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Nowadays, beekeeping is widely recognised for its importance in supporting the environmental sustainability and the socioeconomic development of rural territories. However, it faces multiple challenges, such as climate change, habitat loss and diseases affecting bee populations, along with the occasionally inappropriate management of beekeeping practices. To overcome these tricky issues, the first step should be focused on identifying the most suitable areas for beekeeping, thus contributing for more informed decisions regarding the selection of the best locations for apiaries, and the prioritisation of interventions in more vulnerable areas. For that purpose, the present study shows a high-resolution multicriteria approach for mapping beekeeping suitability, which was applied to a Portuguese region renowned for its honey Protected Designation of Origin (PDO). The methodology integrates topographic, environmental and climatic criteria, prioritised by category through expert judgments and the Analytic Hierarchy Process (AHP). By using high-resolution spatial data processed from Geographic Information Systems (GIS), it enables a comprehensive assessment of landscape key features (e.g., availability of melliferous flora, proximity to water and rural roads) and potential limitations (e.g., hilly terrain, climate extremes) that can impact the honey production and bee health. Findings reveal that environmental and climatic criteria (43% each) have a greater contribution for the beekeeping suitability than topographic ones (14%). Within these categories, hillside exposure (63%), land use (53%), and annual precipitation (50%) were particularly influential. When overlapping the final suitability map with the apiary influence range, most apiaries were found in locations classified as very-high suitability. This evidence demonstrates that the beekeepers, especially those managing many beehives, have a deep knowledge of both the activity and the territory where they operate. These valuable insights for beekeepers and policymakers are very useful for optimising the beekeeping management and preserving the honey quality, primarily in PDO areas. Furthermore, the proposed approach offers a flexible and scalable framework that can be applied to other regions with beekeeping potential.



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A Multicriteria Spatial Framework for Assessing Beekeeping Suitability

Application to a Portuguese Honey PDO Region

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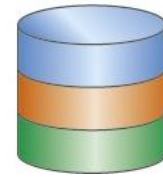
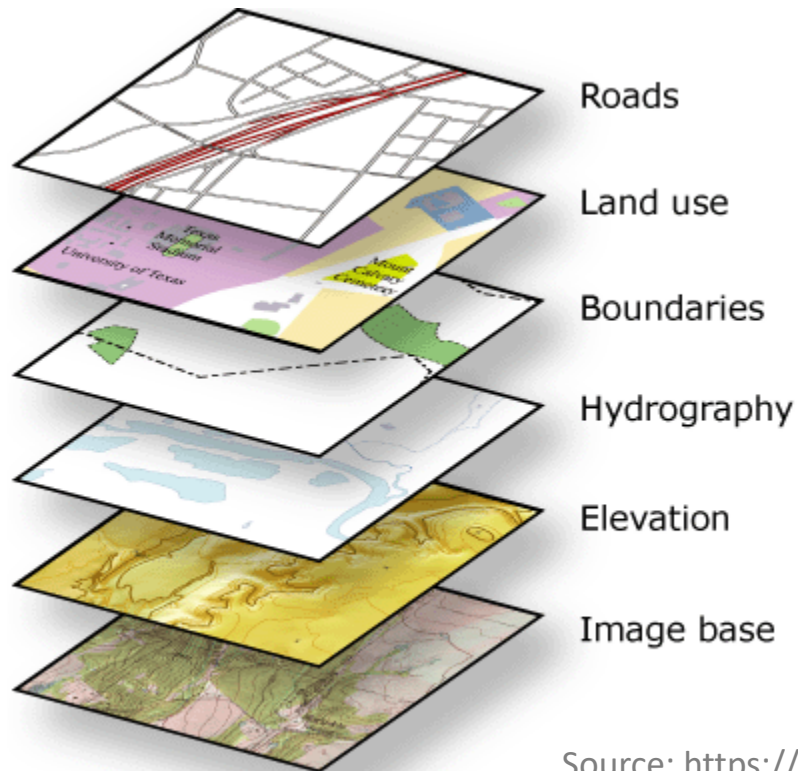
26 September 2025



Beekeeping suitability

Assessing the **potential** and **constraints** of a given area for the development of beekeeping activities.

