FRACTAL ANALYSIS OF THE HYDROLOGICAL INFORMATION OBTAINED FROM HIGH-SPATIAL RESOLUTION DEMS: APPLICATION IN TERROIR ZONING OF D.O. CAMPO DE BORJA (SPAIN)

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Abstract
One of the characteristics of the terroir zoning studies that is more complex to manage is the scale dependence. Thus, terroir zoning studies of the same area at different scales are comparable but not equal. Fractal analysis has demonstrated to be a suitable tool to characterize and model natural elements within a defined range of scales.
Nowadays, the fast evolution of the GISs and the availability of high-resolution topographic information allow to carry out studies considered unthinkable some decades ago.
Parallelism between the elements which condition the drainage networks of a landscape, and the elements which define the terroir has been observed. It is well known by geomorphologists that the shape of the drainage networks (dendritic, parallel, radial, etc.) depends on natural factors such as climate, vegetation and geological characteristics, particularly lithology and structure, which also characterize the terroir of a region.
The main objectives of the present study are the quantitative characterization, using techniques of fractal analysis, of the drainage networks of the D.O. Campo de Borja, and the analysis of its relationship with the vineyard distribution within the region. The studied drainage networks have been extracted from a DEM with a resolution of 5 meters.
The results show the suitability of the study and encourage to deepen into the relationship between the drainage networks crossing the landscape, the geological and topographic characteristics of the environment, and the distribution of the vineyard within the region.

Keywords: fractal analysis, terroir zoning, drainage networks, vineyard distribution, DEM, GIS

1 INTRODUCTION

According to the OIV Resolution VITI/333/2010, the vitivinicultural terroir is a concept which refers to an area in which collective knowledge of the interaction between the identifiable physical and biological environment and applied vitivinicultural practices develops, providing distinctive characteristics for the products originating from this area. Thus, terroir concept includes specific soil, topography, climate, landscape characteristics and biodiversity features. Extracting the vitivinicultural practices from the terroir definition, the physical and biological features that define it are the same factors, additioning time, which determine the Earth’s morphology.
One feature of Earth’s morphology that is also the result of climate, tectonics, geology and time are the drainage networks (Lifton and Chase, 1992). Drainage networks represent the way water flows through the landscape and their shapes are closely related to the flora and fauna distribution within the ecosystem.
The quantitative analysis of drainage networks mainly started with the works of Horton and Strahler in the middle third of the last century (Horton, 1932, 1945; Strahler, 1952, 1957). These studies, which normally took a river basin as study unit, showed up the underlying laws controlling the shape of the drainage networks. In order to address the complexity involved in these features, the coming up of fractal geometry in scientific scene (Mandelbrot, 1983) led to the development of new analysis tools. The fractal and multifractal nature of drainage networks have been widely demonstrated (Rodríguez-Iturbe and Rinaldo, 1997, De Bartolo et al. 2000), but the application of this fractal nature in interdisciplinary fields remains unclear. The importance of using lithological information to the establishment of study units rather than river basins, has been recently suggested (Bloomfield et al. 2011, Cámara et al. 2013).
Traditionally, drainage networks have been obtained by photogrammetric restitution which is a laborious technique that takes a long time. The evolution of the Geographic Information Systems in the last decades and the development of specific algorithms (O’Callaghan and Mark, 1984; Tarboton, 1997) allow the automatic extraction of drainage networks from digital elevation model (DEM) data. These advances, and the fact that the quantity, quality and availability of DEM data is increasing continuously, encourage to keep investigating the implication of the fractal properties of natural features in applied studies.

The main objectives of the present study are the quantitative characterization, using techniques of fractal analysis, of the drainage networks of the D.O. Campo de Borja, and the analysis of its relationship with the vineyard distribution within the region.

