Journal of Geography and Cartography (2022) Volume 5 Issue 1
doi:10.24294/jgc.v5i1.1766

ORIGINAL RESEARCH ARTICLE

Characterization of soil suitability in the province of Catamarca using geographic information systems

Florencia Cecilia Trabichet

Universidad Nacional de Luján, Luján B6700, Argentina. E-mail: flortrabichet@gmail.com

ABSTRACT

Land suitability analysis using geographic information systems (GIS) is one of the most widely used method today. In this type of studies, GIS and geo-spatial statistical tools are used to evaluate land units and present the results in suitability maps. The present work aims to characterize the suitability of soils in the province of Catamarca for pecan nut production according to the variables: rockiness, salinity, risk of water-logging, depth, texture and drainage described in the Soil Map of Argentina at a scale of 1:500,000 published by the National Institute of Agricultural Technology. A classification of the suitability of the soil cartographic units was made according to crop requirements, applying the methodology proposed by FAO. The standardization of variables made by omega score and the calculation of the spatial classification score were carried out as a result of the synthesis of the spatial distribution of soil suitability. The applied methodology allowed obtaining the soil suitability map resulting in a total of 60,662 km^2 suitable for pecan nut production, which accounts for 59.8% of the total area of the province.

Keywords: Carya Illinoiniensis; Land Evaluation; Geographic Information Systems

ARTICLE INFO

Received: 11 March 2022
Accepted: 10 April 2022
Available online: 22 April 2022

1. Introduction

One of the main steps for sustainable land use planning is land suitability assessment[1] and determining the optimal land use based on its potential. Land assessment is a process used to define[2] and measure the degree of adaptability for certain types of uses[3] and group land units accordingly[1] through a systematic comparison of use requirements with available resources[4].

Various land evaluation approaches have been developed over time and each has a specific methodological procedure[4], The most widespread is the one proposed by FAO[5] which consists of five suitability classes: very suitable, moderately suitable, marginally suitable, temporarily unsuitable and permanently unsuitable. Although there is no standardization in the choice of criteria to be used in this type of work, climatic conditions, topography and soil properties are widely used[2,4].

Land suitability analysis based on geographic information systems (GIS) is a widely used line of analysis for land planning[6] by using a valuable tool to store, retrieve and process a large amount of data in quantitative form needed to calculate and assign land suitability indices[3]. In this type of studies, GIS and geo-spatial statistical tools are used to evaluate land units and present the results in the form of suitability maps[4]. In all cases, it is assumed that a given area is subdivided into a set of basic units of observations and that the problem of land use suitability involves the evaluation and classification of these units according to their suitability for a particular activity[7].

There are several alternatives for the application of GIS technology as a tool for locational decision making. Among them, the Weighted Linear Combination (WLC) is a Multicriteria Evaluation (MCE) technique that applies a weighting to the variables considered and leads the solution to a medium risk level in the decision making[8]. The application work in vector structure is supported by the mathematical processing of the associated data matrix, where each column contains the data that at a cartographic level allows representing and analyzing the spatial distribution of a variable and therefore each column can be considered a map[9]. In a first instance of the WLC, the variable layers go through a standardization process, which in this application was performed from the omega score (OS) and subsequently a spatial classification score (SCS) is obtained that represents the spatial distribution of the result. The cartographic modeling is therefore based on the standardization of data and the combination of columns, with the purpose of synthesizing them in a column that presents, as thematic overlap, the spatial classification scores (SCS).

GIS has been used by various authors to determine the suitability of land for certain uses[4], such as suitability for agricultural crops in Turkey[2] and in rural coastal areas of Italy[6], for wheat cultivation in Egypt[3] and in Algeria[10], for tea cultivation in Zhejiang province in China[11], for cotton production in Central India[4] and citrus crops in India[12]. Similarly, Bunruamkaew & Murayam[13] used this methodology for the selection of optimal areas for the development of eco-tourism in Thailand. Lanzelotti and Buzai[14] designed suitability models for the development of pre-Hispanic agriculture and current agriculture in a sector of the Santa María Valley. It was also used in the province of Catamarca (Argentina). Buzai and Principi[15] used to identify conflicts between land uses in the Luján river basin (Argentina).

