABAMBA | HUAQUIRCA | 6.9 | 17.7 | 11.7 | -31.5 | 17.5 | 3.7 | 3.1 | 3.5 | 4.6 | 3.5 | 2.3 | 2.4 | 2.4 | 1.9 | 2.4 |
| CUSCO | ANTA | HUAROCONDO | 12 | 12.9 | 17.6 | -11.2 | 13.4 | 2.9 | 2.8 | 2.8 | 3.3 | 2.9 | 2.7 | 2.7 | 2.9 | 2.3 | 2.7 |
| APURIMAC | GRAU | HUAYLLATI | 9.4 | 16.1 | 15.6 | -27.1 | 18.1 | 3.6 | 3.1 | 3.4 | 4.6 | 3.4 | 2.4 | 2.5 | 2.5 | 2.2 | 2.6 |
| AREQUIPA | LA UNION | HUAYNACOTAS | 2.1 | 15.3 | 1 | 18.6 | 25.5 | 3.7 | 3.4 | 3.3 | 4.4 | 3.7 | 1.9 | 1.9 | 1.8 | 1.8 | 2.2 |
| AREQUIPA | CAYLLOMA | ICHUPAMPA | -3.3 | 7.8 | -1.4 | -23.1 | 11 | 3.8 | 3.5 | 3.4 | 4.6 | 3.9 | 1.7 | 1.8 | 1.7 | 1.6 | 2 |
| CUSCO | CALCA | LAMAY | 9.6 | 10.8 | 15.1 | -17.4 | 9.3 | 3 | 2.8 | 2.8 | 3.3 | 3 | 2.6 | 2.6 | 2.8 | 2.2 | 2.6 |
| APURIMAC | ABANCAY | LAMBRAMA | 11.1 | 17.6 | 18.5 | -23.8 | 15.5 | 3.3 | 3 | 3.1 | 4 | 3.2 | 2.4 | 2.6 | 2.6 | 1.9 | 2.5 |
| LIMA | YAUYOS | LARAOS | -7.6 | -2.5 | -9.2 | 7.5 | 3.2 | 3.4 | 3.2 | 3.1 | 3.8 | 3.5 | 2.2 | 2.2 | 2.3 | 2 | 2.4 |
| CUSCO | CALCA | LARES | 9.6 | 10.8 | 15.1 | -17.4 | 9.3 | 3 | 2.8 | 2.8 | 3.3 | 3 | 2.6 | 2.6 | 2.8 | 2.2 | 2.6 |
| AREQUIPA | CAYLLOMA | LARI | -3.3 | 7.8 | -1.4 | -23.1 | 11 | 3.8 | 3.5 | 3.4 | 4.6 | 3.9 | 1.7 | 1.8 | 1.7 | 1.6 | 2 |
| CUSCO | CANAS | LAYO | 8.1 | 4.3 | 10.9 | -12.1 | 5 | 3.7 | 3.4 | 3.5 | 4.4 | 3.6 | 2.2 | 2.7 | 2.2 | 1.3 | 2.8 |
| CUSCO | ANTA | LIMATAMBO | 12 | 12.9 | 17.6 | -11.2 | 13.4 | 2.9 | 2.8 | 2.8 | 3.3 | 2.9 | 2.7 | 2.7 | 2.9 | 2.3 | 2.7 |
| CUSCO | CHUMBIVILCAS | LLUSCO | 4.7 | 14.3 | 9 | -16.5 | 20 | 3.8 | 3.4 | 3.5 | 4.6 | 3.8 | 2.2 | 2.3 | 2.1 | 1.9 | 2.5 |
| AREQUIPA | CAYLLOMA | LLUTA | 0.6 | 4.7 | 3.7 | -41.7 | 2 | 3.4 | 3.1 | 3 | 4.2 | 3.5 | 2.2 | 2.3 | 2.4 | 2 | 2.4 |
| AREQUIPA | CAYLLOMA | MACA | 0.6 | 4.7 | 3.7 | -41.7 | 2 | 3.4 | 3.1 | 3 | 4.2 | 3.5 | 2.2 | 2.3 | 2.4 | 2 | 2.4 |
| AREQUIPA | CASTILLA | MACHAGUAY | 2.7 | 12.4 | 6.5 | -20 | 14 | 3.6 | 3.3 | 3.2 | 4.3 | 3.7 | 1.9 | 1.9 | 2 | 1.7 | 2.1 |
| PUNO | CARABAYA | MACUSANI | -4.6 | -1.8 | -1.7 | -34.8 | -5.8 | 3.4 | 3.2 | 3.1 | 4 | 3.4 | 2.1 | 2.3 | 2.2 | 1.6 | 2.3 |
| AREQUIPA | CAYLLOMA | MADRIGAL | -3.3 | 7.8 | -1.4 | -23.1 | 11 | 3.8 | 3.5 | 3.4 | 4.6 | 3.9 | 1.7 | 1.8 | 1.7 | 1.6 | 2 |