GIS data layers



Integration



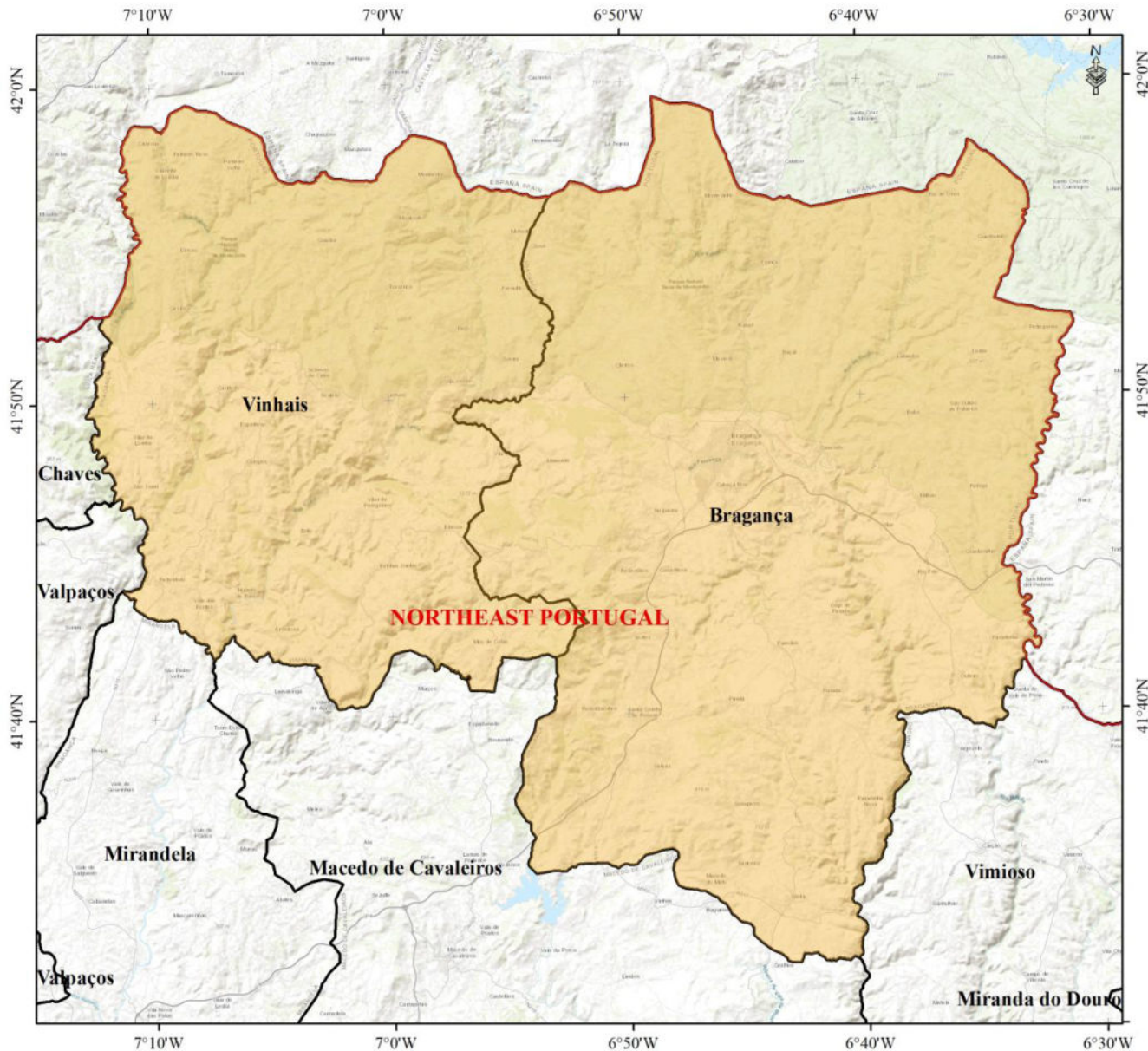
Earth's spatial representation

Objectives

- Support decision making in **selecting the best locations for apiaries**, thus maximising honey production and reducing risks of bee colony loss.
- By promoting pollination, an **increase in agricultural crop yields** is expected.



Case study



Legend:

Study area

Municipalities

CARTOGRAPHIC SOURCE:
Directorate General for Territory (DGT)

SPATIAL REFERENCE SYSTEM:
ETRS89 / Portugal TM06 (EPSG:3763)

0 2 4 8 12 km

Portuguese
region with
honey Protected
Designation of
Origin (PDO)

PDO products

- Certified quality
- Guarantee of origin
- Brand image of a region
- Higher economic value
- Sustainable production practices



Methodology – multicriteria analysis

Decision-making model Selection and weighting of criteria

Criteria categories

Climatic



Environmental



Topographic



Relative importance

Expert perceptions

Analytic Hierarchy Process



	Criterion 1	Criterion 2	Criterion n	Weighting
Criterion 1	$\frac{a_{1,1}}{\sum_{i=1}^n a_{i,1}}$	$\frac{a_{1,2}}{\sum_{i=1}^n a_{i,2}}$	$\frac{a_{1,n}}{\sum_{i=1}^n a_{i,n}}$	$\frac{\sum_{j=1}^n a_{1,j}}{n}$
Criterion 2	$\frac{a_{2,1}}{\sum_{i=1}^n a_{i,1}}$	$\frac{a_{2,2}}{\sum_{i=1}^n a_{i,2}}$	$\frac{a_{2,n}}{\sum_{i=1}^n a_{i,n}}$	$\frac{\sum_{j=1}^n a_{2,j}}{n}$
Criterion n	$\frac{a_{n,1}}{\sum_{i=1}^n a_{i,1}}$	$\frac{a_{n,2}}{\sum_{i=1}^n a_{i,2}}$	$\frac{a_{n,n}}{\sum_{i=1}^n a_{i,n}}$	$\frac{\sum_{j=1}^n a_{n,j}}{n}$



GIS processing model

Normalisation and aggregation of criteria

Beekeeping suitability

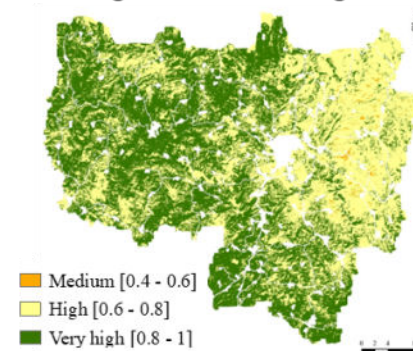
In each category

Normalised geospatial data

Criterion 1	Criterion 2	Result
0.2 0.5 0.7	0.7 0.6 0.4	0.4 0.5 0.6
0.4 0.8 0.9	0.9 0.7 0.3	0.6 0.8 0.7
0.4 0.7 0.9	0.8 0.8 0.6	0.5 0.7 0.8
Weight: 70%	Weight: 30%	Weighted sum

Final suitability

Weighted sum of categories



Land management

Location of apiaries

Land use planning



Results

Questionnaire

- Directed to experts in the beekeeping sector
- Comparison between pairs of criteria by data category (**Saaty scale**):

Numerical value	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Demonstrated importance
9	Absolute importance

Decision-making model

(Selected criteria for assessing beekeeping suitability)

Categories	Criteria
TOPOGRAPHIC [Topo]	Elevation (m) [Elev]
	Slope (%) [Slope]
	Hillside exposure [Asp]
ENVIRONMENTAL [Env]	Land use / Melliferous flora [Flora]
	Proximity to water (m) [Water]
	Proximity to rural roads (m) [Roads]
	Distance to ionizing radiation sources (m) [Ion]
	Risk of rural fires [Fire]
CLIMATIC [Clim]	Solar radiation ($\text{Wday}^{-1}/\text{m}^2$) [Rad]
	Maximum temperature of the warmest month ($^{\circ}\text{C}$) [Temp]
	Wind speed (m/s) [Wind]
	Annual precipitation (mm) [Prec]

