METHODOLOGICAL STRATEGY TO MEASURE THE RESILIENCE OF GIAHS TO CLIMATE CHANGE: RAISIN GRAPE OF THE AXARQUÍA, MALAGA (SPAIN)

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CONTENTS

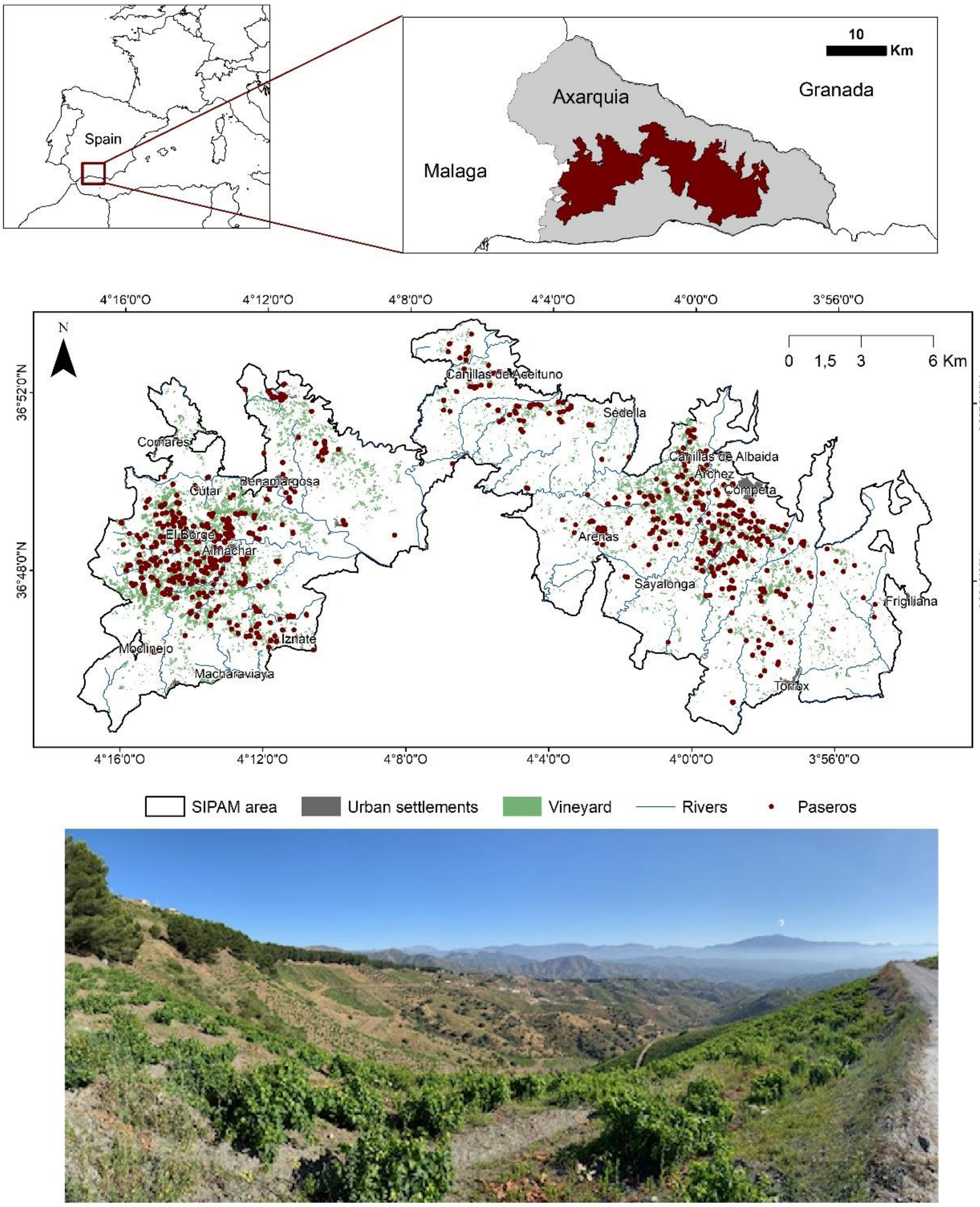
1.- INTRODUCTION: THE GIAHS AREA AND CLIMATE CHANGE

The future climate scenarios published by the IPCC (2017) link the Andalusian Mediterranean area as one of the most uncertain areas of the Iberian Peninsula, where an increase in average temperature slightly higher than that of the rest of the planet is proposed, in addition to a decrease in average annual rainfall. In this sense, an increase in the number of extreme climatic events is highlighted, such as the duration and frequency of droughts, the greater presence of heat waves, days of extreme cold and heat or the appearance of torrential rainfall events.

As a consequence of global change, these climatic changes will affect the Mediterranean eco-geomorphological system, where a significant reduction in water resources (around 20%) is expected, with a direct impact on agricultural production and, therefore, on food security. Thus, agriculture appears to be one of the most vulnerable sectors in this regard, which also has the highest erosion rates on a global scale, causing landscape degradation processes, with the consequent impoverishment of the soil, loss of nutrients, biodiversity and, of course, of its productive potential (IPCC, 2019).

The "Sistema Productivo de la Uva Pasa de Málaga en la Axarquía" (GIAHS area), located in the Axarquía region, in the easternmost sector of the province of Málaga (southern Spain; Fig. 1), is part of these future predictions. This territory covers a total of 280.4 km2 and 20 municipalities (Almáchar, Árchez, Arenas, Benamargosa, Canillas de Aceituno, Canillas de Albaida, Comares, Cómpeta, Cútar, El Borge, Frigiliana, Iznate, Macharaviaya, Moclinejo, Salares, Sayalonga, Sedella, Torrox, Vélez Málaga, Viñuela). Thus, it is an area with very similar economic, historical and cultural features, where the cultivation of the vine and, more specifically, the production of raisins, has been the backbone of the life and economy of the area since at least the 10th century.

Fig. 1. Location of the Axarquia GIAHS area



Currently, the GIAHS area has a population of approximately 118,000 inhabitants, with a growing average age, due, among other reasons, to the processes of rural exodus, as a consequence of the loss of profitability of the primary sector and the search for greater proximity to a multitude of goods and services.

From an environmental point of view, this GIAHS area has typical characteristics of the Mediterranean mid-mountain landscape, with a physiography characterised by steep slopes, with an average of over 45%, and a high average altitude (391 m above sea level), despite its proximity to the Mediterranean Sea. The distribution of land uses shows great heterogeneity and landscape complexity. Most of the agricultural surface area alternates between rain-fed woody crops, such as vines and olives, but there are also numerous areas of crop mosaic and a growing presence of tropical crops (avocado and mango). Thus, a remarkable element of the GIAHS landscape is the scattering of constructions or structural elements (e.g., the raisins), which demonstrate the strong roots of a territory and its population to a specific economic activity, thus forming a true landscape, which according to the European Landscape Convention would be defined as "any part of the territory as perceived by the population, the character of which is the result of the action and interaction of natural and/or human factors" (Council of Europe, 2000). In other words, a traditional Mediterranean landscape that has been used anthropically for more than 20 centuries in general, and especially for the last 5 centuries with regard to the specific territory of GIAHS. This landscape cannot be understood without assuming the human imprint.

GIAHS area is located in Mediterranean climatic conditions, in a transition zone between a dry Mediterranean climate and a semi-arid climate.Thus, temperatures show contrasting characteristics between the western and eastern half. The western area registers an average annual temperature of 17.4ºC (1979-2019), while the average in the eastern area drops by almost one degree, to 16.7ºC. In this sense, the evolution of these mean annual temperatures has also been highly differentiated (Fig. 2), with an increasing trend parallel to the IPCC scenarios in the western area (A) since 1979 and more accentuated in recent decades. On the contrary, a decreasing trend is identified in the eastern sector (B), which is being reversed in the last 20 years, presenting a similar evolution to the western area.

Fig. 2. Evolution of the mean annual temperature in the GIAHS area between 1979 and 2019 (A, westerna area; B, eastern area)

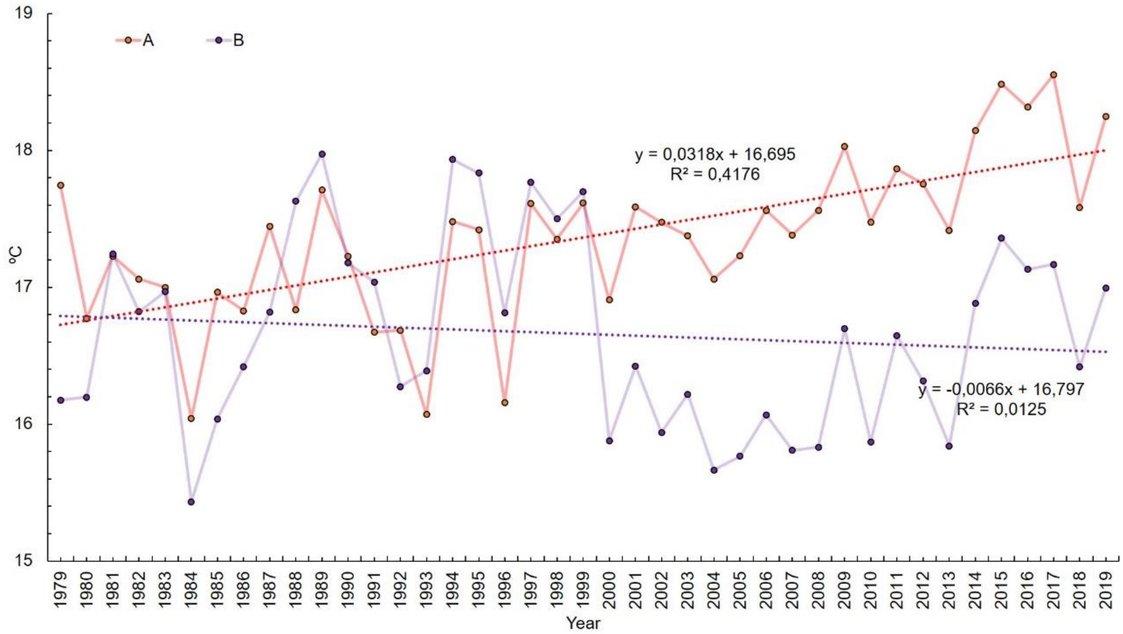
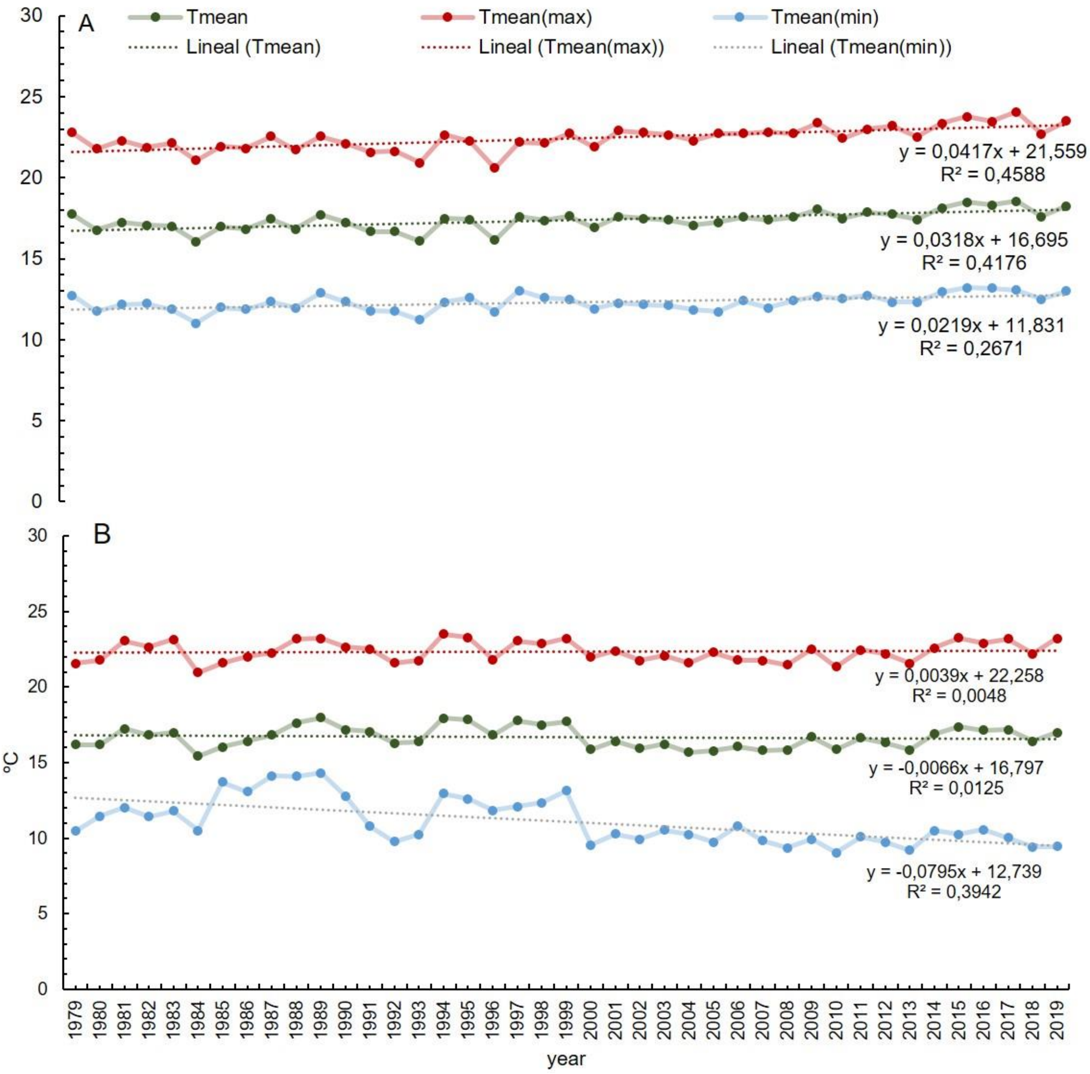


Figure 3 shows the mean temperature, mean maximum and mean minimum temperatures for each part of the GIAHS area. In the western area, the trend is generally positive, with an average maximum temperature (1979-2019) of 22.4ºC and an average minimum temperature of 12.3ºC.

In the eastern sector, the decrease in the average minimum temperature over the last 40 years is striking, with an average value of 11ºC, while the average maximum temperature is 22.3ºC.

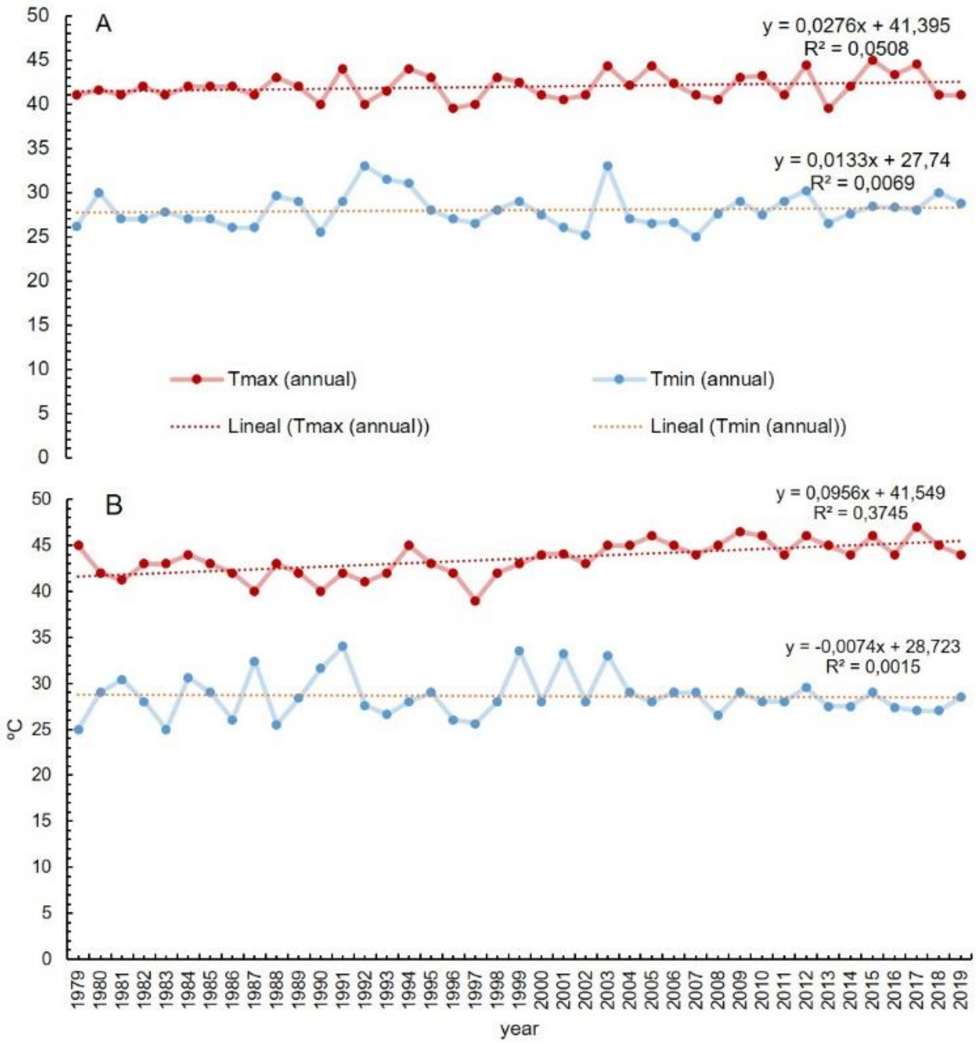
Fig. 3. Annual change in mean temperature and mean maximum and minimum temperatures in the GIAHS area between 1979 and 2019 (A, western area; B, eastern area)



Considering the increase in extreme values projected by the IPCC, the absolute maximum temperature registers a positive trend throughout the GIAHS area (Fig. 4), more pronounced in the eastern sector.Thus, the mean of the series is 42ºC (A) and 43.6ºC (B), being higher in the last twenty years, 42.3ºC and 44.8ºC, respectively.

As for the maximum temperature of the minimums, no clear trend has been identified in the western half, which presents very similar values over the last 40 years.However, the eastern area shows a slight decrease in minimum temperatures, with more homogeneous data over the last two decades, around 28ºC.

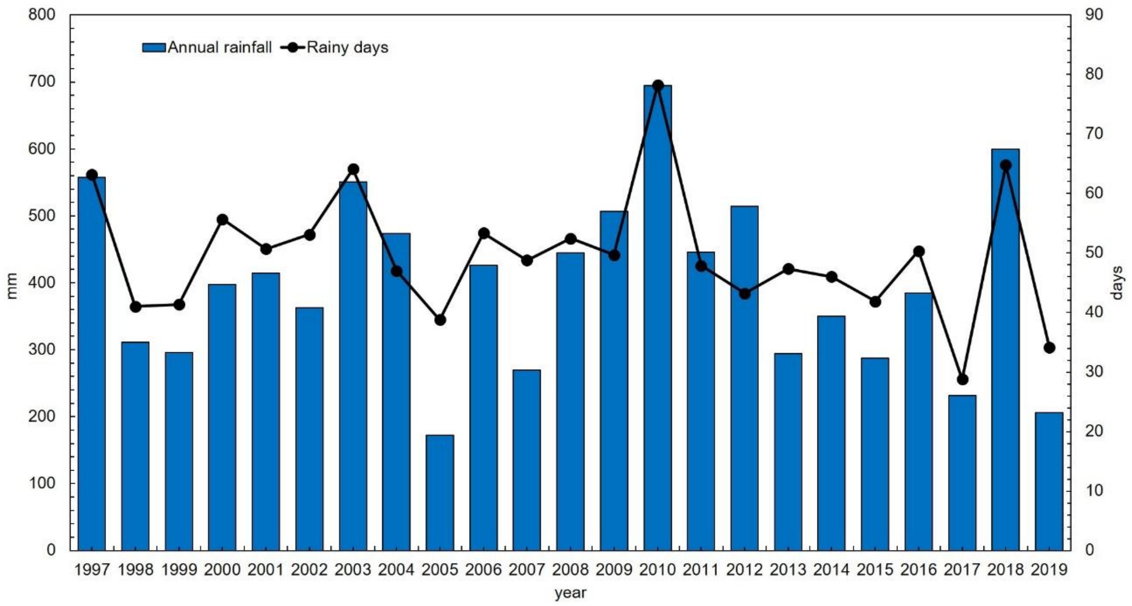
Fig. 4. Annual evolution of absolute maximum temperature and minimum maximums in the GIAHS area between 1979 and 2019 (A, western area; B, eastern area)



The pluviometric pattern is characterised by high interannual irregularity, with an average annual rainfall, in the period between 1997 and 2019, of 400±133 mm (Fig. 5). This high variability is reflected in the recording of data close to 700 mm (2010) and, on the other hand, others that do not reach 200 mm (2005). Thus, the evolution identified for this area is perfectly in line with climate change forecasts, with a decrease in annual precipitation in recent decades.

The same is true for the number of rainy days, which show a downward trend, with an average of 49.6±10.8 days. As with the accumulated rainfall data, there is a high interannual irregularity, with years with figures close to 80 days of rain (2010) and others with only 28 drainy days (2017).

Fig. 5. Annual evolution of total rainfall and number of rainy days in the GIAHS area between 1997 and 2019



In short, the climatic characteristics of the GIAHS area correspond to those of a Mediterranean climate, following the trends identified and expected by the latest IPCC reports (2014, 2019) for this area of the Iberian Peninsula.

Based on these previous considerations and the general description of the GIAHS territory of Axarquia, the objective of this study is to evaluate its vulnerability to climate change, paying maximum attention to the agricultural areas cultivated with vineyards, which give this territory this mention. In addition, the main socio-economic characteristics of the municipalities that make up this area will be studied in order to analyse their fragility in this highly dynamic situation. Finally, possible adaptation measures to this new climatic situation will be proposed, identifying the level of resilience achieved by these crops.

Traditional agricultural systems, under the dynamics of climate change, may be susceptible to certain affectations derived from their sensitivity. Different authors have been concerned with assessing the different levels of vulnerability in other territories in order to determine the mechanisms of adaptation to the new climatic conditions. It is difficult to establish a general framework for vulnerability analysis, especially when the spatial, temporal and thematic variability of GIAHS is affected by different climatic conditions. Therefore, regional and local factors play a major role in determining the specific criteria for quantifying and assessing this vulnerability (Ducusin et al, 2019).

Under these general approaches, the methodological scheme for determining the vulnerability and resilience of GIAHS will be based on the following phases (Fig. 6):

1.- To assess the "exposure" within the area in which the GIAHS territory is circumscribed to the main indicators of Climate Change.

2.- To evaluate the specific "sensibility" of the GIAHS area to these effects.

3.- To assess the "affection" of the GIAHS area according to this sensitivity.

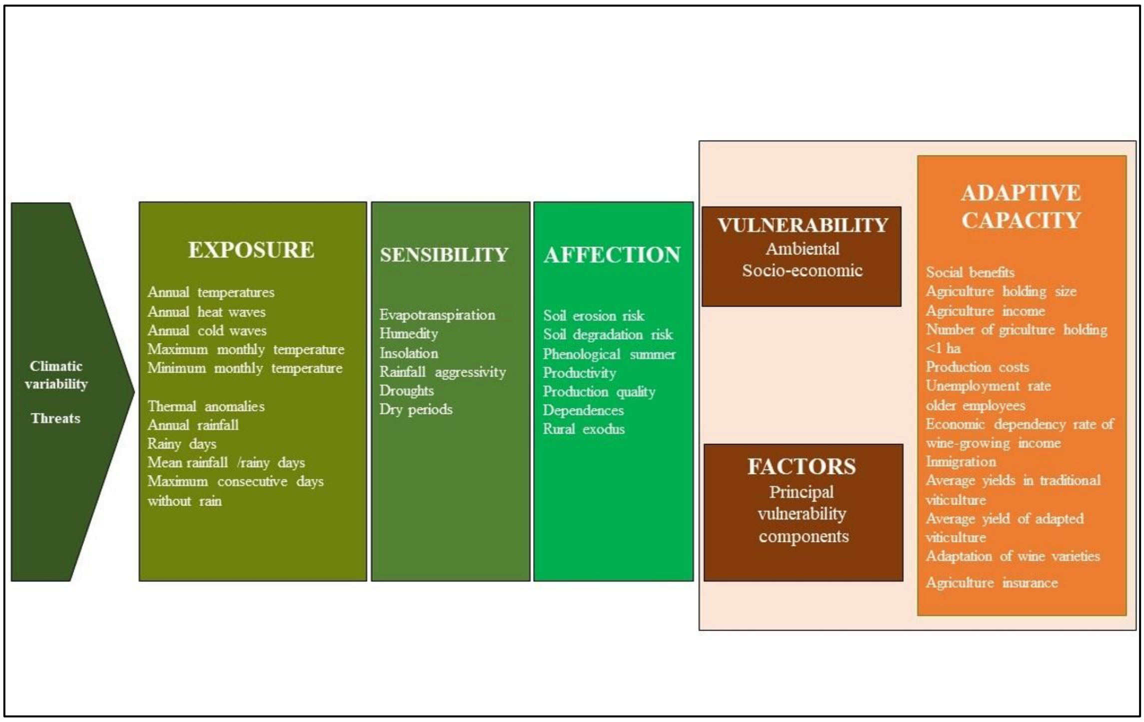
4.- To determine the vulnerability, both environmental and socio-economic.

5.- To identify the main factors, indicators of vulnerability.

6.- To evaluate the "adaptive capacity" or resilience mechanisms.

7.- To assess the general risks of the GIAHS area.

Fig. 6. Methodological scheme for determining the vulnerability and resilience of GIAHS



2.- MAIN EXPOSURE VARIABLES OF THE GIAHS AREA

The main climatic changes to which the whole of the territory under study is exposed have been considered, differentiating especially between thermal and pluviometric factors.

For this reason, the presentation is approached from the perspective of changes in the main climatic variables in the GIAHS area.

2.1. Changes in the temperature pattern

One of the most important variables to which the GIAHS environment is exposed is temperature, which, in a context of climate crisis, has undergone significant changes in recent decades. Thus, regardless of the evolution of the average annual temperatures identified, the changes are giving way to a greater occurrence of extreme events, or thermal anomalies.

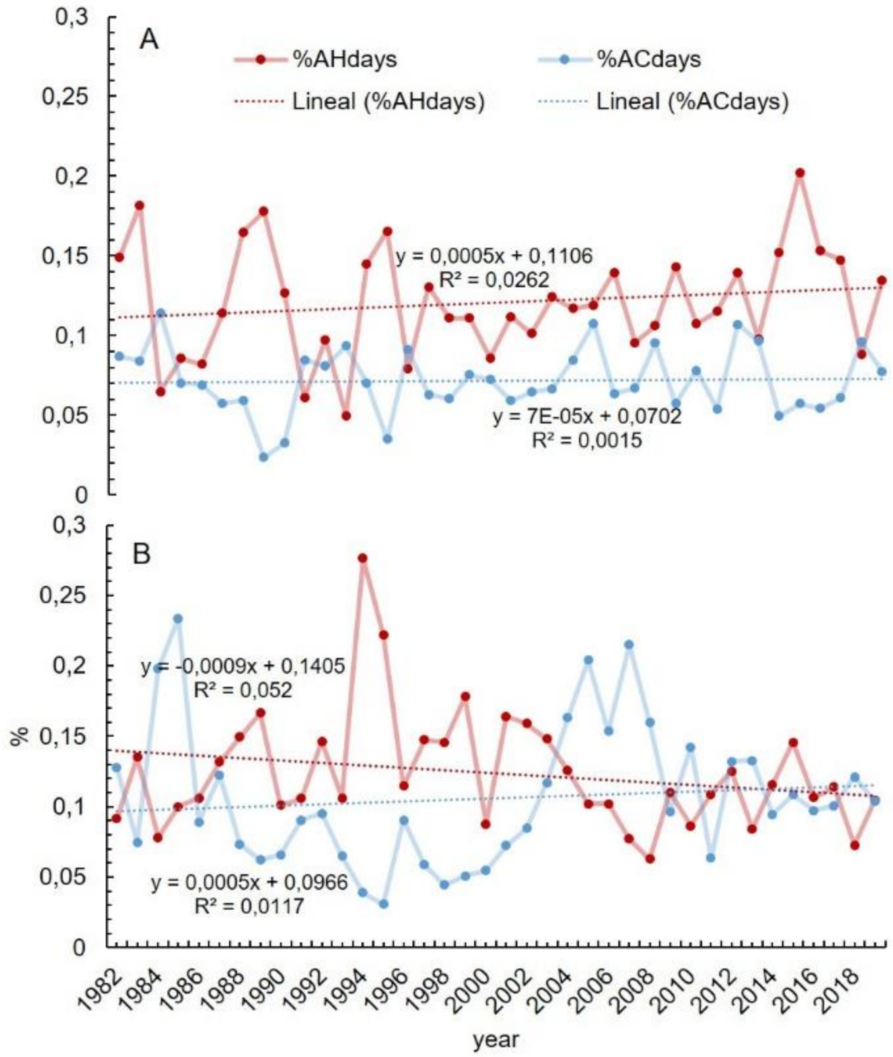
For the analysis of these thermal anomalies, the temperature data have been obtained from 64 weather stations of the Agencia Estatal de Meteorología (AEMET), distributed throughout the nearby area of the study area and divided into western and eastern sectors.

