Identifying Areas for Cultivating Industrial Hemp in Puerto Rico Using Geospatial Technologies

Author: Alejandro Ramos De Jesús
Advisor: Raúl Matos Flores
Master in Geospatial Science and Technology

Abstract

This investigation focuses on determining areas that are optimal for growing industrial hemp in Puerto Rico. Using a multi-criteria decision-making model, weights were calculated and assigned to each variable. Weights help establish a hierarchy between the criteria of precipitation, temperature, slope, organic carbon, and pH. These criteria are then combined to create a suitability map. The results of the analysis found that the most suitable lands are in the south and center-east parts of the island. A sensitivity analysis demonstrated that the model is considered highly sensitive to the organic carbon data, meaning that changing its parameters alters drastically suitability map results.

Introduction

This research is focused on the use of geographic information systems (GIS) as a tool to analyze and identify suitable areas for hemp cultivation in Puerto Rico. The goal of this investigation is to highlight fields of land that meet optimal criteria that produces the best yields. The analysis takes into consideration that some criteria have parameters that are more ideal than others. Using a multi-criteria decision-making model such as an analytical hierarchy process helps add weights to rank each criterion; this method is known to produce accurate and logical results [1]. A site selection process will be conducted using existing available data on the island's temperature, precipitation, soil type, slope, and land use. And a sensitivity analysis will be done to determine the effect of the models' assumptions on the results; this will be evaluated by modifying one parameter at a time.

Background

Hemp is the non-intoxicant variant of the cannabis plant, which produces fiber, seeds, and flowers. These are extracted from the plant to create hemp-based products for commercial and industrial use. Countries around the world are competing to become major exporters in a currently billion-dollar industry. Recent legislation has given the opportunity to Puerto Rico to participate in this emerging market; but for this to become a reality hemp must be cultivated on the island. To be able to rely on a stable crop, it is important to find the best lands for cultivation. Implementing GIS for crop suitability analysis, farmers can make more informed decisions about land use. There has been an abundance of studies regarding land suitability, all of them found the analysis to be a useful method to easily identify areas of interest; helping them cut down on cost and time.

Problem

Because of the lack of formal investigations of hemp cultivation in Puerto Rico and in the Caribbean, this research seeks to encourage the common practice of site selection that occurs around the world. To persuade the industry to implement the use of geospatial technologies as a part of their agricultural business operations.

Methodology

The data acquired for this investigation was downloaded directly from the ArcGIS Living Atlas which is a collection of geographical information from around the world. A total of six raster data layers are used to obtain the final results of the suitability analysis: Annual Mean Precipitation, Annual Mean Temperature, Topography Slope, Organic Carbon in Soil, pH Levels and Farmland Classification. An analytical hierarchy process was conducted to make it possible to identify the relationship between each criteria. To determine this a pairwise comparison matrix was conducted for all possible combinations, assigning values according to their relative importance; from 1 (equally important) to 9 (extremely important). The coherence of the pairwise matrix was verified using the Consistency Ratio (CR), which was determined based on the Consistency Index (CI) and the number of criteria being compared, applying the Random Consistency Index (RI).

$$CI = \frac{\lambda_{Max} - n}{n-1} \qquad (1)$$

$$CR = \frac{CI}{RI} \qquad (2)$$

Equation (1) and (2) were used to calculate CR, where λ (lambda max) is the value representing consistency vectors and n is the number of criteria.

The investigation was done using ArcGIS Pro, an Esri GIS platform. The suitability modeler tool in this software provides an ease of use to represent each criterion and combining them into a single surface that meets the model goal. A mask was applied to define the spatial extent using the Farmland Class data. The values of each dataset that represents a criteria was then transformed into a 1-to-5 suitability scale. The suitability scale in a weighted model ranges from 1, the lowest preference, to 5, most preferable. Weights, calculated in the previous step, were assigned to each criterion and the data layers are then combined to create a suitability map.

Lastly a sensitivity analysis was done, the purpose of this is to assess how the outcome of the model are influenced by its underlying assumptions. To understand how much the value of each variable affect the results. This was applied by modifying a weight in the original model. Since the soil criteria has two datasets of evaluation, it was chosen to change its weight percentages by only 5%. Every data layer was re-combined to create a new suitability map and observe the changes.