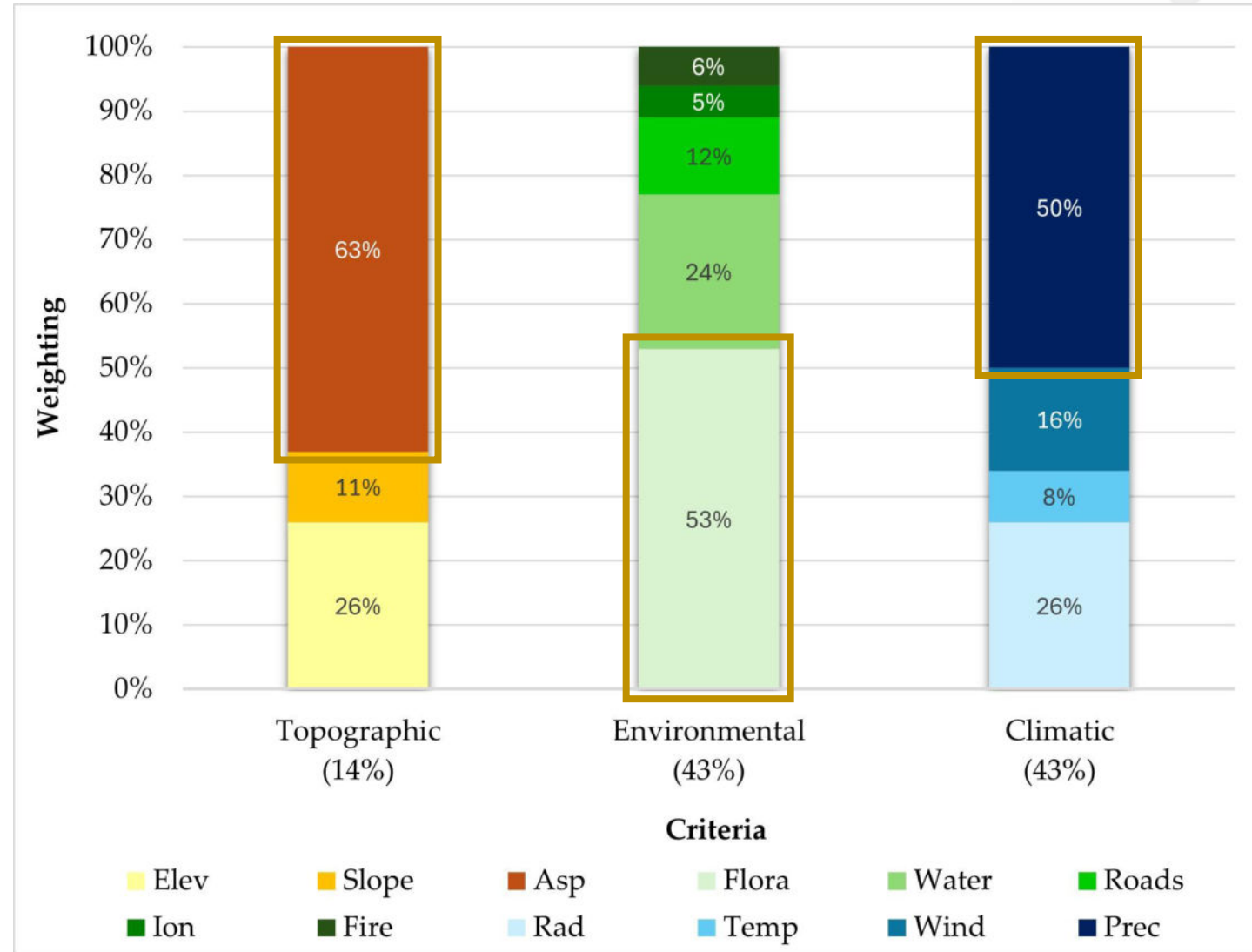
Results

Decision-making model

Criteria weighting

- **Expert judgments must be logical and coherent**, in agreement with the AHP consistency ratio recommended ($CR < 0.1$).
- **Environmental and climatic criteria** were equally important (43%).
- In each category, greater weight was assigned to **hillside exposure** (Asp, 63%), **land use** (Flora, 53%), and **annual precipitation** (Prec, 50%).

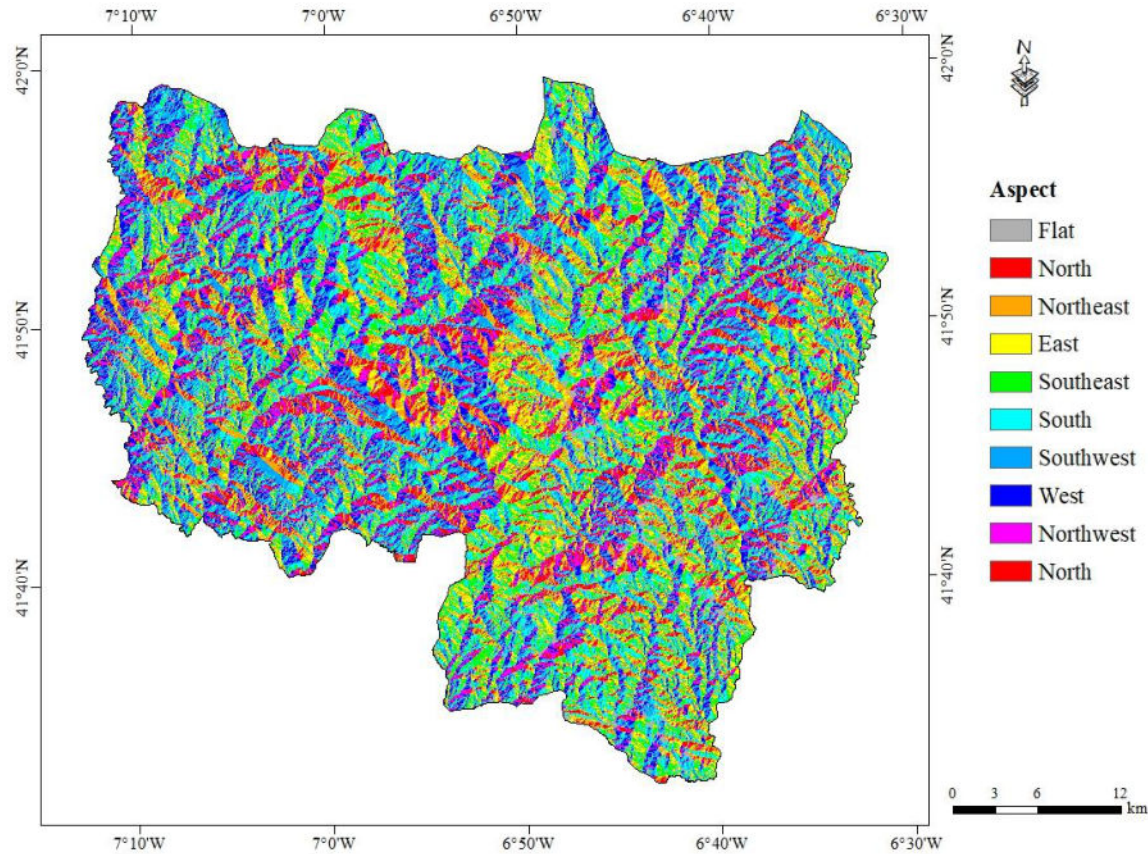
(Based on the AHP – Analytic Hierarchy Process)