Firstly, as an indicator of these changes, Figure 7 shows the annual evolution of the percentage in which anomalous temperatures have been reached. For this purpose, the methodology described by Bárcena-Martín (2018) has been followed, which describes what is understood by anomalous.

The results show contrasting developments between the western (A) and eastern (B) zones. The mean percentage of anomalous heat days of the series in the western zone is 0.12±0.03 % and registers a strong increase, especially in the last two decades. However, in the eastern area, the trend is completely reversed, identifying a clear recession in the first decade of the 21st century. Thus, the average percentage of the data series in this eastern area is practically similar to that of the western area, also with a value of 0.12 ±0.04 %.

On the other hand, the percentage of anomalously cold days shows a clear increase in the eastern zone, while in the western zone there is no definite trend. In the western sector, the mean value of the series is 0.07±0.02 %, while in the eastern it is 0.11±0.05 %.

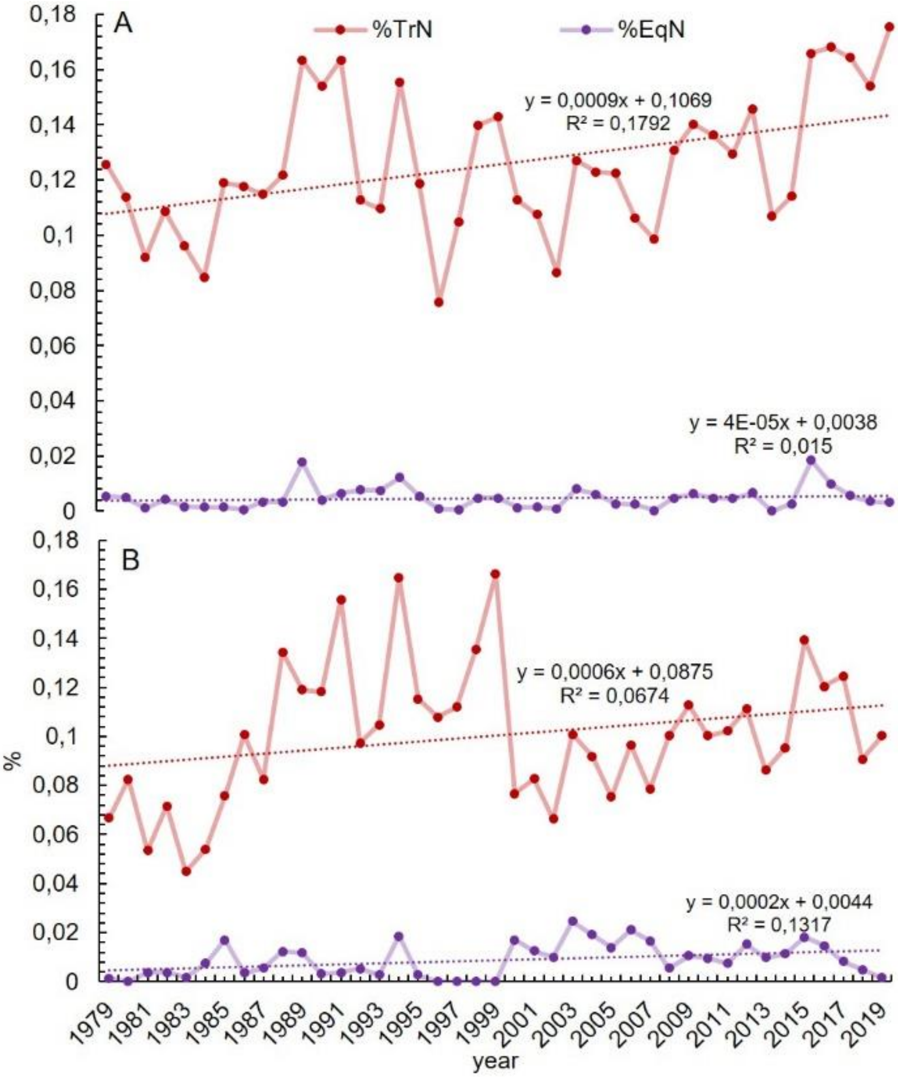
Fig. 7. Annual evolution of the percentage of anomalous hot and cold days in the GIAHS area between 1982 and 2019 (%AHdays, anomalous hot; %ACdays, anomalous cold)



Another important variable is the percentage of tropical and equatorial nights in the GIAHS area. For its calculation, tropical nights have been considered those in which the minimum temperature is equal to or higher than 20ºC, while, in the case of equatorial nights, the minimum temperature must rise to at least 25ºC.

The results show hardly any differences across the territory (Fig. 8), in both cases there is a positive trend, both in tropical and equatorial nights. Thus, the average value of the percentage of tropical nights is higher in the western area, where 0.13±0.03 % is recorded, compared to 0.1±0.03 % in the eastern area. As for tropical nights, the situation is much more similar, where in both cases the value is 0.004 %.

Fig. 8. Annual evolution of the percentage of tropical and equatorial nights in the GIAHS area between 1979 and 2019 (%TrN, tropical nights; %EqN, equatorial nights; A, western area; B, eastern area)



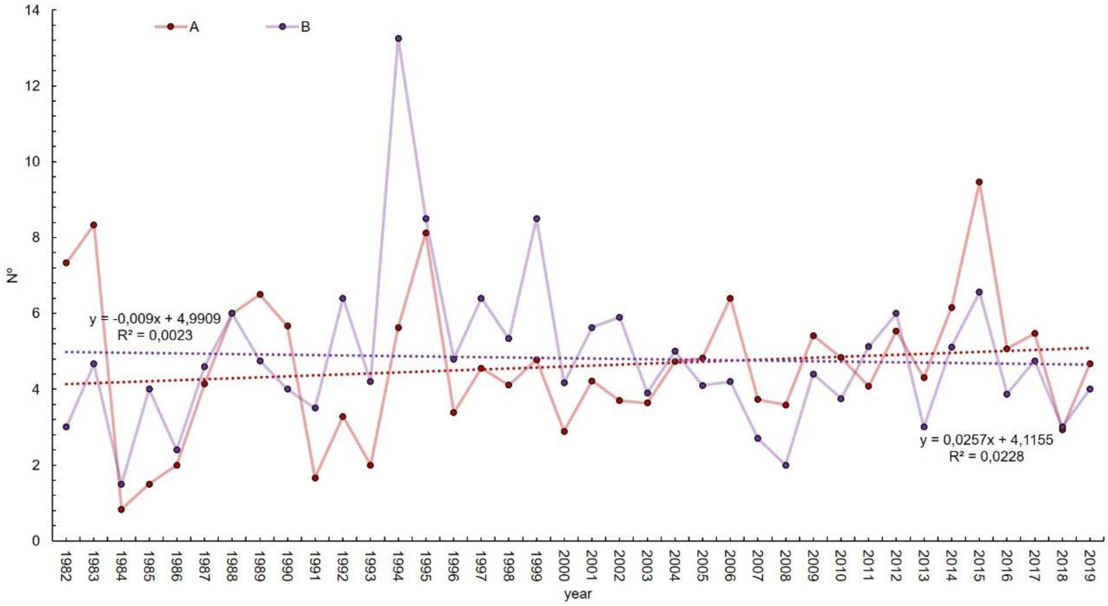
On the other hand, the number of heat and cold waves occurring in the GIAHS area is another of the key indicators to which it is exposed.

Thus, the calculation of this variable has been carried out based on the methodology proposed by Bárcena-Martín (2018), which identifies a moving reference period and a specific temperature threshold for the different parts of the year.

On the one hand, regarding the number of heat waves (Fig. 9), the results show a positive trend in the western sector, with an increase of more than 13% in the total data series. Also, the average value reaches 4.6±1.9 heat waves, with a maximum of 9.5 in 2015.

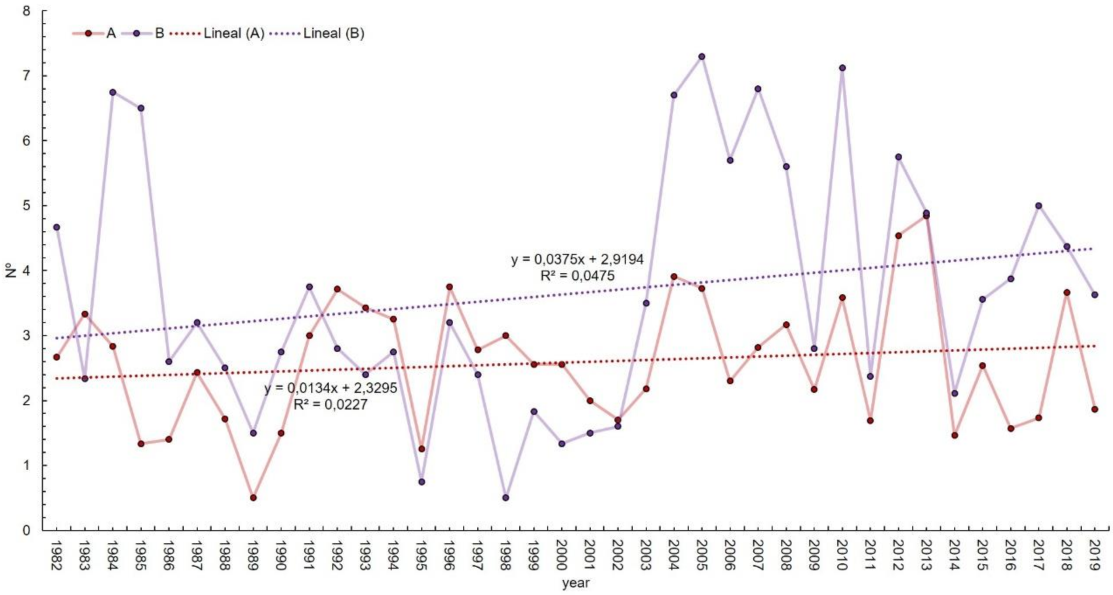
In the case of the eastern zone the trend contrasts with the previous one, as no clear evolution is identified. Until 1999 there was a slight increase, then a subsequent decrease until 2008, and finally a slight increase or stabilisation. Nevertheless, the average of the data series is higher than that of the other half of the territory, with 4.8±2.1 heat waves and a maximum of 13 heat waves in 1994.

Fig. 9. Annual evolution of the number of heat waves in the GIAHS area between 1982 and 2019 (A, western area; B, eastern area).



Finally, cold waves in this area (Fig. 10) suffer a clear increase in the data series. In the 2.6±1 vs. 3.7±1.9. In detail, in 2005 more than 7 cold waves were recorded on average in the eastern GIAHS zone, with the maximum value in the western area being 4.9 and recorded in 2013.

Fig. 10. Annual evolution of the number of cold waves in the GIAHS area between 1982 and 2019 (A, western area; B, eastern area)



In short, these data on thermal changes in the GIAHS area, considering the rise in temperatures and the increase in extreme events, follow the trend expected and projected by the IPCC for this area.

2.2. Changes in the rainfall pattern

Rainfall data have been downloaded from the SAIH Hidrosur Network for a total of nine meteorological stations for the time interval from 1997 to 2019 (Table 1). These reach a ten-minute accuracy and, from them, the total annual rainfall, the number of rainy days, the dry spells and the aggressiveness of the precipitation have been obtained.

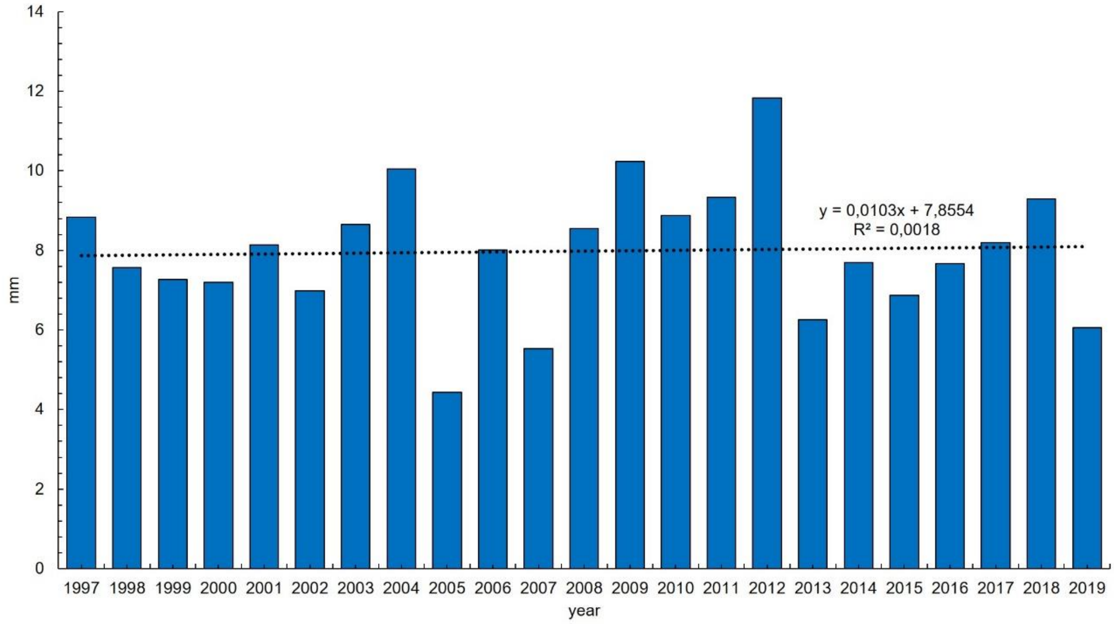
Table 1. Selected meteorological stations for rainfall data in the GIAHS area (1997-2019)

SAIH code	Coordinates XY	Altitude	Name
20	372323 - 4069061	136	Limonero
25	384694 - 4073828	1025	Santon Pitar
36	400926 - 4085001	536	Alcaucín
37	396197 - 4080053	235	Viñuela
41	375462 - 4089046	839	Colmenar
42	388957 - 4090680	675	Alfarnatejo

43	392622 - 4078582	146	Benamargosa
44	416775 - 4067573	340	Torrox
45	400891 - 4068124	10	Torre del Mar

Firstly, considering the annual precipitation and the number of rainy days (Fig. 5), the average rainfall for each of these days has been obtained. Thus, the data reflect the characteristic variability of the Mediterranean climate, without being able to establish or recognise a clear trend. However, three general periods can be observed, ranging from: (i) 1997-2004, (ii) 2005-2012 and (iii) 2013-2019.In each of these, a progressive increase can be observed, with the last year being the maximum of each interval and a sharp decrease in the following year.

Fig. 11. Annual evolution of the average rainfall per rainy day of the GIAHS area between 1997 and 2019

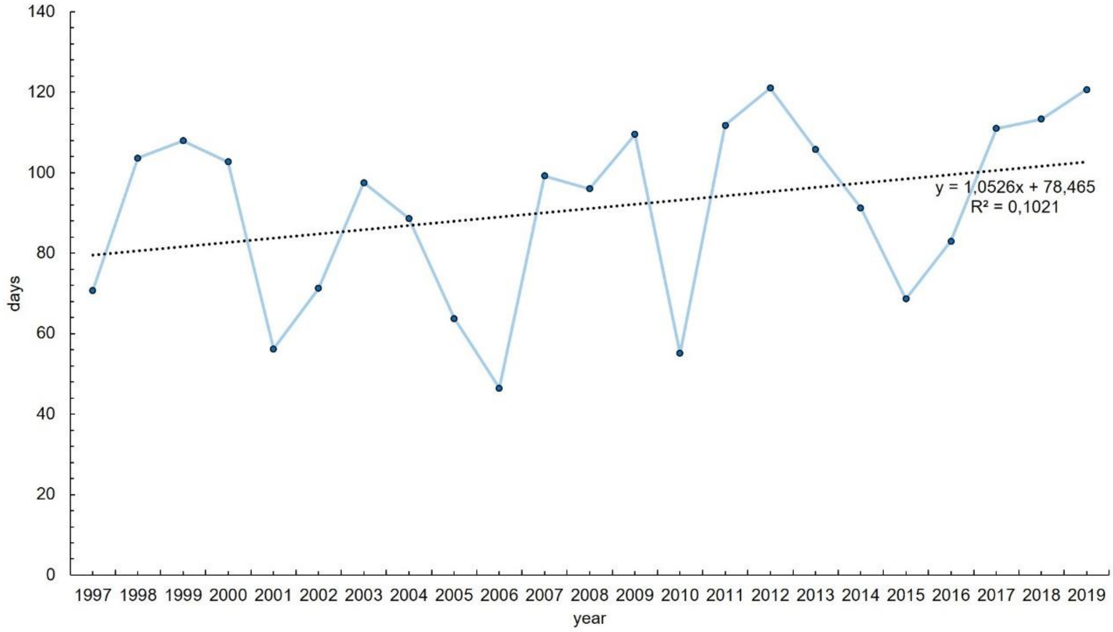


Another fundamental variable that provides basic information about the concentration of rainfall is the presence of dry spells or the maximum number of consecutive days without rain throughout the year. Thus, following the database of the selected meteorological stations (Table 1), we have identified those days without rain that represent the maximum period of time during the year.

Figure 12 shows the evolution of this indicator, from 1997 to 2019, where a clear tendency to increase in this territory can be seen. The maximum value recorded is 121 days, obtained in 2012 and very similar to the one recorded for 2019, with an average of 120.7 days in the selected stations.

On the other hand, the minimum, with 46.4 days, was in 2006. The mean value of the data series is 91.1±22.3 days.

Fig. 12. Annual evolution of the maximum number of consecutive days without rain in the GIAHS area between 1997 and 2019



As climate change projections show, the GIAHS area also faces an increase in extreme rainfall events. As a result, this area is exposed to an increase in rain erosivity, a variable that has been determined from the R factor of the Revised Universal Soil Loss Equation (RUSLE), which measures the kinetic energy exerted by raindrops on the ground.

For its calculation, the methodology published by Abu Hammad et al. (2004) and Diodato (2006) has been used, using the following equation:

$$R = E * I10_{max}$$

Where E is the total energy for a storm and $I10max$ is the maximum intensity collected in 10 minutes. The total energy for a storm is calculated from:

$$E = \sum_{k=1}^{m} e_k \Delta V_k$$

Where e is the unit energy, ΔV the amount of rainfall for period k, k an index for the periods in which the rainfall event is considered constant and m the total number of periods. The unit energy is calculated:

$$e = 0{,}29[1 - 0{,}72\exp(-0{,}082i)]$$

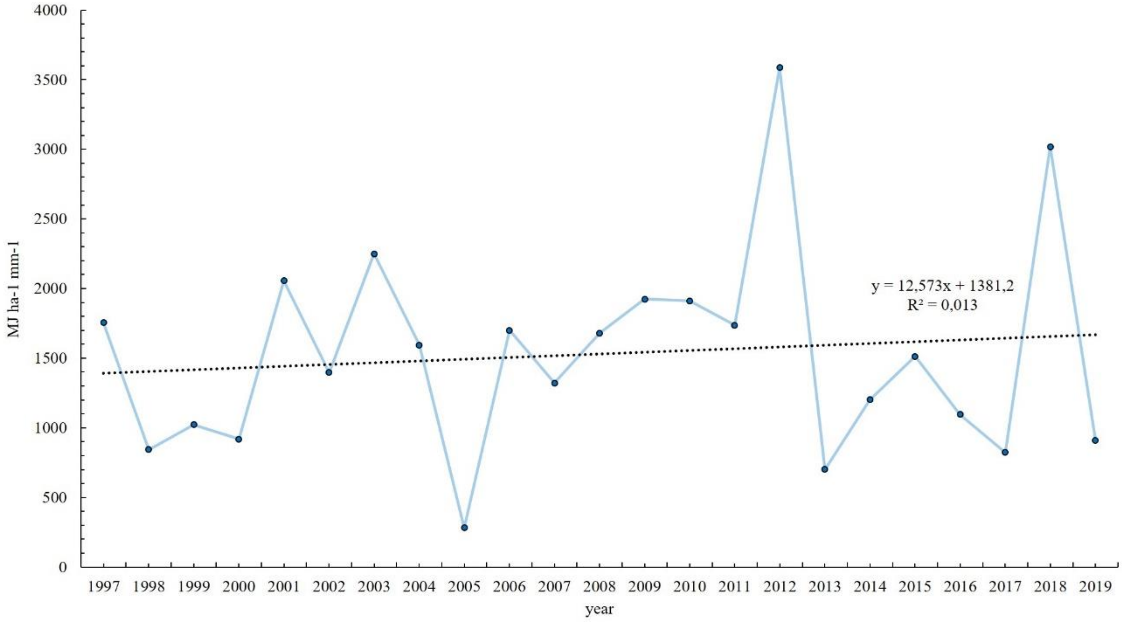
Where the energy unit e has units of MJ ha^{-1} mm^{-1} and i is the rainfall intensity (mm h^{-1}).

The procedure has been carried out both to obtain the erosivity of the annual rainfall and that of each of the seasons of the year, considering the months of (i) December, January and February for the winter season, (ii) March, April and April for the spring season, (iii) June, July and August for the summer season and, (iv) September, October and November for the autumn season.

From this process, the value for each weather station has been obtained, which has been used for the cartographic representation of this variable through a geostatistical interpolation method. However, for the analysis of the interannual evolution of the GIAHS area, the average value of all the stations selected and listed in table 1 has been used.

Figure 13 shows the evolution of the R factor, where an increase in its average values over the last decades can be observed. However, the irregularity that characterises rainfall in the Mediterranean area is once again reflected in this parameter, with wide interannual fluctuations even between two immediate years. The mean value of the data series is 1,532.1±747.2 MJ ha^{-1} mm^{-1}, with the maximum value in 2012, with 3,587.2 MJ ha^{-1} mm^{-1} and, on the contrary, the minimum in 2005 with 281.6 MJ ha^{-1} mm^{-1}, which, as can be seen (Fig. 5), was particularly dry.

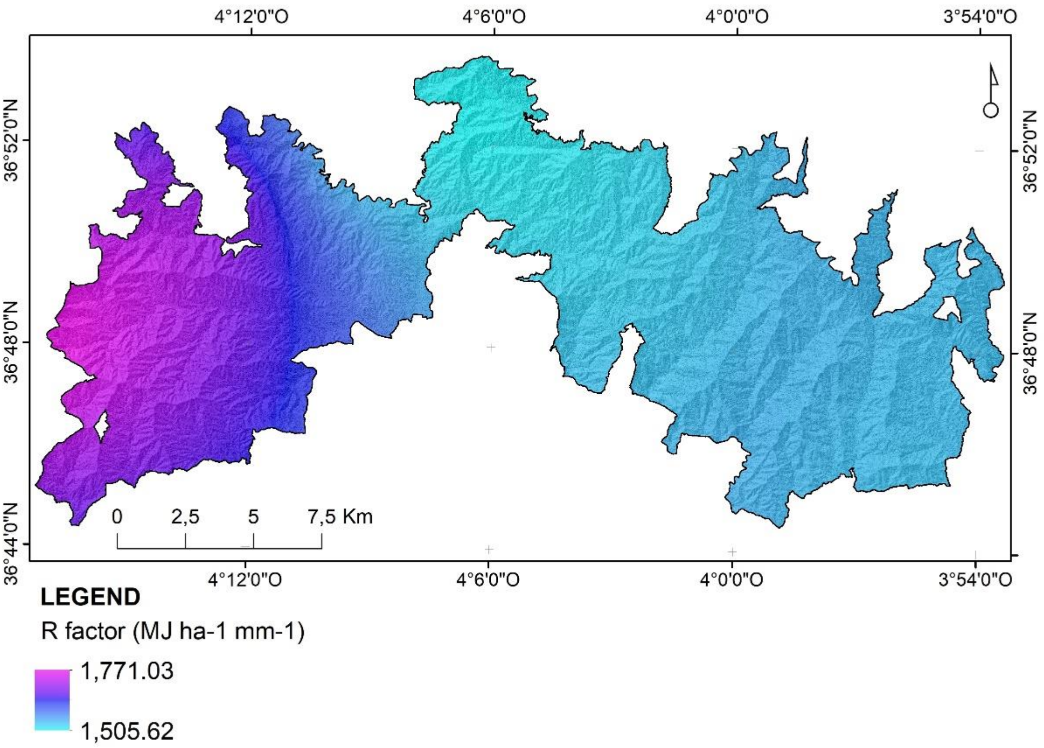
Fig. 13. Annual evolution of rainfall erosivity (R-Factor, RUSLE) in the GIAHS area between 1997 and 2019



The point values of each meteorological station have been interpolated to obtain the cartographic representation and unique values per pixel, thus being able to identify the spatial variability in the GIAHS area of this pluviometric parameter. Thus, as mentioned above, a statistical interpolation method has been used for this same representation, which in this case has been "Kriging" (predicts the unknown values of the data observed in known places), used by the Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente (MAPAMA) in 1996 in the development of the R factor on a national scale.

The results of this procedure, shown in figure 14, show a clear spatial variability, especially between the western and eastern sectors. However, the absolute values collected do not represent a great contrast to each other. The mean value of the series (1997-2018) ranges between 1,771 MJ ha^{-1} mm^{-1} as a maximum value in the westernmost third of the GIAHS area and 1,505.6 MJ ha^{-1} mm^{-1} in the central area of the GIAHS. In this sense, the orographic factor can also be observed, with values generally decreasing in the lower altitude areas.

Fig. 14. Spatial variability of annual rainfall erosivity in the GIAHS area from 1997 and 2019



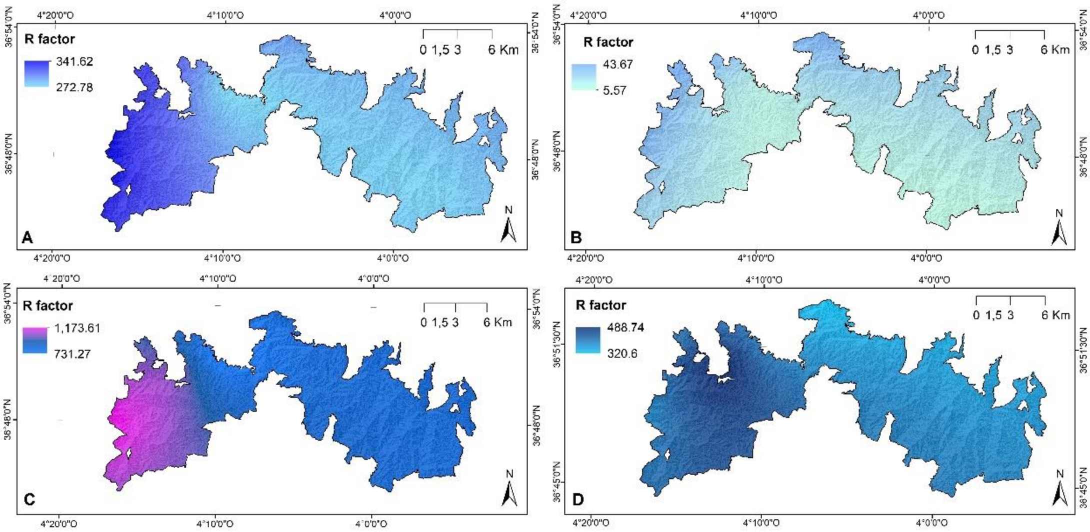
Along the same lines, with the main objective of identifying those periods of the year in which the maximum values are registered and, therefore, to delimit the months in which the greatest exposure is achieved, the values relating to rainfall erosivity in each of the seasons of the year have been represented cartographically (Fig. 15).