2 MATERIALS AND METHODS

The Designation of Origin "Campo de Borja" is the wine growing region where this study has been carried out. This region (65.308 has) is located in the western half of the province of Zaragoza, in the northeast quadrant of the Iberian Peninsula. The DO involves many different lands, in a wide range of altitude (239-1154 m), from the steep slopes of the Moncayo (2.314 m), formed by Triassic and Ordovician materials, to the low lands of the DO, over the quaternaries lower terraces of the Ebro river. Nowadays, the wines made from Garnacha grapes of this region enjoy recognized standing.

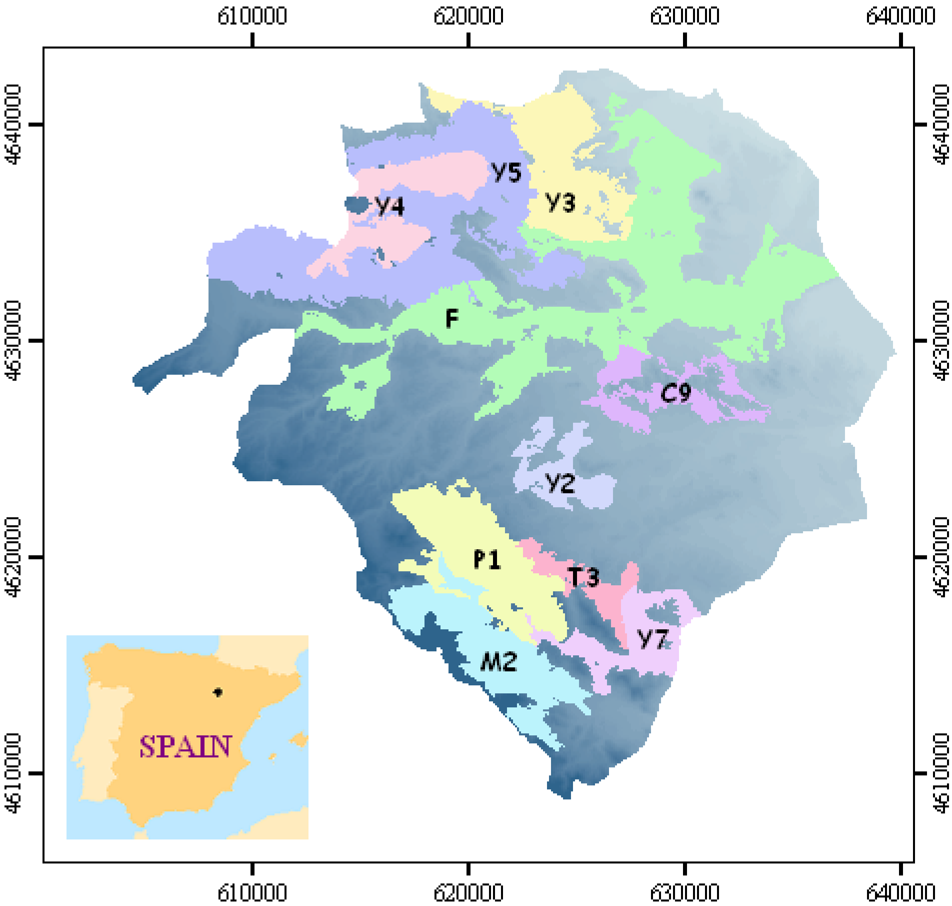

Figure 1: Overview of the study area showing the lithologic units under investigation. Projected Coordinates System UTM ETRS89 30N

Three sources of information have been used in this study; DEM data, vineyard information and the lithological information of the region. DEM data come from the Instituto Geográfico Nacional de España® and correspond to a DEM generated from LiDAR data. Density of this LiDAR data is 0.5 point/m^2 and DEM resolution is 5 meters. These data are freely available under registration. DEM data have been used to generate the drainage networks and to obtain the hypsometric curves. The vineyard information corresponds to data of the year 2012 from the Viticultural Registry of Aragón. This information has been joined to georeferenced information of the agricultural plots for the cartographic operations. The lithological information used in this study, scale 1:25.000, corresponds to the lithological information included in the soil map of the D.O. Campo de Borja, scale 1:25.000, that is being developed. Lithological information has been rescaled, by photointerpretation of aerial photograms (23x23 cm) scale 1:18.000, from the National Geographic Map of Spain scale 1:50.000. The 10 lithological map units analyzed in this study correspond to the 10 mayor lithologies (Table 1) of the 52 different lithologies identified in the study area. These 10 lithologies together involve the 81.0 % of the total area of the DO.