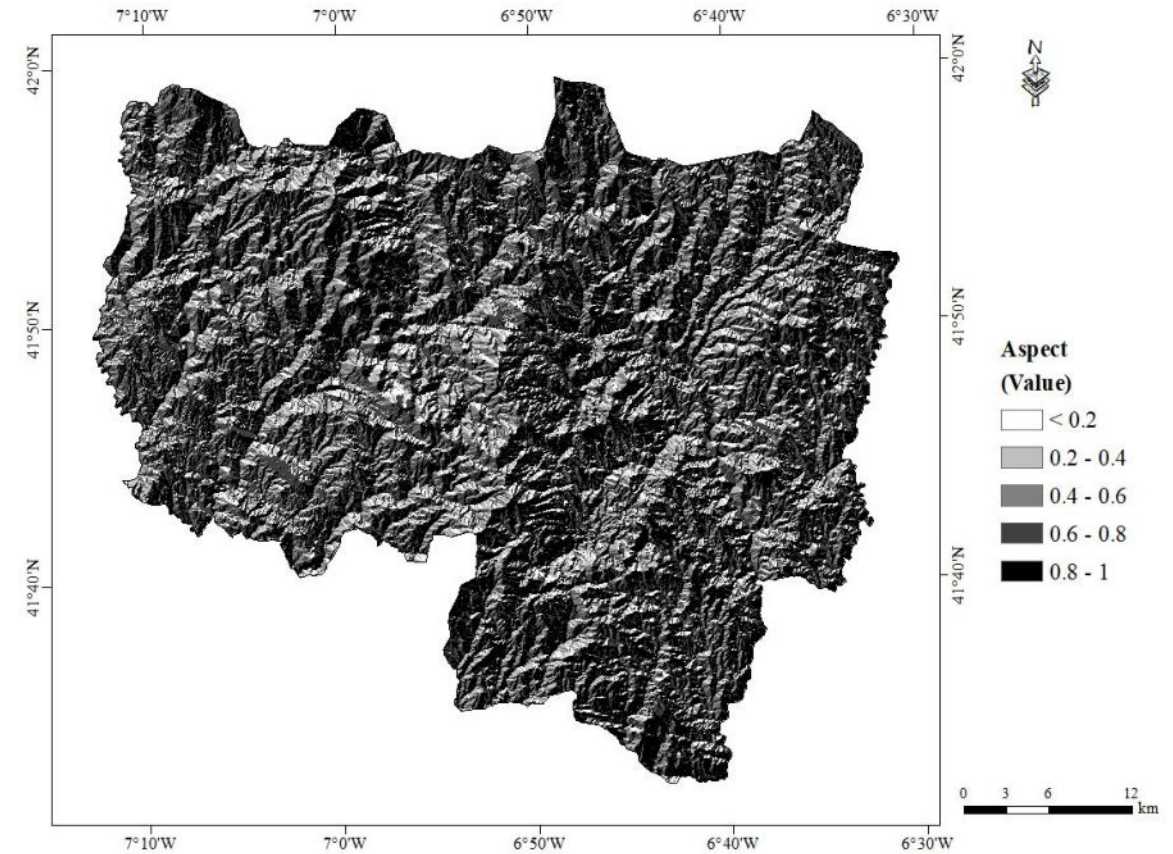
Results

GIS processing model

Topographic – hillside exposure



Spatial representation
(Derived from 10 m DTM)

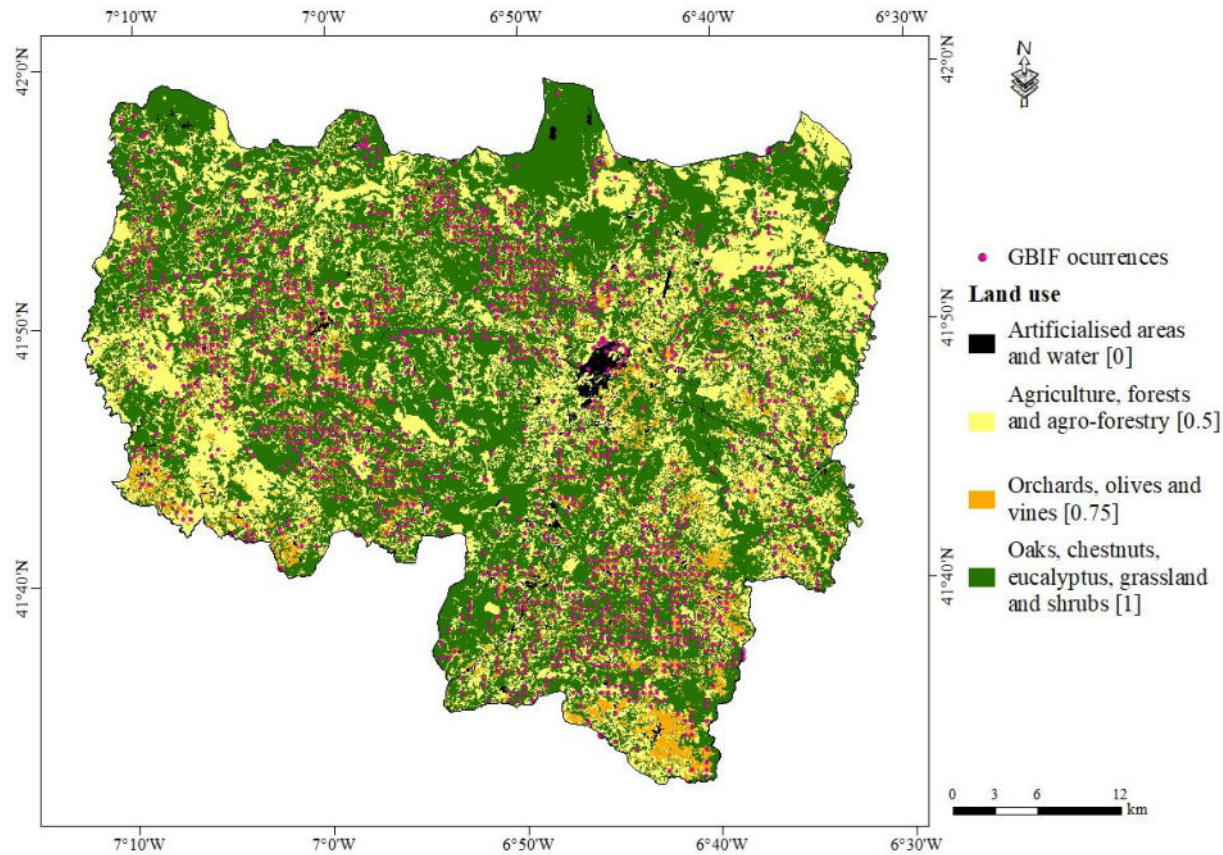


Normalised suitability map
(Reclassification: Flat, E, SE, S = 1; NE, SW = 0.75; W = 0.50; NW = 0.25; N = 0.1)