Thus, the autumn months are those with the highest rainfall erosivity, with an average value in the series ranging from 1,173.6 MJ ha^{-1} mm^{-1} in the western area to 731.3 MJ ha^{-1} mm^{-1} in the east. In spatial terms, this autumn map practically underlines the results that have been discussed for the year. On the other hand, considering the dry season (summer drought) characteristic of Mediterranean climatic conditions, summer is the season with the lowest values. The results vary between 5.6 MJ ha^{-1} mm^{-1} and 43.7 MJ ha^{-1} mm^{-1}, the key to this variability being the altitude factor (higher values at higher altitudes and lower values at lower altitudes).

As for the spring and winter seasons, the values are very similar; however, the spring months show a greater territorial variability, with the highest values (341.6 MJ ha^{-1} mm^{-1}) gain recorded in the westernmost sector and the lowest in the east (272.8 MJ ha^{-1} mm^{-1}).

In winter, the maximum value of 488.7 MJ ha^{-1} mm^{-1}, s reached in the western area. Moreover, the relatively higher values no longer appear in the higher areas, indicating the presence of rainfall characteristics more related to frontal systems and less to orography.

Fig. 15. Spatial variability of seasonal rainfall erosivity in the GIAHS area from 1997 and 2019 (A, spring; B, summer; C, autumn; D, winter)



Great attention should be paid to the data achieved in the autumn months. These, as shown in table 2, represent a high percentage of the total erosivity recorded in the year, exceeding 90% on several occasions (2012, 93.7%; 2015, 94.8%).

The mean value in the data series is 55.7±28.2%, which means that, as a general rule, more than half of the aggressiveness of the rainfall collected in the year belongs to the months of September, October and November.

On the other hand, there are years in which the summer season has been prolonged, leading to a reduction in the values of R in autumn and, therefore, a reduction in its annual significance. These years include 1998 (8.1%), 2004 (3%) and 2010 (10.4%).

Table 2. Significance of the R-factor of the autumn months with respect to the annual R-factor (1997-2019)

	R anual	R otoño	Significancia (%)
1997	1,754.1	763.3	43.5
1998	842.6	68.2	8.1
1999	1,023.2	790.4	77.3

2000	919.5	172.9	18.8
2001	2,056.1	1,748.6	85.0
2002	1,396.1	701.2	50.2
2003	2,249.7	1,120.6	49.8
2004	1,593.9	47.5	3.0
2005	281.6	176.1	62.5
2006	1,699.8	1,084.8	63.8
2007	1,322.0	840.3	63.6
2008	1,679.6	1,110.2	66.1
2009	1,923.9	404.7	21.0
2010	1,910.8	198.1	10.4
2011	1,736.6	832.3	47.9
2012	3,587.2	3,362.4	93.7
2013	700.7	85.9	12.3
2014	1,202.3	877.6	73.0
2015	1,512.1	1,433.2	94.8
2016	1,096.0	432.9	39.5
2017	823.2	475.8	57.8
2018	3,018.5	2,196.0	72.8
2019	909.3	721.8	79.4
Mean	***1,532.1***	***854.1***	***55.7***
SD	***747.1***	***774.8***	***28.2***

In summary, the changes in the rainfall pattern resulting from the climate crisis, especially in terms of the distribution of rainfall and the erosivity of the rainfall reached, could lead to strong landscape modifications and a conditioning of the eco-geomorphological system of the GIAHS area.

3.- SENSIBILITY

Those variables that have a greater incidence due to the general characteristics of the eco-geomorphological system and, therefore, those that have a greater predisposition to give rise to modifications in the territory have been included in this "sensibility" section.

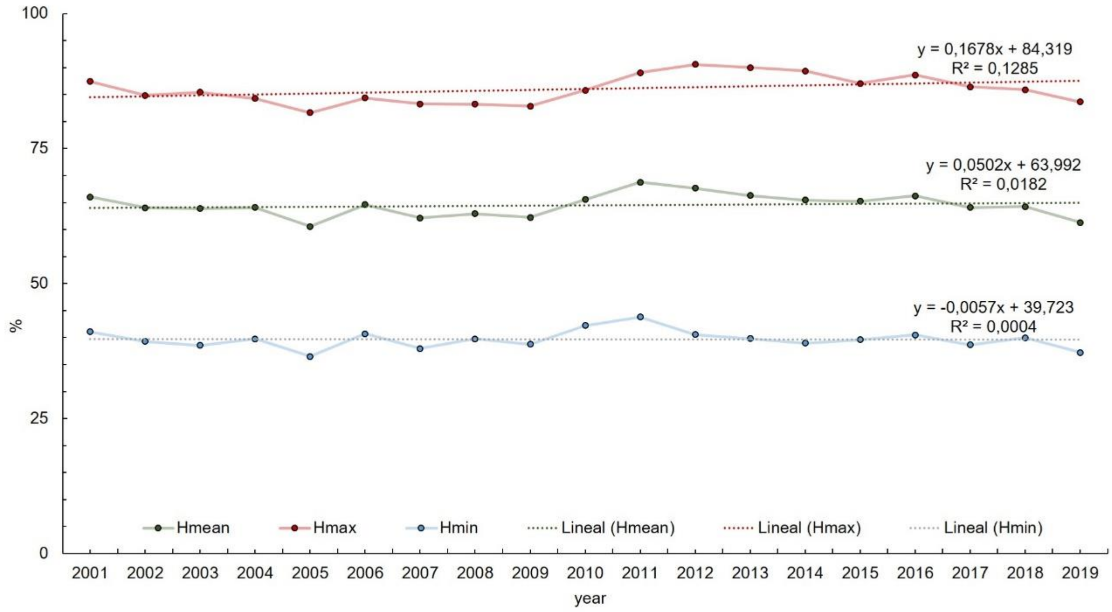
The sensibility has been approached as a consequence of the exposure, adding information in the sense of the variables that have the greatest impact in this area.

Under the considerations discussed in the presentation of the GIAHS area, it has been identified that this territory of the province of Malaga is highly sensitive in the context of Climate Change. Thus, the consequent problem of altered rainfall is particularly striking, which can lead to a conditioning of the soil's water conditions and which, therefore, will directly influence aspects such as the degree of vegetation cover, the production of certain crops, the loss of biodiversity, vulnerability to erosion processes, etc.

Changes have also been observed in other climatic variables, such as relative humidity (maximum, minimum and average), insolation and evapotranspiration. The data available in the Red de Información Ambiental de Andalucía (REDIAM) for the Vélez-Málaga station (Málaga), with a period of 19 years (2001-2019), have been used for the analysis.

Firstly, the average value of the mean relative humidity data series is 64.5±2%, with a maximum of 68.8% and a minimum of 60.6%. Thus, despite the temporal variability visible in figure 16, no clear trend could be determined for this parameter, which despite its fluctuations remains relatively stable. The same is true for the maximum and minimum relative humidity, which show mean values of 86± 2.6% and 39.7±1.7% respectively.

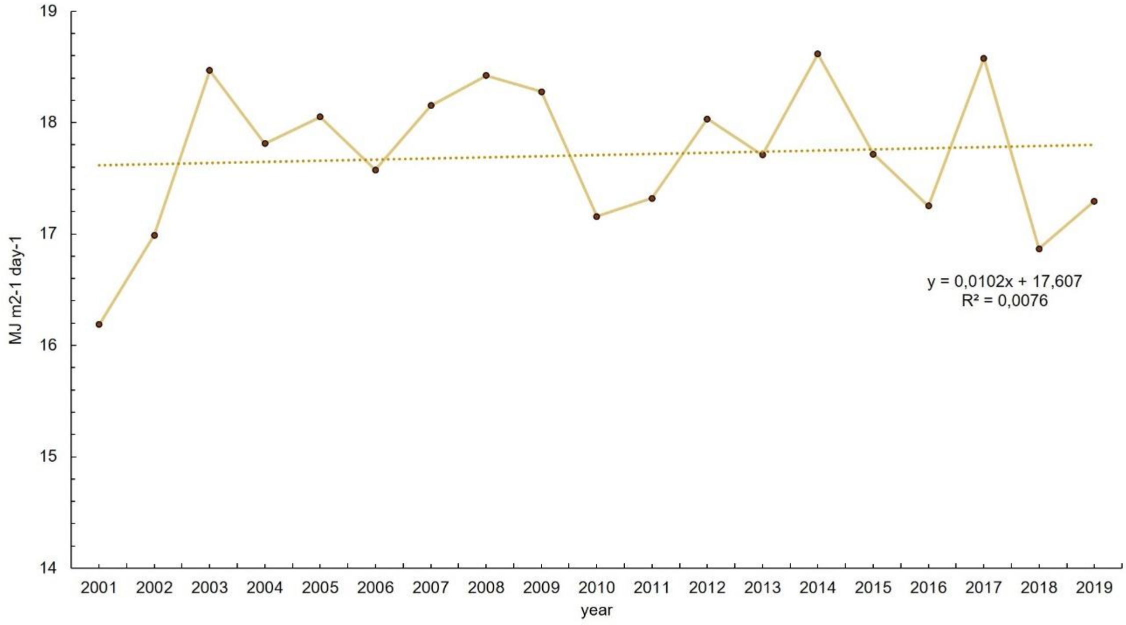
Fig. 16. Annual evolution of mean, maximum and minimum humidity in Vélez-Málaga between 2001 and 2019



Sunshine, measured in MJ per day, does describe a clear trend towards a higher number of sunny days, with a mean value for the data series of 17.7±0.6 (Fig. 17). Thus, although the interannual variability is quite clear, the values collected for this variable are very high, in line with the high radiation collected by the Mediterranean areas of southern Spain.

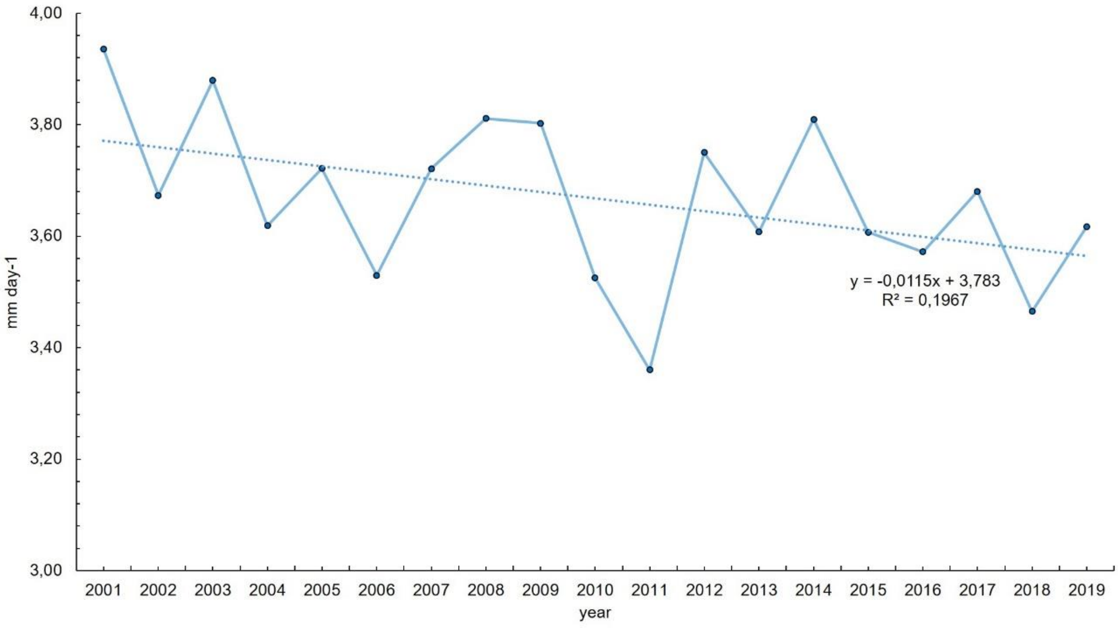
This is a key factor for this territory, as the cultivation of vines, a priority in the GIAHS area, requires a large number of hours of sunshine. More specifically, it needs around 1,600 hours a year, which is key to aspects such as grape ripening.

Fig. 17. Annual evolution of insolation in Vélez-Málaga between 2001 and 2019



However, the evapotranspiration (Fig. 18) shows a decrease in its values, which could be due to the lower presence of the water sheet on the land surface itself. However, the change is minimal considering the graphic scale. In numerical terms, the average value for Vélez-Málaga between 2001 and 2019 is 3.7±0.1 mm day^{-1}, the highest being 3.9 mm day^{-1} and the lowest 3.4 mm day^{-1}.

Fig. 18. Annual evolution of evapotranspiration in Vélez-Málaga between 2001 and 2019



The factor related to water and its availability must be considered as one of the most important elements for plant production in a territory. Therefore, possible alterations in the availability of water in the soil in the GIAHS area, as a result of changes in its permeability, rainfall patterns, changes in use, overexploitation or any other factor, could have clear repercussions on the eco-geomorphological system and put the presence of some plant species at risk. In addition, it is important to remember the location of this area, situated in a transition zone between a dry Mediterranean climate and a semi-arid climate, which heightens concern for this vital resource, which is sometimes so limited.

For the consideration of this indicator, the hydrological state of the soil in recent decades has been measured. Thus, it has been understood that the "available water" status, i.e. the water situation in which plants can access and extract water from the soil, is the optimum soil situation for the development of species. Therefore, the time when the soil does not reach this well known threshold, and therefore the water status is lower than this (wilting point) will be considered as a period of drought or, in terms of Mediterranean climatic conditions, as "xeric".

Thus, the high affection and conditioning of this factor on the phenology of the plants has led this critical situation to be classified as a "phenological summer".

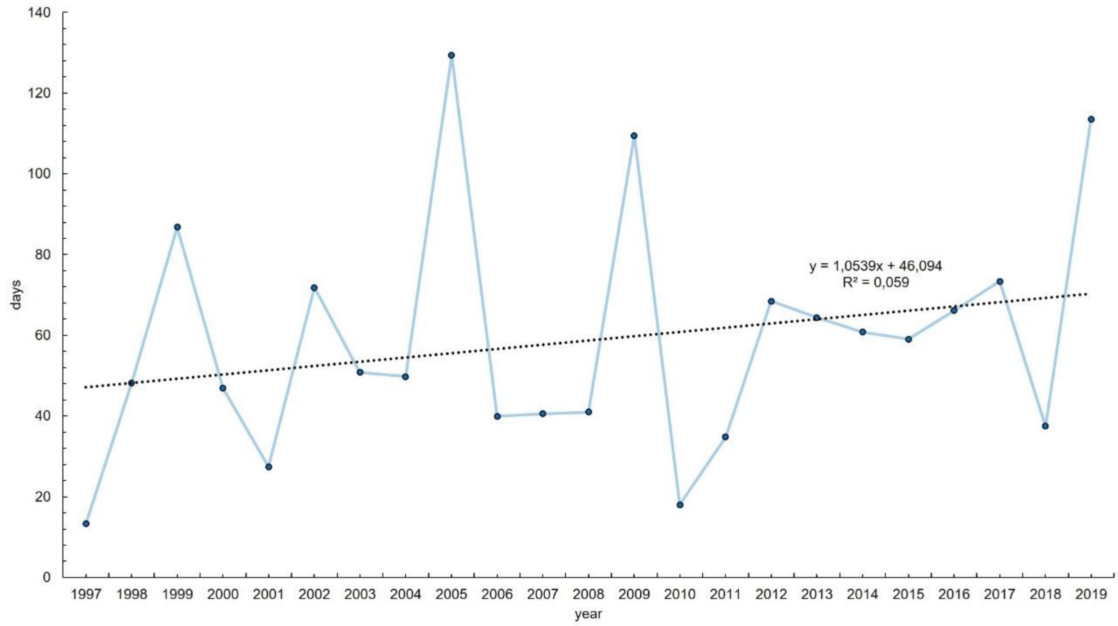
The methodology used to obtain the number of days in which the soil is in this phenological summer state is based, on the one hand, on the analysis of soil properties in the laboratory and in the field and, on the other hand, on the hourly rainfall database of the Agencia Estatal de Meteorología (AEMET). In this way, the samples collected have been subjected to wetting and drying tests, as well as weekly humidity measurements using TDR probes. In addition, their texture, bulk density, depth, porosity and permeability were determined in order to obtain the maximum detail of the soil characteristics of this territory.

Based on all this information, it has been possible to create a model that simulates the hydrological dynamics of the soil in the period between 1997 and 2019 and, therefore, to know the number of days in which the soil's water status was in a phenological summer situation.

Figure 19 shows this evolution of the number of days per year in which plants have not had access to soil water, showing a trend towards an increase in this situation.

However, a high inter-annual variability is recognised, similar to the evolution of the total rainfall recorded during the year. The mean value of the data series is 58.7±29.4 days, with a maximum of 129.3 days in 2005 and a minimum of only 13.3 days in 1997.

Fig. 19. Annual evolution of the number of days in phenological summer of the soil in GIAHS area between 1997 and 2019



In short, from the perspective of the sensitivity of the GIAHS in the context of climate change, these are the main variables that must be considered and that can lead to changes in the landscape and, with it, in the history, culture, traction and general way of life of society.

4.- AFFECTION

The possible consequences on the vineyard (the main integrating element of the GIAHS area landscape) of changes in the general climatic dynamics have been addressed in this section.

As has been described, there are many climatic variables that have registered alterations in recent years and that follow a similar trend to that projected by the latest IPCC reports (2014, 2019). This reality has a direct effect on the GIAHS territory, giving rise to possible modifications in such transcendental aspects as its source of economy (agriculture), which could be placed in conditions of high vulnerability and require adaptation measures to the current climate dynamics.

Mediterranean climatic conditions, especially semi-arid ones, show how situations of water stress have increased (Fig. 19). Thus, the consequence of this increase could have a variable environmental impact depending on the specific characteristics of each area. The agricultural sector could be especially fragile to this water stress, however, the incidence will also depend on the type of crop and especially in the agricultural sector, where the incidence may also depend on the type of crop and its particularities.

However, there are many other factors that could be indirectly affected by this fact, such as a decrease in production, loss of profitability due to the increase in costs, abandonment of crop areas, rural exodus, etc. In short, a series of variables that would mean that the GIAHS territory or part of it would be considered vulnerable to certain aspects that are affecting it, whether of an environmental, social or economic nature.

4.1. Affection to the vineyard

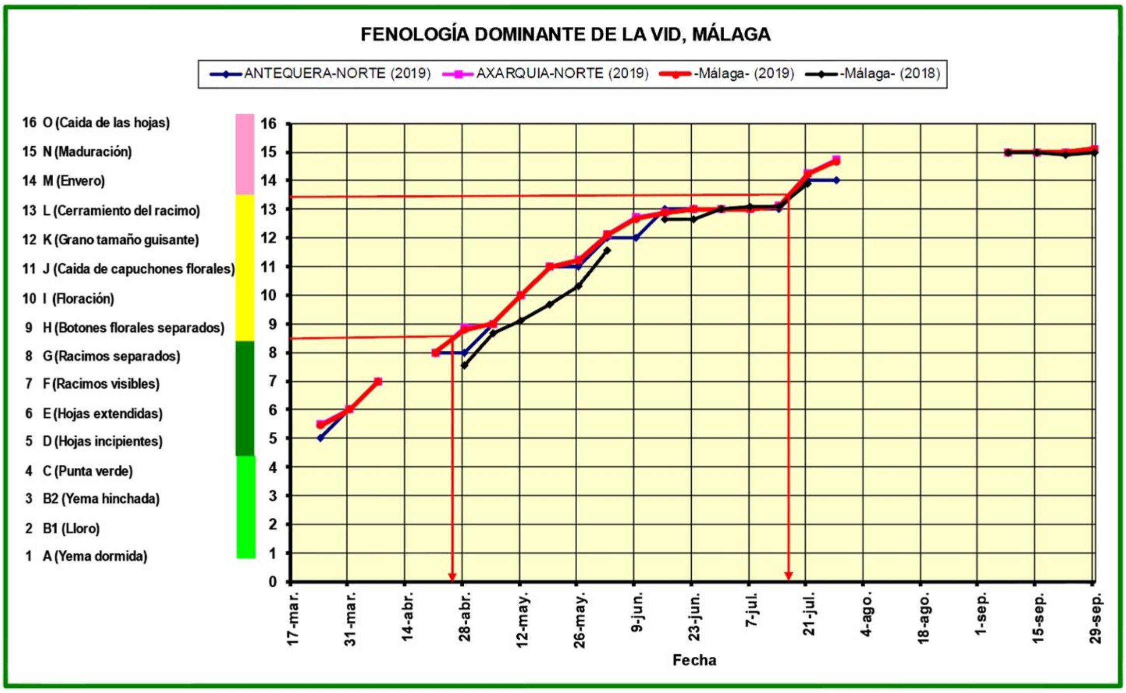
The vineyard, central to the organisation and way of life of the GIAHS area, is a classic use of the soil in Mediterranean agriculture. In phenological terms, it is a species that is deeply rooted in this climatic zone and very resilient to its irregular conditions. However, this does not mean that the crop does not have to develop mechanisms to adapt to the new conditions and can be severely affected by these changes, directly or indirectly.

In this sense, the annual reports published by the Red de Alerta de Información Fitosanitaria de Andalucía (RAIF) bring the phenological information on vines in the Axarquia area of Malaga to a regional scale, with eight Biological Control Stations (ECBs), four in Almáchar and four in El Borge. Furthermore, this document also speaks of a crop of great antiquity and deep-rootedness but with a high difficulty of tillage, where the average production is quite low, with a maximum of 5,000 kg per hectare.

Thus, after analysing the reports, we have obtained fundamental data on the phenology of the vine in this area of Axarquia, where GIAHS area is located. Thus, the first phase recorded corresponds to the pre-vegetation phase, which lasts until the end of March, when the stage known as the "punta verde" comes to an end. From then until the end of April or the beginning of May, the stage in which the plant begins to vegetate, with the extension of the leaves and even separate clusters. This is followed by the flowering phase, which ends in the first weeks of July when the clusters close. Finally, the second part of July and the rest of the summer season corresponds to the ripening stage, which includes the harvesting of the fruit (grape), with the veraison of the grape (the main process in which the grape changes colour and undergoes the greatest modifications) in the first few days and, at the end, with leaf fall (Fig. 20). At the end of this period, the vine enters a period of vegetative rest, which would last until the first stage of the cycle. These months are known as the latency or dormancy stage.

Fig. 20. Vine phenology in the province of Malaga (Axarquia) in 2019

Source: Red de Alerta de Información Fitosanitaria (RAIF). Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible of Junta de Andalucía.



Climatic changes and the extreme nature of events at certain periods of phenology can lead to consequences such as loss of fruit quality or loss of quantity (production).In the case of temperatures, vine cultivation is extremely sensitive to frost, which is considered to be one of the greatest risks in viticulture. It is therefore important to keep track of the number of annual frosts and their annual distribution and intensity for a multitude of vine quality indices. The grape crops can be particularly affected by the presence of these extreme cold events, which, if they occur in the vegetation stage (spring), can cause major losses.

The GIAHS area, despite recording a slight increase in abnormal cold days and cold spells in its eastern area (Fig. 7, 10), falls within the frost-free periods Mediterranean climate zone and does not really a current risk to the viticultural system.

Thermal indicators such as heat waves (Fig. 9), anomalous heat days (Fig. 7), tropical and equatorial nights (Fig. 8), mean, maximum, minimum of maximum temperatures (Fig. 2, 3, 4); report an increase of the hottest episodes in the GIAHS area, especially in the western half, thus, knowing the phenology of the vine, this could lead to an advance of the whole phenological period and a premature ripening (e.g. 2015-2016; 2016-2017 seasons).

More specifically, anomalously hot days increase the risk of dryness of the leaves and, of course, of the fruit. In addition, heat waves can cause grape pigmentation and grape quality to suffer.

In short, the negative effects derived from the already identified general rise in temperatures could be the loss of grape quality, an increase in its alcohol percentage; in the case of the vegetative period, excessive development, an increase in certain pests and diseases that are favoured by high temperatures, greater yield variability and, of course, a greater risk of fire (Resco et al., 2014).

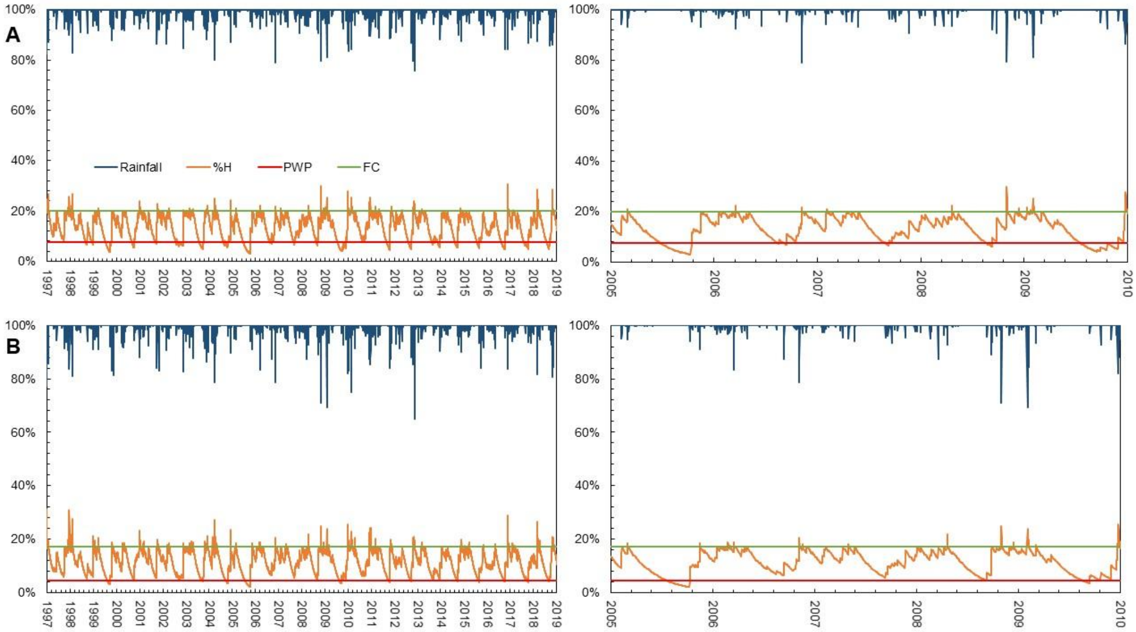
On the other hand, the rainfall factor is another important conditioning element for vines. The vine, however, has optimal conditions for adapting to dry periods and periods of low rainfall, being highly resilient to the irregularity of the Mediterranean climate.Despite this ability to adapt, in order to optimise grape production, a certain level of humidity is required during the vegetation period, without being excessive to avoid the appearance of pests, as well as a dry period during the ripening stage.

Thus, although the projected decrease in total rainfall could also affect a decrease in annual production yields, nevertheless, the greatest dangers associated with rainfall that the GIAHS area faces in the context of climate change would be (i) low water availability and (ii) the agressive nature of rainfall, combined with stormy events.

(i) The model carried out to calculate the hydrological state of the soil, which provides the necessary information to know the availability of water in the soil by the plants, facilitates the adjustment of the phenological summer days in a specific time, and can thus be compared with the phenological situation of the vine itself and draw possible conclusions and affectations.

Figure 21 shows, as an example, the result of the model executed in the stations of Alcaucín and Benamargosa. In 2005 or 2009, the existing water deficit in the summer period can be observed and, in these cases, specifically in the months immediately after, coinciding with the grape harvest period. Thus, although there are occasional situations in the spring months that can lead to a reduction in grape development and production, most of the "phenological summer" periods appear in these summer and autumn months (first part). Therefore, the main problems affecting vine cultivation are those related to fruit ripening, early leaf fall and early stem scorch.

