A MULTIVARIATE CLUSTERING APPROACH FOR A GIS BASED TERRITORIAL CHARACTERIZATION OF THE MONTEPULCIANO D'ABRUZZO DOCG "COLLINE TERAMANE"

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ABSTRACT

The aim of the project was to characterize the Premium Denomination of Guaranteed Origin (DOCG) "Colline Teramane" wine-growing region and to delineate and define homogeneous zones (terroir units) within it, by applying a multivariate clustering approach combined with geomatics. The inventory, characterization and classification of the land resources included components of climate (temperature and rainfall from meteorological stations), landform (Digital Elevation Model) and lithology (geolithologic map). Managing of environmental variables was performed using a GIS. From the environmental variables, vine-related derived indices (bioclimatic: Huglin index, cool night index, Riberau-Gayon-Peynaud index; and morphologic: Aspect, Topographic Wetness Index, Curvature, Slope, Incoming Solar Radiation) were calculated, spatialized and implemented to the GIS. Then, normalized variable values for each raster cell were use in a PCA followed by a multivariate clustering algorithm (Isodata) to obtain a continuous morpho-climatic map, in which each cluster represented a unit or zone. Finally, the morpho-climatic map obtained was overlaid with the geolithologic map. The result shows different morpho-climatic conditions located over different lithotypes.

KEYWORD

Geomatics, GIS, Agro-ecological zoning, multivariate clustering, terroir unit.

INTRODUCTION

The Montepulciano d'Abruzzo "Colline Teramane" is an Italian wine-growing region located in the province of Teramo (Abruzzo Region), between 13°46 and 13°53 east longitude and 42°25 and 42°54 north latitude that awarded the Premium Denomination of Guaranteed Origin (DOCG) in 2003. Yet, within the territory not only DOCG wines are produced, but also DOC ("Denomination of origin" and "table") wines, which counts for the larger extension of vineyards and the greater volumes of wine produced. The Montepulciano d'Abruzzo is among the most produced and sold wines in Italy and one of the Italian wines most exported abroad. However, to rest competitive, today wine industries need to meet not only the quality and price requirements to satisfy the market demands, but must also comply with a series of increasingly stringent standards imposed by Italian and European legislation. In this scenario, sustainable viticultural development requires a systematic effort towards the planning of land use activities in the most appropriate way. An effective action through this direction is represented by the completely knowing all the factors that, in a given environment, can modify the potentiality and performance of vineyards.

Currently it is widely accepted that land variability can be managed to optimize winegrape production and to define reliable criteria for planting and managing of vineyards (Lamb, 2000; Bramley, 2000; Bramley and Lamb, 2003; Van Leeuwen et al. 2004; Brancadoro et al., 2006). The identification of relatively homogenous regions of expected crop performance, within a given territory, has potential benefits for improved agricultural policy formation and resource conservation (Zhou et al. 2003; Patel, 2004; Vadour and Shaw, 2005; Williams et al., 2008). Therefore, spatial and time-related analyses of the physiographic characteristics (topography, geology, climate, etc.) of a wine-growing region, and the evaluation of their interactions with vegetation, are crucial for the success and the sustainability of the vineyard establishment and management process (Seguin and Van Leeuwen, 2006).

The Abruzzo Region lacks from an integrated study of the territory, although information regarding climate, morphology and soil use exist. Thus, this research project aims to contribute to fulfil this gap, taking as model scenario the "Colline Teramane" premium wine-growing area.

MATERIALS AND METHODS

Study area. The Montepulciano d'Abruzzo "Colline Teramane" area of interest (AOI) was defined following the instructions given in the product disciplinary. According to this, vineyards can be placed up to 600mAMSL when exposed to south and up to 500mAMSL otherwise. For this reason the AOI (Fig.1) was delimited using the elevation information contained in a 10x10 m DEM.