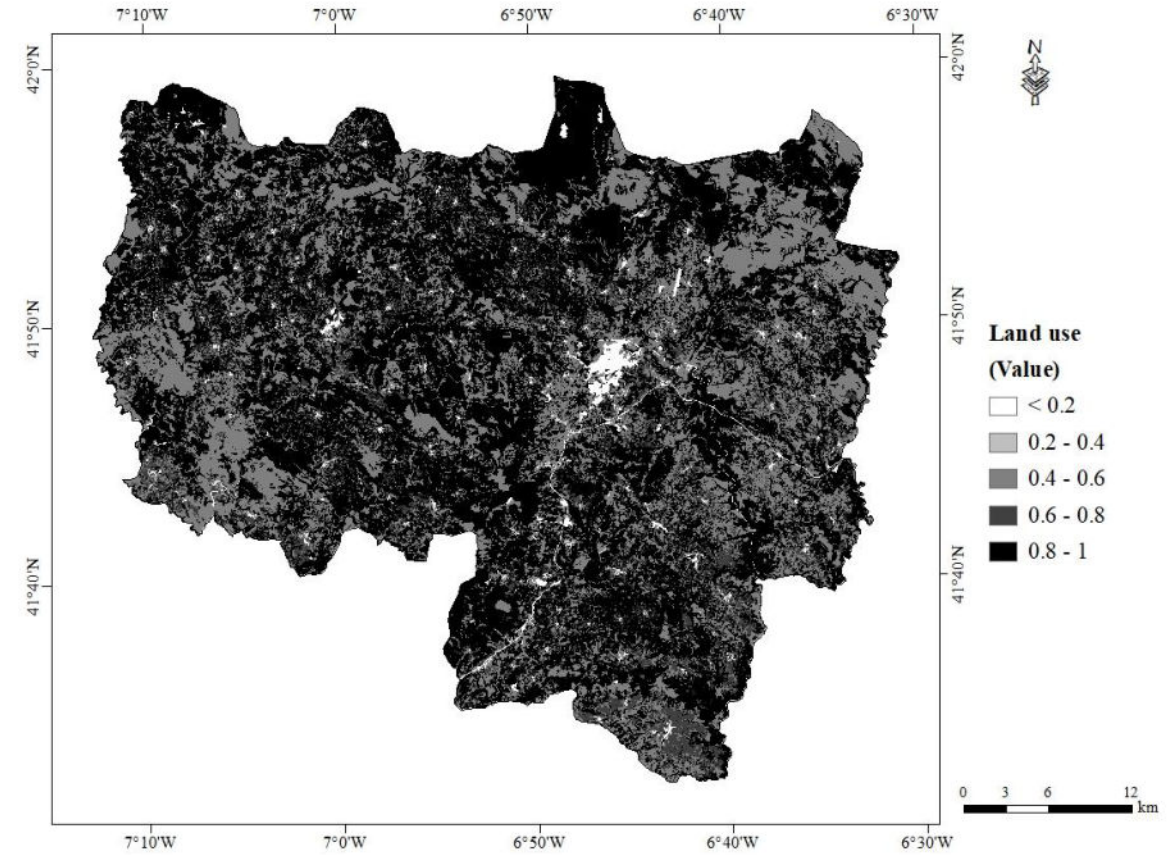
Results

GIS processing model

Environmental – land use



Spatial representation
(Derived from national databases)

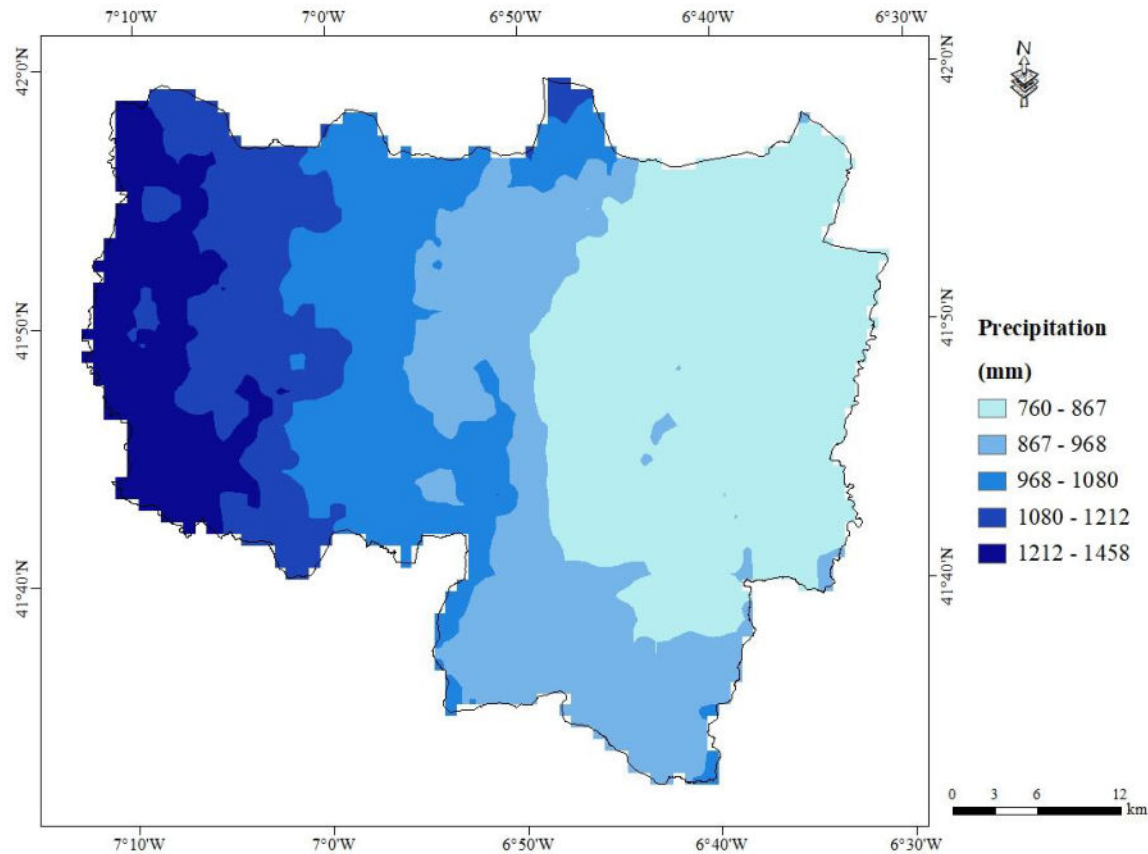


Normalised suitability map
(Reclassification based on beekeeping interest)