Fig. 21. Soil hydrological dynamics of the Alcaucín (A) and Benamargosa (B) stations between 1997 and 2019



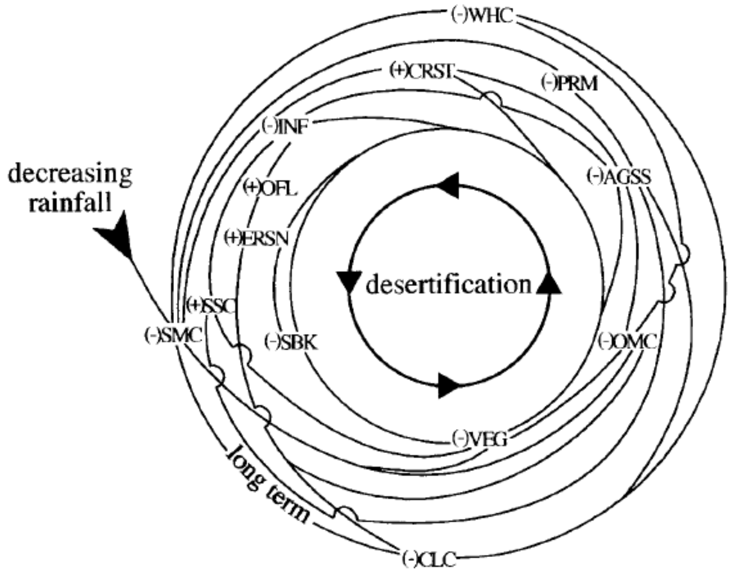
(ii) Intense rainfall has a strong impact on the eco-geomorphological system in general and on vines in particular, being associated with risks derived from runoff, water erosion and, therefore, landscape and soil degradation. On the other hand, this impact can lead to the potential appearance of vine diseases or damage to the plant, as well as the loss of its fruit due to the impact of hail or hail-storms.

From this perspective of degradation, following the predicted trend in the Mediterranean strip towards a decrease in total annual rainfall and its more extreme behaviour, it is possible to determine a series of responses on the part of the elements that make up the soil and which follow on from this premise (Fig. 22).

These rainfall dynamics directly exert pressure on the availability of water in the soil and, therefore, on vegetation growth, which is sometimes severely limited. Under this consideration, the organic matter content in the soil will be reduced and, with it, the salinity of the soil will increase. Thus, the presence of clays will be reduced in parallel to the organic matter but over a much longer period of time.

Fig. 22. Soil degradation cycle as a consequence of decreasing rainfall

Source: Lavee et al., 1998



AGSS = aggregate size and stability; CLC = clay content; CRST = crusting; ERSN = erosion; INF = infiltration; OFL = overlandflow; OMC = organic matter content; PRM = permeability; SBK = seedbank; SMC = soil moisture content; SSC = soluble salts content; VEG = vegetation; WHC = water holding capacity.

It is therefore a process of continuous transformation of the ecosystem towards aridity which, together with this climatic evolution, is encouraged by various forms of demographic pressure exerted on the soil: the change in land use, the abandonment of farmland and many other changes that contribute to erosion, especially water erosion. Thus, this degradation leads to a clear impoverishment of the soil itself and, consequently, to a loss of soil health, quality and fertility. Therefore, vines grown on this soil are directly affected by these processes, leading to an impoverishment of the crop, a loss of quality and production and, in more serious cases, a loss of profitability.

5.- VULNERABILITY

Vulnerability provides fundamental information about the fragility of the territory in the face of certain elements. Thus, in this section a distinction has been made between vulnerability related to environmental aspects and vulnerability linked to social and economic elements.

5.1. Ambiental vulnerability

Axarquia GIAHS area, based on the characteristics of its eco-geomorphological system, presents a high predisposition to suffer risks derived especially from the processes of water erosion. This erosion is a consequence of the spatio-temporal variability of environmental factors, which make the territory highly susceptible. Thus, the key factors to consider in the area in question are (i) physiography, (ii) lithology, (iii) edaphology, (iv) vegetation cover, (v) rainfall and (vi) land use.

In this sense, slope is one of the most important parameters facing the GIAHS area, with very high mean values of 45.5±18.1%. Thus, this physiographic characteristic favours surface runoff and water erosion processes in high intensity rainfall events, leading to a high level of soil degradation and, therefore, of the ecosystem.

The highest values of this factor are found along the entire northern limit, however, at a more general level, it is the eastern sector where the highest figures are found (Fig. 23). More than 80% of the basin has a slope greater than 30% and more than 40% greater than 50% (Table 3), which are very high values that indicate a high level of danger in practically the total area.

Fig. 23. Slope map of GIAHS area (percentage)

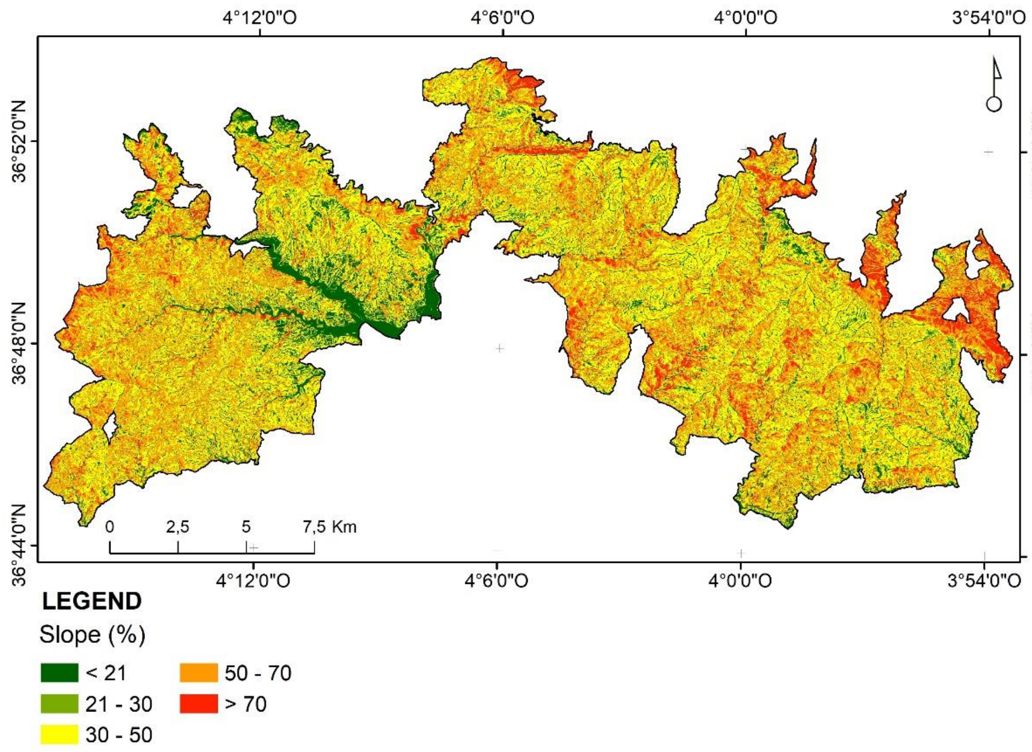


Table 3. Area under each category of slope in the GIAHS area

Slope	Surface (Ha.)	Surface (%)
< 21	2,677.5	9.5
21 – 30	2,561.8	9.1
30 - 50	11,396.8	40.6
50 - 70	9,267.1	33.1
> 70	2,133.6	7.6

Concretely, on a local scale (Table 4), Frigiliana (52.9%), followed by Cútar (49.3%) and Canillas de Albaida (49.3%) are those with the highest average slope. However, Vélez Málaga (33.4%), Iznate (40%) and Benamargosa (40.4%), also with very high average values, are the municipalities with the least danger in this respect.

The vine-growing areas also have very high average values for each town, especially for a cultivated area; however, the slopes recorded in these areas are slightly lower than those identified for the municipal area as a whole. Among the highest values are the vineyards of Cútar, with 46.3%, Arenas, with 45.8% and Sayalonga, with 45.7%; on the contrary, the lowest values are found in the vineyard areas of Vélez-Málaga (33.3%), Iznate (36.8%) and Benamargosa (37.6%), where the vulnerability of this physiographic variable is lower.

Table 4. Pendiente media de los municipios del ámbito GIAHS

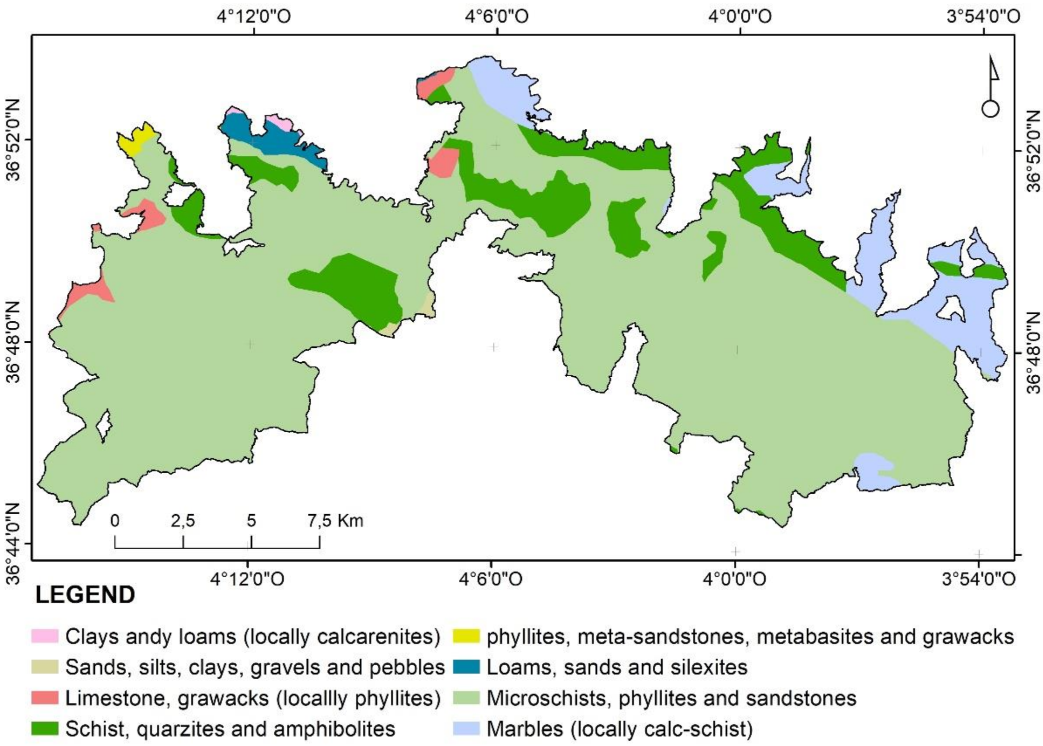
Municipio	Slope (%)	Slope in vineyard areas (%)
Almáchar	43.6	41
Árchez	45.6	42.9
Arenas	48.6	45.8
Benamargosa	40.4	37.6
Canillas de Aceituno	48.2	42
Canillas de Albaida	49.3	41.4
Comares	48	44.2
Cómpeta	47.6	41.9
Cútar	49.3	46.3
El Borge	49.6	45.6
Frigiliana	52.9	38.2

Iznate	40	36.8
Macharaviaya	43.8	40.4
Moclinejo	46.7	44.3
Salares	44	41.5
Sayalonga	49.1	45.7
Sedella	44.8	40.8
Torrox	45	42.1
Vélez-Málaga	33.4	33.3
Viñuela	44.5	41

On the other hand, lithology is another essential factor for assessing the vulnerability of a territory, being a fundamental parameter in processes such as (i) landslides caused by intense or prolonged rainfall, (ii) landslides or (iii) soil erosion.

Thus, the GIAHS area has a very homogeneous lithology, where most of its territory is composed of micaschists, phyllites and sandstones, as well as quartzite schists and amphibolites. In addition, marbles (locally calc-schist) appear in the northeastern fringe, representing a marked and notable differentiation from the rest of the territory (Fig. 24).

Fig. 24. Lithological map of the GIAHS area

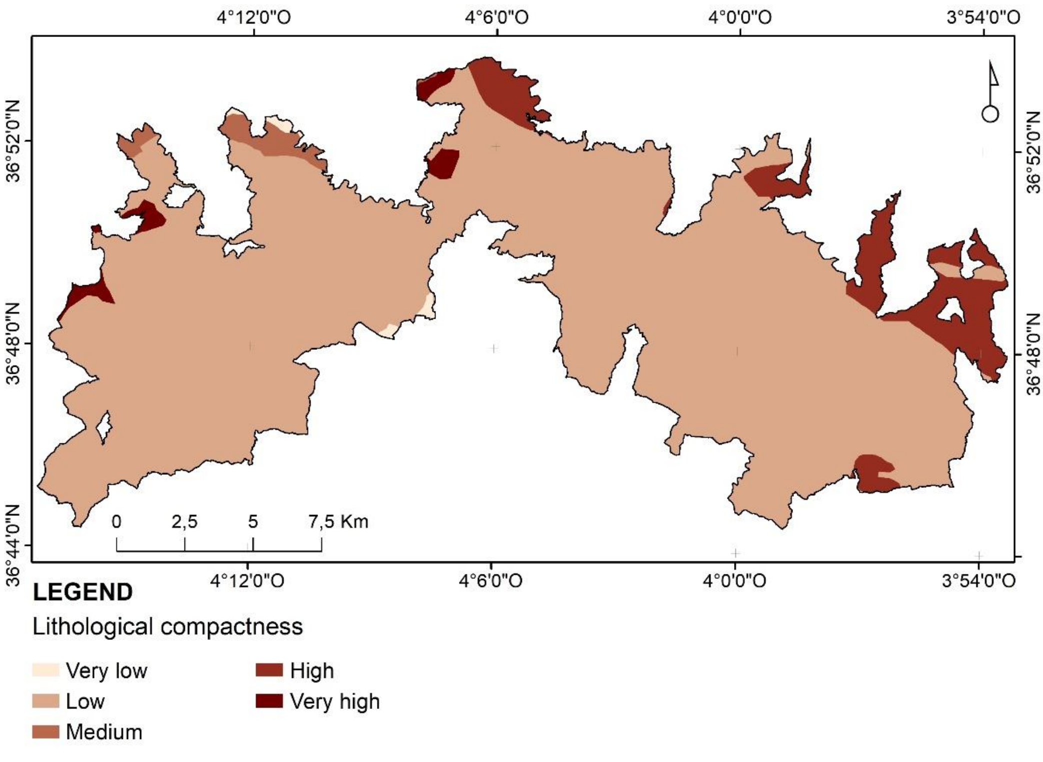


Based on this characterisation and in order to obtain values of relative vulnerability to this environmental factor, it is important to know the levels of lithological compactness. The surface with "low" and "very low" compactness, i.e. with greater susceptibility to erosion, occupies 89.9% of the territory (Table 5), while only 8.8% of the GIAHS area is made up of lithology with more resistant characteristics, located in the northwest (limestones and grawacks) and northeast (marbles) (Fig. 25). In short, this is an area which, from a lithological point of view, could be characterised by its high homogeneity and the great instability of its materials.

Table 5. Surface occupied by each lithological compactness category in GIAHS area

Compactness	Surface (Ha.)	Surface (%)
Muy baja	105.6	0.4
Baja	25,078.5	89.5
Media	391.7	1.4
Alta	2,088.9	7.5
Muy alta	368.5	1.3

Fig. 25. Degree of lithological compactness of the GIAHS area



In consideration of environmental and, more specifically, geomorphological vulnerability, the amount of vegetation cover is another fundamental factor in understanding the current landscape dynamics of the GIAHS area. For this purpose, the information provided by Sentinel-2 images from the Normalised Difference Vegetation Index (NDVI) has been used. (NDVI = [NIR−Red] / [NIR+Red]) (Table 6). This index is used both to indicate the amount and vigour of vegetation and to differentiate between vegetated and non-vegetated areas in an image.

Table 6. Satellite images used

Image	Scene	Resolution (m)	Date
Sentinel-2	T30SVF	10	04/03/2020
Sentinel-2	T30SVF	10	22/06/2020
Sentinel-2	T30SVF	10	20/09/2020
Sentinel-2	T30SVF	10	15/12/2019

Table 6 and figure 26 show the state of vegetation cover in each of the seasons of the year. It can be seen that the spring months show a higher degree of soil protection, where practically 60% of the surface area of the GIAHS area has high and very high levels of vegetation cover. However, only 8.1% of the surface area corresponds to the highest vulnerability, with low or very low vegetation cover. In the case of the summer season, the level of vegetation is much lower, with 25% of the surface area presenting the best conditions and 16.6% of the territory with low or no vegetation cover. In this sense, these data provide sufficient information to determine the importance of seasonal species in the spring months, especially therophytes.

Table 6. Degree of seasonal vegetation cover in the GIAHS area

Vegetation cover	Spring		Summer		Autumn		Winter	
	Ha.	**%**	**Ha.**	**%**	**Ha.**	**%**	**Ha.**	**%**
Very low	12.7	0.0	51.1	0.2	3.7	0.0	11.0	0.0
Low	2,274.3	8.1	4,584.6	16.4	6,720.8	24.0	2,132.6	7.6
Medium	9,144.3	32.6	16,355.9	58.3	15,915.9	56.8	11,728.8	41.8

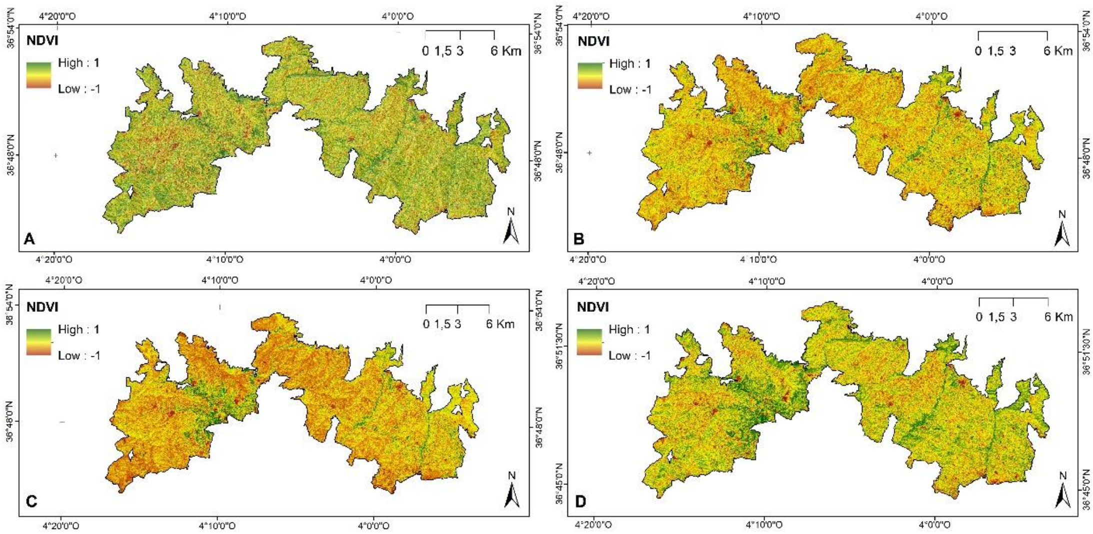
High	13,264.1	47.3	5,966.5	21.3	5,006.3	17.9	11,581.1	41.3
Very high	3,338.7	11.9	1,075.9	3.8	386.9	1.4	2,580.2	9.2

Then, the autumn values, collected from the first part of this season, indicate the water stress to which this territory is subjected during the summer solstice. As a result, low and very low vegetation cover values (greater vulnerability) increase to occupy 24% of the area in question, and this situation is not reversed until the first episodes of post-season rainfall. Finally, the winter months again reach more optimal values, with more than 50% of the area with high and very high vegetation cover. Furthermore, the lowest values are reduced in the territory to only 7.6%.

Spatially, it can be seen that the areas immediately next to the rivers are more stable and the levels of vegetation cover do not reach such extremely low values. The case of the Benamargosa river basin, in the western sector, stands out, where high and very high levels of vegetation cover are preserved. In contrast, the most vulnerable areas in terms of the degree of vegetation are located in the area close to the main towns of Almáchar and El Borge, as well as in the western area of Canillas de Aceituno.

In the months of greatest vulnerability, Sedella, Moclinejo and El Borge are those with the lowest vegetation values, while Frigiliana, Macharaviaya and Vélez-Málaga are the towns where soil protection is preserved at the highest values throughout the year.

Fig. 26. Seasonal NDVI in the GIAHS area (A, Spring; B, Summer; C, Autumn; D, Winter)



Vulnerability to environmental degradation could be assessed by considering the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997), obtaining a result, at pixel scale, of the annual soil loss in the GIAHS area. Thus, the following equation has been used for its elaboration:

$$A = R * K * LS * C * P$$

Where *A* is the soil loss per unit area, measured in metric tonnes per unit area (t ha^{-1}), *R* e the rainfall erosivity factor (MJ ha^{-1} mm^{-1} $year^{-1}$), *K* the soil erodibility factor (t ha h ha^{-1} Mj^{-1} mm^{-1}), *LS* the factor related to slope length and slope, C the vegetation cover factor and finally the factor P related to conservation and erosion control measures.

At first, The methodology described above has been followed for the development of the R factor. The C factor for vegetation cover was based on NDVI, following the results of research such as Durignon et al. (2014) or Pacheco et al. (2019). Thus, it was developed under the application of Van der Knijff et al. (1999, 2000).

$$C = e^{(-\alpha((NDVI)/(\beta-NDVI)}$$

Where α and β are unitless parameters that determine the shape of the curve related to NDVI and the C-factor. The values α=2 and β=1 for these parameters were selected, considering that according to Van der Knijff et al. (2000), they are the most accurate values for European climatic conditions. Furthermore, a high correlation with the Corine Land Cover 2000 of the European Environment Agency is achieved (Kouli et al., 2008).

In the case of the K factor, which evaluates the susceptibility of a soil to erosion, a soil analysis was carried out on 60 soil samples distributed homogeneously throughout the territory. Data on texture, organic matter content, porosity and structure were obtained from these samples. The following equation was then applied to estimate this factor:

$$\text{lOO K} = 10^{-4} 2{,}71\ \text{M}^{1{,}14}\ (12 * \text{a}) + 4{,}20\ (\text{b} - 2) + 3{,}23\ (\text{c} - 3)$$

Where *K* is the erodibility factor per unit of the pluvial erosion rate R, *M* the particle size parameter, defined as the product of silts and very fine sands (0.01-0.002 mm) and 100 times the percentage of clays, a the percentage of organic matter, *b* the soil structure code and *c* the permeability code.

Photo 1. Soil sample collection

The factor relating to the physiographic characteristics of the terrain or LS factor has been developed from the 5 m DEM. The calculation of this LS factor has been carried out using the formula of Moore & Burch (1986):

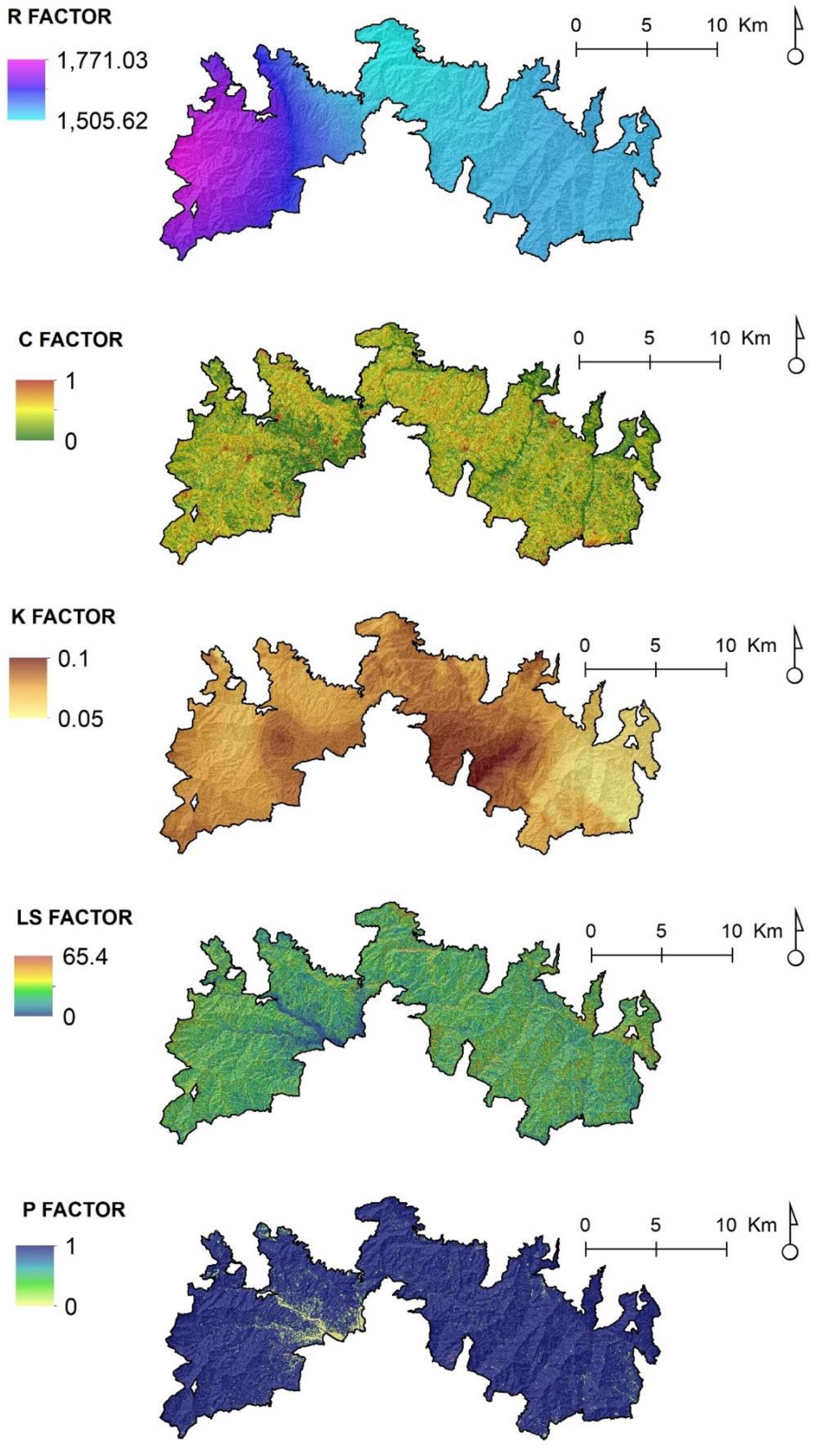
$$\mathrm{LS} = \left(\text{Flow accumulation} * {}^{\text{cell size}}/_{22,13}\right)^{0,4} \cdot [(\text{sin slope} / 0,0896)〛 \text{^}1,3$$

Where *LS* represents the product of slope length and slope steepness; Flow accumulation, the area contributing to a given pixel; cell size, the pixel size of the DEM used (in this case 5 metres); sin slope, the sine of the slope gradient in degrees.

Finally, the P factor gives information about the practices supporting soil loss control and mitigation. The value of this factor ranges from 0 to 1, where 0 represents best conservation practices and 1 represents no conservation practices (Morgan et al., 1998). For its development, the different practices carried out have been identified through the most current digital aerial orthophotography (PNOA). Based on these areas and taking into account the level of slope and land use, a P value was obtained for each pixel, taking into account the classification published by Wischmeier and Smith (1978).

The results of each of these factors that constitute the RUSLE are shown in figure 27 and their combination in figure 28. Thus, the R factor corresponds to the average value of recent years (1997-2019) and presents a maximum value of 1,771.03 MJ ha^{-1} mm^{-1} $year^{-1}$ located in the western end of the territory. The C factor, in relation to the NDVI, shows that the most protected area is the one located next to the Benamargosa river, where mainly fruit crops and irrigated land are grown. The soil erodibility factor K registers its highest values in the eastern half, in the area immediately next to the river Algarrobo, while the lowest values are found immediately to the east of these areas, with steep slopes and predominantly olive groves. The topographic factor or LS reaches a value of 65.4, with the highest values mainly located in the eastern half of the territory, on the north-eastern slopes, in Cómpeta and Frigiliana.