Table 1: Description of the 10 studied lithologies

Symbol	PERIOD	ERA	EPOCH	LITHOLOGY
F	Quaternary	Cenozoic	Pleistocene-Holocene	Alluvial materials and lower terraces of main flows
T3	Tertiary - Q.	Cenozoic	Pliocene-Pleistocene	Glacis
Y5	Tertiary	Cenozoic	Miocene	Detrital materials with carbonate levels
Y4	Tertiary	Cenozoic	Miocene	Compact limestones. Argillaceous and siliceous
Y3	Tertiary	Cenozoic	Miocene	Calcareous clays, brown silts and grey silts
C9	Tertiary	Cenozoic	Miocene	Gypsum with silex. Gypsiferous clays and silts
Y7	Tertiary	Cenozoic	Miocene	Conglomerates, sandstones and siltstones red
Y2	Tertiary	Cenozoic	Miocene	Calcareous clays, red silts and grey silts
M2	Secondary	Mesozoic	Triassic	Conglomerates and sandstones (paleochannels)
P1	Primary	Paleozoic	Ordovician	Quartzites, sandstones and shales.

Drainage networks have been extracted from DEM data using the Hydrology Toolbox included in the software ArcGIS 10.1. The method employed in ArcGIS is based on the D8 algorithm (O'Callaghan and Mark, 1984). An area of 20.000 m^2 has been established as flow accumulation threshold value.

The selected method of fractal analysis for the estimation of the fractal dimension has been the box counting method. Introduced by Russel et al. (1980), this method is clearly described in Rodríguez-Iturbe and Rinaldo (1997). The object, that in this case is the drainage system belonging to each one of the studied lithologic map unit (LMU), is covered by a regular grid of side r. Then, the number of grid boxes containing the object is counted N(r). Value r is progressively halved obtaining the series of N_i values (Figure 2). Taking a reference box size (r_1), the size factor is calculated as $s_i = r_i / r_1$. When r_i is decreasing log N_i/log ($1/s_i$) converges to a finite value defined as box counting dimension (Figure 3). In this study the reference box size is 320 m, and the other box sizes considered for the estimation of the fractal dimension are 160 m, 80 m, 40 m and 20 m. This range of box sizes has been successfully employed in previous works (Cámara et al. 2013).