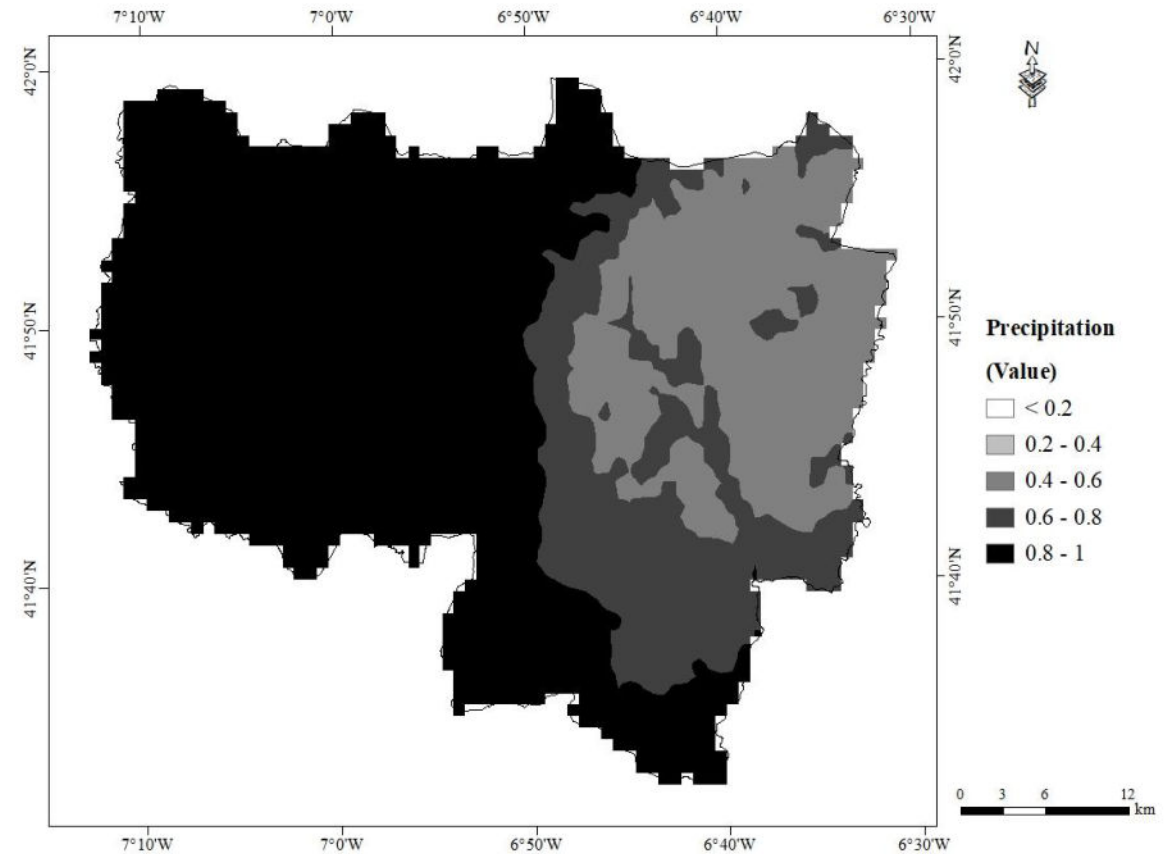
Results

GIS processing model

Climatic – annual precipitation



Spatial representation
(WorldClim, BIO12)



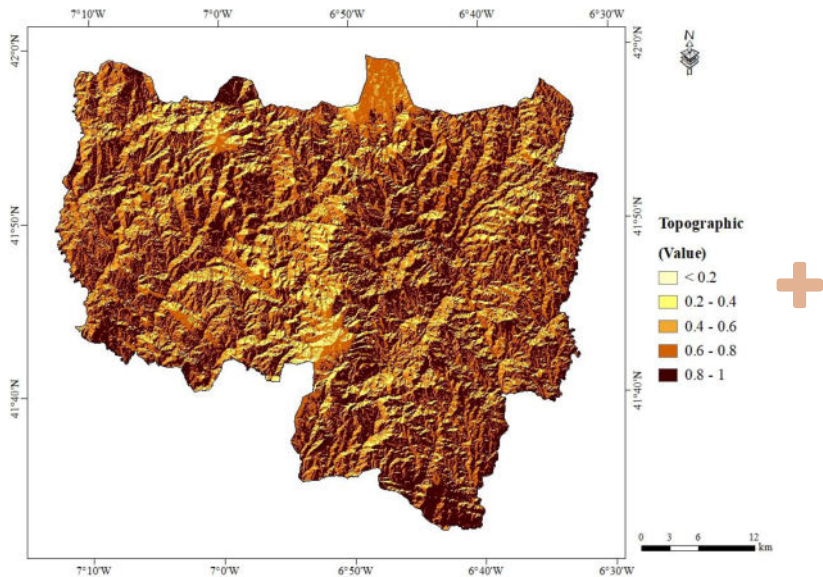
Normalised suitability map
(Minimum suitability value set at 600 mm)

Results

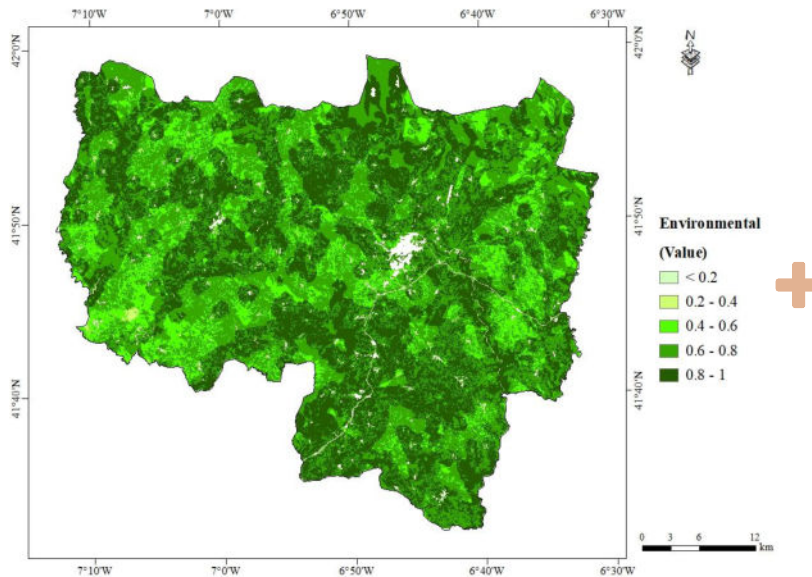
GIS processing model

Criteria aggregation

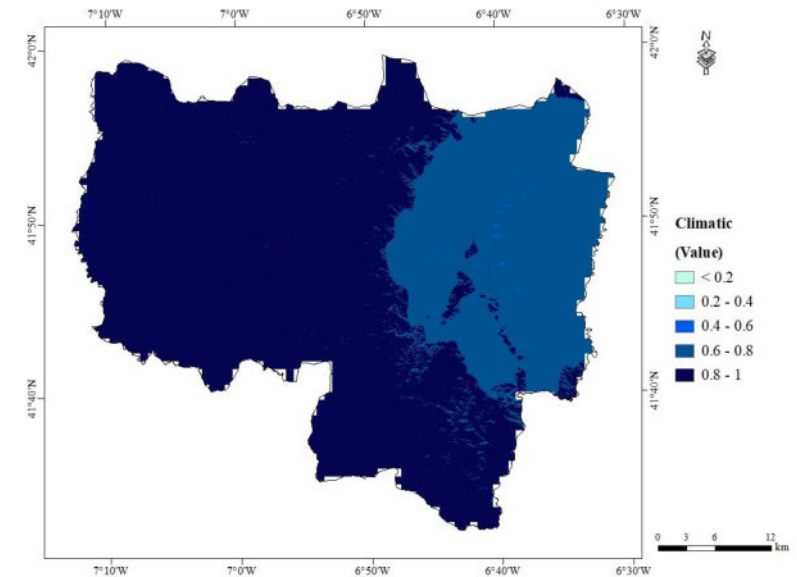
(Beekeeping suitability in each category)



Topographic (14%)



Environmental (43%)



