Zoning of the Querétaro wine region

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Abstract. Understanding the unique characteristics of wine regions, especially those that are developing or expanding like Querétaro, requires a key element known as terroir. In this regard, we have conducted a survey of 69 vineyards in the state, covering a total area of 525 hectares. Additionally, we have studied the composition and texture of the soils, analysed rainfall patterns over a span of 23 years, examined the topography and watershed basins, and compared common climate indices with those of other regions in Europe and the USA, such as Winkler, Huglin, Grown Season Temperature, and Cold Indices. As a next step, we are calculating various vegetation indices, such NDVI, for multiple vineyards throughout the year 2022 to assess the adaptability and development of different grape varieties, and determine which ones thrive best in the soil and climate conditions of the region.

1 Introduction

The objective of this project is to gain a comprehensive understanding of the region, with the aim of classifying and characterizing the wines produced in the area, improving their quality, and expanding vineyards based on scientific studies of soil quality, rainfall, temperature patterns, and suitable grape varieties, among other factors. The findings of this scientific study will be used as a decision-making tool by potential investors interested in implementing viticulture projects in the region. Additionally, it will serve as a marketing and development asset, showcasing the Querétaro Wine Region as a destination focused on ecotourism, enogastronomy and hospitality.

Based on these criteria, our Zoning Project is structured around six pillars:

1. Geographical location
2. Vineyard census and identification
3. Climate (macro and micro)
4. Soil (different types)
5. Wine characterization
6. Communication strategies

Through a thorough analysis of these pillars, we aim to create a comprehensive document that will provide valuable insights for decision-makers and stakeholders interested in the development and promotion of the Querétaro Wine Region. In the following four sections, we show our findings on the characterization of the geographical location, census and identification, climate and soil, for the vineyards in the Querétaro region, based on experimental data provided by the vineyard's archives, publicly available information and satellite data.

2 Geographical location

Querétaro is located between the 20° and 21° parallels of north latitude, outside of what is known as the "wine belt", with a semi-arid climate.

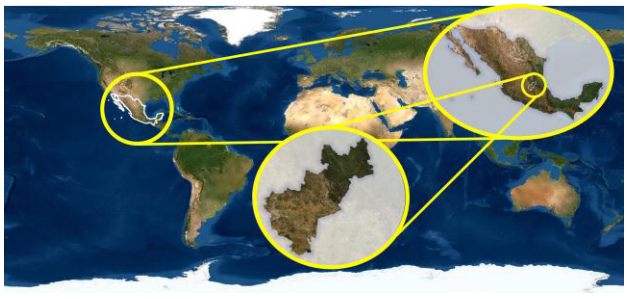

Figure 1. Querétaro in the world. Images taken from ESRI for QGIS and elaborated by the authors.

However, its altitude, which is close to 2000 meters above sea level, compensates for its proximity to the Equator, providing a (usually mild) winter that allows for the seasonal rest of the vine.

Using data from the Shuttle Radar Topography Mission (SRTM) [1] we have calculated the average elevation and slope of each vineyard (Fig. 2).

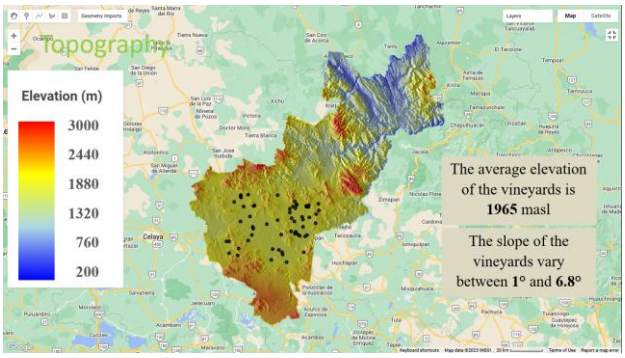

Figure 2. Elevation of Querétaro State.

3 Vineyard census and identification

So far, we have identified 69 vineyards, 32 of which belong to the CVQ (Cluster Vitivínicola de Querétaro), they are displayed in Fig. 3. The cultivated area of vineyards is 525 Ha.

