Enhancing the Integrated Terroir Zoning via Digital Soil Mapping: application in the Designation of Origin Campo de Borja

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Keywords: Integrated Terroir Zoning, Digital Soil Mapping, Spatial disaggregation, Homogeneous Terroir Unit, Terroir vocation

Abstract

The Integrated Terroir Zoning methodology captures soil information from Soil Resource Inventories, which have traditionally been generated by conventional soil mapping methods. However, these have shortcomings in achieving fine cartographic and categorical detail and involve significant investments. A recent framework named Digital Soil Mapping has established quantitative soil-landscape models using statistical techniques and can provide feasible intensive scale cartography. In this study, an existing terroir zoning is renewed by replacing the conventional soil map with polytaxic soil units by a new one from digital techniques that disaggregates them. For the comparison, Homogeneous Terroir Units are quantitatively assessed using the Viticultural Quality Index and categorised per map accordingly. The spatial intersection of these maps gives rise to a confusion matrix where flows of class variations after the substitution are evaluated. The results show a five-fold increase in Homogeneous Terroir Units and a larger differentiation among them in the new zoning, together with a further identification of higher potential areas within previously undervalued uniform zones. These features derive from the implementation of Digital Soil Mapping techniques, and such highly detailed terroir units would benefit precision viticulture and sustainable management practices.

Introduction

The zoning technique is the recommended approach to characterise and delimit terroirs (OIV, 2012). It consists of analysing the territory to divide it into relatively homogeneous zones: those showing similar strengths and limitations for grapevine development in terms of their environmental attributes and geographical location (Fregoni et al., 2003). Zoning methodologies have been closely tied to the development of techniques for environmental characterisation. They were initiated via descriptions and historical justifications and have traditionally taken the form of land use and suitability maps or landscape models (Gómez-Miguel, 2011). Advances in such techniques and new technologies have led the "International Organisation of Vine and Wine" (OIV) to promote new complex methods based on the combination of the existing ones (OIV, 2012). The so-called Integrated Terroir Zoning (ITZ) adopts this approach (Gómez-Miguel & Sotés, 1992, 2002, 2015).
ITZ combines three partial zonings of environmental factors: soil, climate, and landscape (combining geomorphology and lithology), whose integration gives rise to the delimitation and characterisation of "Homogeneous Terroir Units" (HTU). Then, the viticultural vocation of every unit can be expressed quantitatively through the Quality Index (QI) (Gómez-Miguel & Sotés, 2015).
Each partial zoning relies on particular parameters and methodologies from their respective disciplines. Specifically, the soil zoning corresponds to a Soil Resource Inventory (SRI) map, one that has traditionally been generated by conventional methods. The adoption of the recent Digital Soil Mapping (DSM) framework (McBratney et al., 2003), which supersedes the conventional one, along with the cartography produced by it, featuring mostly single component Soil Map Units (SMU), has the potential to improve this partial zoning and, thus, the outcome of the ITZ.
Existing terroir zonings derived from conventional SRIs can be improved by the disaggregation of the map units approaching within the DSM framework. This way, soil information already available in combination with new

data sources can be exploited to increase the cartographic detail of the SRI while using fewer resources. The Designation of Origin (DO) Campo de Borja terroir zoning (Gómez-Miguel & Sotés, 2015) meets these conditions and offers a big potential for improvement.
The present research aims to develop a new terroir zoning following the ITZ methodology for the DO Campo de Borja that outperforms the initial one by improving its SRI, as the partial zoning of the soil. This action is then evaluated. The improvement is achieved by the disaggregation of the conventional soil map containing polytaxic or multi-component SMUs into a new map showing mostly monotaxic or single component SMUs. The result is a new map of new HTUs, that are more detailed and better assessed in quantitative terms than the original ones. Altogether, this series of actions establishes an approach to satisfy part of the demand for detailed cartography required by the Precision Viticulture field.

Materials and methods

Research site

The research was conducted in the DO Campo de Borja, in north-eastern Spain (41° 55' 28.9" to 41° 37' 15" N and 1° 44' 34.5" to 1° 19' 1.6" W). It is an old wine-growing region of 653.37 km^2 where 6,416.14 ha of vineyards are grown (2019), and it extends from the piedmont of the Moncayo Range (2,316 masl) to the Ebro river terraces, between 250 and 900 masl. The river network shapes its relief and it is composed of geological materials from Mesozoic formations, with an alternation of limestone, marl, and sandstone. The climate is continental with an Atlantic influence in winter.