Climatic (43%)

$$\text{Suitability by category} = \sum_{i=1}^n \text{Normalised map}_i \times \text{Weighting}_i$$

n – number of criteria in each category
 i – denotes each criterion

Results

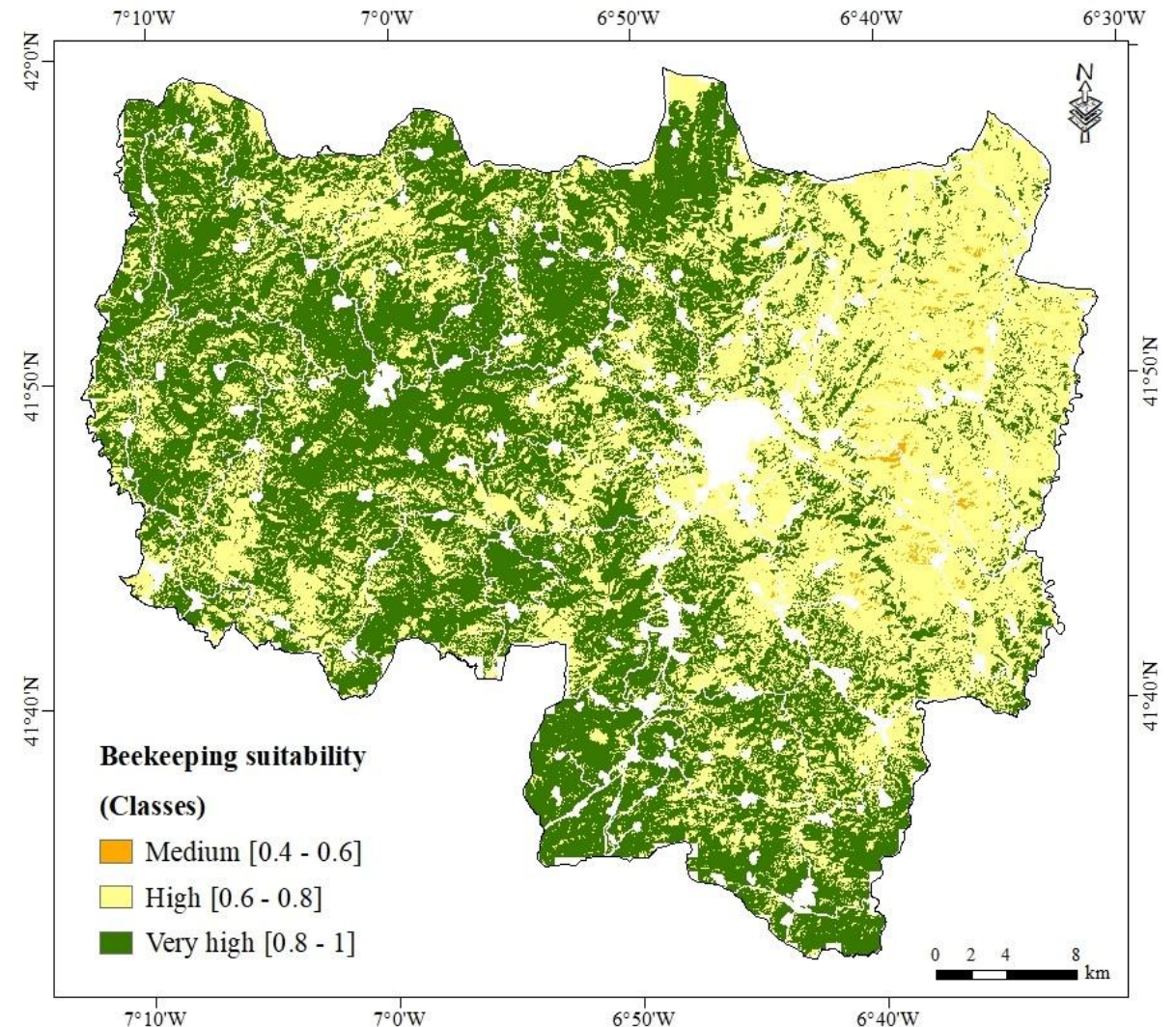
GIS processing model

Criteria aggregation

Legal constraints to beekeeping activity (Decree-Law no. 203/2005) – **100 m from any building in use and 50 m from the main roads** – were extracted (9% of the study area).

Classes	Area (%)
Medium [0.4 - 0.6]	0.6
High [0.6 - 0.8]	48.1
Very high [0.8 - 1]	51.3

(Final beekeeping suitability map)