Fig. 27. RUSLE factors in the GIAHS area

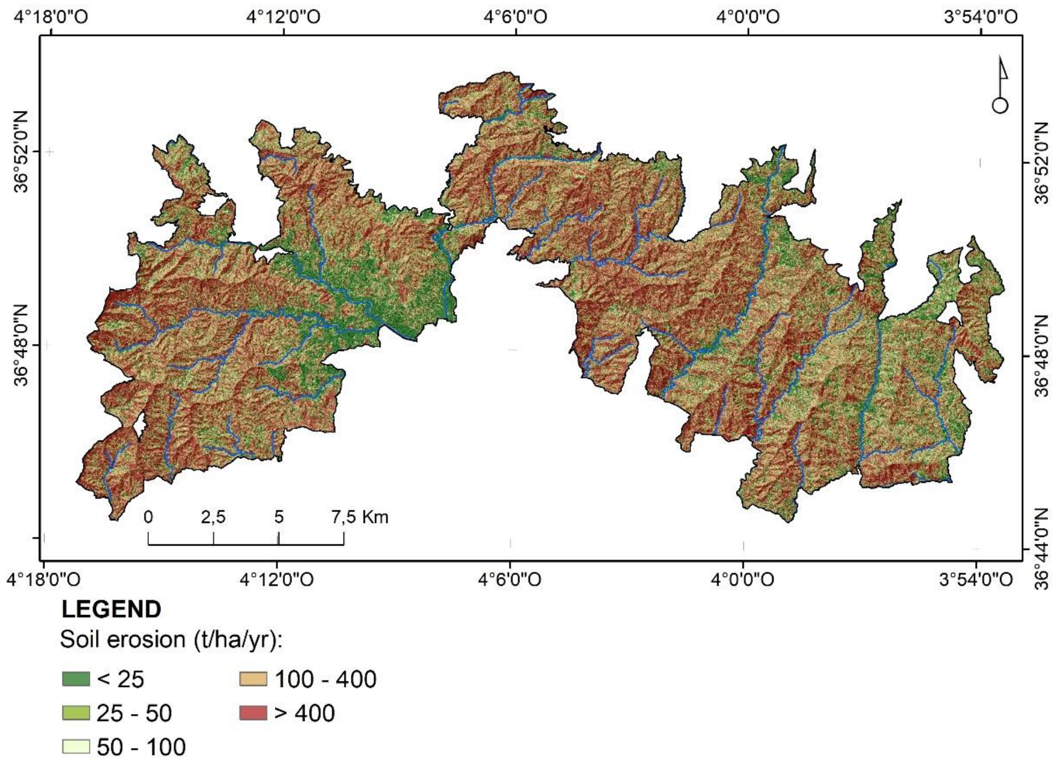


Finally, erosion support measures generally correspond to terraced cultivation areas, appearing most frequently around Benamargosa and Almáchar rivers.

In this sense, the result of annual soil loss derived from the combination of these factors (Fig. 28) reflects the aforementioned reality of each one of them. In general, although a high soil loss is observed throughout the GIAHS territory, the lower areas of the Benamargosa and Almáchar rivers register lower values, below 25 t $h^{-1}yr^{-1}$.

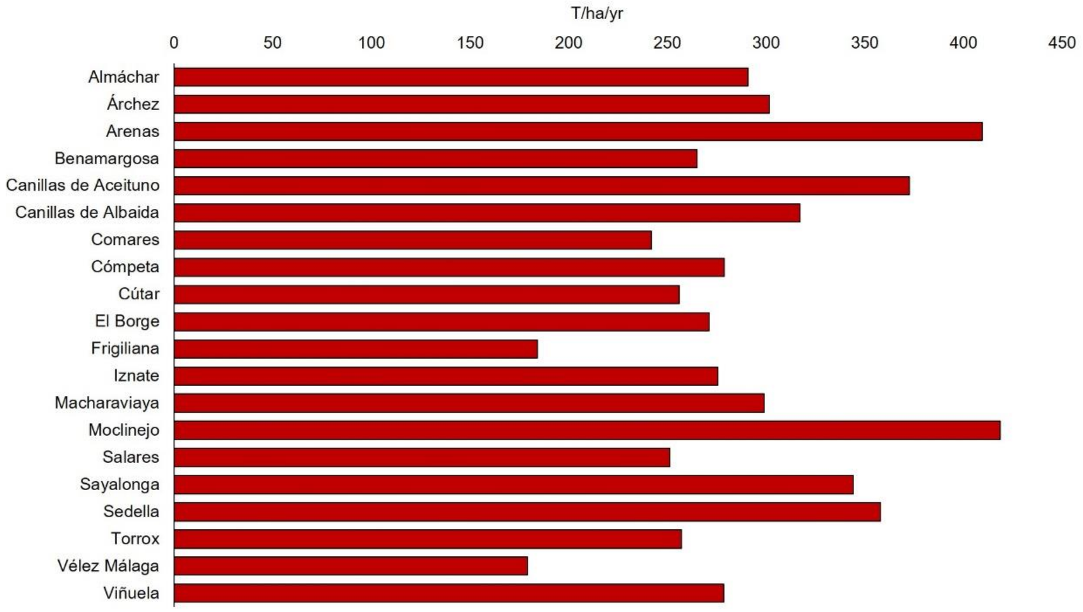
The western area reaches very high values, as for example in El Borge, however, these values are more heterogeneously identified than in the eastern sector. In this side, the areas located further north and in the surroundings of the Seco and Torrox rivers present more moderate values, with the rest having soil loss values of more than 400 t $h^{-1}yr^{-1}$.

Fig. 28. Annual RUSLE in the GIAHS area. Average values of the series 1997-2019



At the municipal scale (Fig. 29), the highest average annual soil loss rates, where vulnerability and erosion risk is highest, are registered in Moclinejo, with 418.6 t $h^{-1}yr^{-1}$; Arenas, 409.5 t $h^{-1}yr^{-1}$ and Canillas de Aceituno con 372.4 t $h^{-1}yr^{-1}$. However, Vélez-Málaga, followed by Frigiliana, with 179.1 t $h^{-1}yr^{-1}$ y 183.9 t $h^{-1}yr^{-1}$ respectively, register the lowest average values in the area in question.

Fig. 29. Average annual RUSLE values in the GIAHS municipalities



The spatial distribution of soil loss has been related to land uses (Table 7), thus, the highest mean values appear in grassland areas, with 360.8 t $h^{-1}yr^{-1}$, s followed by grassland with 357.1 t $h^{-1}yr^{-1}$. Considering the standard deviation, the areas of the GIAHS area with the greatest heterogeneity of soil loss would again be those occupied by grassland (401.7).

On the other hand, areas of forest use identify the lowest soil loss, e.g. mixed forest, with 84.6 t $h^{-1}yr^{-1}$ and coniferous forest 142.2 t $h^{-1}yr^{-1}$. Their low standard deviation values (123.7; 200.5) also indicate the highest homogeneity within this same use.

Table 7. Annual soil loss (t $h^{-1}yr^{-1}$) according to different land uses in the GIAHS area

Land use	Mean	STD
Vineyards	323.3	313.7
Olive plantations	310.4	326.0
Irrigated crops	107.7	212.6
Fruit trees	228.2	306.6
Mixed cultivations	274.3	314.8
Agroforestry systems	355.6	332.2

Abandoned fields	315.3	333.0
Meadow	360.8	401.7
Rangeland	357.1	360.9
Shrubland	286.3	330.1
Bare soil	347.7	401.0
Decidious forest	260.4	278.1
Coniferous forest	124.2	200.5
Mixed forest	84.6	123.7

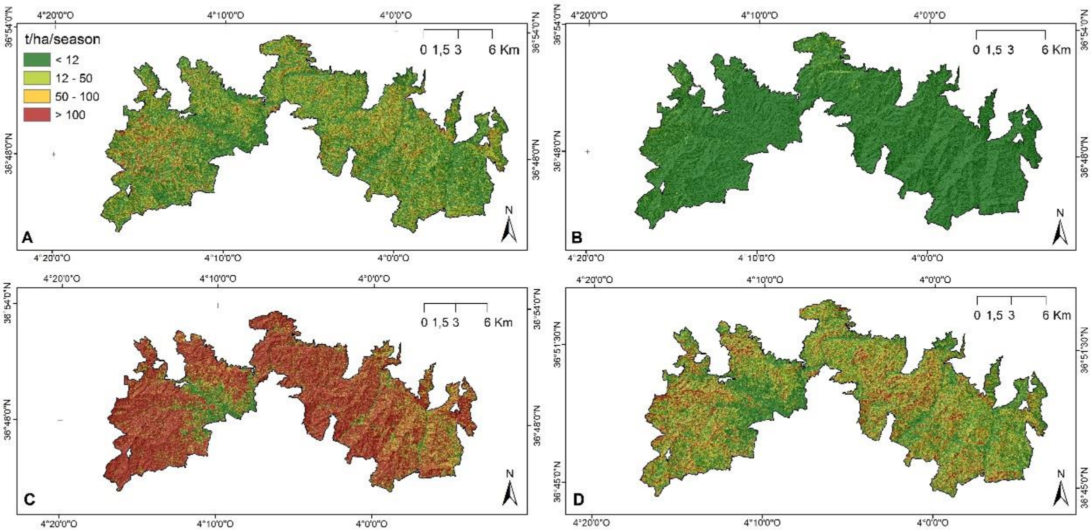
Seasonally, the Mediterranean climate variability modifies the environmental conditions and, therefore, the results of the RUSLE application. Therefore, C and R factor values have been considered for each of the seasons of the year, resulting in the maps shown in figure 30.

This shows very differentiated soil losses, especially for the R factor, which is extremely variable in each of the seasons. The spring months show relatively low levels of soil loss, as a result of moderate rainfall and a high percentage of vegetation cover. In the summer months, little or no rainfall is reflected in soil loss, which is non-existent throughout most of the territory. The autumn season, immediately after a long period of water stress following the summer drought, is a time of maximum vulnerability. The eco-geomorphological characteristics linked to the maximum aggressiveness of rainfall in these months give rise to high soil loss, which are by far the highest rates of the year.

Finally, the greater protection of the soil and the more moderate rainfall generally mean that the winter months present a soil loss very similar to that of the spring months.

Thus, the territorial reality again shows strong contrasts, with the areas near toAlmáchar, Benamargosa, Seco and Torrox rivers being the least vulnerable. The rest of the GIAHS area presents levels that could be considered of great concern, with irreplaceable annual soil losses that generate a continuous impoverishment of both the soil and the ecosystem in general.

Fig. 30. Result of seasonal RUSLE at GIAHS level. Mean values of the series 1997-2019 (A, spring; B, summer; C, autumn; D, winter)



On the other hand, changes in land use could be understood as a key process in assessing the vulnerability of the GIAHS area. The relatively recent changes in land use in favour of subtropical crops would be a clear handicap for the persistence of rainfed crops, especially vines.However, the sustainability of these new crops is questionable as they require high amounts of water and we find ourselves in a context of a dry-semiarid Mediterranean climate and, of course, in a paradigm of climate change in which, as has been mentioned, the tendency is towards water deficit.

Regarding the surface area of irrigated crops in the Axarquia region, in 1983 there were 8,688 hectares (Yus Ramos et al., 2020), at a time when the current reservoir that provides water to the region had not yet been built (La Viñuela water reservoir). However, the bubble created around irrigated crops has led to a vertiginous increase in this surface area in recent years, amounting to 12,989.96 in 2017 for this same territory and, therefore, representing an increase of more than 49%. Thus, by way of example, mango cultivation in Axarquia was practically non-existent just over a decade ago and currently occupies 3,497.71 hectares.

Table 8 shows the area of subtropical crops for the specific case of the GIAHS municipalities. In total there are 8,648.86 hectares of subtropical crops, of which 5,443.86 hectares belong to avocado and 3,309.39 hectares to mango.

Table 8. Subtropical crop surface (ha) in the GIAHS area in 2017

Source: Yus Ramos et al (2020)

Municipio	Avocado	Mango	Subtropical Total
Almáchar	72.35	104.44	179.79
Árchez	38.58	92.94	40.06
Arenas	51.62	69.94	121.56
Benamargosa	115.23	241.72	356.95
Canillas de Aceituno	38.89	23.79	60.69
Canillas de Albaida	62.27	2.86	65.13
Comares	60.86	15.57	76.42
Cómpeta	106.78	28.94	130.78
Cútar	153.41	121.31	274.72
El Borge	22	52.92	74.91
Frigiliana	375.33	98.28	473.61
Iznate	140.5	156.67	297.17
Macharaviaya	14.31	38.25	52.57
Moclinejo	24.7	11.86	36.56
Salares	1.99	2.13	4.13
Sayalonga	133.13	80.9	214.03
Sedella	19.93	7.62	18.55
Torrox	540	270.09	810.09
Vélez Málaga	3,383.19	1,815.06	5,198.25
Viñuela	88.79	74.1	162.89
GIAHS	**5443.86**	**3309.39**	**8648.86**

Based on these surface area data, it can be seen that despite the growing dynamics of subtropical crops and irrigated crops in general, vine cultivation accounts for more than 200% more surface area than subtropical crops. Vélez-Málaga is the one in which subtropical crops (5,198.25 ha) have a larger surface area than that dedicated to vines (2,871.04 ha).

Thus, the real vulnerability of the GIAHS territory should not be focused on the change of some plots from dry land (olive groves, almond trees, vines, etc.) to irrigated land. The fundamental problem lies in the increase in water demand and excessive pumping to bring water to higher elevations.

Thus, although the Guaro Plan, designed to cover the irrigated area of the Axarquia, established a maximum irrigation threshold of 140m, the current irrigated area in the Axarquia has been extended by 5,312.62 hectares outside the area foreseen by the aforementioned plan.

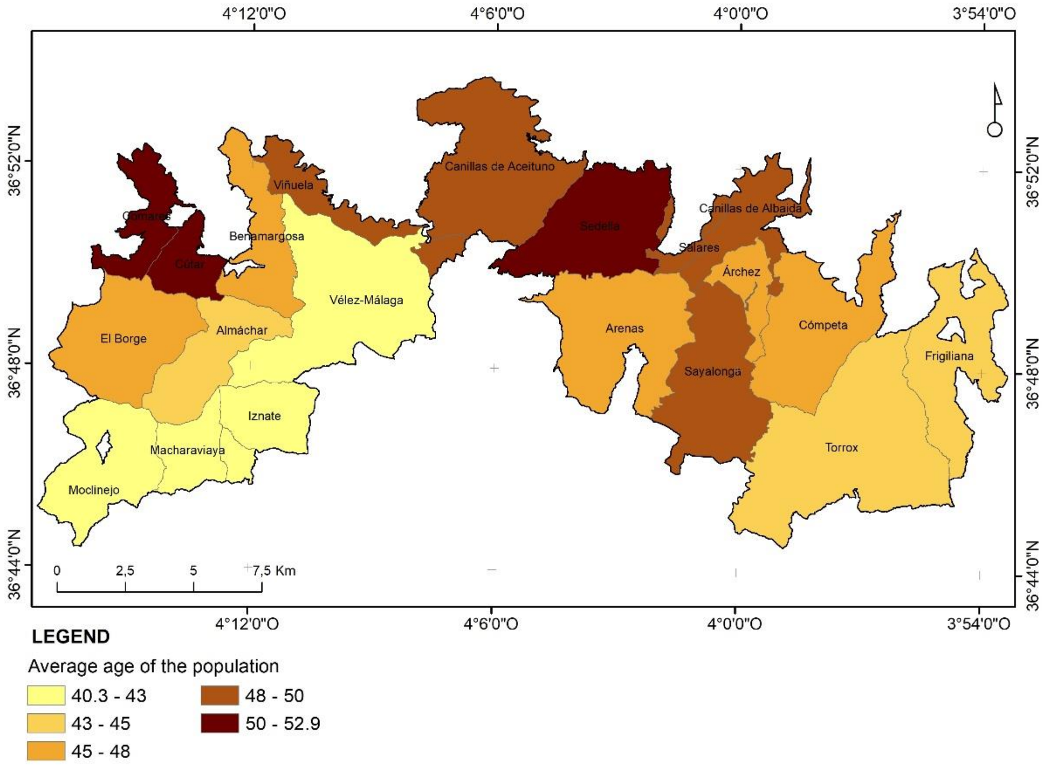
5.2. Socio-economic vulnerability

The socio-economic characteristics of the population living in the GIAHS area will determine the type of human response to the new situations resulting from climate change. Thus, there are several variables of this nature that can provide data to assess the fragility of the population in the face of a dynamic and highly uncertain situation such as the current one.

The variables that have been selected to assess this type of vulnerability are: (i) average age of the population, (ii) population under 18 years old, (iii) population aged 65 and over, (iv) median household size, (v) single person households, (vi) population, (vii) population with income per consumption unit below 40% of the median, (viii) population with income per consumption unit below 50% of the median, (ix) population with income per consumption unit below 60% of the median, (x) population with income per consumption unit below 140% of the median, (viii) population with income per consumption unit below 50% of the median, (ix) population with income per consumption unit below 60% of the median, (x) population with income per consumption unit below 140% of the median, (xi) population with income per consumption unit below 160% of the median, (xii) population with income per consumption unit below 5,000€, (xiii) population with income per consumption unit below 7,500€, (xiv) population with income per consumption unit below 10,000€, (xv) population with "pensions" as a source of income, (xvi) population with "unemployment benefits" as source of income, (xvii) population with "other income" as source of income, (xviii) average income per person, (xix) average income per household, (xx) average disposable income and (xxi) registered unemployment.

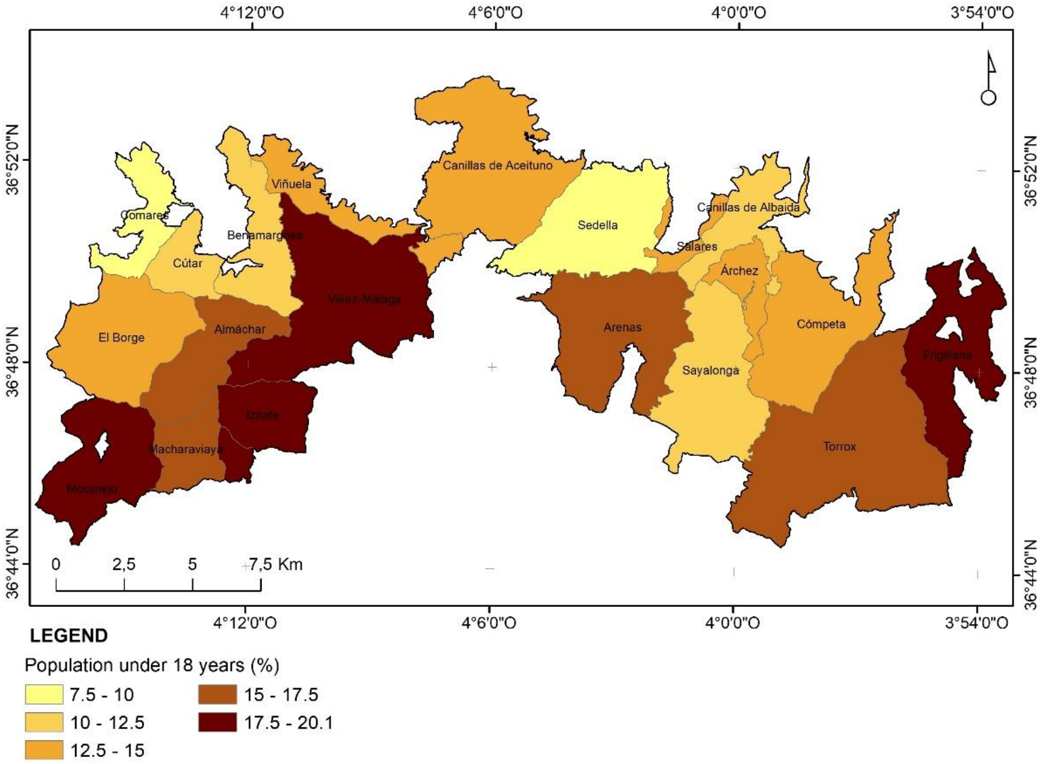
Firstly, the average age of the population is, in general, very high. Knowing that the Andalusian average has been between 41 and 42 years of age in recent years, all the municipalities in the GIAHS area, except Moclinejo, Macharaviaya, Iznate and Vélez-Málaga, exceed this threshold and the age of 43. Thus, Comares, Cútar and Sedella register the highest average age values, being over 50 years old. They are followed by Viñuela, Canillas de Aceituno, Salares, Canillas de Albaida and Sayalonga, where the average values are between 48 and 50 years of age, showing an ageing population (Fig. 29).

Fig. 29. Average age of the population of GIAHS municipalities in 2017



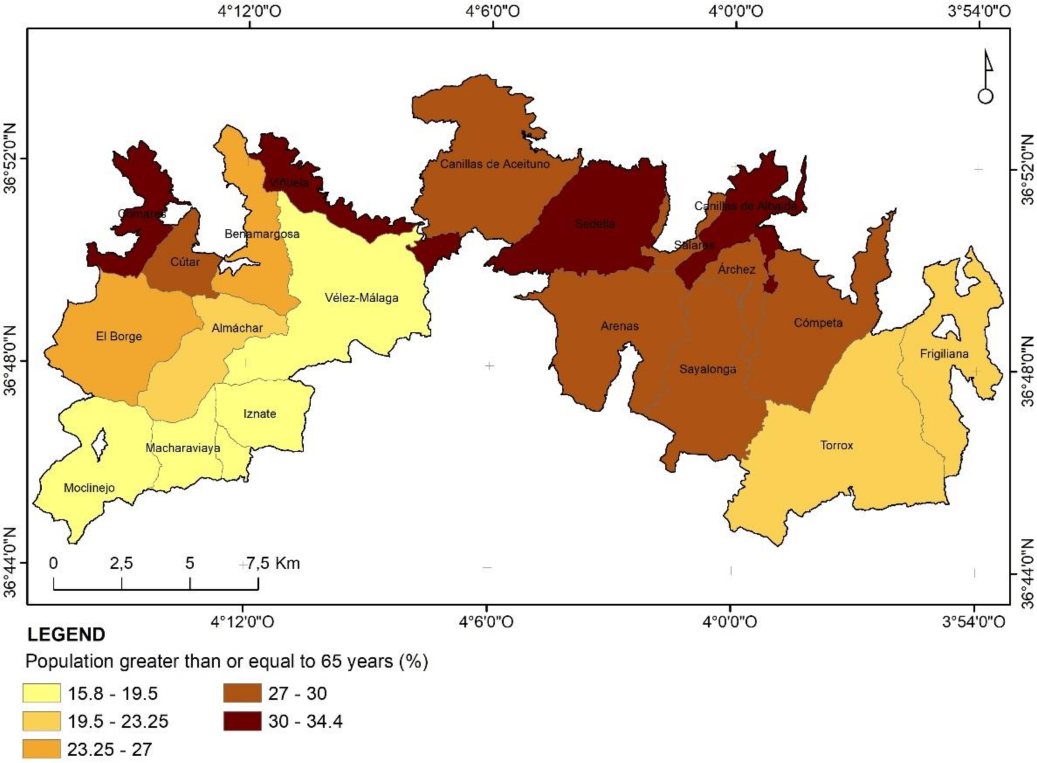
Along the same lines, the percentage of the population under 18 years of age again reflects to a certain extent the previous information, with the municipalities with the highest average age registering a lower percentage of this variable. Thus, while Comares and Sedella have the lowest values of the entire GIAHS area (7-10%), Moclinejo, Iznate, Vélez-Málaga and Frigiliana are, in contrast, which have the highest proportion of young people (> 18%) (Fig. 30).

Fig. 30. Population under 18 years old of GIAHS municipalities in 2017



The percentage of the population aged 65 and over (Fig. 31) again gives very similar information to that of the previous figures, with Comares, Viñuela, Sedella and Canillas de Albaida registering the highest values (30-34.4%) and Moclinejo, Macharaviaya, Iznate and Vélez-Málaga showing the lowest percentage of population over 65 and, therefore, of an ageing population (15.8-19.5%).

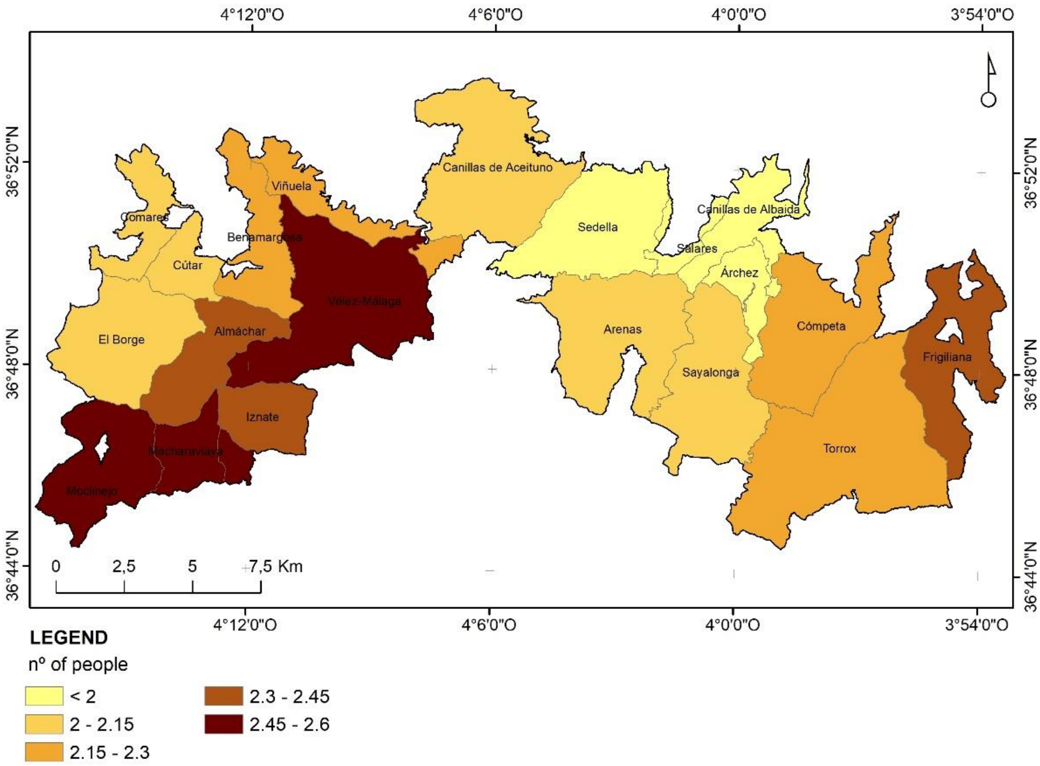
Fig. 31. Percentage of population aged 65 and over in GIAHS municipalities in 2017



In short, contrasting characteristics can be observed within the study area. While the southwestern area shows a younger population (Moclinejo, Macharaviaya, Iznate and Vélez-Málaga), Comares, Sedella and Cútar show the greatest social vulnerability in this respect.

