Lab 6 — Suitability/Capability

Objective: In this lab, you will choose your own data layers and your own specific objective of either 1) finding areas where a species can be found / can live, or 2) finding a site for a new location of some entity.

Background

Quinoa (depicted in Figure 1) is a grain that has risen to popularity in recent decades. Due in large part to the significant increases in demand, the price of quinoa tripled from 2006 to 2013 (NPR). The spike in prices is reflective of the fact that the substantial increase in demand was not met with the necessary increase in supply. This lack of significant increase in quinoa has been due to the fact that the quinoa plant has only been successfully grown in one region of the world: the Andes mountains (primarily in Peru and Bolivia) (Whole Grains Council). The region was successful in increasing production by reallocating domestic consumption to the foreign markets, but it has not been enough to meet the substantial demands.

Quinoa production is challenging, and this is best represented by the fact that, despite this spike in demand for the product, Bolivia and Peru continued to account for over 80% of the world quinoa production (FAO). I include in Figure 2 an image of how quinoa is grown in the Andes mountain region. The setting provides an indication of the environment in which quinoa is successfully grown. Many other countries attempted to produce the grain domestically but were not able to replicate the success of the Andes quinoa production. This is what motivated my research. I am interested in identifying viable and suitable growing areas for the quinoa plant in the hopes of finding viable areas to expand the production of the grain.

My study area is the world except for Antarctica as it seemed reasonable to assume quinoa cannot be grown there nor would it make sense logistically to attempt growing it there. I provide a map of my study area in Figure 3. The base map of the study region also depicts the global soil pH data that was used in the suitability analysis; a description of the soil data used is provided in Table 1. I chose to cover most of the world because the demand for growing this grain exists in many countries and suitability analyses on this scale have yet to be conducted. Additionally, since many countries are independently studying the suitability of their own regions, I believe there is an identified demand for such an analysis to be conducted. I believe it is also beneficial as there appears to be no regions that have been identified as truly suitable for quinoa production. Given the grain's commercial as well as nutritional benefits, it is important to identify regions outside of the Andes which are suitable for quinoa production.

Analysis

For my suitability analysis, I focused on four key variables as identified in the literature on quinoa production; these variables are elevation, annual precipitation, soil pH, and temperature. In Table 1, I provide a description of the data used in my suitability analysis. The primary challenge to this analysis was in the collection of the factor data. Datasets on the factors I identified at reasonable resolutions were challenging to obtain and implement. In particular, the dataset Climatic Research Unit (CRU) Time-Series (TS) version 4.04 was challenging to implement since it contained rasters that had time variables. I was able to subset the data by month and generate annual variables as needed.

To evaluate the suitability/capability of the world, I implemented a Weighted Linear Combination (WLC) model following the ratings schedule presented in Table 2. The combined score of each grid cell was computed using the standard equation presented below.

$$\text{Score} = \sum_{j=1}^{4} \left(\text{FR}_j \times w_j \right)$$

As the equation above indicates, I combined the layers used by adding together the weight factor ratings of each layer.

I compiled ratings using my perception of the conditions needed for quinoa production, based on the information obtained regarding the growth needs of the quinoa plant. It was noted in Oelke et al. (1992) desired temperatures for quinoa growth were provided. I supplemented this information with additional sources and identified that quinoa plants are reasonably well-suited for most temperatures with identified ideal ranges but they are intolerant to temperatures below 30℉ (approximately -1.1℃); this information motivated my ratings scales for temperature. The literature indicated that quinoa plants are drought tolerant as well with higher yields obtained at particular levels of precipitation (Hinojosa, 2018). Given the soil conditions in which quinoa is traditionally grown, I identified annual total rainfalls between 400 mm to 800 mm to be ideal (Bazile et al., 2016).

It was challenging to identify acceptable soil pH ranges for quinoa growth as the literature did not appear to reach a consensus on the topic. As such, I decided to implement two of the appropriate ranges identified with the smaller range reflecting the sufficient and thriving pH conditions. The sufficient requirement for elevation (0m – 4,000m) was obtained from the literature (Angeli et al., 2020). The thriving range of 2,500m to 4,000m for elevation was identified as the elevation of the Andean region in which it has been successfully grown.