The pecan walnut (*Carya illinoiniensis*) crop adapts very well to varied environmental conditions[16] and in Argentina, by 2015, there were approximately 8,000 hectares planted[17]. Gomez & Cruzate[18] used soil maps of Argentina at scales 1:500,000 and 1:1,000,000[19] and moisture and temperature regimes to determine the suitability of Argentine soils for pecan walnut production taking into account the crop requirements defined by Herrera[20]. As a result of this study, four suitability classes were established: optimum, suitable, marginal and unsuitable. These results have allowed the delimitation of regions with different degrees of suitability for pecan nut production according to the biological-productive requirements of the species and this information served as a basis for the pre-selection of areas in which pecans can be produced at the national level, within which the province of Catamarca is located.

The objective of this work is to characterize the suitability of the soils of the province of Catamarca for pecan nut production according to 6 (six) edaphic variables, according to the requirements defined by Herrera[20], and through the use of GIS, in order to generate a tool for the spatial planning of pecan nut production.

2. Description of the study area

The province of Catamarca is located in the northwestern region of Argentina (**Figure 1**) between 25º12′ S and 30º 04′ S and between 69º 03′ W and 64º 58′ W. It covers an area of 102,602 km^2 and only 22% of this area is made up of valleys and plains, the rest being mountainous, which is unsuitable for agricultural activities[21]. It has a temperate continental climate with an average rainfall that varies between 400 and 500 mm per year in the east, decreasing towards the west to less than 150 mm in the Puna Cordillera, where the water deficit is compensated by snowfall[21,22].

3. Selection, evaluation and classification of edaphic variables

The application was carried out using QGIS 3.10.4 software and taking the vector layer (polygon) of soils as a data source. Argentina 1:500,000 comes from the National Institute of Agricultural Technology (INTA 2011). This layer has the soil cartographic units described by INTA and a total of 32 edaphic variables associated with these units.

The soils of Argentina layer was clipped using as a mask the polygon Province of Catamarca obtain-

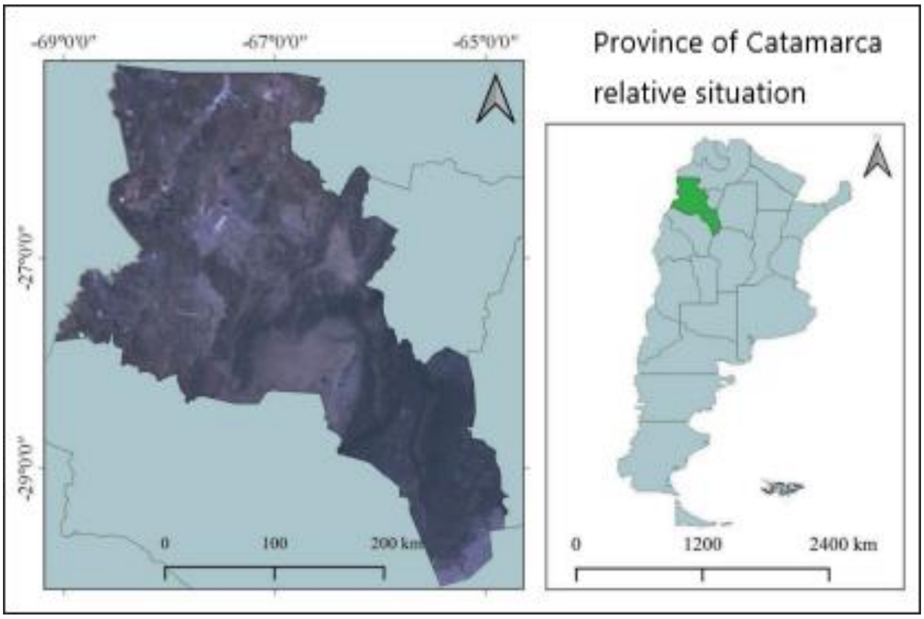

Figure 1. Province of Catamarca.

Source: Own elaboration. Landsat 5 background image natural color composition (RGB, p. 321) obtained from Google Earth Engine. Cloud-free mosaic from January to December 2010.
Reference system: EPGS: 4326, WSG84.

ed from the SDI (Spatial Data Infrastructure) of the National Geographic Institute[23], so as to extract the cartographic units corresponding to the province. The obtained layer was reprojected from the EPSG: 4326-WGS84 system to the EPSG: 5344 POSGAR 2007/Argentina 2 coordinate system. When estimating the surface area of the layer, a total of 101,491.7 km^2 was obtained, a value that differs from the surface area cited by Nuñez Aguilar and Alvarez de Toledo[21] of 102,602 km^2.