Figure 1. Abruzzo Region, Teramo Province and "Colline Teramane" Area of Interest (AOI)

Acquisition of environmental dataset. Data regarding climate, morphology, lithology, and soil use was incorporated into a GIS (ArcGIS version 9.1; ESRI Inc. USA):

- *Climate*. Series from 1996 to 2007 inter-annual daily means of climatic variables (minimum, maximum and mean air temperature, precipitation) were acquired from 28 georefered meteorological stations located along the AOI and boundaries (Ascoli Piceno and Pescara). The following bioclimatic indices were calculated for each station: Huglin Index (HI), Cool Night Index (CNI) (Tonietto & Carbonneau, 2004), estimated potential evapotranspiration as Ribereau-Gayon-Peynaud (RGP) index (Giomo et al., 1996). The bioclimatic indices were interpolated for the whole AOI using the Inverse Distance Weighted algorithm.
- *Morphology*. A raster format 10x10 m/pixel Digital Elevation Model (DEM) was acquired from the Abruzzo Regional Agency for the Development and Services in Agriculture (ARSSA). DEM derivates (slope, topographic wetness index (TWI), curvature and incoming

solar radiation (ISR)) were calculated using the ArcGIS tools to incorporate them as layers into the classification algorithm.

- *Soil use*. The line border of every vineyard present in the territory was acquired from AGEA (Italian Agency for the Supplies in Agriculture) as shapefile format.

PCA and multivariate geographic clustering. Zones were created by applying a Principal Component Analysis (PCA) followed by a multivariate clustering. The multivariate space was equal to the number of layers used: HI, CNI, RGP, DEM, Slope, Topographic TWI, Curvature and ISR. First, variable values of each raster cell in the 8 layers were standardized (from 0 to 1). Then a PCA was performed using a forward rotation. Similarity of cells within the 8-dimensional data space was then coded as Euclidean separation distance. Cells were then clustered using the non-hierarchical unsupervised iterative algorithm ISODATA –"*Iterative Self-Organizing Data Analysis Technique*" (Mather, 2004) setting the maximum change threshold to 5%.

Overlaying. The morpho-climatic map resultant from the multivariate clustering was overlaid with a 1:200.000 scale geolithological map (D'Alessandro et al., 2007) to distribute the morpho-climatic zones in different lithotypes. We called these zones viticultural Agroecozones.

RESULTS AND DISCUSSION

The spatial analysis of the different environmental layers permitted a preliminary characterization of the "Colline Teramane" winegrowing area, from a climatic and morphologic point of view. However, soil parameters (pedology) are lacking because unavailability of data within the Teramo Province. It is evident that such information is crucial especially when aiming sustainable agronomic practices. Nevertheless, derived vine-related indices such as bioclimatic and morphologic modelled in a GIS, allowed to better understand the spatial variability of the main morpho-climatic parameters affecting wine grape development. On the other hand, the classification approach has enabled a preliminary identification of eight homogeneous zones (terroir units) within the AOI. Considerations derived from these classifications are important for differentiated management, decision making assessment and agricultural regional policies recommendations.

Bioclimatic indices. The HI (Fig 2a) ranges from 2100 to 2900 day-degrees which correspond to temperate warm class and warm class of viticultural climate, characterized by a potential which exceeds the heliothermal needs to ripen the Montepulciano d'Abruzzo grapevine and other varieties currently grown within the AOI, even the late ones (with some associated risks of stress). The CNI (Fig 2b) ranges from 12 to 17°C, which means that there is an intermediate condition between cool nights and warm nights and that a maximum threshold of night temperature favourable to ripening will not be exceeded for any variety. The estimated potential of evapotranspiration (RGP index) is higher near the coast (Fig 2c), and when combined with high HI values, conditions for hydric stress may be favoured.