Results & Comments

I present the results of the WLC estimation model in Figure 4. We can see that almost every continent has a region that is capable of quinoa production. These areas tend to coincide with mountain ranges, but the existence of a mountain range did not ensure quinoa growth suitability. This phenomenon is visible for the Rocky Mountain region in the United States as well as the Northern portion of the Appalachian Mountain range. An area that I did not expect to be as suitable for quinoa production was South Africa, which we can see in the map to be suitable for most of the country.

In Figure 5, I present the four suitability factors and their respective ratings for the world. In the figure, we see that soil pH appears to be the limiting criterion in this analysis. Elevation is the factor that is least limiting in this set of four factors considered. Since quinoa can grow in a wide range of elevations, we see that it does not limit the regions we may consider for quinoa growth suitability.

One area worth noting in this report is the United States. Since the 1980s, quinoa production has been attempted in Colorado with limited success. This map suggests that the reason for the lack of success is that, while parts of Colorado satisfy the elevation requirements, most areas of the State do not meet the combined suitability requirements for quinoa production. The results of my analysis suggest that Northern Texas is a suitable candidate region for quinoa within the United States. Additionally, my results indicate that significant portions of Mexico are likely to be suitable for quinoa cultivation.

One of the primary limitations of the analysis is the use of annualized temperatures. This limitation could not be avoided given the scope of the analysis, but it is important to consider the implications of using aggregated atmospheric data. As with all plants, quinoa has a cultivation schedule which is dependent on the seasons. Since I am considering both hemispheres in my analysis, it is difficult to appropriately account for the differences in the timings of seasons between the two hemispheres, which is why an annual median temperature was appropriate for the consideration. It is important to note however that the temperature sensitivity of the quinoa plant is dependent on the stage of growth of the plant. Once the plant reaches maturity, the temperature and water requirements of the plants are less constrained. Thus, it is worth noting that the suitability conditions considered in this analysis are conservative requirements to account for the stages of the plant's maturation cycle in which it is most sensitive to the elements.

Based on the results, we see that there are greater portions of the Andes mountain region which are suitable for quinoa production. This highlights the limitations of my analysis as those areas are not suitable based on the soil composition in that region. Upon conducting my analysis, I realized that while my factors are valid; they do not entirely account for the complexities of quinoa growth suitability. I believe I could improve my model in the future by accounting for soil texture. Quinoa has been identified to grow well in sandy-loam to loamy-sand soils (Oelke et al., 1992). Given time limitations, I was not able to incorporate soil texture as a factor.

References

Aguilar, P. C., & Jacobsen, S. E. (2003). Cultivation of quinoa on the Peruvian Altiplano. *Food Reviews International*, *19*(1-2), 31-41.

Angeli, V., Miguel Silva, P., Crispim Massuela, D., Khan, M. W., Hamar, A., Khajehei, F., Graeff-Hönninger, S., & Piatti, C. (2020). Quinoa (*Chenopodium quinoa* Willd.): An Overview of the Potentials of the "Golden Grain" and Socio-Economic and Environmental Aspects of Its Cultivation and Marketization. *Foods (Basel, Switzerland)*, *9*(2), 216. https://doi.org/10.3390/foods9020216

Bazile, D., Pulvento, C., Verniau, A., Al-Nusairi, M. S., Ba, D., Breidy, J., Hassan, L., Mohammed, M. I., Mambetov, O., Otambekova, M., Sepahvand, N. A., Shams, A., Souici, D., Miri, K., & Padulosi, S. (2016). Worldwide Evaluations of Quinoa: Preliminary Results from Post International Year of Quinoa FAO Projects in Nine Countries. Frontiers in plant science, 7, 850. https://doi.org/10.3389/fpls.2016.00850

Danielson, J. J., & Gesch, D. B. (2011). *Global multi-resolution terrain elevation data 2010 (GMTED2010)* (p. 26). US Department of the Interior, US Geological Survey.

Global Soil Data Task. 2014. Global Soil Data Products CD-ROM Contents (IGBP-DIS). Data Set. Available online [http://daac.ornl.gov] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A. http://dx.doi.org/10.3334/ORNLDAAC/565.