| APURIMAC | GRAU | MAMARA | 6.9 | 17.7 | 11.7 | -31.5 | 17.5 | 3.7 | 3.1 | 3.5 | 4.6 | 3.5 | 2.3 | 2.4 | 2.4 | 1.9 | 2.4 |
| CUSCO | CANCHIS | MARANGANI | -8.4 | -6.4 | -7.6 | -28.2 | -8.5 | 4.4 | 4 | 4.1 | 5.1 | 4.2 | 3.9 | 3.3 | 3.7 | 5.2 | 3.8 |
| CUSCO | QUISPICANCHI | MARCAPATA | -0.1 | 4.3 | 2 | -25.9 | 0.6 | 4.1 | 3.8 | 3.9 | 4.7 | 4 | 4.3 | 3.5 | 4.1 | 5.8 | 4 |
| APURIMAC | GRAU | MICAELA BASTIDAS | 6.9 | 17.7 | 11.7 | -31.5 | 17.5 | 3.7 | 3.1 | 3.5 | 4.6 | 3.5 | 2.3 | 2.4 | 2.4 | 1.9 | 2.4 |
| LIMA | YAUYOS | MIRAFLORES | -7.6 | -2.5 | -9.2 | 7.5 | 3.2 | 3.4 | 3.2 | 3.1 | 3.8 | 3.5 | 2.2 | 2.2 | 2.3 | 2 | 2.4 |
| CUSCO | ANTA | MOLLEPATA | 17.6 | 21.6 | 27 | -7.9 | 21.8 | 2.9 | 2.7 | 2.7 | 3.2 | 2.8 | 2.9 | 2.9 | 3 | 2.7 | 2.9 |
| PUNO | MELGAR | NUÑOA | -4.6 | -1.8 | -1.7 | -34.8 | -5.8 | 3.4 | 3.2 | 3.1 | 4 | 3.4 | 2.1 | 2.3 | 2.2 | 1.6 | 2.3 |
| CUSCO | QUISPICANCHI | OCONGATE | 7 | 9.9 | 10.8 | -26.6 | 7.9 | 3.3 | 3.1 | 3.1 | 3.9 | 3.2 | 2.5 | 2.5 | 2.7 | 2 | 2.5 |
| CUSCO | URUBAMBA | OLLANTAYTAMBO | 12 | 12.9 | 17.6 | -11.2 | 13.4 | 2.9 | 2.8 | 2.8 | 3.3 | 2.9 | 2.7 | 2.7 | 2.9 | 2.3 | 2.7 |
| AREQUIPA | CASTILLA | ORCOPAMPA | -3.1 | 7.8 | -1.8 | 1.8 | 16.3 | 3.8 | 3.5 | 3.5 | 4.5 | 3.9 | 1.9 | 2 | 1.9 | 1.9 | 2.3 |
| APURIMAC | ANTABAMBA | OROPESA | 4.2 | 15.8 | 8.5 | -13.7 | 19.2 | 3.8 | 3.3 | 3.5 | 4.7 | 3.8 | 2 | 2 | 2 | 1.8 | 2.3 |
| AREQUIPA | CASTILLA | PAMPACOLCA | 6.8 | 13 | 11.1 | -22.8 | 15.2 | 3.4 | 3.1 | 3 | 4 | 3.4 | 2.2 | 2.3 | 2.4 | 1.9 | 2.4 |
| AREQUIPA | LA UNION | PAMPAMARCA | 2.1 | 15.3 | 1 | 18.6 | 25.5 | 3.7 | 3.4 | 3.3 | 4.4 | 3.7 | 1.9 | 1.9 | 1.8 | 1.8 | 2.2 |
| APURIMAC | GRAU | PATAYPAMPA | 6.9 | 17.7 | 11.7 | -31.5 | 17.5 | 3.7 | 3.1 | 3.5 | 4.6 | 3.5 | 2.3 | 2.4 | 2.4 | 1.9 | 2.4 |
| CUSCO | PAUCARTAMBO | PAUCARTAMBO | 8 | 11.9 | 14.2 | -26.4 | 9.3 | 3 | 2.9 | 2.8 | 3.3 | 3 | 2.9 | 3 | 3 | 2.6 | 3 |
| APURIMAC | ABANCAY | PICHIRHUA | 6.1 | 18.8 | 14.7 | -33.9 | 13.1 | 3.4 | 3 | 3.2 | 4 | 3.3 | 2.4 | 2.6 | 2.6 | 1.9 | 2.5 |
| CUSCO | CALCA | PISAC | 9.6 | 10.8 | 15.1 | -17.4 | 9.3 | 3 | 2.8 | 2.8 | 3.3 | 3 | 2.6 | 2.6 | 2.8 | 2.2 | 2.6 |