The variables defined as edaphic requirements for pecan production according to Herrera[20] were selected from the database: Effective depth, subsurface texture, rockiness, drainage characteristics, salinity and risk of water-logging.

The description of the main, secondary and tertiary limitations and the position in the landscape of the cartographic units were also taken into account. These last parameters were later used as auxiliary information to define the suitability of each variable for each cartographic unit.

For the classification of the variables according to their degree of suitability, the principles of the FAO land evaluation methodology[5] were applied, This methodology consists of a multidisciplinary approach through which the spatial units are evaluated and classified according to the degree of limitations they present with respect to specific types of uses. these degrees of limitations correspond to reductions in potential yields. In this case, a suitability index was assigned to each spatial unit for each selected variable according to the percentage of expected yield, with the following categories being defined: Very suitable (80–100%), suitable (60–80%), moderately suitable (40–60%), marginally suitable (20–40%) and not suitable (0–20%).

- A physical evaluation of the soil mapping units was carried out according to the requirements defined by Herrera[20]:
- Depth of soil: Greater than 100 cm.
- Texture of the sub-surface horizon: Loam.
- Salinity: Non-saline to weakly saline soils.
- Drainage: Well drained and moderately well drained.
- Waterlogging: No danger and very little.
- Rockiness: Less than 20%.

Table 1 (see next page) presents the fitness categories assigned and a summary of the criteria used for the classification of each variable.

Effective depth is a variable that represents the volume of soil where crop roots perform nutrient absorption, water and gas exchange[24]. This variable presented values between 0 and 120 cm depth.

The subsurface texture considers the granulometric composition of the subsurface horizon and influences soil moisture retention capacity and root growth. The criteria used for the classification of the different units were defined taking into account the Productivity Index (PI) values estimated by Morales Poclava *et al.*[24] for different textural classes of soils in Northwest Argentina. It was considered that the silty clay loam, sandy loam and clay loam classes may present problems for root exploration due to their clay and silt percentages. The sandy and sandy loam classes have a good texture for root exploration but low water retention. The clayey class has a fine texture and may present problems for root exploration. The sandy-gravelly, sandy-gravelly, sandy-gravelly, sandy-gravelly and coarse sandy classes have very low water retention.

Table 1. Classification of edaphic variables according to their degree of suitability

	Very Suitable	Suitable	Moderately Suitable	Marginally Suitable	Not Suitable
Depth (cm)	>=100 cm	80–100 cm	60–80 cm	>0–60 cm	0 cm
Texture	Franca	Sandy loam, clay loam and silty clay loam	Clayey	Sandy loamy, sandy	sandy-gravelly, sandy-gravelly, sandy-gravelly, coarse sandy, not determined
Drainage	Well drained without limitations	Well drained associated with poor drainage associated with tertiary limiting, moderate	Somewhat excessive drainage associated with low moisture retention as a limiting factor. secondary	Imperfect drainage, excessive drainage, somewhat excessive drainage associated with low moisture retention as a primary limiting factor.	Poor drainage as primary constraint, rocky outcrops, excessive drainage, lagoons, salt ponds, salt pans
Rockiness	Units with no rockiness constraints, no "interferes with tillage" classification, no stoniness in soil descriptions	Units with less than 35% rockiness in the profile according to soil description.	Units that, due to the characteristics of their soils, have low stoniness but are classified as "interferes with tillage".	Units that, according to the soil description, present abundant stoniness and are classified as "interfering. Tillage"	Units with "interfering tillage" or that present rockiness as limiting, rocky outcrops, lagoons, salt pans, etc.
Salinity	Non-sodium. Unlimited.	No cartographic unit	No cartographic unit	Weak alkalinity without limiting factors	Weak alkalinity, salinity and/or alkalinity in the first 50 cm as limiting factors. Strong alkalinity
Waterlogging	Middle, apical, or upper cone sector, plains and extended plains, sandy plains, esplanades, hillocks, steep slopes, steep slopes and steep slopes	Plains	Runoff paths	Lowlands, floodplains and flood plains	Alluvial plains, rocky outcrops, lagoons and salt flats

Source: Own elaboration.