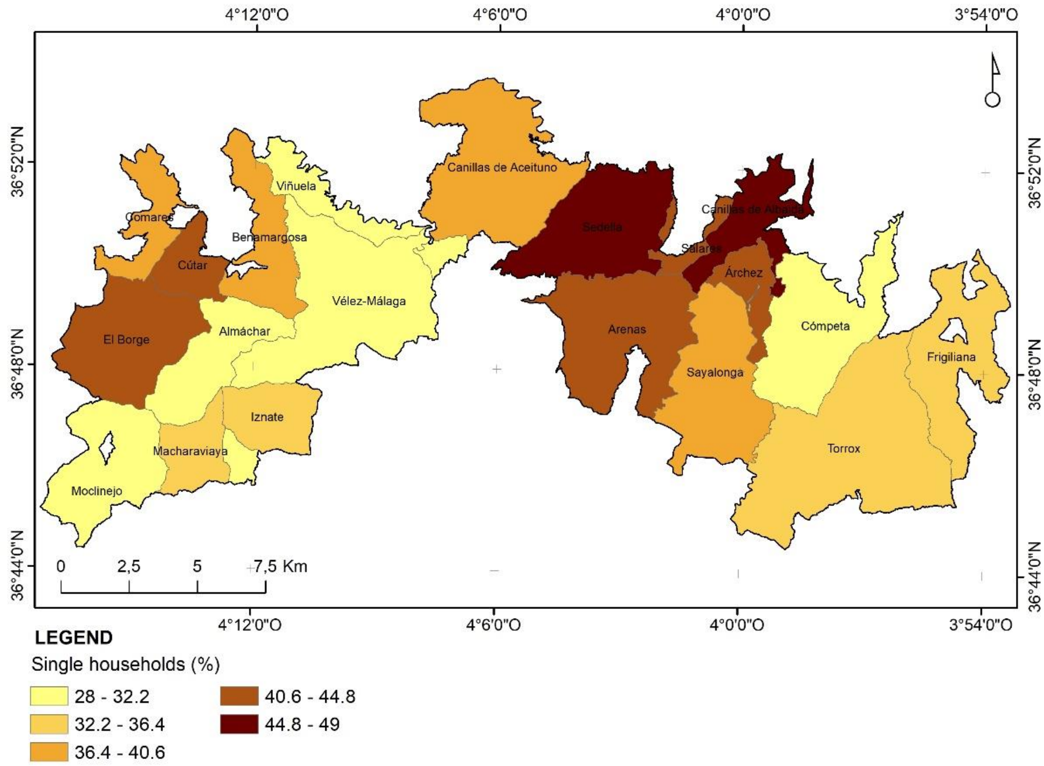
On the other hand, the average size of the average household (Fig. 32) of the municipalities that make up the GIAHS area is 2.2 persons, somewhat lower than the Spanish and Andalusian average of around 2.5 persons. Sedella, Canillas de Albaida, Salares and Árchez register the lowest values, with values below 2. However, Moclinejo, Macharaviaya and Vélez-Málaga have higher values, close to the average for Spain.

Fig. 32. Average household size in GIAHS municipalities in 2017



The percentage of single-person households, i.e. population living alone and therefore presumably mainly elderly (Fig. 33), reaches its highest values in Sedella and Canillas de Albaida (48.8-49%), where the average household size presented minimum values (< 2 persons). This fact is mainly due to the presence of a greater number of elderly people (> 65 years old) who continue in their usual residence after the emancipation of their children and possible widowhood, leaving the household composed of one or, at most, two persons. In contrast, Vélez-Málaga, Viñuela and Almáchar register the lowest percentages of single-person households, with 28%, 29.3% and 29.5% respectively.

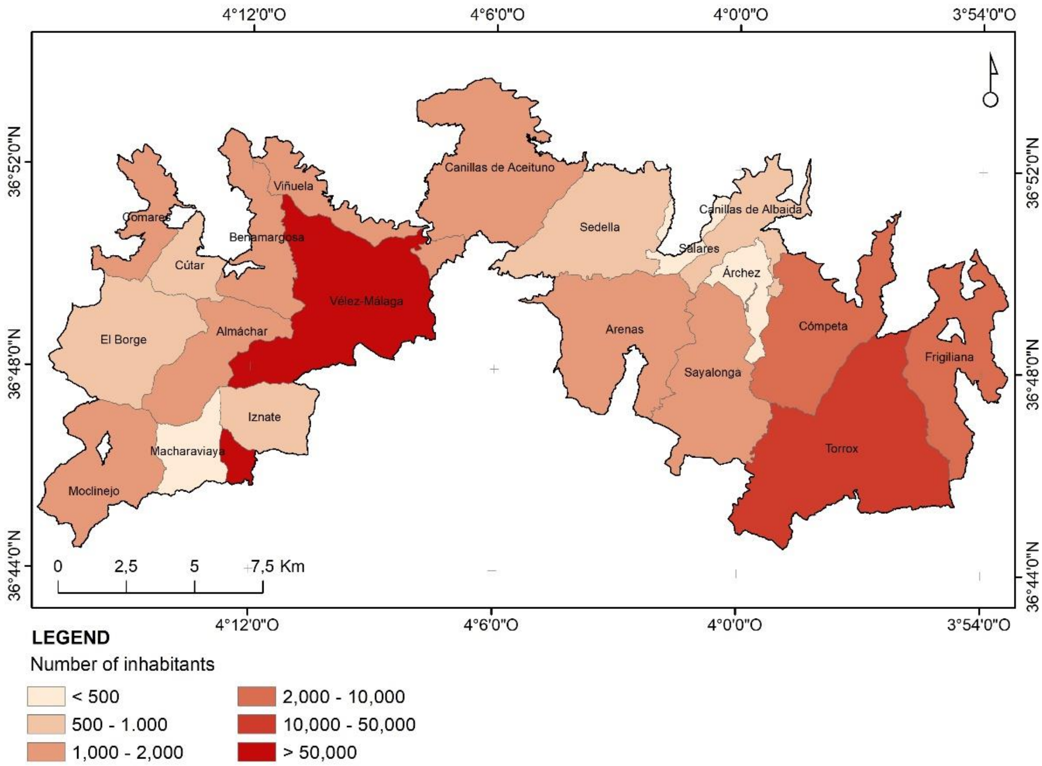
Fig. 33. Percentage of single-person households in GIAHS municipalities in 2017



The total population of the municipalities is considered a fundamental variable in the study of social vulnerability in this area. Thus, GIAHS area, located in the Axarquia of Malaga, presents the municipality of Velez-Malaga as the regional capital which, with a population of around 80,000 inhabitants, acts as the backbone of all the surrounding municipalities. Torrox and Cómpeta, with a total population of 15,649 and 3,521 inhabitants respectively, are the municipalities with the next largest number of inhabitants to Vélez-Málaga which, nevertheless, show a low regional influence.

As for the municipalities with the smallest population, widely affected by the depopulation processes, there are: Salares (177 inhab.), Árchez (379 inhab.), Macharaviaya (439 inhab.), Sedella (570 inhab.) and Cútar (575 inhab.); these being the ones that could be catalogued as having the greatest demographic vulnerability.

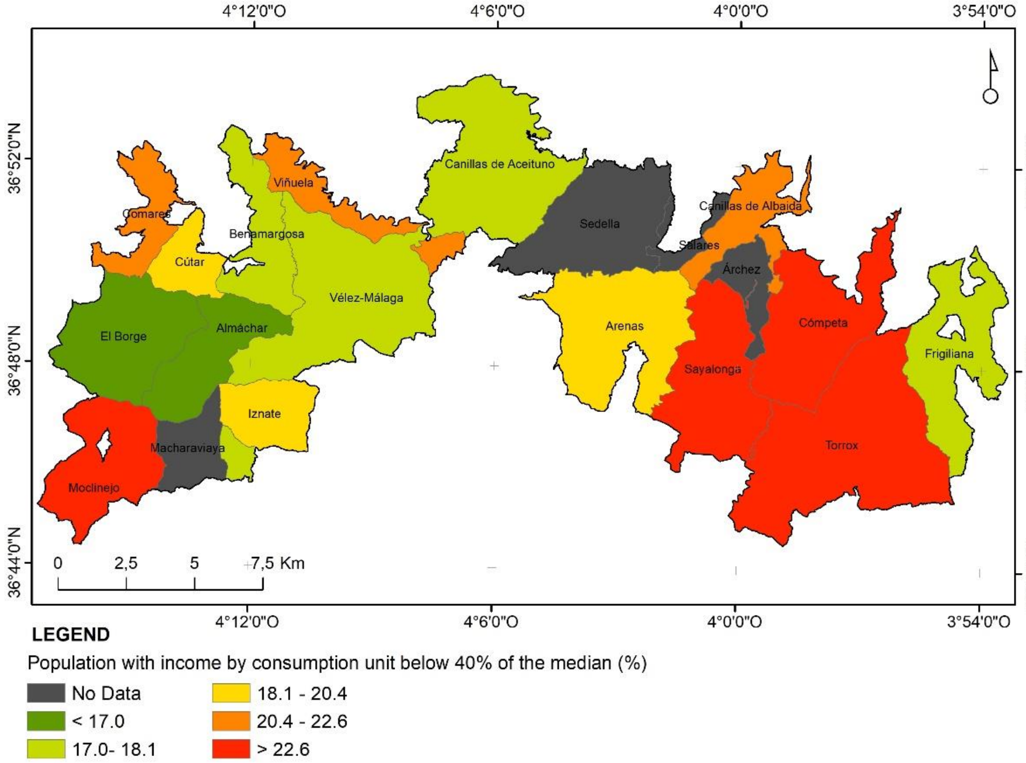
Fig. 34. Population of the GIAHS municipalities in 2017



From an economic perspective, indicators such as the percentage of population with income per consumption unit below 40%, 50% and 60% of the median can provide key information to delimit the poverty situation in the study area.

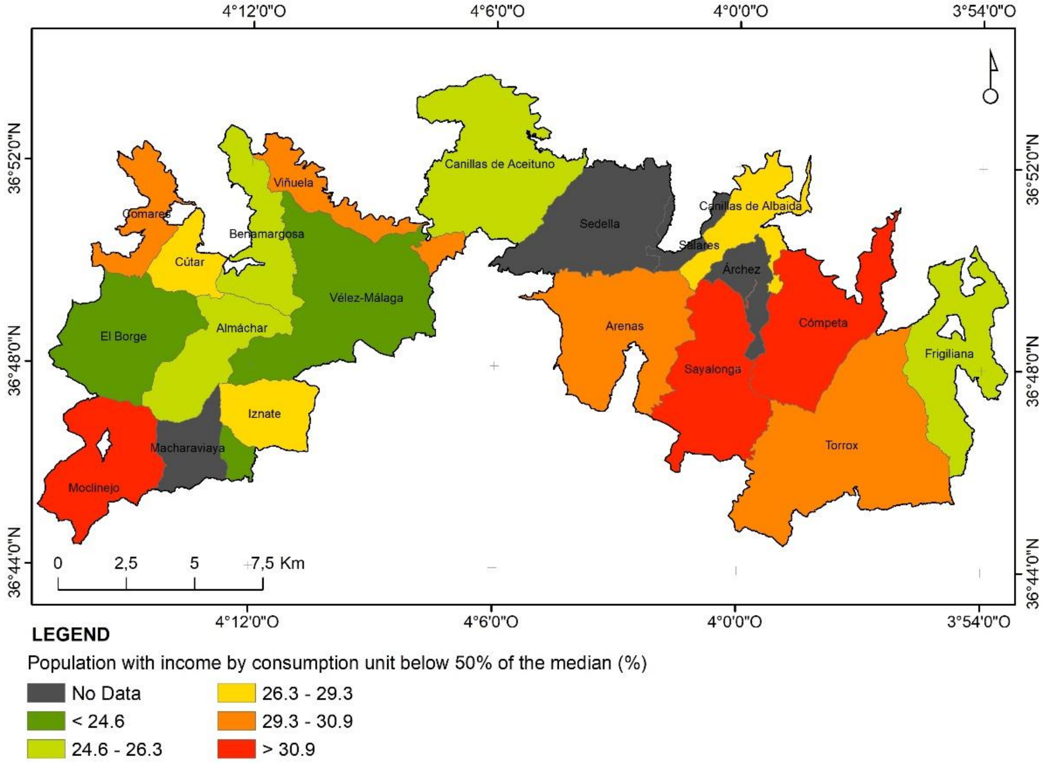
Firstly, the rate of population with high poverty (< 40%) is most worrying in the easternmost sector of the GIAHS area (Fig. 35). Thus, the municipalities with the highest poverty values are Cómpeta (24.8%), Sayalonga (23.7%), Moclinejo (23.3%) and Torrox (23.1%), while those with the lowest percentages and, therefore, the lowest economic vulnerability are Almáchar (16%), El Borge (17%) and Vélez-Málaga (17.5%).

Fig. 35. Population with income per consumption unit below 40% of the median in the GIAHS municipalities in 2017



For the population with income per consumption unit below 50% of the median, the data shows very similar information to that discussed in the previous figure, with the most vulnerable in Cómpeta (34.3%), Moclinejo (34.2%) and Sayalonga (32.9%) and, on the contrary, Frigiliana (25.6%), Vélez-Málaga (24.6%) and El Borge (24%) presenting a less worrying situation (Fig. 36).

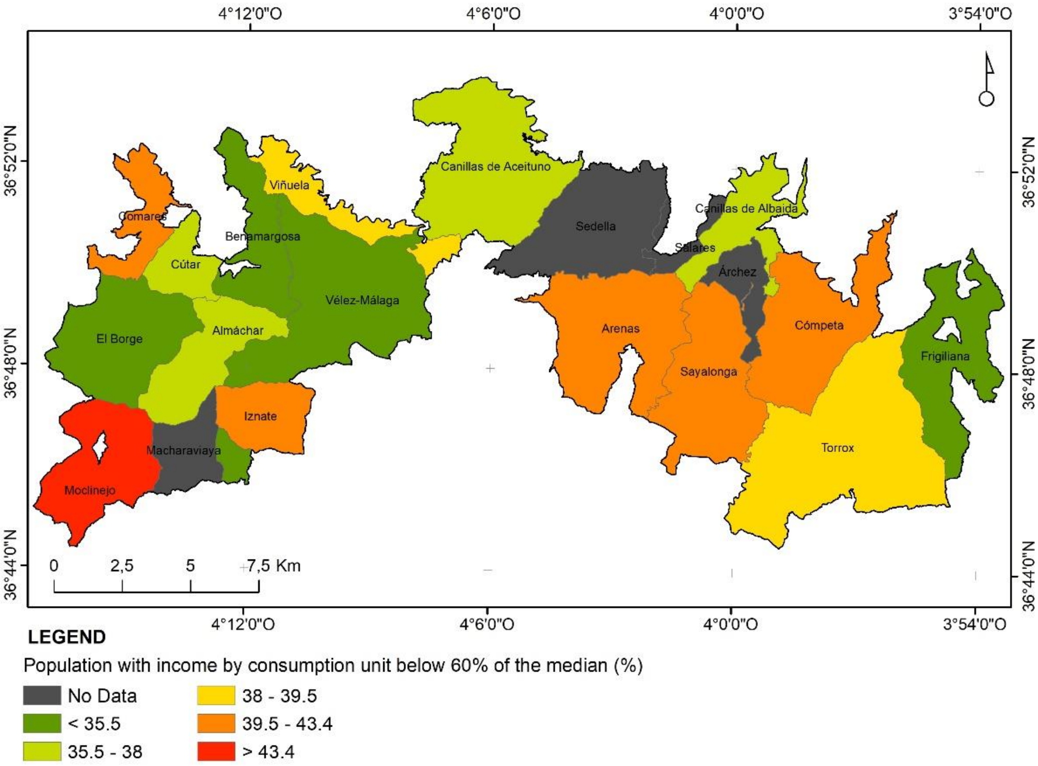
Fig. 36. Population with income per consumption unit below 50% of the median in the GIAHS municipalities in 2017



In this same sense, the percentage of the population at risk of poverty, indicated by the population with income per consumption unit below 60% of the median is, in general, very high. Comparatively, in 2017, the percentage of the Spanish population below this threshold was 21.6%, which means that all the municipalities in the GIAHS region exceed this figure and even double it.

Thus, the minimum values, where the vulnerability recorded is the lowest in this area, correspond to Vélez-Málaga (33%), Frigiliana (33.9%) and El Borge (35.2%). In the opposite case, the municipalities with the highest risk of poverty are again Moclinejo (46.6%) and Cómpeta (43.4%), followed by Iznate (42%) (Fig. 37).

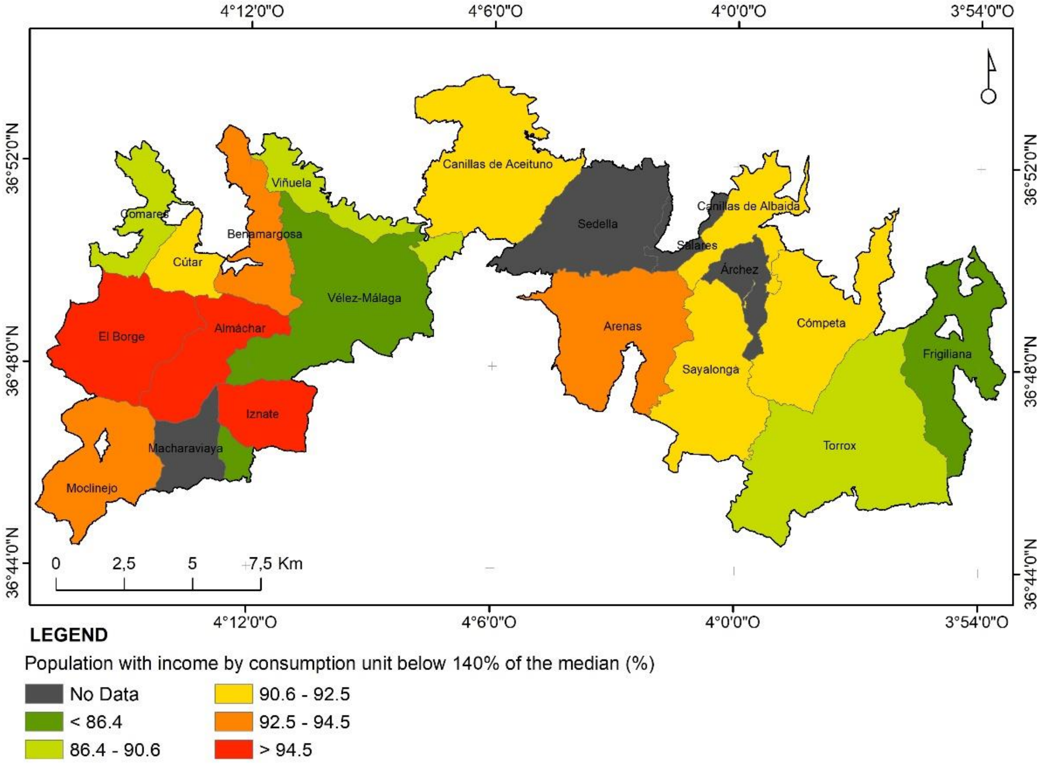
Fig. 37. Population with income per consumption unit below 60% of the median in the GIAHS municipalities in 2017



The percentage of the population with income per consumption unit below 140%, 160% and 200% of the median provides substantial information, with the understanding that those people who do not reach this value do not present a situation of economic unburdening and, therefore, present a situation of certain vulnerability.

Vélez-Málaga (82.5%), Frigiliana (86.4%) and Torrox (87.8%) show the highest values of economic well-being, while Iznate (91.1%), Almáchar (96.4%) and El Borge (96.1%) show the highest levels of fragility (Fig. 38).

Fig. 38. Population with income per consumption unit below 140% of the median in the GIAHS municipalities in 2017



Increasing the percentage of variation with respect to the median, Vélez-Málaga and Frigiliana identify the lowest percentage of population with income per consumption unit below 160% and 200% of the median, which indicates the existence of a greater number of people in a situation of economic relief. However, the opposite situation is shown in Iznate, El Borge and Moclinejo, with values above 98% in both indicators (Fig. 39 and 40).

Fig. 39. Population with income per consumption unit below 160% of the median in the GIAHS municipalities in 2017

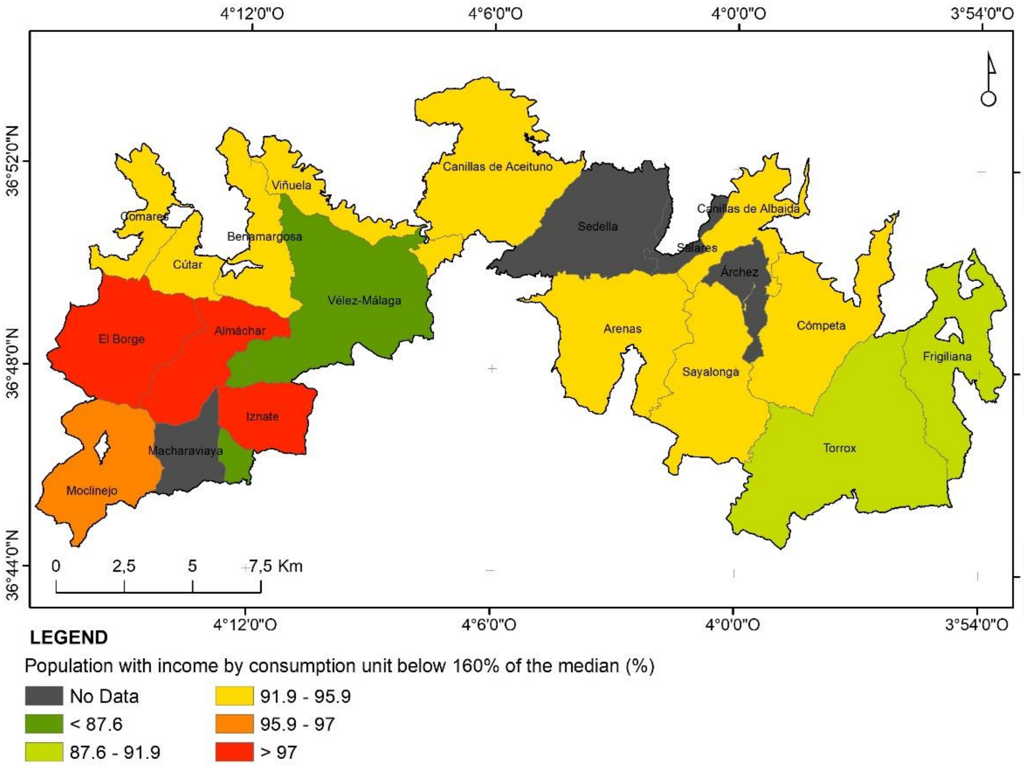
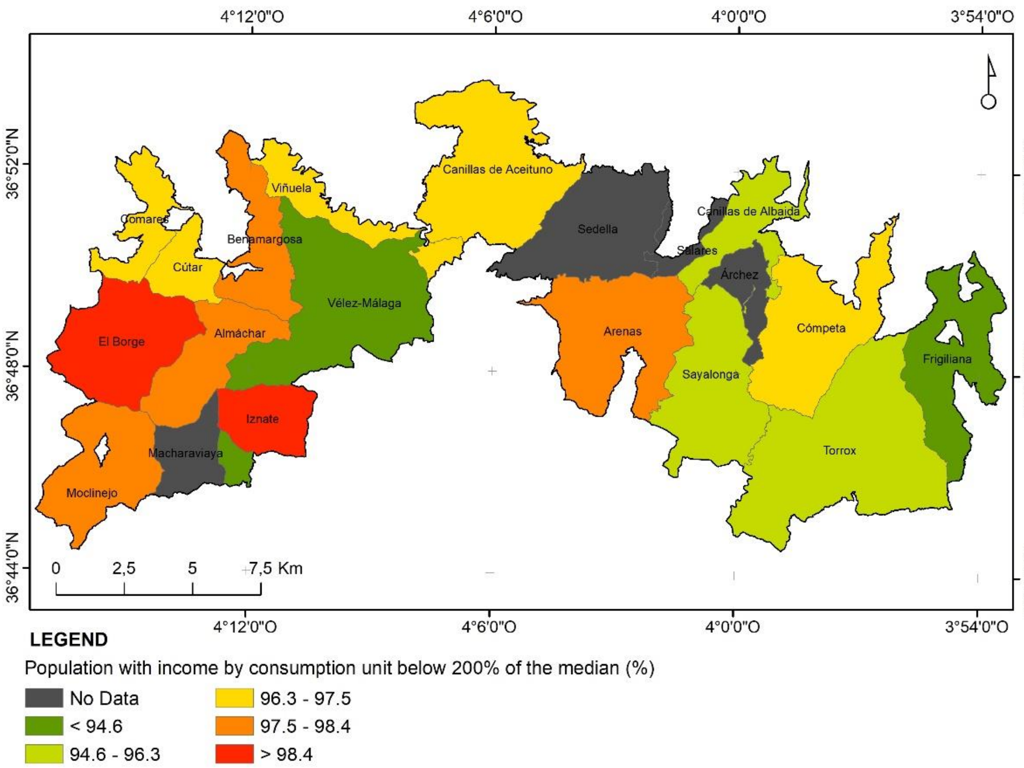


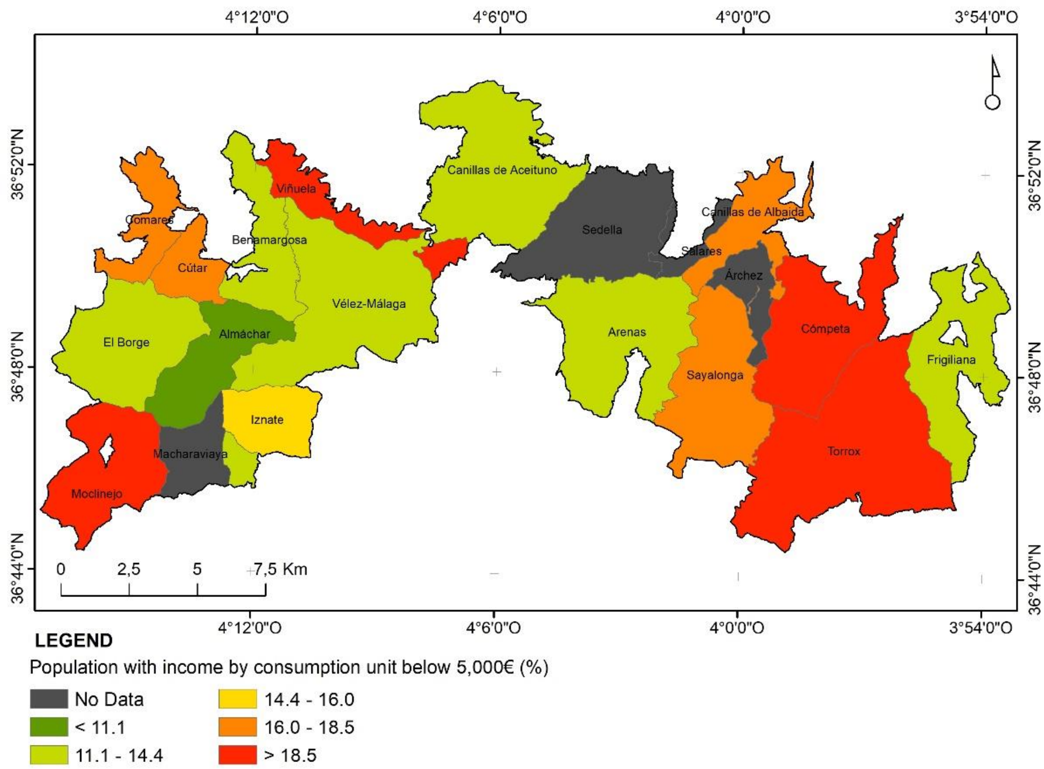
Fig. 40. Population with income per consumption unit below 200% of the median in the GIAHS municipalities in 2017



In short, these indicators show the fragility and vulnerability to which the GIAHS area is subjected from an economic and social perspective. Thus, Cómpeta, Iznate, Moclinejo and Sayalonga present a worrying situation. In these municipalities, the population that is economically well off is very low, with very high rates of people living in poverty and at risk of poverty. However, despite the fact that there are data of maximum vulnerability in the entire area in question in comparison with the national territory, Vélez-Málaga and Frigiliana present data of greater socio-economic resilience and solidity.

Other variables such as population with income per consumption unit below €5,000, €7,500 or €10,000 can provide absolute information on the economic level of the GIAHS municipalities, as well as the degree of vulnerability to which their inhabitants are subjected. Figure 41 shows the percentage of the population with an income per consumption unit below €5,000, where Moclinejo (19%), Viñuela (18.9%), Cómpeta (19.9%) and Torrox (19.3%) show maximum values, with more than 18.5% of the population. However, in contrast and with the lowest vulnerability of the territory in relation to this parameter, Almáchar stands out, with less than 11% of the population.