Harris I, Osborn TJ, Jones P and Lister D (2020) Version 4 of the CRU TS Monthly High-Resolution Gridded Multivariate Climate Dataset. *Sci Data* **7,**, 109 (2020). https://doi.org/10.1038/s41597-020-0453-3

Hinojosa, L., González, J. A., Barrios-Masias, F. H., Fuentes, F., & Murphy, K. M. (2018). Quinoa Abiotic Stress Responses: A Review. *Plants (Basel, Switzerland)*, *7*(4), 106. https://doi.org/10.3390/plants7040106

Oelke, E. A., Putnam, D. H., Teynor, T. M., & Oplinger, E. S. (1992). Quinoa. *Alternative Field Crops Manual*.

Quinoa, F. A. O. (2011). An ancient crop to contribute to world food security. *Regional Office for Latin America and the Caribbean*, *2*, 73-87.

Tables

Table 1: Data Layers Used

Variable	Description	Data Source	Raster or vector	Resolution	Date
Annual precipitation	Monthly total values of precipitation. Summed up the monthly precipitation data (mm/month).	https://crudata.uea.ac.uk/cru/data/hrg/ CRU TS 4.04 dataset	Raster	0.5x0.5 degrees	2017
Median annual daily temperature	Median temperature (in °C) was computed using the monthly average of daily mean temperature from the CRU TS 4.04 dataset.	https://crudata.uea.ac.uk/cru/data/hrg/ CRU TS 4.04 dataset	Raster	0.5x0.5 degrees	2017
Soil pH	Contains data on the topsoil pH (in H2O).	Harmonized World Soil Database (HWSD) v1.2	Raster	0.05x0.05 degrees	2000
Median Elevation	Contains global terrain elevation data reported in meters from the GMTED2010 dataset.	Global multi-resolution terrain elevation data 2010 (GMTED2010)	Raster	7.5 arc seconds	2010

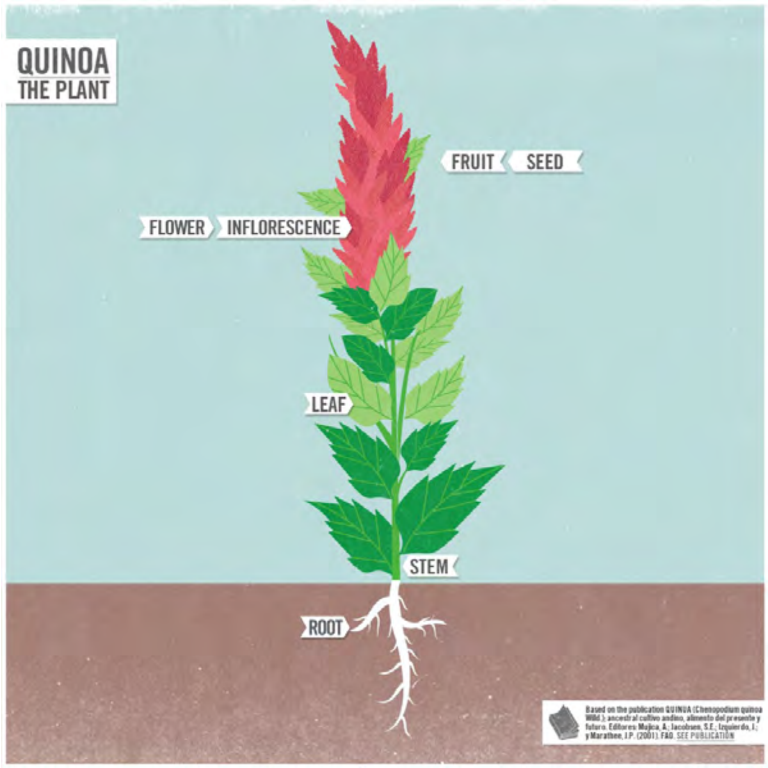
Note: For Figure 4, the IPUMS world map GIS boundary shapefile was used in generating country borders.