The drainage variable presented the following qualitative data: Poor, imperfect, well drained, somewhat excessive, excessive, moderate. For the assignment of suitability values, in this case, the primary, secondary and tertiary limiting factors of each cartographic unit were also taken into account as auxiliary data.

The descriptions of the cartographic units of the Atlas de Suelos de la República Argentina[19,25] and the primary, secondary and tertiary limitations of the Suelos de Catamarca layer were taken into account to classify and assign suitability for the variable rockiness, since in the data matrix there were cartographic units without data for the column corresponding to this variable. The presence of rocks in the soil profiles that compose each unit was analyzed taking the descriptions of epipedons and diagnostic horizons of the Key to Soil Taxonomy of the United States Department of Agriculture[26] as a reference.

The salinity variable was classified taking into account the description of alkalinity and those limiting factors about primary, secondary and tertiary.

The variable of water-logging (risk of waterlogging) of the Catamarca soils layer was classified, taking into account the position in the landscape of each mapping unit.

4. Creation of the suitability field

In the GIS attribute table, the fields ap_salinity, ap_depth, ap_rockiness, ap_texture, ap_water-logging and ap_drainage were created. These fields were completed with the suitability indexes assigned in the previous procedure according to the classification presented in **Table 2**.

Table 2. Suitability categories assigned to the cartographic units

Suitability Category	Index
Very suitable	4
Suitable	3
Moderately suitable	2
Marginally suitable	1
Not suitable	0

5. Standardization by Omega Score and PCE calculation

For the soil suitability map, the spatial classification score was calculated by calculating the average of the columns standardized by omega score (1):

Omega Score = $((x_i - x_m))/((x_M - x_m))*100$

Where x_i is the value of the variable in each spatial unit, x_m and x_M are respectively the minimum and maximum value of the data series. The results provide values between 0 and 100, where 0 corresponds to the worst situation and 100 to the best situation in the case of profit variables as in this work. Once the variables were standardized, the PCE was calculated according to formula 2.

PCE = (salinity + drainage + depth + rockiness + water-logging + texture)/6

As a last step, the PCE was reclassified into five fitness categories according to the **Table 3**.

Table 3. Reclassification of the PCE into five categories of aptitude

PCE Omega	Suitability index	Fitness class
100-80	4	Very suitable
80-60	3	Apt
60-40	2	Moderately suitable
40-20	1	Marginally suitable
20-0	0	Not suitable

Source: Own elaboration.

6. Soil suitability for edaphic variables

The results obtained regarding the spatial distribution of soil suitability for the selected variables are presented below. The suitability maps obtained for each edaphic factor are shown (**Figures 2a**, **2b**, **3a**, **3b**, **4a** and **4b**) and a summary of the areas obtained (km^2) for each suitability category according to each of the variables (**Table 4**).

For the analysis of these results, the description of the cartographic units of the soil layer of Catamarca (INTA 2011) was taken into account as auxiliary information, especially the position in the landscape and the primary, secondary and tertiary limitations.

Table 4. Surface areas (km^2) of each suitability category according to selected variables

Category	Waterlogging	Depth	Rocosity	Salinity	Texture	Drainage
Not suitable	42,509.8	54,639.6	57,874.1	59,930.5	68,687.9	57,209.7
Marginally suitable	381.4	0	14,129.4	25,682.7	3,963.5	30,935.1
Moderately suitable	555.1	378.8	18,308.0	0	15,534.7	373.8
Apt	2,195.4	11.015.6	1,166.2	0	9,978.6	1,568.1
Very suitable	5,850.0	35,457.7	10,014.0	15,878.5	3,327.0	11,405.0

Source: Own elaboration.

For the depth variable (**Figure 2a**) the areas classified as very suitable and suitable are distributed in plains, alluvial plains and also in middle, apical and lower cone sectors (in mountainous areas). According to the information presented in **Table 4**, these categories total around 46,473.3 km^2, which corresponds to 45.8% of the province's surface area.

With respect to the texture variable, the units classified as very suitable represent a small proportion of the total surface area of the province (a total of 3,327 km^2, see **Table 4**). **Figure 2b** shows that these units are distributed towards the southeast of the study area and correspond to esplanades and plains with loamy textures. On the other hand, the areas classified as suitable represent 9,978.6 km^2 (**Table 4**) and are distributed in mountainous areas. Both categories (very suitable and suitable) represent 13.1% of the total provincial surface. It should also be mentioned that for this variable, there is a total of 15,534.7 km^2 of land classified as moderately suitable (**Table 4**) distributed in mountainous areas, mainly in units with clayey textures.