Morphology. The morphology of the Teramo Province is well modelled by the accurate resolution of DEM (Fig 3a). The slope (Fig 3b) indicates the inclination grade of the hills. The Topographic Wetness Index (TWI) (Fig 3c), indicates that the major probability for water logging is present near the river curses and downhill (TWI higher values), where the slope is minimum. The curvature index is in accordance with the TWI and slope maps, as it indicates the convex or concave zones. The slope affects the overall rate of movement downslope while the aspect defines the direction of flow. The profile curvature affects the acceleration and deceleration of flow and, therefore, influences erosion and deposition. The planform curvature influences convergence and divergence of flow. The incoming solar radiation (Fig 3d) evidence the grater sunlight irradiation over the hilly zones exposed to south and through plane zones as those near the river courses.

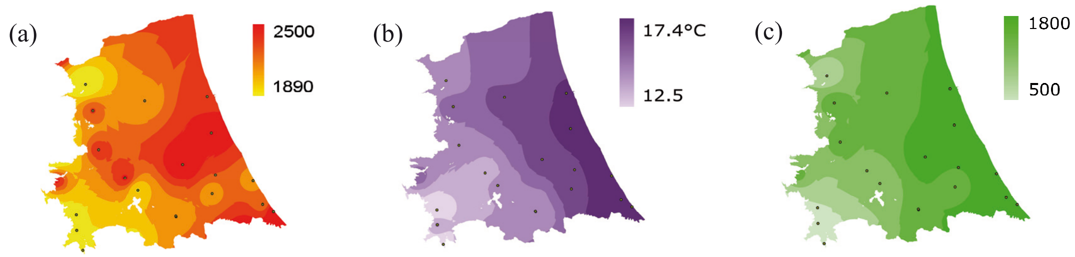

Figure 2. Bioclimatic indices: (a) HI in day-degrees, (b) CNI in °C and (c) RGP.

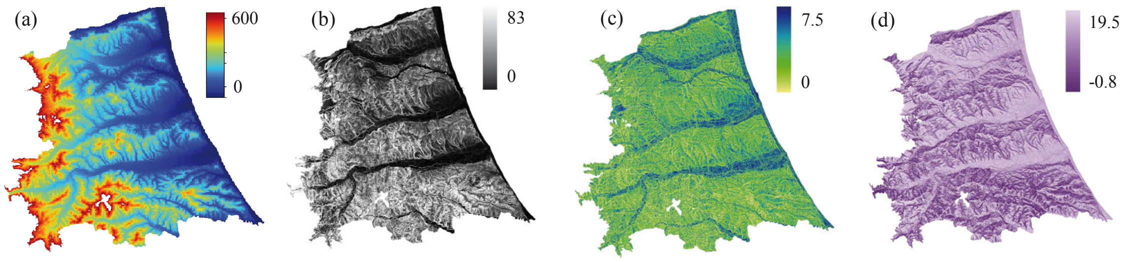

Figure 3. DEM (a) and derivates (b) Slope degrees, (c) TWI, (d) ISR.

PCA and Multivariate Clustering. The results of PCA applied to the bioclimatic and morphologic layers are shown in Table 1. Because the first PC counts for the 94% of total variability, it was the only one considered for the multivariate ISODATA clustering, which produced a morpho-climatic map with three different homogeneous zones or classes (Fig. 4). Class A and B extend from the coast to hill zones and are predominant in extension. Class C occupies the higher altitudes of the territory, but because the reduced extension and low vineyard presence it was not taken into account for the further classification. Class A presents the highest energy potential because it comprises the hilly zones mainly exposed to south and the plane zones (rivers and coast), which means higher values of incoming sunlight and temperatures. Class B is mainly exposed to north and comprises only hills. Moreover, vineyards are mainly located on Class A counting for the 81% of total vineyards within the AOI, while the 18% is located in Class B and only the 1% in Class C.