Table 2: Ratings Schedule

Factor	Ranges	Rating	Weight
Elevation (in meters)	-618 – 0 4,000+	0	1
	0 – 2,500	1	
	2,500 – 4,000	2	
Annual Rainfall (in millimeters)	0 – 100 800+	0	5
	100 – 400	1	
	400 – 800	2	
Soil pH	3 – 4.5	0	3
	4.5 – 4.8	1	
	4.8 – 8.5	2	
	8.5 – 9.5	1	
	9.5+	0	
Median Near-Surface Temperature (in degrees Celsius)	< -1.1	0	5
	-1.1 – 15	2	
	15 – 20	3	
	20+	1	

Figures

Figure 1: Quinoa Plant Diagram



Source: FAO

Figure 2: Quinoa Field

Source: Huffpost

Figure 3: Map of Study Area

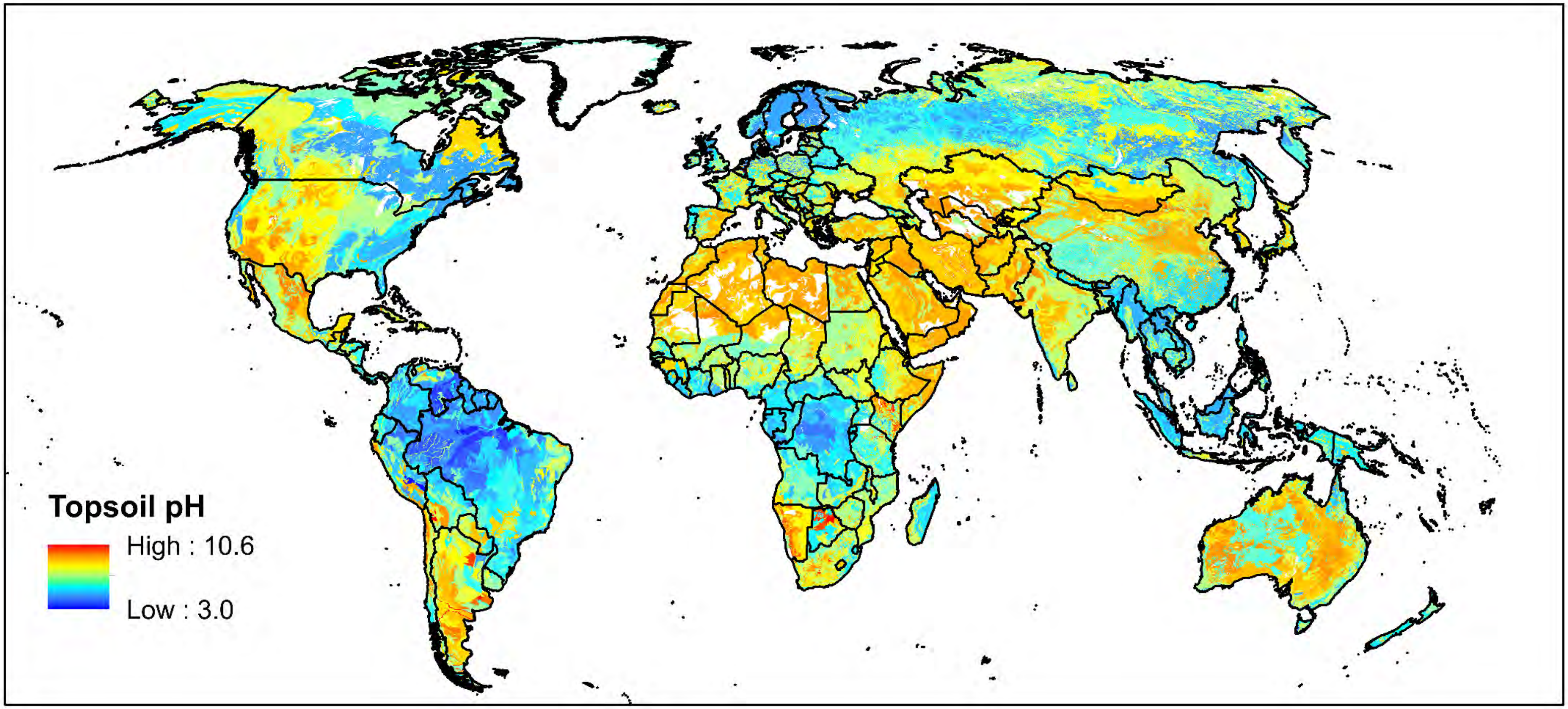


Figure 4: Map of Suitability Analysis Results

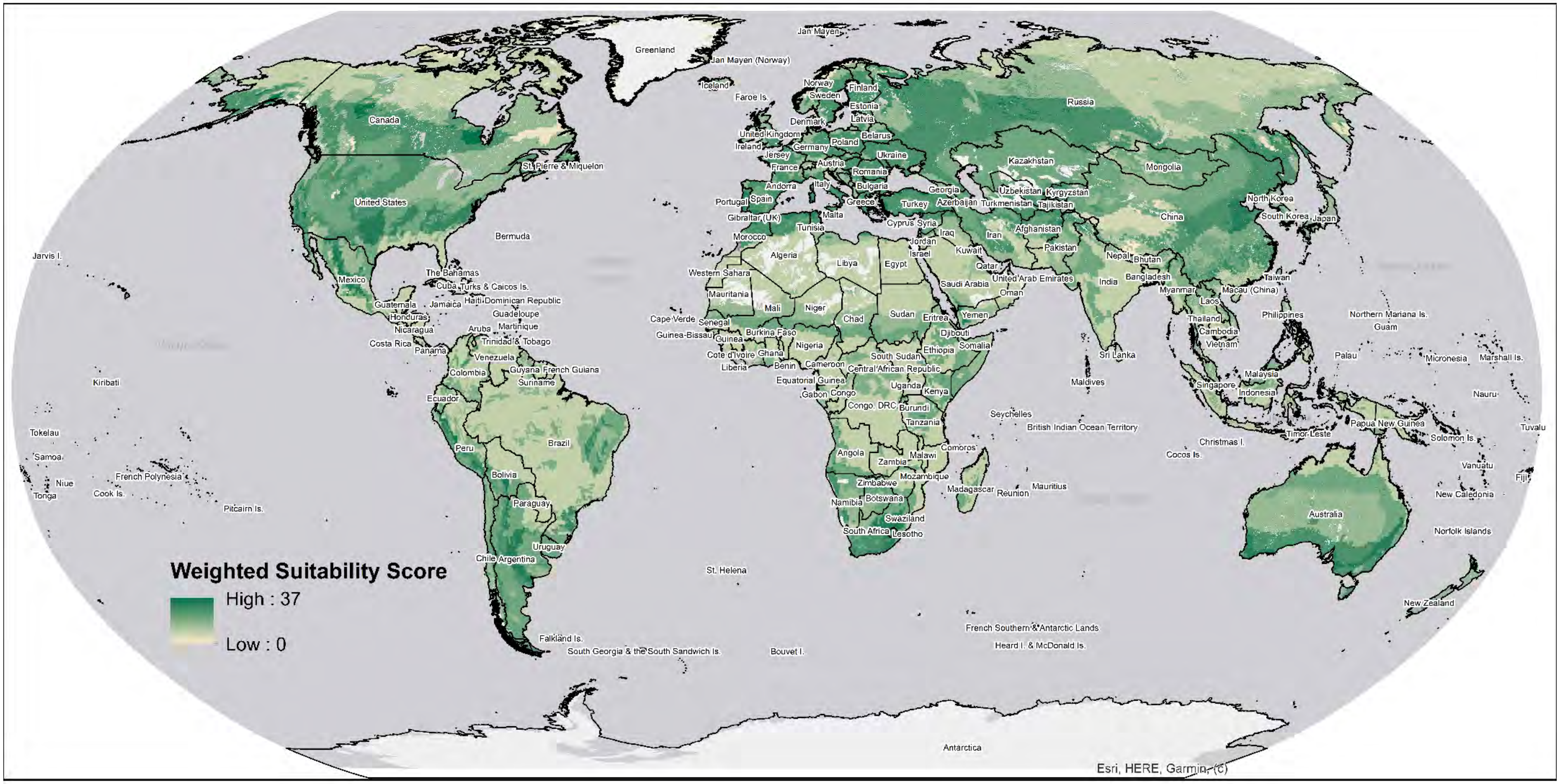


Figure 5: Map of Factor Suitability Ratings