Regarding the drainage and rockiness factors (**Figures 3a** and **3b** respectively), the units classified as very suitable and suitable are those distributed in the southeast of the province, corresponding to esplanades and plains, without stoniness or drainage limitations. For the rockiness variable, these categories total 11,180.2 km^2, while for the drainage factor, they yield a total of 12,973.1 km^2 (**Table 4**); these values represent 11% and 12.8% of the total provincial surface area, respectively. For the rockiness variable, there are also 18,308 km^2 of areas classified as moderately suitable, distributed in mountainous areas, mainly in units with stoniness as a primary limitation.

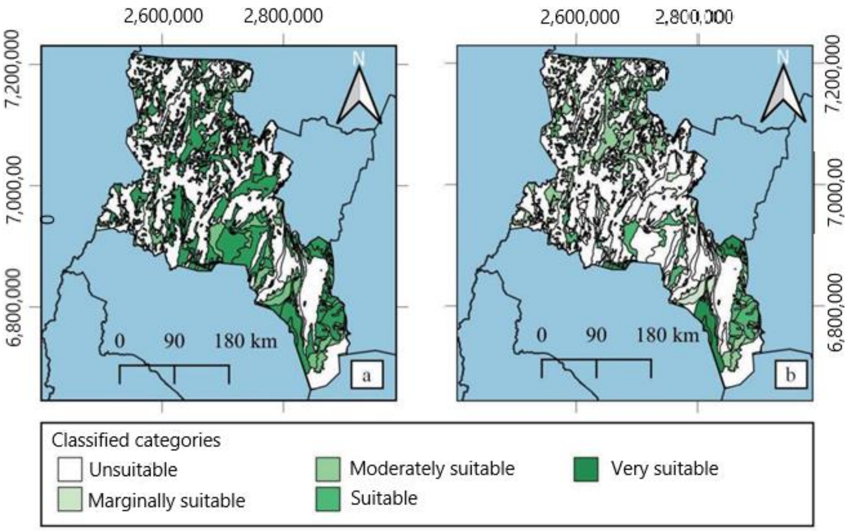

Figure 2. Soil suitability for the variables depth (a) and texture (b).

Source: Own elaboration.

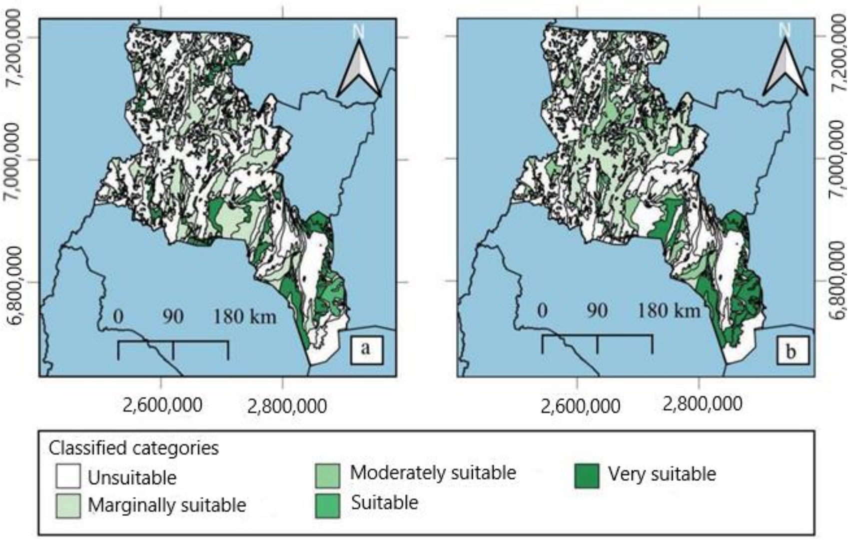

Figure 3. Soil suitability for drainage (a) and rockiness (b) variables.

Source: Own elaboration.

With respect to the salinity variable (**Figure 4a**), the areas classified as very suitable are distributed in mountainous areas (in middle and apical sectors of cones), and in esplanades and plains in the southeast of the province. This category has an area of 15,878.5 km^2 (**Table 4**), which represents 15.6% of the total study area.