| CUSCO | CANCHIS | PITUMARCA | -0.1 | 4.3 | 2 | -25.9 | 0.6 | 4.1 | 3.8 | 3.9 | 4.7 | 4 | 4.3 | 3.5 | 4.1 | 5.8 | 4 |
| PUNO | AZANGARO | POTONI | -8.6 | -10.2 | -7.8 | -33.4 | -13.7 | 3.7 | 3.5 | 3.3 | 4.3 | 3.7 | 2.4 | 2.5 | 2.3 | 2.3 | 2.7 |
| APURIMAC | GRAU | PROGRESO | 9.4 | 16.1 | 15.6 | -27.1 | 18.1 | 3.6 | 3.1 | 3.4 | 4.6 | 3.4 | 2.4 | 2.5 | 2.5 | 2.2 | 2.6 |
| AREQUIPA | LA UNION | PUYCA | 2.1 | 15.3 | 1 | 18.6 | 25.5 | 3.7 | 3.4 | 3.3 | 4.4 | 3.7 | 1.9 | 1.9 | 1.8 | 1.8 | 2.2 |
| AREQUIPA | LA UNION | QUECHUALLA | 6 | 7.8 | 10.5 | -37.9 | 9.1 | 3.3 | 2.9 | 2.9 | 3.9 | 3.3 | 2.6 | 2.7 | 2.8 | 2.3 | 2.8 |
| CUSCO | QUISPICANCHI | QUIQUIJANA | 7 | 9.9 | 10.8 | -26.6 | 7.9 | 3.3 | 3.1 | 3.1 | 3.9 | 3.2 | 2.5 | 2.5 | 2.7 | 2 | 2.5 |
| AREQUIPA | CONDESUYOS | SALAMANCA | 6.8 | 13 | 11.1 | -22.8 | 15.2 | 3.4 | 3.1 | 3 | 4 | 3.4 | 2.2 | 2.3 | 2.4 | 1.9 | 2.4 |
| AREQUIPA | CAYLLOMA | SAN ANTONIO DE CHUCA | -4.1 | 7 | -2.8 | -37.1 | 8.3 | 4 | 3.6 | 3.5 | 5 | 4.2 | 1.7 | 1.8 | 1.6 | 1.7 | 2 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AREQUIPA | AREQUIPA | SAN JUAN DE TARUCANI | 0.8 | 7.6 | 2.9 | -42.2 | 4.8 | 3.7 | 3.3 | 3.2 | 4.7 | 3.9 | 2 | 2.1 | 2 | 1.8 | 2.1 |
| CUSCO | CANCHIS | SAN PABLO | -8.4 | -6.4 | -7.6 | -28.2 | -8.5 | 4.4 | 4 | 4.1 | 5.1 | 4.2 | 3.9 | 3.3 | 3.7 | 5.2 | 3.8 |
| CUSCO | CALCA | SAN SALVADOR | 9.6 | 10.8 | 15.1 | -17.4 | 9.3 | 3 | 2.8 | 2.8 | 3.3 | 3 | 2.6 | 2.6 | 2.8 | 2.2 | 2.6 |
| PUNO | MELGAR | SANTA ROSA | 8.1 | 4.3 | 10.9 | -12.1 | 5 | 3.7 | 3.4 | 3.5 | 4.4 | 3.6 | 2.2 | 2.7 | 2.2 | 1.3 | 2.8 |
| CUSCO | LA CONVENCION | SANTA TERESA | 17.6 | 21.6 | 27 | -7.9 | 21.8 | 2.9 | 2.7 | 2.7 | 3.2 | 2.8 | 2.9 | 2.9 | 3 | 2.7 | 2.9 |
| CUSCO | CHUMBIVILCAS | SANTO TOMAS | 4.7 | 14.3 | 9 | -16.5 | 20 | 3.8 | 3.4 | 3.5 | 4.6 | 3.8 | 2.2 | 2.3 | 2.1 | 1.9 | 2.5 |
| CUSCO | CANCHIS | SICUANI | -8.4 | -6.4 | -7.6 | -28.2 | -8.5 | 4.4 | 4 | 4.1 | 5.1 | 4.2 | 3.9 | 3.3 | 3.7 | 5.2 | 3.8 |
| APURIMAC | COTABAMBAS | TAMBOBAMBA | 8.9 | 10.7 | 15.7 | -20.1 | 9.2 | 3.4 | 3 | 3.2 | 4 | 3.2 | 2.5 | 2.5 | 2.5 | 2.3 | 2.4 |