Table 1. Eigenvalues and original layer contribution to the first three PCA

Layer	Eigenvalues (%)	DEM	TWI	SLOPE	ISR	CURV	HI	CNI	RGP
PC1	94.24	0,043	0,027	0,009	0,183	0,059	0,246	0,224	0,210
PC2	4.05	0,880	0,014	0,040	0,000	0,000	0,006	0,016	0,044
PC3	0.81	0,024	0,199	0,544	0,166	0,010	0,008	0,014	0,035

Overlaying. The morpho-climatic map was overlaid with the geo-lithologic one, resulting eight important classes. From the viticulturist point of view, four classes are of great importance: A5 (class A in clayey lithotypes) that counts the 58.7% of total vineyards, B5 (class B in clayey lithotypes) that counts for the 18.3% of total vineyards, A2 (class A in gravelly-sandy lithotypes) that counts for the 20% of total vineyards and B8 (class B in pelitic arenaceous lithotypes) that counts for the 2.3% of total vineyards.

Classes A5 and B5 interest hilly and coastal areas over a common clayey lithotype. Clayley lithotypes are generally impermeable, and thus, are characterized by a high hydric retention capacity; as a consequence, the influence of the exposure is strong: when hills are exposed to south (as happens when class A5 occurs) erosive phenomena could be favoured as well as the formation of badlands, with evident soil erosion risk; otherwise, when hills are exposed to north (as happens when class B5 occurs) runoff phenomena could be favoured. On the other hand, when gravelly-sandy lithotypes occurs, because they are very permeable and are usually placed over waterproof lithotypes, they could be sites of local water tables even at modest depths. Moreover, when the potential of evapotranspiration is too high (i.e. south-east of the AOI), in this kind of lithotypes the risk for hydric stress is elevated. Nevertheless, this preliminary territorial classification must be improved by incorporating pedology information (currently not available within the Teramo Province).

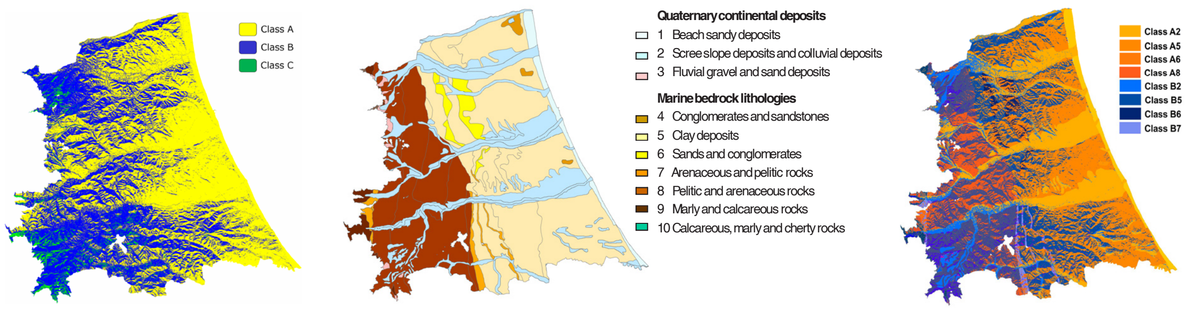

Figure 4. (a) Clustering map, (b) Geolithologic map and (c) AEZ map

CONCLUSION

The GIS-based characterization of the "Colline Teramane" premium wine-growing area evidence that a differentiated agronomic approach is necessary to overcome the different scenarios identified in each class or AEZ. However, to enhance the prediction value of the AEZs delineated in this research work and ensure strong bases for further studies, two important activities are crucial: (1) the incorporation of soil composition information into the model (currently non available within the Teramo Province), and (2) the correlation and validation of AEZs with canopy and yield/quality response of grapevines. This would permit to study and put over statistical basis the terroir of the Montepulciano d'Abruzzo grapevine. As a first contribute for a better and more complete integrated knowledge of the viticultural system of the "Colline Teramane", this knowledge should be addressed towards a more rational agronomic management of the viticultural patrimony, as well as to the planning and programming of new vineyard implants, especially taking into account the new EU regulations for the wine market.

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