The flooding variable (**Figure 4b**) shows the highest proportion of very suitable land (55,850 km^2, see **Table 4**) distributed in slopes and mountainous areas. If we also add the areas classified as suitable (2,195.4 km^2, **Table 4**), we obtain that 57.2% of the provincial surface has good suitability in terms of this variable.

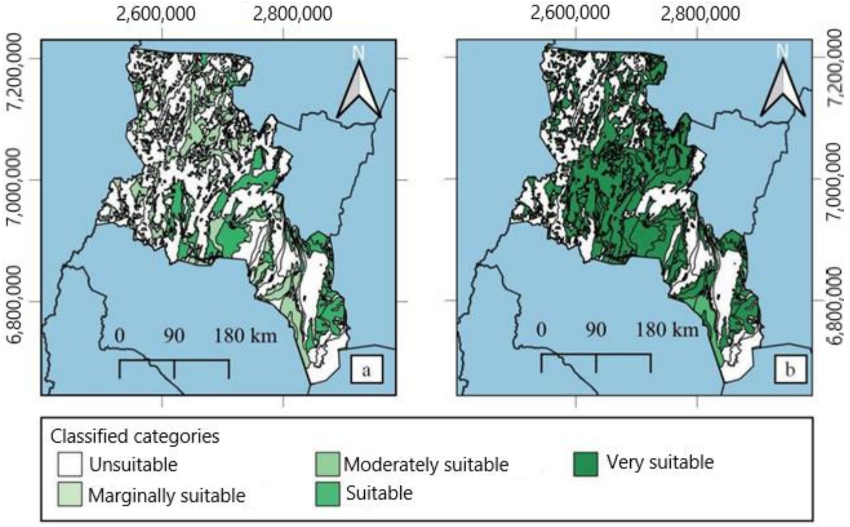

Figure 4. Soil suitability for salinity (a) and water-logging (b) variables.

Source: Own elaboration.

In relation to the lowest categories of suitability (marginally suitable and unsuitable), it can be observed that the variables drainage, rockiness and salinity present significant areas of units classified as marginally suitable (**Table 4**), mainly distributed in mountainous areas and steep slopes (**Figures 3a**, **3b** and **4a**). In general, for all variables, the areas classified as unsuitable are distributed mainly in cartographic units composed of rocky outcrops (in mountainous areas), salt flats and lagoons (these last two units located in the southeast of the province). Considering the total surface of the study area, the lowest proportion of unsuitable land is presented by the flooding variable with 42,509.8 km^2 (44.8%), while the texture variable presents the highest proportion for this category with a total of 68,687.9 km^2 (67.7%, see **Table 4**).

7. Soil suitability for pecan nut production

The final soil suitability map obtained (**Figure 5**) and a summary of the areas obtained for the final soil suitability map of the province of Catamarca in percentages and km^2 (**Table 5**) are presented below.

The soil suitability map standardized by PCE (**Figure 5**) shows 59.8% of land area suitable for pecan nut production (**Table 5**: Sum of very suitable, suitable, moderately suitable and marginally suitable categories) distributed in areas of plains, extended plains and plains located in the southeast of the province, and in middle and apical sectors of cones in mountainous areas. Only 13.3% of these lands correspond to the highest suitability categories (very suitable and suitable). The rest of the suitable land is distributed in the moderately suitable (30%) and marginally suitable (16.5%) categories. The areas classified as moderately suitable are distributed in middle and apical sectors of cones with steep slopes, low water retention and stoniness problems, while those classified as marginally suitable are distributed in flood plains with limitations due to the presence of salinity, poor drainage and coarse textures.

Table 5. Surface area (in km^2 and in %) according to soil suitability category for pecan nut production

Category	Surface area (km^2)	Surface area (%)
Not suitable	40,829.5	40.2
Marginally suitable	16,743.6	16.5
Moderately suitable	30,411.0	30.0
Apt	7,607.7	7.5
Very suitable	5,899.9	5.8
Total	101,491.7	

Source: Own elaboration.

The total land classified as unsuitable represents 40.2% of the provincial surface (**Table 5**) and is mostly distributed in the cartographic units classified as salt pans, lagoons and rocky outcrops, and in units that present limitations due to rockiness or effective depth, mainly located in mountainous areas.