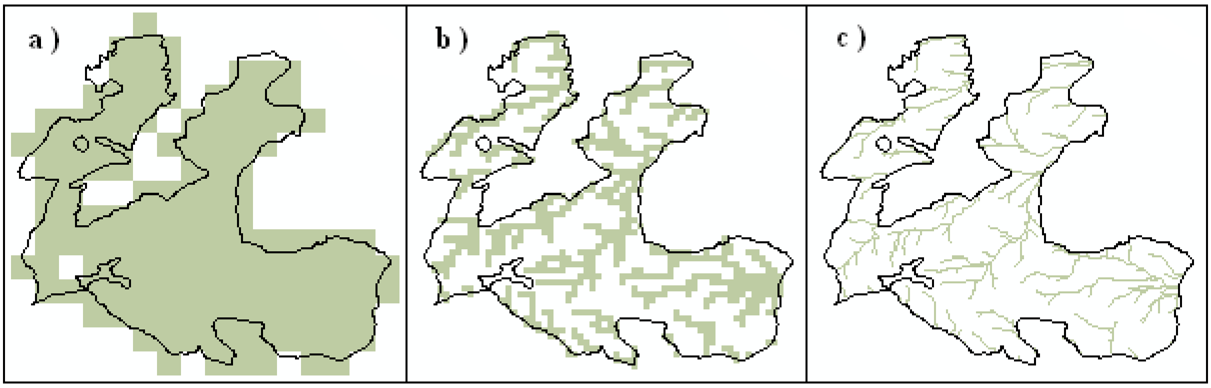

Figure 2: Images of the box-counting method applied to the drainage network of the lithologic unit Y2. Boxes intercepted by the drainage networks with boxes sizes of 320 m (a), 80 m (b) and 20 m (c)

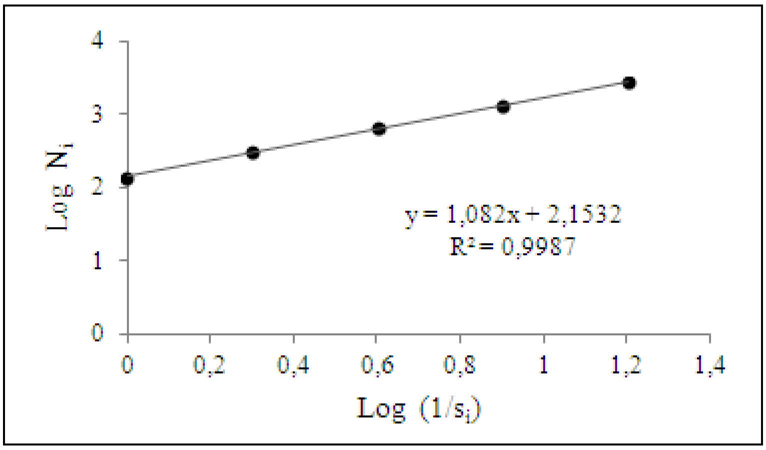

Figure 3: Log-log plot of the number of boxes that intersect the object (N_i) vs. the size factor of the intersected boxes ($1/s_i$) for the drainage network of the lithologic unit Y2

3 RESULTS AND DISCUSSION

A quantitative approach to the morphological properties of the 10 lithological map units (LMUs) has been conducted in order to complement the results of the fractal dimension estimation. Table 2 shows that the selected LMUs involve the 43.3 % of the total area of the DO, and encompass the 82.8 % of the altitude range of the DO. Estimations of the fractal dimension are also shown in Table 2. Values of fractal dimension range from 1.2760 for the alluvial materials of unit F, to 1.0785 for the compact limestones of unit Y4. It is remarkable that the coefficient of determination (R^2) of the linear fit in the log-log plot (Figure 3) for estimation of the box-counting dimension is higher than 0.994 in the 10 studied drainage networks. This result clearly shows the suitability of the selected fractal technique, which includes the box counting method and the box size range, to capture the complexity involved in the shapes of the drainage networks at the study scale. Three highest values of fractal dimension appear in the three youngest lithologies, which suggests that higher values of fractal analysis correspond to less consistent lithological materials. Results show a positive linear relationship between the fractal dimension and the drainage density, with a coefficient of determination $R^2 = 0.7055$, and a weak negative linear relationship between the D and the HI (R2 = 0.3544).

Table 2: Quantitative description of the extension, the topography and the drainage network of the LMUs

Lithologic map unit (LMU)	Total area (hectares)	Altitude range (m.a.s.l.)	Hypsometric Integral (HI)	Fractal dimension (D)	Coefficient of determination for D estimation (R^2)	Drainage density (km/km^2)
F	8554,8	276 - 721	0,1798	1,2760	0,9940	7,72
T3	725,5	491 - 699	0,4279	1,1740	0,9940	6,45
Y5	5865,6	365 - 783	0,4928	1,1834	0,9957	5,56
Y4	1765,1	567 - 808	0,6722	1,0785	0,9986	3,48
Y3	2558,9	308 - 453	0,3655	1,1730	0,9970	5,36
C9	1255,2	368 - 512	0,5069	1,0872	0,9976	5,26
Y7	1371,3	487 - 748	0,3103	1,1199	0,9959	5,57
Y2	1020,9	457 - 577	0,4083	1,0820	0,9987	4,83
M2	2422,1	563 - 972	0,5134	1,1571	0,9965	5,01
P1	2764,1	583 - 1034	0,3636	1,1002	0,9989	3,66