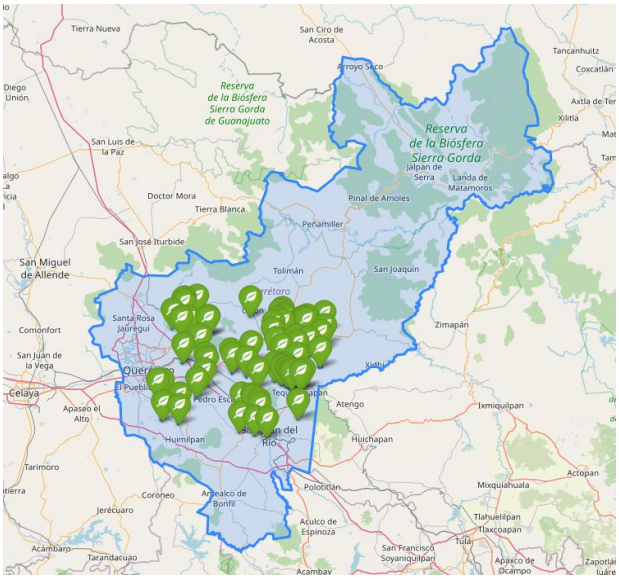

Figure 3. Location of the vineyards.

The vineyards are located in 8 municipalities, where the majority of cultivable land is found. The distribution of vineyards by municipality is as follows: Tequisquiapan, 17; El Marqués, 13; Ezequiel Montes, 12; San Juán del Río, 9; Colón, 9; Huimilpan, 6; Cadareyta de Montes, 2; and Pedro Escobedo, 1.

96% of vineyards are in two watershed basins, Moctezuma river basin and Laja river basin, as shown in Fig. 4.

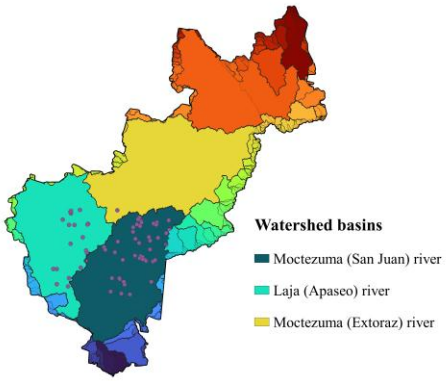

Figure 4. Watershed basins calculated from SRTM data.

4 Climate

According to the Köppen-Geiger classification [2], there are 5 different macroclimates in Querétaro: tropical, savannah (Aw), temperate, dry winter, hot summer (Cwa), temperate, dry winter, warm summer (Cwb), arid, steppe hot (Bsh), and arid, steppe cold (Bsk). All the vineyards in Querétaro are located in the last three, most of them in Bsk (see Fig. 5), similar to Rueda (Spain), or the wine regions in southern Texas and California (USA).

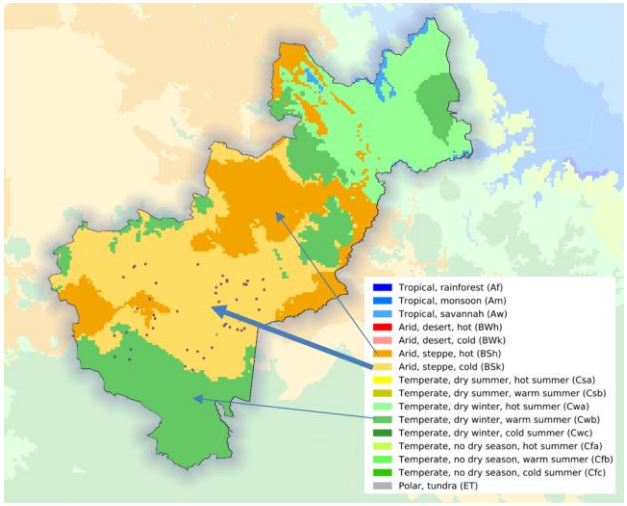

Figure 5. Köppen-Geiger classification for Querétaro.

The thermal indices utilized in this study are widely used in viticulture, providing complementary information, and allow us to compare our results with those from different parts of the world. Altogether, classifying vineyards with thermal indices can provide valuable insights for vineyard management and grape production.

Thermal indices are used in vineyards to assess the suitability of climate conditions for grapevine growth and development. Several thermal indices have been developed specifically for viticulture, including the Winkler (WI), Huglin (HI), Growing Season Temperature (GST), and Cold Index (CI). The indices were calculated yearly, for the specific period, and then averaged from

2000 to 2022. For Winkler and GST indices, we obtain the data from [3]. For Huglin and Cold Night indices, we obtain the data from [4].

5.1 Winkler index

The Winkler Index (WI) was proposed by Amerine and Winkler [5] and later modified by Winkler et al [6] to climatically classify the wine growing regions based on heat summation or growing degree-days.

This index, also referred to as the Winkler Scale or Winkler Regions, is a method of categorizing wine-growing regions based on the accumulation of heat. The technique divides geographical areas into five climate regions, labelled as Regions I to V, based on the temperature that is converted to growing degree-days. This index determines the suitability of crop growth in different climates.