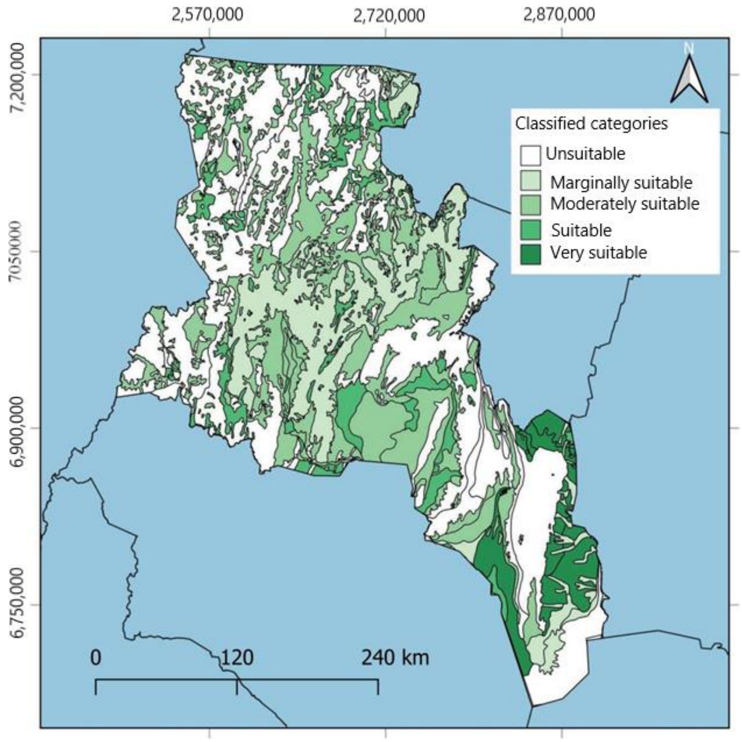

Figure 5. Soil suitability map for pecan nut production in the province of Catamarca.

Source: Own elaboration.

8. Final considerations

Through the application developed in this work, it was determined that the province of Catamarca has 59.8% of land area suitable for pecan nut production. Of this total, only 13.3% corresponds to the very suitable and suitable categories, where the crop could reach between 60 and 100% of its potential yield according to the categorization adapted from FAO[5]. The remaining 46.5% of the suitable land corresponds to the moderately suitable and marginally suitable categories, which implies that the crop could reach between 20 and 60% of its potential yield. For these categories, the implementation of management practices aimed at modifying or eliminating edaphic limitations can be considered, depending on their origin, nature and magnitude, in order to improve growing conditions and achieve increases in expected yields.

It was also determined that unsuitable lands represent 40.2% of the provincial total and are distributed mainly in salt flats, lagoons, rocky outcrops, and cartographic units with limitations due to rockiness or effective depth in mountainous areas.

The methodology applied in this work allowed meeting the objectives set, obtaining the characterization of the suitability of soils in the province of Catamarca for pecan nut production. The location of areas with different degrees of suitability was achieved by adapting the methodology proposed by FAO[5] and taking into account the spatial distribution of the edaphic factors considered for this study.

Finally, the results obtained constitute a tool for decision making in the establishment of pecan walnut orchards in the province of Catamarca.

Conflict of interest

The author declared no conflict of interest.

References

1. Zolekar RB, Bhagat VS. Multi-criteria land suitability analysis for agriculture in hilly zone: Remote sensing and GIS approach. Computers and Electronics in Agriculture 2015; 118: 300–321. doi: 10.1016/j.compag.2015.09.016.
2. Akıncı H, Özalp AY, Turgut B. Agricultural land