Data sources

Soil zoning and soil information

The initial soil zoning it is a conventional soil map that comes from an ITZ project of the region (Gómez-Miguel & Sotés, 2015). It was produced at a 1:25,000 scale following the Soil Survey Manual (Soil Survey Division Staff, 1993) and includes SMUs of associations and complexes with phases (343) gathering 5.6 components on average of main Soil Taxonomy Units (STU) and inclusions (Figure 1). These are classified according to Soil Taxonomy into soil series (20) and, where not possible, families assigned to specific lithologies (122). From the entire set of observations sampled during the conventional process, a set of 519 soil point observations is used. They correspond to soil profiles described, sampled, and analysed in all their horizons, and they are classified according to Soil Taxonomy and are allocated to one of the STUs listed in the map legend. Conversely, a disaggregated soil map derived from the conventional one provides the revised and more detailed soil zoning at an approximate scale of 1:10,000. It was generated following a disaggregation methodology from the DSM framework, where SMUs are divided by the unsupervised classification algorithm CLARA with Mahalanobis distance to reveal soil homogeneous areas that are then correlated with the STUs from the map legend (Lázaro-López, 2022).

Climate and landscape zonings

The climate and the landscape zonings are sourced from the initial ITZ project (Gómez-Miguel & Sotés, 2015) (Figure 1). The climate zoning comprises 9 units, mainly defined by climatic parameters and bioclimatic indexes. Moreover, the landscape zoning is made out of a stratification from the geological map of the project, with 50 lithostratigraphic units, and the aerial photo interpretation, regarding aspect, slope, elevation, and the presence of distinctive conditions such as hydromorphism, gypsum and soluble salts, gravels and rock fragments, and terraces.

Vineyards

A dataset of vineyard characteristics and delimitations is built upon the «Vineyard Register» (REVI), an inventory of viticultural data by plots in Spain, and the «Geographical Information System for Agricultural Plots» (SIGPAC). Altogether, it is formed by 10,046 geometries of plots with a total area of 6,252.2 ha, most of which are dedicated to the Garnacha and Tempranillo varieties.

Data management, GIS, and statistical software

The project data was managed from a database implementing a model for SRI in Spain and terroir (Lázaro-López et al., 2018), powered by PostgreSQL and its spatial extension PostGIS. The workflow was developed with R and using specialized packages: ‘Tidyverse’, ‘sf’, and ‘caret’, as well as the QGIS desktop software.

Procedure

The ITZ methodology aims to characterise and to delimit homogeneous areas by intersecting several partial zonings of major factors that influence vineyard growth, namely soil, climate, and landscape (lithology and geomorphology). This involves the spatial intersection of the corresponding zoning maps to generate geographical units of unique combinations of all the attributes, the HTUs. In this application, the original climate and environmental zonings are combined with the disaggregated soil map to form the new zoning and HTUs.
Afterwards, the viticultural quality of the HTUs is quantitatively assessed using the QI, as a numerical value projected over a range from 0 to 100. Similarly, the occupancy rate of growing areas per HTU is estimated in the so-called Occupation Index (OI), as the percentage of the total surface. For every index and according to its distribution within the project region, a non-linear categorisation by hierarchical clustering into 5 classes is established to facilitate its analysis. This evaluation system is applied individually both to the original terroir zoning and to the new one based on the disaggregated soil map.
The QI class memberships of both maps are confronted with a confusion matrix based on their spatial intersection. The analysis of reallocation flows between the zonings, i.e., changes in the quality ratings on the same areas among the maps, attempts to estimate the effects introduced by the enhancement of the new soil zoning while keeping the other two partial zonings equal. In addition, an OI model is built from partial QIs regarding environmental parameters to support the terroir assessment and the analysis developed based on it are relevant to characterise the vineyard distribution.

Results and discussion

New HTUs from the disaggregated soil map

The integration of the disaggregated map and the other two partial zonings by intersection resulted in the new zoning units, characterised by higher cartographical detail and smaller average size (Table 1). Altogether, 4,460 unique combinations of soil, climate, and landscape properties and parameters were identified as the new HTUs, compared to 957 in the original one. Meanwhile, the number of delineations corresponding to these units on the new map rose from 3,142 to 38,445.