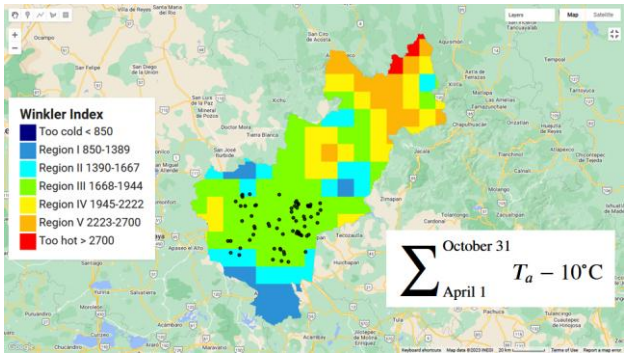

Figure 6. Winkler index from 2000 to 2022 with the vineyards.

In Fig. 6 we can see that most of the vineyards in Querétaro are in zone III, similar to parts of Languedoc (France), Tuscany (Italy) or Rioja (Spain).

5.2 Growing Season Temperature

The Growing Season Temperature (GST) index is a tool used in viticulture to help predict grapevine growth and development during the growing season. It is calculated by adding up the average daily temperatures during the growing season, which is typically defined as the period between budbreak and harvest.

The GST index is useful because grapevines have specific temperature requirements for optimal growth and development. If the temperature is too low, the grapevines may not grow and ripen properly, while high temperatures can lead to excessive vine growth and poor fruit quality.

By calculating the GST index, viticulturists can get a better understanding of the temperature conditions during the growing season and make informed decisions about vineyard management practices, such as pruning, irrigation, and canopy management, to optimize grapevine growth and fruit quality.

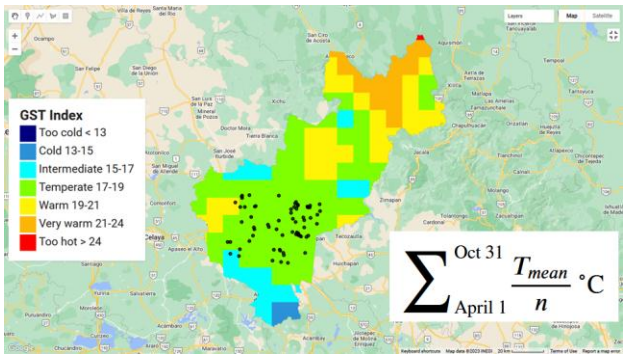

Figure 7. GST index from 2000 to 2022 with the vineyards.

Figure 7 shows that most of the vineyards are in the temperate zone (17-19 °C), only two are in the intermediate zone (15-17 °C) and one is in the warm zone (19-21 °C). Other temperate areas in the world are Gironde (France), Peloponnese, (Greece) or parts of Ribera del Duero (Spain).

5.3 Huglin index

The Huglin Heat Sum Index (HI) is a bioclimatic heat index developed by Pierre Huglin [7] for vineyards. It calculates the temperature sum over a threshold of 10 °C, by summing the average daily and maximum temperatures for all days from the beginning of April to the end of September. The calculated total is slightly modified based on the latitude of the area. The HI is used to determine the suitability of an area for cultivating different grape varieties over the long term, as each variety requires a specific amount of heat for successful cultivation.

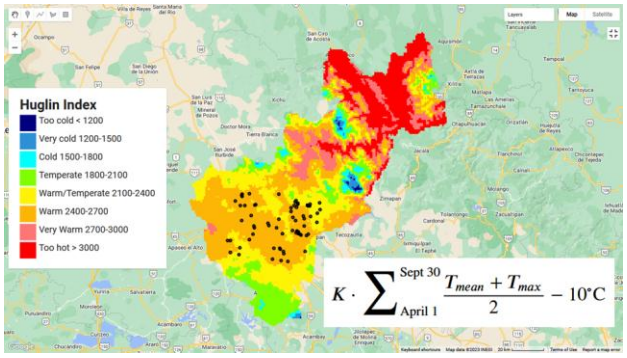

Figure 8. Huglin index from 2000 to 2021 with the vineyards.

Figure 8 shows that vineyards in Querétaro are in the warm-temperate and warm zones, this is similar to the contiguous area of Napa and Sonoma counties in the USA.