The study of the vineyard distribution shows that vineyards represent the 9.5 % of the total area of the D.O. This percentage is a little higher in the 10 studied lithologies (11.1 %). The selected LMUs seem to be a representative sample of these lithologies including a vineyard area of the 11.4 % of the total area.
Values of D, shown in Table 2, are weakly related to some variables reported in Table 3. The fractal dimension of the drainage networks shows positive linear relationships with the percentage of the total area of the LMU covered by irrigated vineyard ($R^2 = 0.4114$). Results show that there is not any relationship between D and the percentage of vineyard area ($R^2 = 0.0123$).

Table 3: Some characteristics of the vineyards of the 10 studied LMUs

Lithologic map unit (LMU)	Vineyard area (hectares)	Vineyard area (%)	Irrigated vineyard (%)	Remaining vineyard previous to 1960 (%)	Remaining vineyard previous to 1990 (%)
F	1567,6	18,3	79,6	4,20	17,69
T3	294,9	40,7	5,4	6,23	27,02
Y5	194,7	3,3	22,9	3,86	28,31
Y4	1,1	0,1	0,2	0,00	22,94
Y3	258,1	10,1	92,2	1,36	11,58
C9	146,4	11,7	10,3	1,54	8,90
Y7	171,4	12,5	0,0	3,83	48,05
Y2	369,7	36,2	19,2	1,10	26,38
M2	117,6	4,9	0,0	2,70	47,23
P1	104,6	3,8	0,0	0,58	6,96

There exists a positive linear relationship, with a $R^2 = 0.4280$, between the fractal dimension of the drainage networks and the percentage of the productive vineyards older than 50 years, but there is not any relationship between the fractal dimension and the percentage of productive vineyards older than 20 years ($R^2 = 0.0016$). It is necessary to consider for the results interpretations that the 79.4 % of the vineyard included in the 10 LMUs were established after 1990, and if these vineyard were planted out of the traditional growing areas the presence of vineyards could not be an evidence of viticultural suitability.

4 CONCLUSION

The relationship between the drainage networks that cross the landscape and the vineyard distribution within the winegrowing region D.O. Campo de Borja was investigated on 10 areas of homogeneous lithology which represent the 10 mayor lithologies in the area of the D.O.

Drainage networks were generated from high-spatial resolution DEM using GIS technologies, and they were characterized estimating its fractal dimension by the box-counting method.

The results of the fractal dimension estimations, supported by the high values of the coefficient of determination (R^2), show the suitability of the adopted method to characterize the drainage networks developed on different lithological materials.

Although the terroir is characterized by the same natural factors that control the shape of the drainage networks, no clear relationships have been found between the fractal dimension of those networks and the distribution of the vineyards within this winegrowing region.

However, there are weak positive linear relationships between the fractal dimension of the drainage network and different variables such as the percentage of irrigated vineyard or the percentage of vineyards planted more than 50 years ago.

The inclusion of more viticultural information in this study, such as rootstocks, grape varieties and historical production data, could enlighten new relationships and would enrich the results.

A useful application in terroir zoning of the characterization of drainage networks showed in this work could be the development of new tools based on GIS technologies for lithologic identification and delineation from topographic data.

The results of this study encourage to deepen into the relationship between the drainage networks crossing the landscape, the geological and topographic characteristics of the environment, and the distribution of the vineyards in winegrowing regions.

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