QI

A QI value was calculated for each of the new HTUs. Its distribution within the region is skewed towards very low values, where few HTUs account for the highest values. Dividing it into 5 classes by hierarchical classification resulted in dense clusters with clear spacings: class 1 show the highest mean, which decreases markedly in class 2 and to a lesser extent between the successive classes 3, 4, and 5. Areas corresponding to each of these classes were uneven (Figure 2). Out of the 61,423 ha belonging to the project region (excluding miscellaneous areas), approximately 2% was covered by class 1 and 6% by class 2, whereas the remaining 92% was similarly distributed among the other classes. In contrast to the initial zoning map, there was a substantial increase in class 1 (approximately 600%) as well as a 30% decrease in class 2 and slight variations in the remaining classes (Table 2).
The confusion matrix from the intersection between the HTUs categorised by the QI of both zoning maps shows a high degree of coincidence, either based on the 63% Overall Accuracy or the 0.48 value of the Kappa Index (Table 2). From the perspective of how the new zoning was shaped from the baseline, the agreement between classes 5 is high, i.e., those with the lowest QI values. This fact and a minimal variation in the class area reflect the stability of delimitation and quantification of those potentially less favourable terroirs. The agreement is also strong between classes 2, 3, and 4, although somewhat lower. However, such agreement is remarkably weak between classes 1. Nearly half of the total size of this class in the original zoning map was kept, yet the total area in the new zoning increased significantly due to a shift from lower categories, most noticeably from class 2. A similar flow was repeated in classes 2 and 3 leading to a relatively large amount of area within a lower category gaining in valuation. In term of zoning this may indicate an upgrading trend, whereby delineations were further fine-tuned, and higher QI zones were identified within them. In this sense, this is a positive result of the new zoning. Between classes 4 and 5 there were exchanges with a low net value, which could similarly denote the restructuring of the delineations.

OI

Like QI, an OI value was calculated for every HTU based on data of vineyard plots within the region. Approximately 43% of the 4,460 new HTUs were covered to some extent by vineyards. Nevertheless, this distribution was not uniform and was skewed towards low values with a few HTUs showing high occupation rates. Such a distribution may point out that vineyard locations might not have been random, but rather conditioned by certain criteria of the winegrowers. Part of these criteria would be related to those environmental factors that influence the grapevine development and that are indeed embedded within the terroir notion. In this regard, there is no direct correlation between OI and QI (0.16). However, modelling the OI from partial QI factors of the parameters is significant (p-value: $< 2.2e^{-16}$) with a slight variance explanation (R^2: 0.142). In other words, parameters included in the QI give a limited but relevant explanation of how vineyard distribution is characterised. Specifically, the following factors are identified as significant (p value < 0.05) in positive: slope, climate, SMUs, active limestone in the profile and lithostratigraphic units; and in negative: the highest soil electrical conductivity measured in the saturated paste extract within the profile, the ratio between concentration and percentage of exchangeable potassium in the profile, and the textural class within the profile.

Conclusion

Using a disaggregated soil map as SRI within the ITZ methodology to renew the terroir zoning of the DO Campo de Borja led to:

i) A larger identification of HTUs within the project region, with a five-fold increase in number.
ii) A better differentiation takes place, evidenced by a wider range in the quantification through the QI.
iii) A substantial amount of higher potential areas by QI noted within originally undervalued uniform zones, although the two maps are fairly consistent. This effect was much more pronounced in those areas with better QI.
iv) Such QI considered a range of parameters that were identified as significant to understand the vineyard distribution in the project region.

These insights come directly from the improvements in terms of cartographic and categorical detail via DSM techniques. Ultimately, they would benefit precision viticulture and sustainable management practices.

Table 1. Cartographic features of the reference zoning and the new zoning maps.

Map	Homogeneous Terroir Units (nº)	Delineations (nº)	Average-size area (ha)	Optimal scale of publication[1]
Reference zoning (from conventional soil map)	957	3,124	20.39	1:35,700
New zoning (from disaggregated soil map)	4,460 (+466%)	38,445 (+1,207%)	1.59 (-93%)	1:9,993

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Table 2. Confusion matrix from the intersection between the Homogeneous Terroir Units categorised by the Quality Index of the reference zoning (columns) and the new zoning (rows), showing cumulative areas (ha) and relative accuracy metrics.

		Area from the Reference zoning (ha)					Total area (ha)	User's accuracy (%)
		1	2	3	4	5		
Area of classes from the New zoning (ha)	1	75.49	879.14	57.74	5.00	2.60	1,019.97	0.074
	2	60.78	2,341.36	1,351.62	160.84	21.33	3,935.93	0.595
	3	2.27	1,700.35	8,462.34	5,052.71	416.49	15,634.16	0.541
	4	0.42	183.43	3,781.98	11,895.04	3,711.68	19,572.55	0.608
	5	20.52	28.69	1,181.90	4,141.52	15,877.08	21,249.71	0.747
Total area (ha)		159.48	5,132.97	14,835.58	21,255.11	20,029.18	61,412.32	
Producer's accuracy (%)		0.473	0.456	0.570	0.560	0.793	Overall accuracy (%)	0.629