Fig. 41. Population with income per consumption unit below €5,000 in the GIAHS municipalities in 2017



As the threshold rises to €7,500, the population figures increase considerably, with Moclinejo and Cómpeta still registering maximum values of over 36%. On the other hand, Vélez-Málaga and El Borge register the lowest percentage of population with income per consumption unit below €7,500, at 26.4% and 26.3%, respectively (Fig. 42).

In terms of population with income per consumption unit below €10,000, Moclinejo again identifies the highest percentage, with 58.4% of its population. Thus, up to nine municipalities in the territory exceed 50%, which means that more than half of the population lives with less than €10,000 per year in their consumption unit.

In the opposite case, Cútar, Frigiliana and Vélez-Málaga stand out, with 44.5%, 41.5% and 41.7% respectively, the latter two having the lowest vulnerability in all the economic parameters observed in the area analysed.

Fig. 42. Population with income per consumption unit below €7,500 in the GIAHS municipalities in 2017

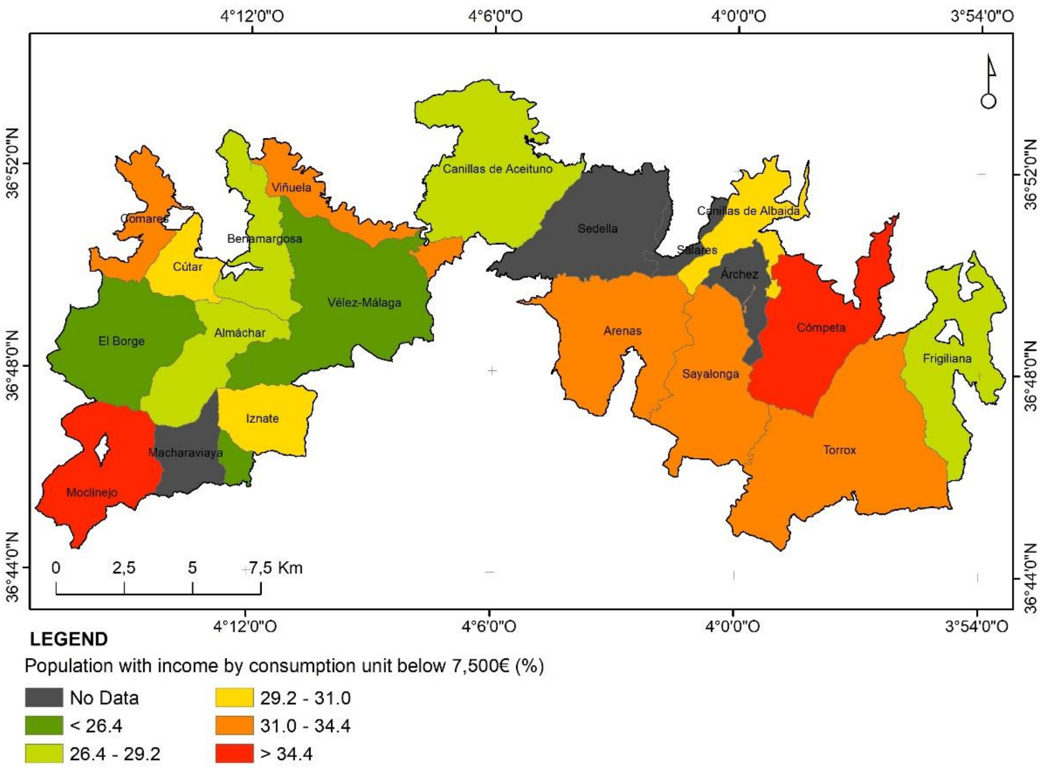
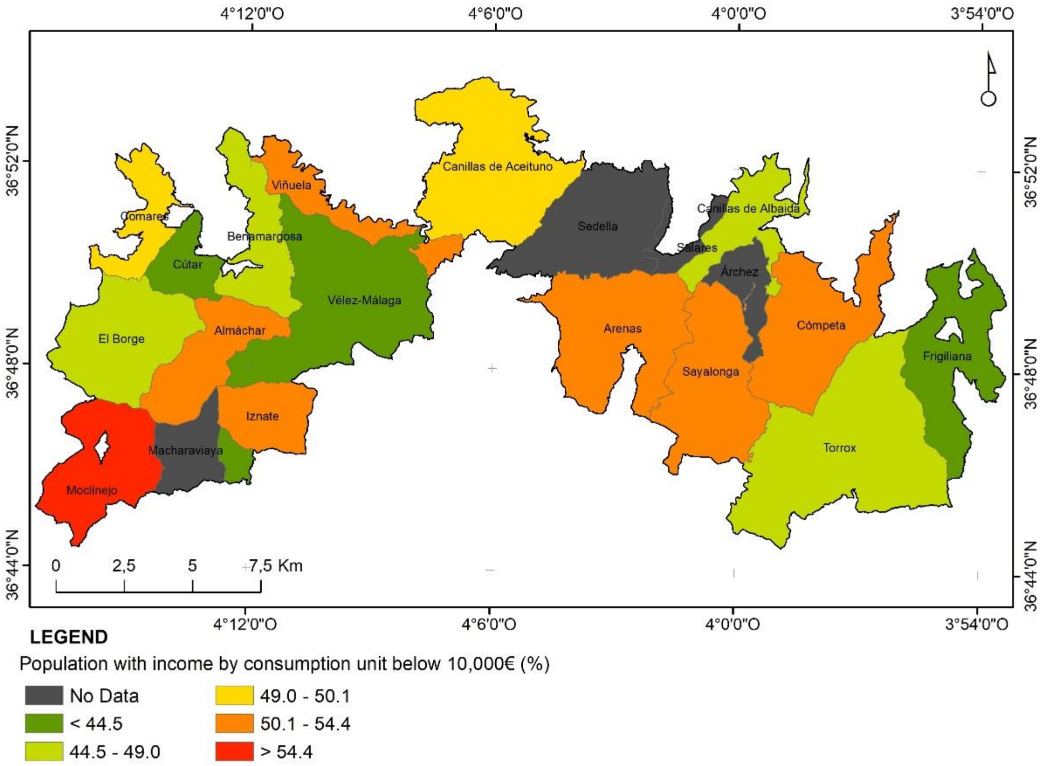


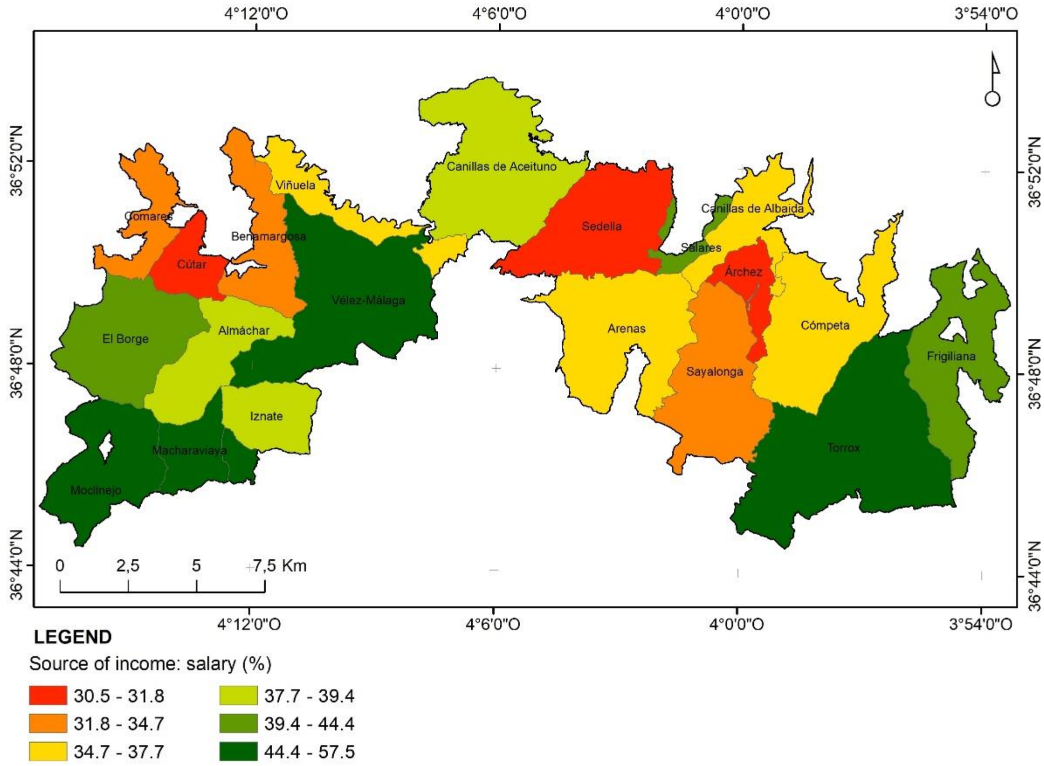
Fig. 43. Population with income per consumption unit below €10,000 in the GIAHS municipalities in 2017



The source of income of the population that makes up the GIAHS area is another fundamental indicator for understanding the state and, therefore, the economic fragility to which this area is subjected. Figure 44 shows the percentage of the population whose source of income is a salary.

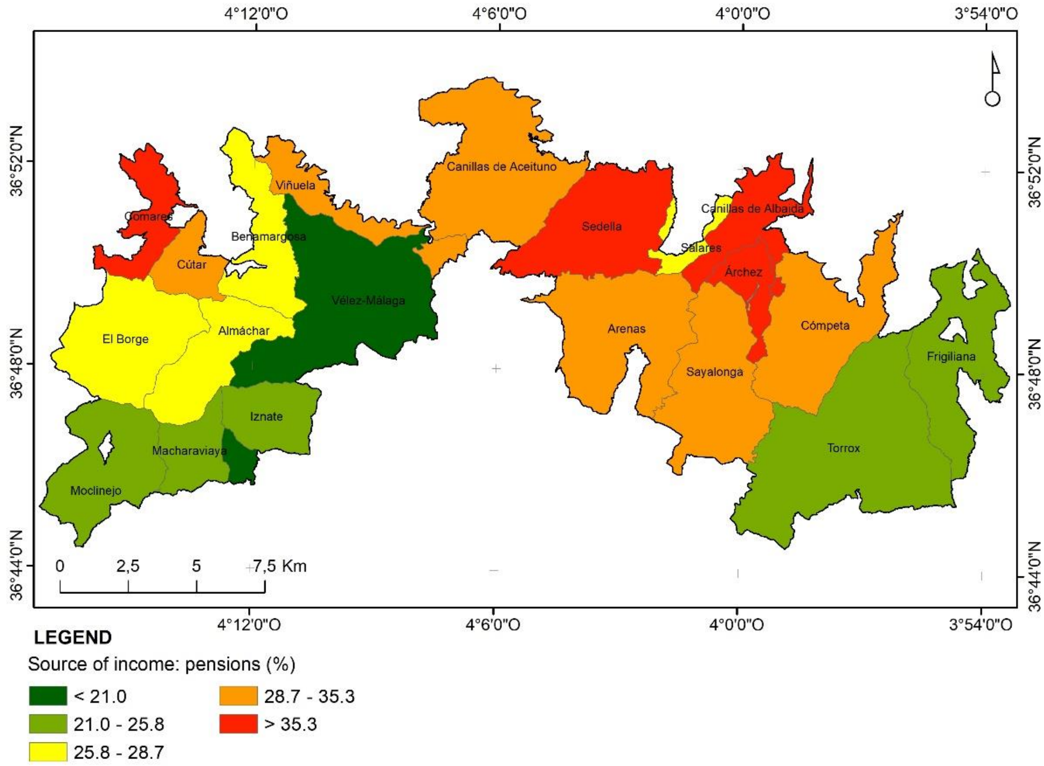
Vélez-Málaga, with 57.5%, Torrox, with 51.3% and Macharaviaya, with 50%, are the three municipalities with the highest percentage of salaried workers and, therefore, those with the best economic situation. However, the rest of the municipalities in the GIAHS area are below the 50% threshold, with Cútar (30.5%), Sedella (31.8%) and Árchez (31.8%) standing out in a negative way.

Fig. 44. Population with "salary" as a source of income in the GIAHS municipalities in 2017



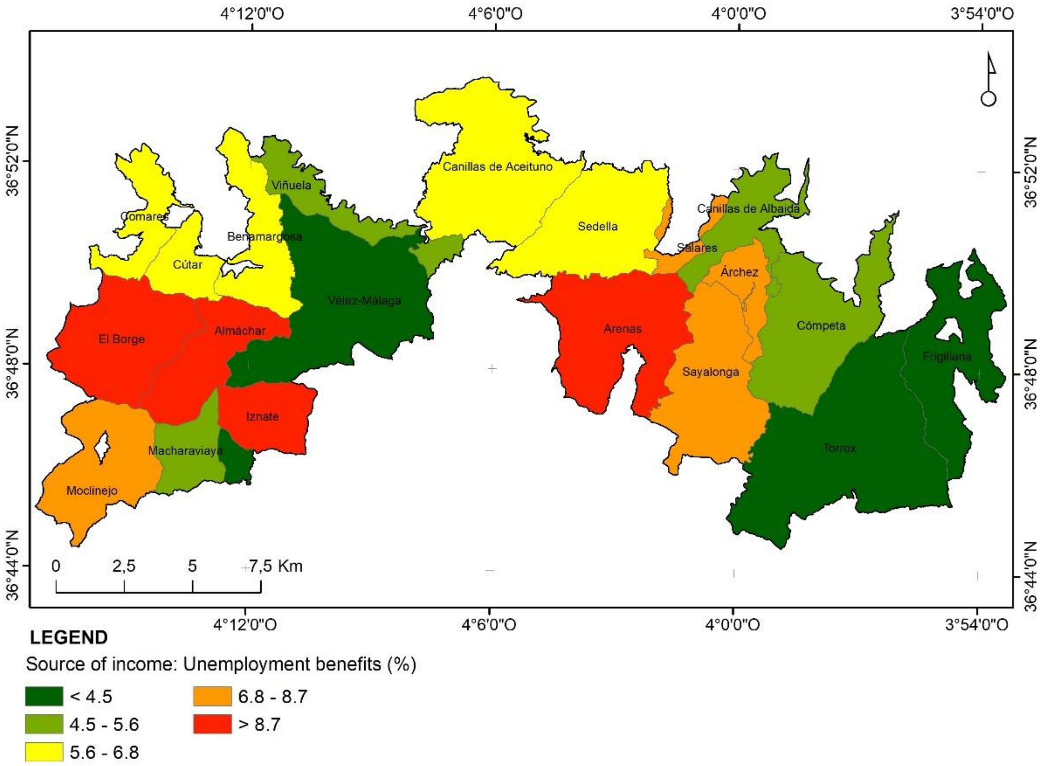
The population with pension as the main source of income registers the highest percentages in Sedella (41.8%), Árchez (37.7%) and Comares (36.6%) (Fig. 45), denoting the ageing of the population residing in these municipalities. In contrast, Vélez-Málaga (20.7%), Moclinejo (23.9%) and Torrox (24%) are the municipalities with the lowest incomes in the area in question. Thus, an inverse relationship can be observed between the results in figures 44 and 45, where the higher the percentage of the population with a salary, the lower the value of pensions and, therefore, the lower the vulnerability of the population.

Fig. 45. Population with "pension" as a source of income in the GIAHS municipalities in 2017



The population with unemployment benefits as a source of income (Fig. 46) ranges from 3.6% in the case of Vélez-Málaga, as a minimum value, to 11.2% in Almáchar, as a maximum. Likewise, Frigiliana (3.9%) and Torrox (4.5%) show low values, maintaining an inverse relationship with the high percentage of salaried workers in these municipalities. After Almáchar, El Borge (10.1%) and Iznate (9.8%) are the municipalities with the highest number of people receiving unemployment benefits.

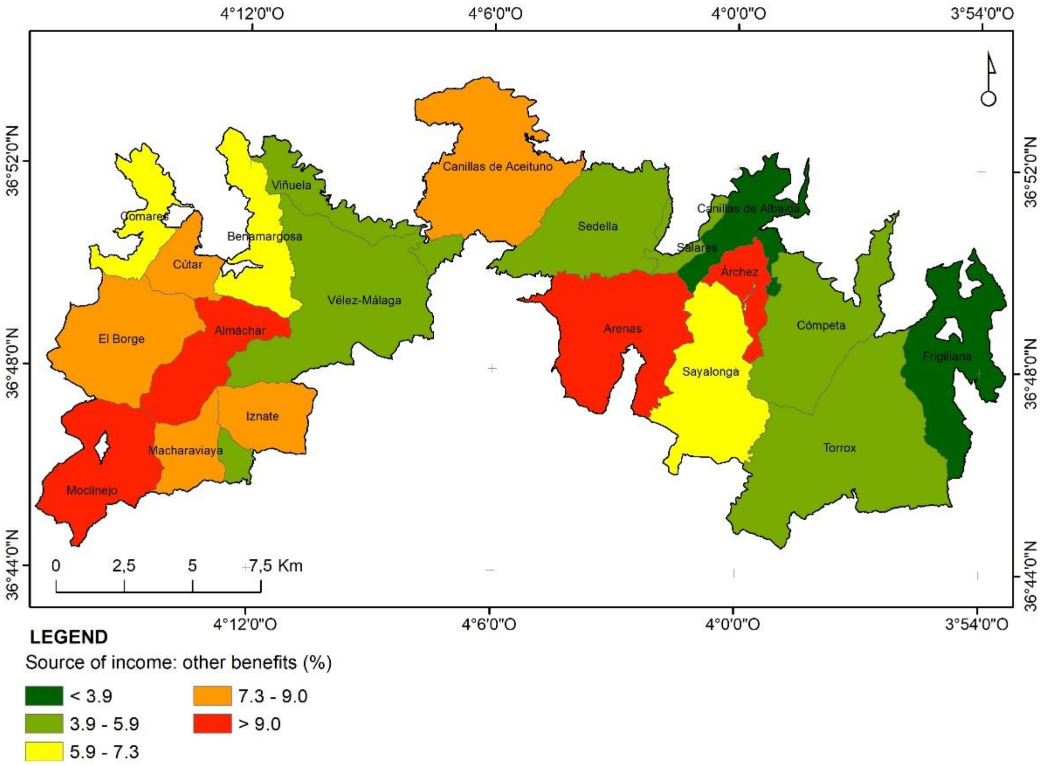
Fig. 46. Population with " unemployment benefits " as a source of income in the GIAHS municipalities in 2017



Taking into account other types of benefits such as family benefits, childbirth and child care benefits, compulsory old age and disability insurance (SOVI), self-employment benefits, retirement benefits, etc., Arenas (10.2%), Árchez (9.8%) and Moclinejo (9.5%) are the municipalities with the highest percentage of population dependent on this source of income (Fig. 47).

In contrast, Canillas de Albaida (3.9%), Frigiliana (3.9%) and Salares (4.9%) register the lowest values and, therefore, have a lower dependence on the income provided by the Social Security.

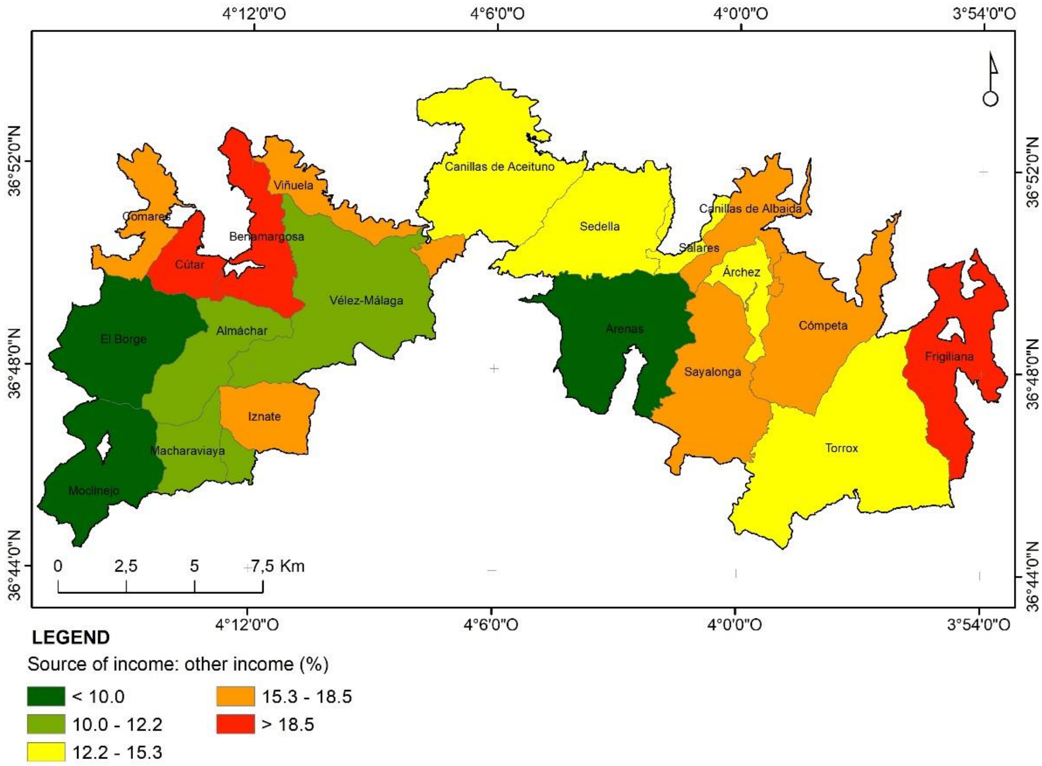
Fig. 47. Population with "other benefits" as a source of income in GIAHS municipalities in 2017



Finally, the remaining sources of income not included in any of the previous categories have been catalogued as "other income" and show how the western area and Arenas have the lowest values, maintaining an inverse relationship with the percentage of wage earners (Fig. 48). In contrast, Frigiliana (23.7%), Benamargosa (22.9%) and Cútar (20.5%) have a higher percentage of the population with this category as their main source of income.

In short, the GIAHS municipalities denote clear differences in terms of their source of income, distinguishing the more rejuvenated and dynamic municipalities, with a greater number of salaried workers (closer or better connected to the coast), from those with fewer inhabitants and more traditional and aged municipalities, where pensions, unemployment and other benefits serve as the main economic support for the majority of the municipal population.

Fig. 48. Population with "other income" as a source of income in GIAHS municipalities in 2017



These characteristics based on economic activity have an impact on the income of the local population, and therefore on their economic and social vulnerability. Figure 49 shows the average income per person in the municipalities of the area studied. Thus, considering the national and Andalusian income per person, which in recent years has been around €11,000 and €9,000 respectively, all the GIAHS municipalities register lower values. However, starting from the general situation of vulnerability identified in this area, Vélez-Málaga (8.725€), Macharaviaya (8.233€), Salares (8.032€) and Frigiliana (8.030€) show the highest values of average income per person. In the opposite case, Moclinejo (6,671€), Cómpeta (6,684€), Iznate (6,822€) and Viñuela (6,871€), register the lowest values, being practically half the national average and 30% lower than the Andalusian regional average.

Fig. 49. Average income per person in the GIAHS municipalities in 2017

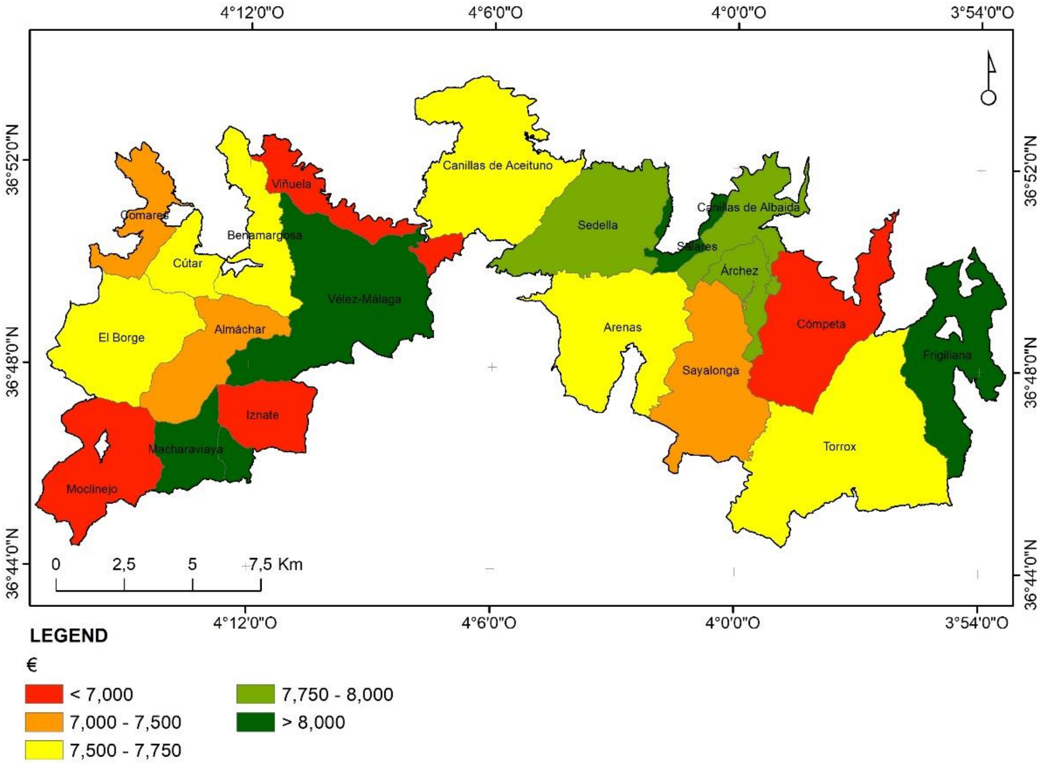
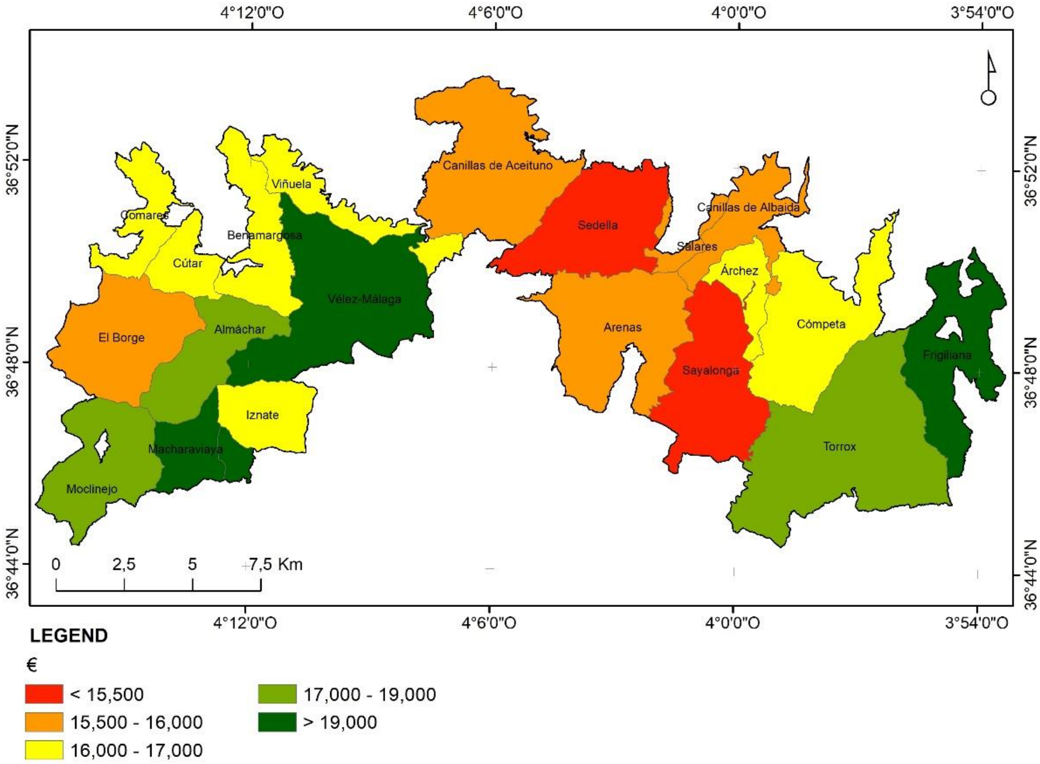


Figure 50 provides information about the average income, in this case, of the household. The general situation follows the same line as above: Spain in 2017 had an average income per household of €27,558 and Andalusia, €23,699. Thus, the GIAHS area does not reach an average value of €17,000, with the highest values in Vélez-Málaga (€23,083) and Macharaviaya (€21,277) and the lowest in Sedella (€14,773), Sayalonga (€15,426) and Canillas de Albaida (€15,501).