use suitability analysis using GIS and AHP technique. Computers and Electronics in Agriculture 2013; 97: 71–82. doi: 10.1016/j.compag.2013.07.006.
3. El Baroudy AA. Mapping and evaluating land suitability using a GIS-based model. CATENA 2016; 140: 96–104. doi: 10.1016/j.catena.2015.12.010.
4. Walke N, Obi Reddy GP, Maji AK, *et al*. GIS-based multicriteria overlay analysis in soil-suitability evaluation for cotton (*Gossypium* spp.): A case study in the black soil region of Central India. Computers & Geosciences 2012; 41: 108–118. doi: 10.1016/j.cageo.2011.08.020.
5. FAO. A framework for land evaluation. Soils Bulletin 32; 1976.
6. Romano G, Dal Sasso P, Trisorio Liuzzi G, *et al*. Multi-criteria decision analysis for land suitability mapping in a rural area of Southern Italy. Land Use Policy 2015; 48: 131–143. doi: 10.1016/j.landusepol.2015.05.013.
7. Malczewski J. Ordered weighted averaging with fuzzy quantifiers: GIS-based multicriteria evaluation for land-use suitability analysis. International Journal of Applied Earth Observation and Geoinformation 8(4): 270–277. doi: 10.1016/j.jag.2006.01.003.
8. Buzai GD, Baxendale CA. Sociospatial analysis with geographic information systems. Scientific perspective (in Spanish). 1st ed. Buenos Aires. 2011.
9. Buzai G. Multi-criteria evaluation methodology in the spatial analysis of health (in Spanish). Toluca de Lerdo: Universidad Autónoma del Estado de México; 2014. p. 90–97.
10. Mendas A, Delali A. Integration of MultiCriteria Decision Analysis in GIS to develop land suitability for agriculture: Application to durum wheat cultivation in the region of Mleta in Algeria. Computers and Electronics in Agriculture 2012; 83: 117–126. doi: 10.1016/j.compag.2012.02.003.
11. Li B, Zhang F, Zhang LW, *et al*. Comprehensive suitability evaluation of tea crops using GIS and a modified land ecological suitability evaluation model. Pedosphere 2012; 22(1): 122–130. doi: 10.1016/S10020160(11)60198-7.
12. Zabihi H, Ahmad A, Vogeler I, *et al*. Land suitability procedure for sustainable citrus planning using the application of the analytical network process approach and GIS. Computers and Electronics in Agriculture 2015; 117: 114–126. doi: 10.1016/j.compag.2015.07.014.
13. Bunruamkaew K, Murayam Y. Site suitability evaluation for ecotourism using GIS & AHP: A case study of Surat Thani Province, Thailand. Procedia Social and Behavioral Sciences 2011; 21: 269–278. doi: 10.1016/j.sbspro.2011.07.024.
14. Lanzelotti S, Buzai G. Spatial suitability models for pre-Hispanic and present-day agriculture in the Santa María valley, Catamarca (in Spanish). Estudios Socioterritoriales. Revista de Geografia 2015; 18: 139–150.
15. Buzai GD, Principi N. Identification of areas of potential conflict between land uses in the Luján River basin (Argentina) (in Spanish). Revista Geográfica de América Central 2017; 59: 91–124.
16. Zhang R, Peng F, Li Y. Pecan production in China. Scientia Horticulturae 2015; 197: 719–727. doi: 10.1016/j.scienta.2015.10.035.
17. PROSAP-UCAR. Competitive improvement plan. Pecan nut cluster (in Spanish) [Internet]. Available from: https://clusterdelanuezpecan.net/plan-demejora-competitiva/.
18. Gomez LA, Cruzate GA. Suitability of Argentine soils for pecan (in Spanish). In: Produccion de pecán en Argentina. 2007. p. 1–9.
19. SAGyP-INTA. Soil Atlas of the Argentine Republic (in Spanish). 1st ed. Buenos Aires: SAGPyA-INTA; 1990.
20. Herrera E. Selecting soil and site for a pecan orchard. Las Cruces: New Mexico State University; 1999.
21. Nuñez Aguilar FA, Alvarez de Toledo JM. Irrigation in the Province of Catamarca (in Spanish).
22. Cabrera AL. Phytogeography of the Argentine Republic (in Spanish). Boletín de La Sociedad Argentina de Botánica 1971; 14: 1–42.
23. IGN. Provinces (in Spanish). 2018 [cited 2019 Apr 15]. Available from: http://ign.gob.ar/NuestrasActividades/InformacionGeoespacial/CapasSIG.
24. Morales Poclava C, Sobral R, Nakama V, *et al*. Land evaluation using parametric methods (in Spanish). 2004.
25. Panigatti L. Argentina, 200 years, 200 soils (in Spanish). 2010. Available from: https://inta.gob.ar/sites/ default/files/script-tmp-inta-200-suelos.pdf.
26. USDA. Keys to soil taxonomy natural resources conservation service. 2014. Available from: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_051546.pdf.