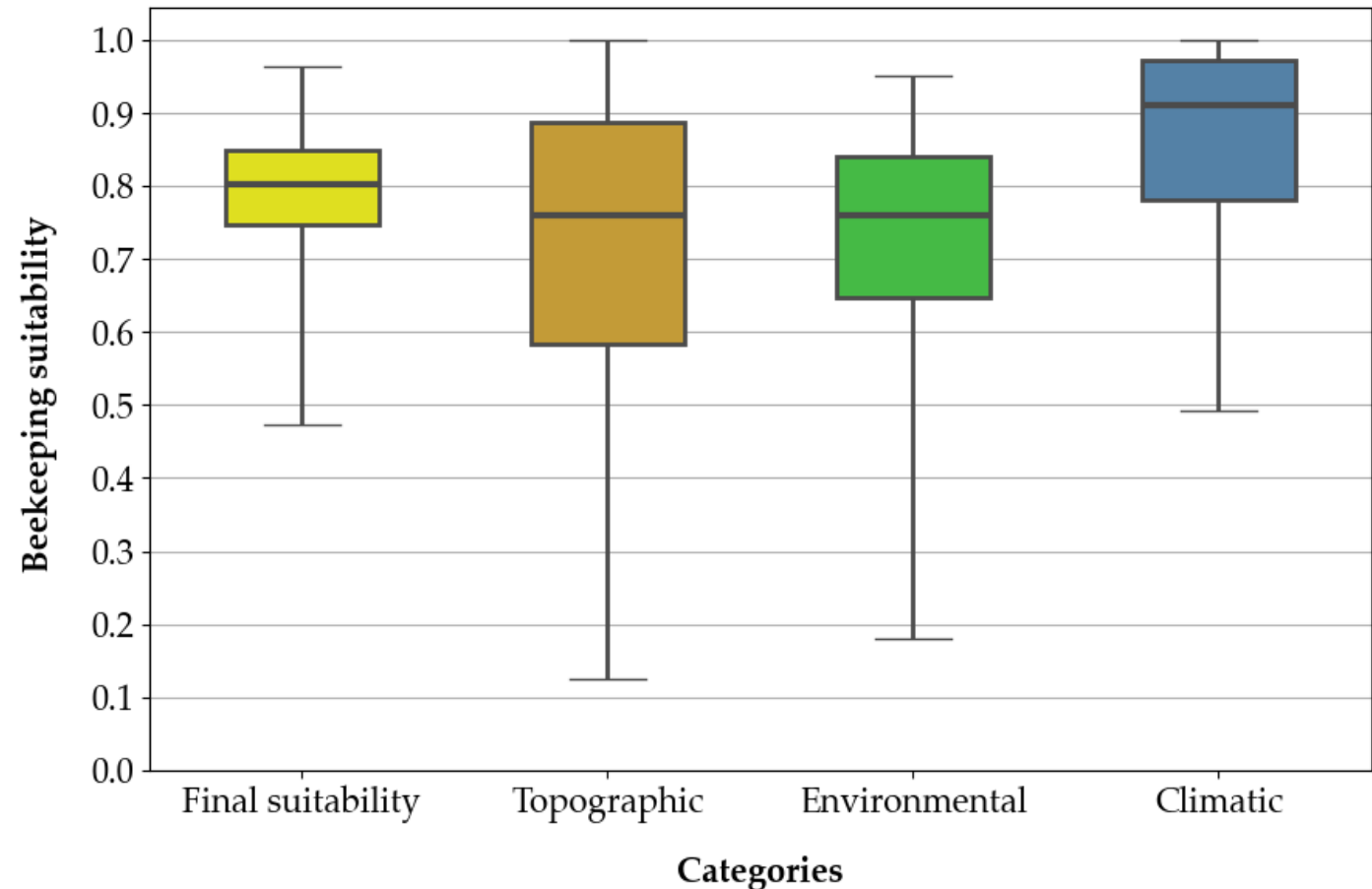
Results

GIS processing model

Criteria aggregation

- Greater dispersion of topographic values is due to the **complex terrain morphology and the finer data scale** (10 m² resolution).
- In contrast, the range of climatic values is lower, as a result of the more homogeneous spatial pattern – **coarser data resolution, and scale at which meteorological variations occur.**

(Variability of beekeeping suitability in the study area)



Results

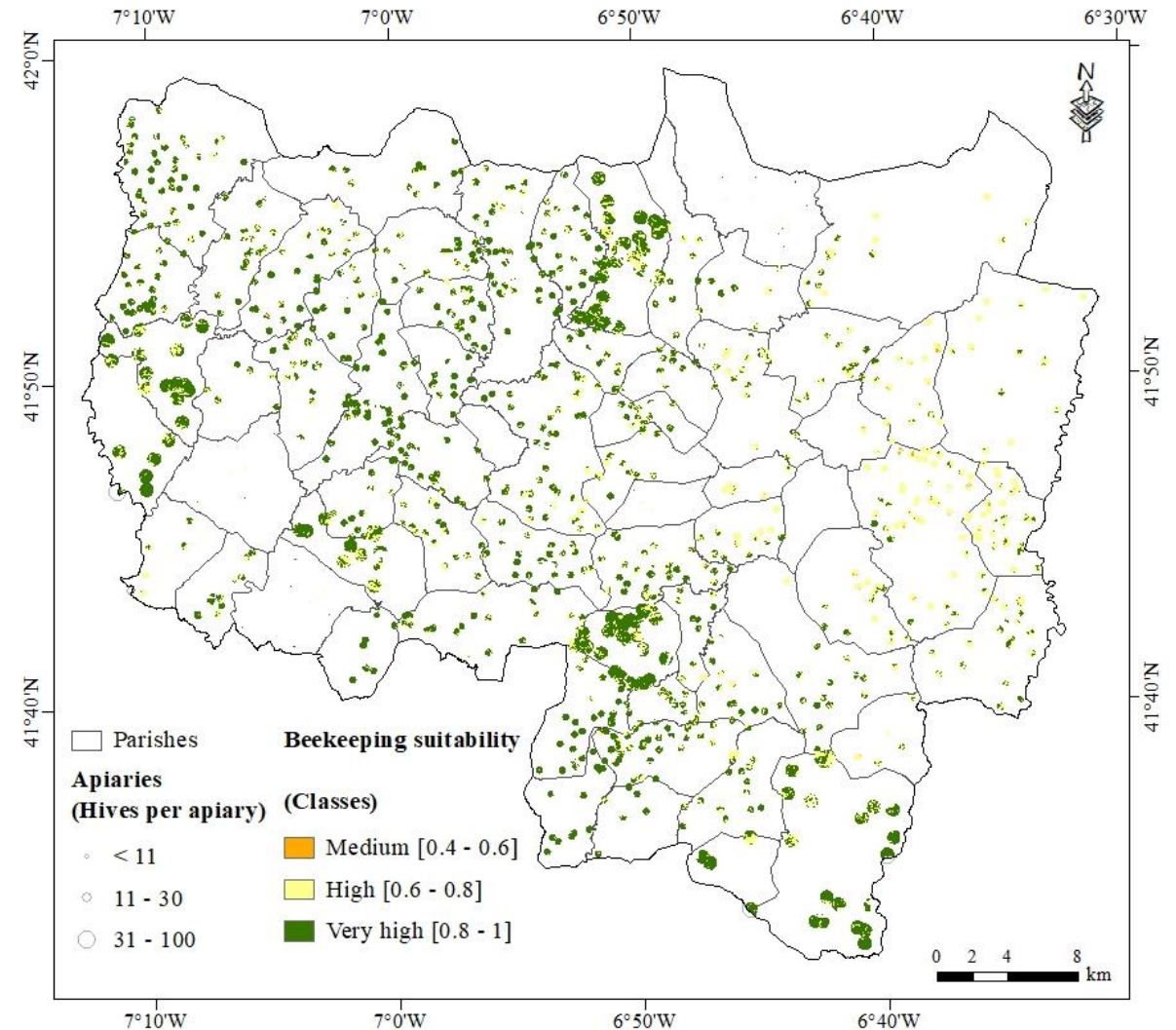
GIS processing model

Validation

Crossing the beekeeping suitability classes with the geographic location of the apiaries (1077), assuming radius of 50 m (< 11 hives), 200 m (11-30 hives) and 400 m (31-100 hives) to **set their influence range** (Dec-Law no. 203/2005).

Classes	Area (%)
Medium [0.4 - 0.6]	0.3
High [0.6 - 0.8]	36.2
Very high [0.8 - 1]	63.5

(Existing apiaries and their beekeeping suitability)



Results

GIS processing model

Validation

(Beekeeping suitability in the apiary influence range)

Classes (Potential)	Study area		Apiary influence range					
			50 m (40 apiaries)		200 m (926 apiaries)		400 m (111 apiaries)	
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Medium [0.4 – 0.6]	945	0.6	—	—	41	0.4	—	—
High [0.6 – 0.8]	80472	48.1	2	66.7	4145	40.3	1179	26.8
Very high [0.8 – 1]	86029	51.3	1	33.3	6110	59.3	3213	73.2
Total	167446	100	3	100	10296	100	4392	100

Final remarks

- **Effective engagement of beekeeping experts** is crucial for designing a robust and contextualised decision-making model.
- **Integrated analysis of biophysical and human criteria** provides a solid basis for beekeeping policy and land use planning.
- **Criteria prioritisation at the category level** reduces subjectivity in decision-making.

Final remarks

- **Reliable and detailed spatial data** are vital for identifying most suitable areas for beekeeping.
- **AHP and GIS coupling** proved to be a powerful analytical and geoprocessing methodology.
- Findings contribute to enhance the beekeeping management and honey quality in PDO areas – **environmental and socioeconomic sustainability**.
- This approach offers a **flexible and scalable framework** – projection to other regions with beekeeping potential.



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Thanks for your attention!



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