Table 1

Pairwise Comparison Matrix

	P	T	S	OC	pH	CW
P	1	2	5	2	5	0.3750
T	0.50	1	5	2	5	0.2736
S	0.20	0.20	1	0.25	3	0.0773
OC	0.50	0.50	4	1	7	0.2232
pH	0.20	0.20	0.33	0.14	1	0.0459

P: Precipitation, T: Temperature, S: Slope, OC: Organic Carbon, pH: pH Balance, CW: Criteria Weight

Results and Discussion

The pairwise comparison matrix, shown in Table 1, was normalized; then mean values were calculated for each row that belongs to the normalized pairwise comparison matrix values. The multi-criteria decision-making model provided the following weights for each variable: precipitation 0.3750, temperature 0.2736, slope 0.0773, organic carbon 0.2232 and ph 0.0459. The consistency ratio was checked. The lambda max is 5.2761, which helped determine the consistency index. CI equals to 0.0690. RI is the consistency index of randomly generated pairwise matrix; for the number of criteria used in this research (five in total) the RI is 1.12. With the results of CI and RI, the consistency ratio was calculated to be 0.0616. Do to the fact that the consistency ratio is less than 0.10, it is not necessary to generate a pairwise matrix again [2]. Thus, the calculated weights for each criteria will be used.

Most of the island of Puerto Rico is shown to have medium to low suitability for hemp growth. The absolute best locations are found in the center south of the island heading in-land. These areas are in the coastal municipalities of Ponce, Juana Diaz, Santa Isabel, and Salinas; with the interior municipalities being Coamo, Cayey, Cidra and Aguas Buenas. The lands that are or near the value of 4 (light green color) find to be situated around the center mountainous region. These areas are in the south-west municipalities like San German, Sabana Grande and Yauco; with northern municipalites being Florida, Manati and Vega Baja. These last two mentioned also have territory with the value of or near 1. The zones that are least suitable are all around the coast with the exception of the south of the island. Most of these lands are in the east, inside the municipalities of Viequez, Culebra, Naguabo, Maunabo, Ceiba, Humacao, Las Piedras, Yabucoa, Juncos and Gurabo. The center of Puerto Rico, where highest peaks are located, have medium values of suitability. Municipalities found in this region are Utuado, Jayuya, Ciales, Adjuntas and Lares.

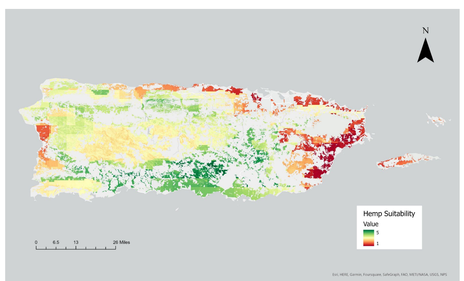

Figure 1
Hemp Suitability Results

This investigation has two data layers in the category of soil chemical characteristics. Past research mentions high organic carbon as an important factor for agricultural cultivation, which led for it to have a higher weight percentage than pH. These data layers were used to conduct a sensitivity analysis. The original weight per data sets are 22.32% for organic carbon and 4.59% for pH. A 5% change was made, for a new total weight percentage of 17.32% for organic carbon and 9.59% for pH. A new suitability map was created using the adjusted weight percentages (Figure 8).

The difference in results, from the original Hemp Suitability Map (Figure 7), are distinguishable in the center region of the island of Puerto Rico. All the medium values in that area have turned into a less suitable zone, with a new value of 2 and 1; on a scale from 5 to 1, where 5 is the most suitable and 1 the least. There also seems to be a change in the far-left corner of the island, where the municipalities of Guanica, Lajas and Cabo Rojo are located, are now higher in the suitability scale than previously.

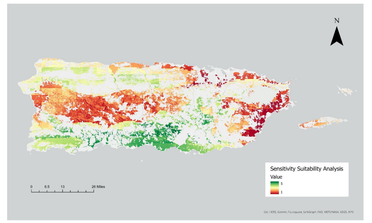

Figure 2
Sensitivity Analysis Results

Conclusions

The use of geographical information systems, with the aid of an analytical hierarchy process, help identify the areas that are ideal for hemp growth. The ease of use of these applications made it possible to understand that not all lands in Puerto Rico are preferable for cultivating this crop. Hemp is a robust product that can grow in many environments, but for it to be commercially available it needs to be in the optimal conditions. The most suitable places found to be in the south and center-east leaning parts of the island. Hopefully, the next investments in this market targets real estate in the most suitable locations illustrated in the final results (Figure 1). Better yet, existing entities should conduct their own investigation implementing the widely available tools of GIS. This research provides an example of a strategy that should be taken when introducing an emerging agricultural product in Puerto Rico.

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