5.4 Cold night index

The Cool Night Index (CI) is a viticultural climate index developed by Tonietto [8] and Tonietto & Carbonneau [9] to estimate the nictothermal condition during the grape maturation period. The index utilizes minimum

temperatures as an indicator of the region's potential characteristics related to secondary metabolites such as polyphenols, aromas, and colour in grapes and wines. The primary aim of the CI is to enhance the evaluation of the grape's qualitative potentials, particularly in terms of secondary metabolites (polyphenols, aromas) in grapes.

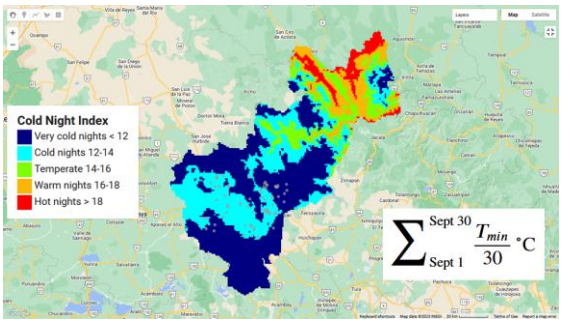

Figure 9. Cold index from 2000 to 2021 with the vineyards.

As mentioned in Sect. 3, the elevated location of the vineyard region above sea level results in cool temperatures that promote vine dormancy (Fig. 9). The vineyards of Querétaro are in the zone of cold or very cold nights, similar to the vineyards of Napa and Sonoma in the USA. The vineyards with very cold nights have a CI (cooling index) of ≳10 °C, and their temperature rarely drops to 0 °C.

6 Soil

We obtained data on the dominant (primary), secondary, and tertiary soil classes, as well as soil group classifiers, from the INEGI website [10]. We have used their same colour scale in our maps.

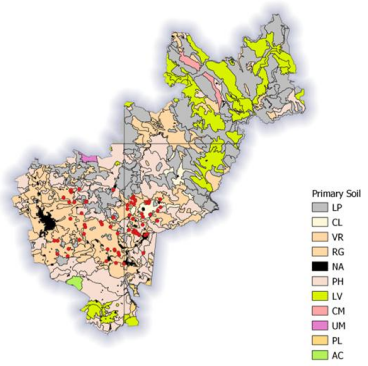

Figure 10. Primary soil for Querétaro and location of the vineyards.

Most of the vineyards (72.5%) have vertisol (VR) as their primary soil class (covering over 60% of the area). Vertisols are highly clayey soils, which mix with a high proportion of expandable clays. These soils form wide and deep cracks from the surface down when they dry out, which happens in most years. Large areas of vertisols in semi-arid tropics are still unused or only used for extensive grazing, woodcutting, charcoal burning, and similar activities. These soils have considerable agricultural potential, but proper management is a precondition for sustained production. The comparatively good chemical fertility and occurrence on extensive flat plains where recovery and mechanical tillage can be considered are advantages of vertisols.

The second largest group (15.9%) has phaeozem (PH) as their primary soil class. Phaeozems are dark soils rich in organic matter, porous, and fertile, which are mainly used worldwide for growing grains (wheat, barley, maize, soybeans...) and vegetables.

In a much smaller proportion, other vineyards have leptosol (LP), (very shallow soils over continuous rock and extremely gravelly and/or stony soils) and calcisol (CL), (soils in which there is a substantial secondary accumulation of lime) as their primary soil class (see Fig. 10).

For a first approximation of soil texture in vineyards we have used SoilGrids™ data from ISRIC [11]. Our findings indicate that 79.7% of the vineyards have a clay-loam soil texture, while 17.7% have sandy-clay-loam and 2.9% have a clay texture (see Fig. 11).

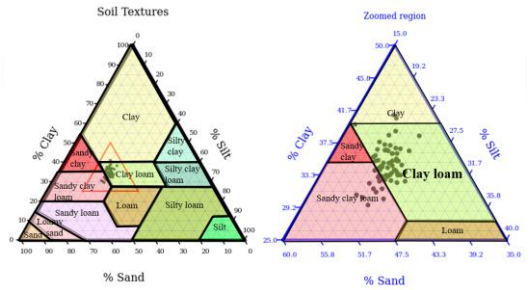

Figure 11. Position of vineyards in the Texture Triangle.

Although regions such as Jerez, Priorat, or Rioja (Spain) share also clay-loam soil textures, they differ in the proportion of silt and sand. Specifically, these regions have a higher percentage of silt and lower percentage of sand in their soils than the vineyards in Querétaro.

7 Rainfall

The annual precipitation in the vineyard area is highly irregular, as shown in Fig. 14 which displays the average annual rainfall of the last 23 years in this region. We can observe that the values are very similar among all the vineyards (Fig. 12). The rainfall data was taken from [12].