| APURIMAC | ABANCAY | TAMBURCO | 11.1 | 17.6 | 18.5 | -23.8 | 15.5 | 3.3 | 3 | 3.1 | 4 | 3.2 | 2.4 | 2.6 | 2.6 | 1.9 | 2.5 |
| APURIMAC | AYMARAES | TINTAY | 6.1 | 18.8 | 14.7 | -33.9 | 13.1 | 3.4 | 3 | 3.2 | 4 | 3.3 | 2.4 | 2.6 | 2.6 | 1.9 | 2.5 |
| LIMA | YAUYOS | TOMAS | -12.3 | -7.4 | -16.3 | -1.4 | -1.4 | 3.5 | 3.4 | 3.2 | 3.9 | 3.6 | 2 | 2.1 | 2 | 1.7 | 2.2 |

### 4.3 Analysis of climate projections under the RCP8.5 emission scenario with the HadGEM2-ES-RCA4 model

Changes in annual precipitation in this scenario ranges from -14.4 to 17.6%. Most of the districts show positive changes and those that show negative changes are those located on the SW and SE subregions. The annual Tx ranges from 2.9 to 4.4°C. The major changes are found on the SE subregion. The Tn ranges from 1.6 to 4.3 ° C. The regions with the least change are found on the SW subregion; however, the most warming ones, are located at the border of SE and A subregions.

The season that shows the greatest changes in Pr in most districts is JJA, which shows negative changes with high values (between -42.2 to 18.6%). Within this season, there are positive changes in a few districts located in the SW subregion. Contrary to what was obtained for RCP4.5, the greatest positive changes occur in MAM in most districts and in DJF in the rest (eastern of SE).

Regarding the seasonal changes of Tx, JJA is the season that shows the greatest warmings, ranging from 3.2 to 5.1 °C. Instead, DJF is the season with the least changes. In general, the largest Tx changes are found at the border of SE and A subregions, which is the head of the Urubamba river basin. This is consistent with what was found in SENAMHI, 2009, SENAMHI, 2012 and MINAM, 2016, where greater warming is also shown on the Vilcanota, La Raya and Carabaya mountain ranges.

Seasonal changes of Tn occur in SON in most of the districts, except for the ones located at the east of the SW subregion. In most districts, the lowest values are in JJA. It is important to note that, in this season, six districts show a very large warming, which is above 4°C. These are located between 4000 to 5000 meters above sea level at the border of SE and A subregions.