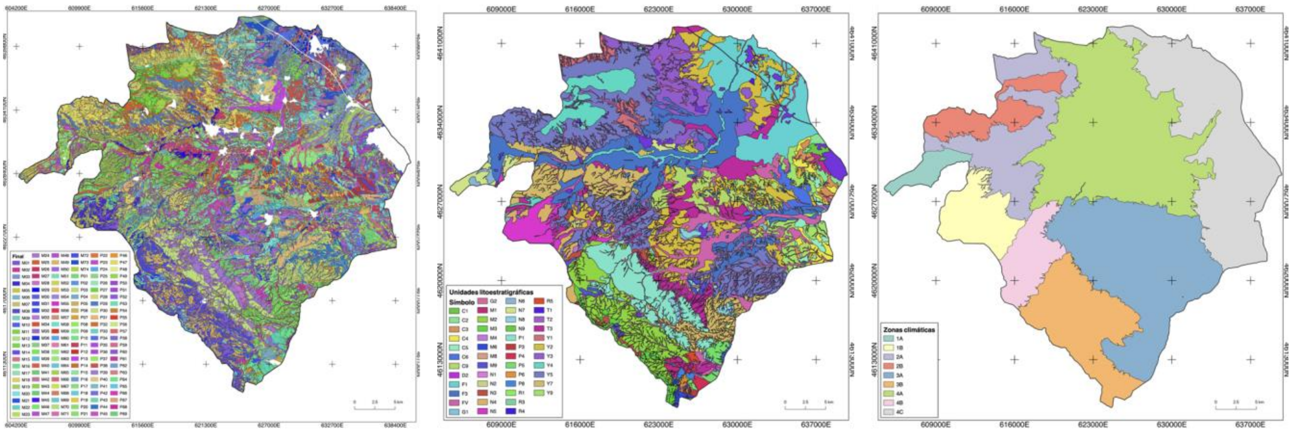

Figure 1. Partial zonings for the new terroir zoning: disaggregated soil map (left), geological map with lithostratigraphic units (middle), and climate zoning (right).

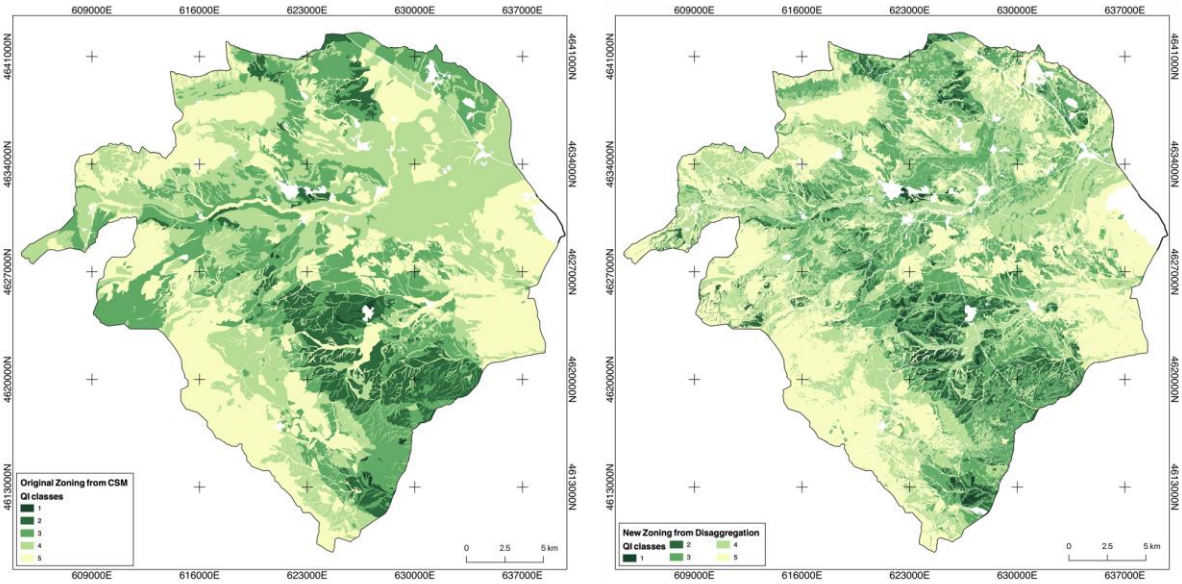

Figure 2. Homogeneous Terroir Units categorised using the Quality Index of the initial zoning map (left) and the new zoning from the disaggregated soil map (right). They show a high degree of coincidence.

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