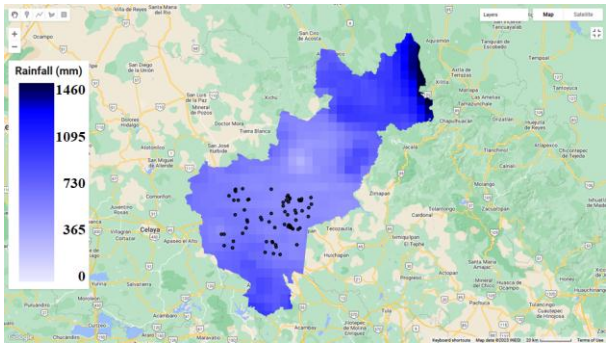

Figure 12. Average rainfall by year from 2000 to 2022.

The rainy season occurs from May-June to September-October, with the driest months being from November to February.

The average rainfall from the period of 2000-2022 over the vineyards region was 548 mm, but there are much drier years (2005, 2011, and 2022) with values below 370 mm, and more rainy years, such as 2021, which was the rainiest of the entire period with 834 mm (see Fig. 13). This instability makes irrigation essential during the months prior to flowering/budding of the vines.

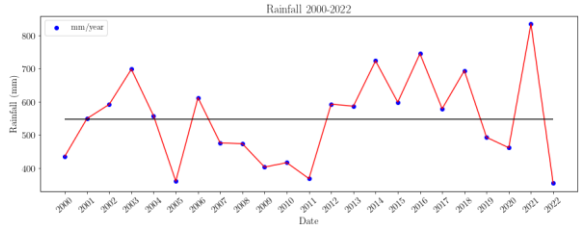

Figure 13. Yearly timeseries rainfall from 2000 to 2022 over the vineyards' area of Querétaro. The black line represents the average value.

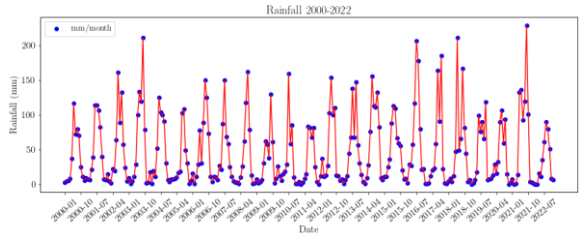

Figure 14. Monthly timeseries rainfall from 2000 to 2022 over the vineyards' area of Querétaro.

8 Machine learning classification

We employed the Hopkins statistic [13] to assess the clustering potential of the dataset. This metric evaluates the spatial randomness of the data and indicates the cluster trend or how well the data can be clustered. If the value is greater than 0.7, it has a high tendency to cluster and therefore likely to have statistically significant clusters. We ran the test on all the numerical variables of the entire dataset and the test statistic we got is 0.81 which indicates that data has a high tendency to cluster. With the physical data that we have so far (elevation, slope, watershed, soil type, textures and climatic indices) we have made a first unsupervised classification with kmodes [14] in Python. The results obtained are shown in Fig. 13.

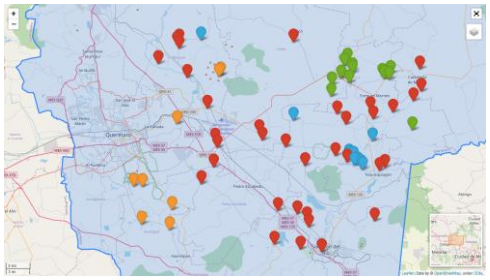

Figure 13. Clustering of vineyards.

The optimal number of clusters that we found is 4. We can observe a strong spatial correlation in the "green" cluster and a marked North-South distribution in the "orange" cluster. The "blue" cluster expands in an approximate Northwest-Southeast direction, and finally, the "red" cluster shows a considerable spatial dispersion. As we increase the number of variables (such as cultivated varieties, annual production, orientation, rootstocks, planting frames, etc.), we can refine this classification.

9 Conclusions

Querétaro is an area in full development with great potential for expansion. The characteristics of its soil make it very suitable for a variety of crops, including grapevines, and although the rainfall regime is irregular, the aquifers are replenished in years of higher rainfall. Its climatic characteristics are similar to other wine regions with a long tradition in Europe, USA, and South America. Therefore, it is a perfect location for growing premium wines, offering ample opportunities for the expansion of these vineyards. This work is the result of collaboration between Arkansas State University, Querétaro Campus (ASUCQ), Cluster Vitivinícola de Querétaro (CVQ), and Escuela de Vinos del Altiplano (EVA).

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