In this sense, municipalities such as Moclinejo or Almáchar, despite having a minimum average income per person, the average income per household is increased and the situation of vulnerability improves in comparison with the rest of the municipalities in the GIAHS area. The opposite occurs in Sedella and Canillas de Albaida, where vulnerability from this indicator would be higher than that mentioned in the previous figure.

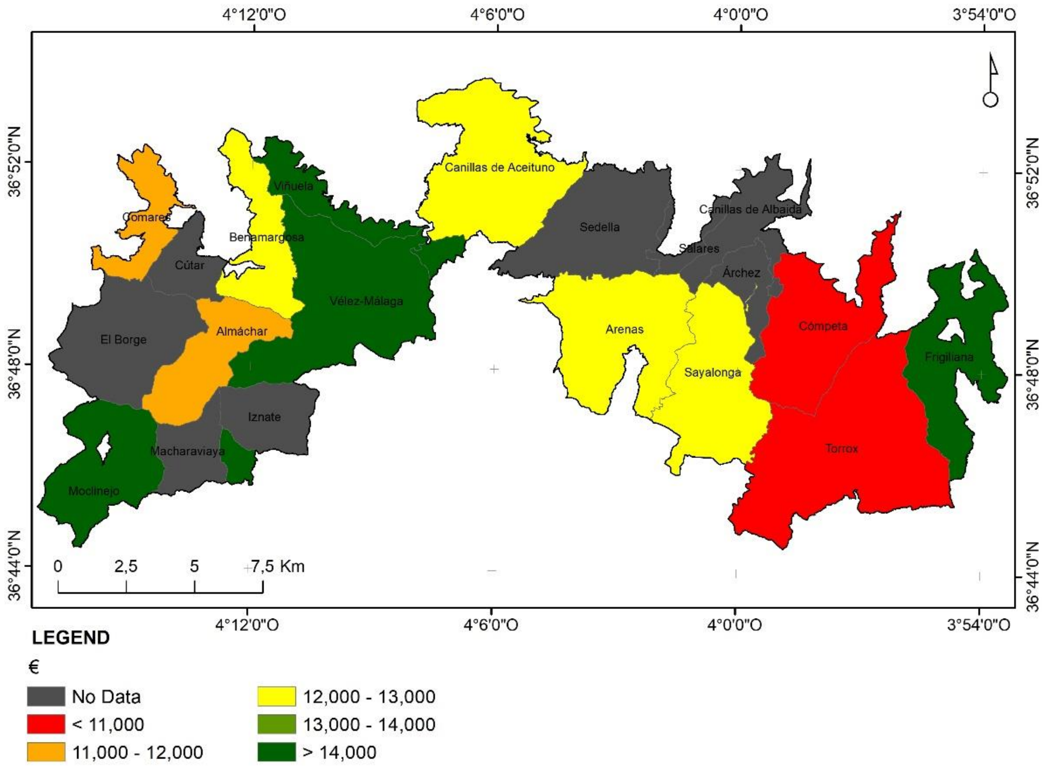
Fig. 50. Average household income in the GIAHS municipalities in 2017



In short, and as a general indicator, the average disposable income of the GIAHS municipalities indicates a situation of high economic and social vulnerability. Based on larger scale data, the European Union registers an average value of €30,000, Spain €25,000 and Andalusia more than €18,700. Consequently, the figures in Figure 51 follow the trend discussed above, categorising the GIAHS, in general, as being highly socio-economically vulnerable.

Municipalities such as Cómpeta and Torrox do not reach €11,000 and, at best, Viñuela, Frigiliana, Moclinejo and Vélez-Málaga exceed €14,000, reaching a maximum, in the latter town, of €17,703 in average available income.

Fig. 51. Average available income in the GIAHS municipalities in 2017

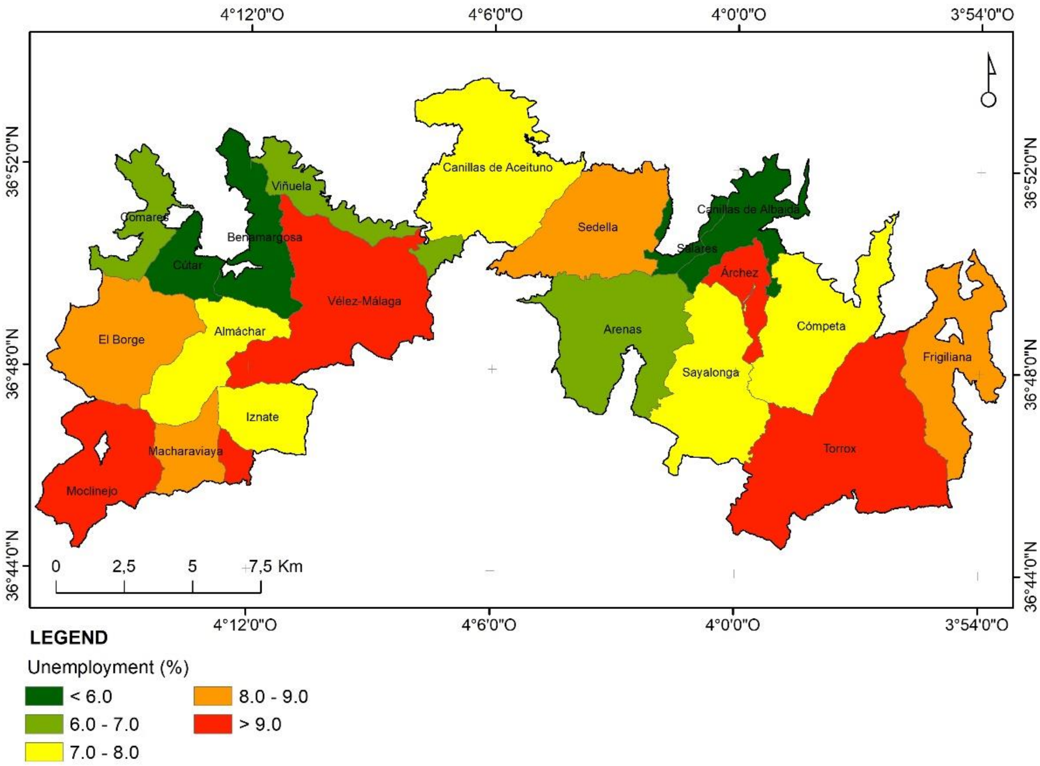


Finally, a fundamental indicator when analysing the socio-economic vulnerability of the GIAHS area is registered unemployment. The highest values appear in Vélez-Málaga (9.9%), Torrox (9.9%), Árchez (9.8%) and Moclinejo (9.2%) and the lowest in Cútar (5%), Salares (5.6%) and Canillas de Albaida (5.8%). Thus, this variable is totally related to the average age of the population, where municipalities with a higher number of inhabitants over 65 years of age register lower rates, as they are not in a job search situation and have finished their working period.

In short, all the social and economic variables analysed are fully connected, giving coherence to the current situation of the GIAHS territory.

The current state of the study area is one of high or very high socio-economic vulnerability, especially from a comparative perspective with the rest of Andalusia and Spain. Thus, there are strong contrasts within the area, with municipalities with greater dynamism showing greater resilience in the face of current social and economic development.

Fig. 52. Registered unemployment in the GIAHS municipalities in 2017



6.- FACTOR ANALYSIS OF VULNERABILITY INDICATORS

There are a series of general features inherent to the incidence of climate change indicators with a greater impact in the Mediterranean, such as exposure to climatic, thermal, pluviometric and hydric risks.In these, the sensitivity of the GIAHS area is greater in relation to thermal anomalies, successive heat waves, increased torrential rainfall and, consequently, the succession of periods with lower net precipitation, which means less water availability for the soil.

However, given the specific characteristics of the Axarquia GIAHS, a series of specific effects can be determined. Some are of an agricultural nature, due to competition from other more profitable crops, which compete for the same territory. From an environmental point of view, the greatest impact is the increase in risks related to torrential rainfall, manifested in the processes of erosion and soil degradation, and also in the modification of the rainfall pattern, which has resulted in an increase in the number of days of what we can call the phenological summer, and of course, with all its consequences in terms of dependence on water resources. Fortunately, vineyards are a rainfed crop. In terms of productivity, vineyards can withstand the main consequences inherent to climate change, in the same way that, as a centuries-old crop, they have adapted phenologically to different situations. This is not applicable to other crops, not even to other economies based on tourist activities, for example. Precisely for this reason, the GIAHS territory is demographically characterised by high rates of economic dependence on the population and ageing.

Therefore, in order to find out which factors mainly affect the current dynamics of the GIAHS area in a context of Global Change, a Principal Component Analysis (PCA) has been carried out. Numerous data on different variables of a physical, social and economic nature have been used for this purpose. This analysis was carried out with SPSS version 25 (corporate licence of the University of Malaga) for Windows (IBM Corporation 2017).

The variables considered for this factorial analysis were, in the case of the physical parameters: slope, hectares of vineyard, soil organic matter, soil structural stability, soil permeability, sand, silt and clay content, rainfall erosivity, Normalised Difference Vegetation Index (NDVI) and annual soil loss (RUSLE). On the other hand, for the socio-economic variables: average age of the population, average household size, population, source of income: salary, source of income: pensions, average income per person, registered unemployment, number of raisins.

In addition, factor analysis was performed using the covariance (raw data) and correlation matrix (standardised data). Using the correlation matrix, factors with eigenvalues >1 were retained and subjected to a varimax rotation to maximise correlations between factors (Shukla et al. 2006). Finally, Bartlett t and KMO (Kaiser-Meyer-Olkin) tests were applied.

In this sense, in the case of the physical parameters, the results show a high consistency, as corroborated by the principal components analysis (KMO test = 0.500; Bartlett's sphericity = 0.000) (Table 9).

Table 9. Bartlett and the KMO (Kaiser-Meyer-Olkin) tests of physical parameters from GIAHS area

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		**0.500**
Bartlett's test of Sphericity	Aprox. Chi-square	114.881
	df	45
	Sig.	0.000

Thus, table 10 shows the correlation between each of the selected parameters and, in table 10, the percentage of variance shown by the main groups of variables (components).

Table 10. Correlation matrix of physical parameters from GIAHS área

Abbreviations: OM, organic matter (%); AS, estructural stability (%); Ksat, permeability; RE, rainfall erosivity; C, correlation; S, significance.

		Slope	Ha vineyards	OM	AS	Ksat	Sands	Silts and clays	RE	NDVI	RUSLE
C	**Slope**	1.000	0.036	-0.229	0.114	0.004	-0.119	0.155	-0.105	0.073	0.184
	Ha vineyards	0.036	1.000	-0.276	-0.277	-0.072	0.140	-0.301	-0.366	-0.074	0.214
	OM	-0.229	-0.276	1.000	0.540	0.576	-0.220	0.223	0.385	-0.679	0.399
	AS	0.114	-0.277	0.540	1.000	0.342	-0.168	0.339	0.449	-0.480	0.115
	Ksat	0.004	-0.072	0.576	0.342	1.000	-0.042	0.069	0.266	-0.580	0.082
	Sands	-0.119	0.140	-0.220	-0.168	-0.042	1.000	-0.931	-0.700	0.061	0.061
	Silts and clays	0.155	-0.301	0.223	0.339	0.069	-0.931	1.000	0.809	-0.082	-0.171
	RE	-0.105	-0.366	0.385	0.449	0.266	-0.700	0.809	1.000	-0.239	-0.190
	NDVI	0.073	-0.074	-0.679	-0.480	-0.580	0.061	-0.082	-0.239	1.000	-0.612
	RUSLE	0.184	0.214	0.399	0.115	0.082	0.061	-0.171	-0.190	-0.612	1.000
S	**Slope**		0.440	0.165	0.316	0.493	0.308	0.257	0.330	0.380	0.219
	Ha vineyards	0.440		0.119	0.118	0.381	0.279	0.099	0.056	0.378	0.182
	OM	0.165	0.119		0.007	0.004	0.176	0.173	0.047	0.001	0.041
	AS	0.316	0.118	0.007		0.070	0.240	0.072	0.024	0.016	0.315
	Ksat	0.493	0.381	0.004	0.070		0.430	0.386	0.128	0.004	0.365
	Sands	0.308	0.279	0.176	0.240	0.430		0.000	0.000	0.399	0.400
	Silts and clays	0.257	0.099	0.173	0.072	0.386	0.000		0.000	0.365	0.236
	RE	0.330	0.056	0.047	0.024	0.128	0.000	0.000		0.155	0.212
	NDVI	0.380	0.378	0.001	0.016	0.004	0.399	0.365	0.155		0.002
	RUSLE	0.219	0.182	0.041	0.315	0.365	0.400	0.236	0.212	0.002	

The PCA results identify that three groups of components explain 71.6% of the total variance of the data (Table 11). Thus, C1 explains 35.1% of the variance and is directly related to the role of the organic components of the eco-geomorphological system. The relationships recorded group together those points with a lower annual NDVI value, a higher organic matter content, greater soil permeability and greater stability of the aggregates that make up the soil (Table 12).

On the other hand, C2 (23.5% of the variance) is related to a greater extent with soil erodibility and erosivity. This group of components, the texture with a higher silt and clay content, has a greater consistency and, therefore, greater structural stability. Thus, despite being, a priori, more stable areas, it shows the highest values of rain erosivity, which would inform us of a simple potential stability of the soil (Table 12).

In the case of C3 (13% of the variance), the result provides fundamental information, as those areas with the steepest slopes in the GIAHS territory are those with the greatest annual soil loss and the largest vineyard surface area. In short, the areas with the greatest vulnerability to soil erosion are mainly those covered by vineyards (Table 12).

Table 11. Principal component analysis of physical parameters from GIAHS area

	Initial eigenvalues			**Sum of the saturations to the square of the extraction**			**Sum of the saturations to the square of the rotation**		
	Total	%Var	%Acc	Total	%Var	%Acc	Total	%Var	%Acc
1	3.510	35.103	35.103	3.510	35.103	35.103	2.901	29.012	29.012
2	2.346	23.458	58.561	2.346	23.458	58.561	2.853	28.529	57.540
3	1.305	13.047	71.608	1.305	13.047	71.608	1.407	14.068	71.608
4	0.982	9.822	81.430						
5	0.766	7.656	89.086						
6	0.558	5.585	94.671						
7	0.263	2.631	97.302						
8	0.151	1.507	98.809						
9	0.093	0.931	99.740						
10	0.026	0.260	100.000						

Table 12. Component matrix obtained in the PCA analysis of physical parameters from GIAHS area

Abbreviations: OM, organic matter (%); AS, estructural stability (%); Ksat, permeability; RE, rainfall erosivity.

	Components		
	1	**2**	**3**
NDVI	-0.906		
% OM	0.879		
Ksat (cm/h)	0.712		
AS	0.617	0.355	
Silts and clays		0.979	
Sands		-0.915	
RE		0.822	
Slope (%)			0.708
RUSLE (t/ha/yr)			0.636
Vineyards (ha)		-0.344	0.556

The socio-economic parameters also show high consistency (KMO test = 0.711; Bartlett's sphericity = 0.000) (Table 13). Table 13 shows the total correlations between each of the selected parameters and their significance.

Table 13. Bartlett and the KMO (Kaiser-Meyer-Olkin) tests of socio-economic parameters from GIAHS area

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		**0.711**
Bartlett's test of Sphericity	Aprox. Chi-square	73.918
	df	28
	Sig.	0.000

Table 14. Correlation matrix of socio-economic parameters from GIAHS area

Abbreviations: X, average; SI, source of income; C, correlation; S, significance.

		X age	X household size	Inhabitants	SI salary	SI pension	X income	Unemployment	Raisins
C	X age	1,000	-0,697	-0,357	-0,692	0,794	-0,096	-0,598	-0,232
	X household size	-0,697	1,000	0,449	0,667	-0,685	-0,008	0,487	-0,034
	Inhabitants	-0,357	0,449	1,000	0,649	-0,476	0,246	0,445	0,142
	SI salary	-0,692	0,667	0,649	1,000	-0,767	0,338	0,552	-0,034
	SI pension	0,794	-0,685	-0,476	-0,767	1,000	-0,114	-0,338	-0,039
	X income	-0,096	-0,008	0,246	0,338	-0,114	1,000	0,155	-0,086
	Unemployment	-0,598	0,487	0,445	0,552	-0,338	0,155	1,000	0,189
	Raisins	-0,232	-0,034	0,142	-0,034	-0,039	-0,086	0,189	1,000
S	X age		0,000	0,061	0,000	0,000	0,343	0,003	0,162
	X household size	0,000		0,024	0,001	0,000	0,487	0,015	0,443
	Inhabitants	0,061	0,024		0,001	0,017	0,148	0,025	0,275
	SI salary	0,000	0,001	0,001		0,000	0,072	0,006	0,443
	SI pension	0,000	0,000	0,017	0,000		0,316	0,072	0,435
	X income	0,343	0,487	0,148	0,072	0,316		0,258	0,359
	Unemployment	0,003	0,015	0,025	0,006	0,072	0,258		0,213
	Raisins	0,162	0,443	0,275	0,443	0,435	0,359	0,213	

The PCA analysis reports that only three components explain 77.6% of the total variance (Table 15). Thus, C1 (49.8% of the variance) is mainly related to the main social and economic characteristics of the GIAHS municipalities. Thus, those municipalities with a larger number of inhabitants have a higher average household size and a less aged population. In addition, these territories have fewer pensioners and a higher number of wage earners, which translates into a higher percentage of working-age population and, therefore, a higher unemployment rate (Table 16).

C2 (14.8% of the variance) focuses more directly on the economic variable, where more populated municipalities identify a higher percentage of wage earners and better income conditions (Table 16).

Finally, C3 (13% of the variance) relates exclusively to two variables, but offers a disturbing fact. Those municipalities with the highest unemployment rates are also those with the highest number of raisins. In other words, the municipalities most closely linked to the grape-growing tradition are currently among the most vulnerable to the current economic dynamics.

Table 15. Principal component analysis of socio-economic parameters from GIAHS area

	Initial eigenvalues			Sum of the saturations to the square of the extraction			Sum of the saturations to the square of the rotation		
	Total	%Var	%Acc	Total	%Var	%Acc	Total	%Var	%Acc
1	3.984	49.805	49.805	3.984	49.805	49.805	3.670	45.875	45.875
2	1.181	14.760	64.566	1.181	14.760	64.566	1.356	16.950	62.825
3	1.041	13.007	77.573	1.041	13.007	77.573	1.180	14.748	77.573
4	0.635	7.932	85.505						
5	0.619	7.741	93.246						
6	0.285	3.563	96.809						
7	0.156	1.952	98.761						
8	0.099	1.239	100.000						

Table 16. Component matrix obtained in the PCA analysis of socio-economic parameters from GIAHS area

Abbreviations: X, average; SI, source of income.

	Components		
	1	2	3
X household size	0.889		
SI pension	-0.885		
X age	-0.872		
SI salary	0.836	0.416	
Unemployment	0.589		0.388
Inhabitants	0.541	0.497	
X income		0.923	
Raisins			0.955

7.- ADAPTIVE CAPACITY

The capacity of a territory to survive, reinvent itself and develop in the face of these vulnerabilities can be defined as resilience. This aspect involves each of the parts that make up the territory, with public management and territorial planning being a key tool for providing the GIAHS area with this quality.

In the face of the identified vulnerability of the GIAHS area, there is a very diverse adaptive capacity in different aspects, such as landscape, agricultural, demographic, sociological or cultural, and that, we understand, is the real strength of the GIAHS.

1.- Agriculture. This refers to the vineyard and its great capacity to adapt to extreme conditions in terms of both temperature and rainfall. It is a crop with more than 5 centuries of tradition that has survived very different climatic conditions. Thus, with regard to the risks derived from water deficit, as it is a rainfed crop, its capacity to adapt is at its maximum.

Moreover, vine cultivation helps to limit erosion and also to protect against fires, as it is located in areas which, if this activity were not carried out, would correspond to abandoned territories.

In short, from an agricultural point of view, although the current climate context could have specific repercussions on vine cultivation, whether related to its phenological period, the appearance of pests or diseases or the loss of quality of the final product, the adaptive and resilient capacity of the vine makes this crop one of the most resistant to the alterations caused by Global Change.

In view of the increasing emergence of subtropical crops, the main challenge for these crops is linked to the availability of water, and they are therefore in a situation of maximum fragility in the face of climate change and could compromise the security of the system. Thus, this situation could be of great benefit to vines, which, with their greater capacity for adaptation, give them great strength and resilience in these conditions.

Photo 2. Combination of different land uses

2.- Landscape. Runoff processes have historically been controlled through the "agüaeras", forming a highly integrated and recognised landscape element among the local population of the GIAHS area. In the same way, the high vulnerability identified in relation to soil erosion presents the opportunity to be reduced with the construction of walls and staggered planting.

Photo 3. Measures against soil erosion

3.- Demographics. There is a large adult and retired population, which guarantees the transmission of the best and most traditional cultivation techniques. However, the real problem lies in generational replacement, which is very low and hinders the continuation of the activity.

In short, the demographic characteristics of the GIAHS area are totally comparable to those of any rural area in Andalusia, with the main problem being depopulation and ageing. Thus, policies focused on this great demographic challenge should be the main support to reduce the rate of depopulation and obtain a diversification of services that favour the stabilisation of the rural exodus.

4.- Economics. The main resources (source of income) of the GIAHS area come from unemployment and retirement benefits, which guarantees the stability of the economy. In this sense, the population with wages as the main source of income comes fundamentally from (i) tourism and services derived from the coastal municipalities (sun and beach) and (ii) economic activity linked to the production of avocado, mango and other tropical crops.

In short, this information demonstrates the complexity of subsisting through the vineyard itself, which is currently more of a historical, cultural and family activity than a truly economic one.

5.- Cultural. The strong cultural influence of wine-growing activity in the territory can be considered a key pillar in the resilience of the GIAHS area. Thus, the municipalities organise numerous cultural events linked both to the grape harvesting process and to the consumption of the final products.

The "Fiesta de la Uva Moscatel" on the first Saturday of August in Iznate, the "Noche del Vino" on the 15th of August in Cómpeta, the "Fiesta de Viñeros" on the second Sunday of September in Cómpeta, the "Fiesta de la Pasa" on the third Saturday of September in La Viñuela, the "Fiesta de la Pasa" on the third Sunday of September in El Borge or the "Fiesta del Mosto y la Chacina" on the first Sunday of December in Colmenar, are some of the leisure activities linked to the history, tradition and culture of the GIAHS population.

In addition to these festivals, entrepreneurship is playing a fundamental role in consolidating the strong roots of the raisin tradition in this area of Malaga. In this way, the creation of tourist routes such as the "Ruta de la Pasa" with activities such as watching a sunset among the vineyards, visiting a wine press, learning about the workings of a cooperative or drinking a glass of Muscatel wine in a rural village in the area are helping to truly strengthen the tradition and activity linked to the vine.

Photo 4. Popular festivals

Source: Diputación de Málaga

6.- Sociological. The setting up of new associations or the creation of museums with tools and instruments related to grape harvesting can lead to a greater reach of this territorial distinctive feature and, directly, of its products, increasing its offer if the appropriate means are used, such as signposting the GIAHS area on roads, promotion at congresses, fairs, exhibitions and conferences or the advertising and marketing of a GIAHS label through webs or virtual platforms, etc.

In short, the aim would be to translate the strong roots of the population-territory into a local quality label that is capable of extending and generating a market space around it.

8.- CONCLUSION AND GENERAL CONSIDERATIONS

The information gathered for the GIAHS area in this report can be grouped into a number of highlights that could be considered as general conclusions of the report. These are listed below:

- In terms of vulnerability to climate change, the vineyard can be considered a crop that is totally resistant to the changes identified, having survived extreme conditions and having managed to adapt to them. Over the last few centuries, vineyards have adapted to extreme climatic conditions, both in terms of temperature and rainfall, which has had repercussions on their phenology, by means of adaptation mechanisms.
- Therefore, the main threats identify comes from the current demographic and socio-economic dynamics The vineyard as an economic activity has become residual, so much so that the population cannot make a living from it. If current socio-economic and demographic trends continue, with little replacement capacity, there is a significant risk that an entire centuries-old culture dedicated to a way of life and to the maintenance of a landscape by virtue of an economic activity will be lost.
- Vineyards competition with subtropical crops is very unequal. Subtropical crops have a very favourable situation in a large part of Europe, and they are the ones currently maintaining the agricultural economy in La Axarquía. However, their water dependence is very high.This subtropical crops are the ones most vulnerable to climate change, specially in the current situation of climate change in which we are witnessing a progressive reduction of current water resources.
- It is essential for both the local population and the surrounding area to value the GIAHS, its true anthropological heritage maintained over centuries and embodied in a unique landscape. Nevertheless it is not possible to maintain the landscape without maintaining the activity of the population in it.
- It is essential to involve the administration in this strategy of promotion and development, also valuing, for its part, GIAHS recognition. Strategies must be activated to make it visible, and to give it its own dynamic that differentiates it from other agricultural areas.

- Finally, there must be a proactive role and monitoring by the FAO, which goes beyond the designation, monitoring the maintenance of the qualities and features that made it worthy of it.

Historically, the relationship between the population and the territory in this area has given rise to a very consistent connection, which has given the area its own unique identity that has been well recognised with the designation of a GIAHS area.

As general reflections and using a methodology based on the SWOT matrix, the GIAHS area presents evident strengths and opportunities as well as some threats and weaknesses that should be evaluated for mitigation, as far as possible.

The main strengths that make this area strong are related to the existence of vineyards for centuries and in very different environmental and social conditions. Moreover, this fact has given rise to a strong attachment of the population to this activity and to the whole raisin-related culture. The local population has structured its entire way of life around the harvesting of grapes and the production of raisins, and its customs and festivals are a faithful reflection of local history.

In this sense, despite the existence of various threats that could destabilise the area, cultural transmission continues to this day between generations and family groups, who incorporate new techniques innovating and improving strategies in their own work to make it more profitable, but always maintaining very old and traditional but still useful tools and working methods.

The main opportunities begin with the designation of the territory in question as a GIAHS site. Thus, advertising the area as a quality brand through this designation could become a fundamental resource for the social and economic development of the region.

The young development of the different tourist and gastronomic activities on offer, both from the public administrations and the private sector, would be along the same lines. Furthermore, a good indicator of this evolution would be the creation of associations around the raisin, a fact that unites the population with a common feeling and a shared tradition to work for their history and their territory. Thus, it is a key figure for implementing governance and public management mechanisms from local and regional administrations, promoting involvement, cooperation and work towards common and well-defined objectives, such as, for example, the placement of information signs and signposting of the GIAHS area.

On the other hand, the weaknesses are linked to the low production and profitability of vineyards, which in very few cases can sustain a household's economy. For this reason, the local population tends to leave this activity as a secondary or family activity, focusing its main economy on other more profitable and booming sectors.

Evidently, as has been observed in the socio-economic variables, this causes strong contrasts between the GIAHS population and between very close municipalities, leading to a population at risk of poverty, depopulation, high unemployment rates, etc.

Finally, great attention must be given to the main threats facing the area. From a more environmental perspective, the boom in avocado and mango plantations (subtropical crops), which are now much more profitable, could lead to the abandonment of vineyards.could lead to the abandonment of vineyards. However, the water situation in the area makes these new land uses extremely vulnerable.

The ageing of the population, the precarious economic situation and the continuous expansion of economic activity on the Mediterranean coast could lead to a continuous abandonment of the countryside and, therefore, to processes of rural exodus and depopulation of the interior. These would be the main threats from a socio-economic point of view and, at first, the ones that should be given greater attention at the present situation.

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