GIS APPLICATIONS IN VITICULTURE. THE SPATIAL DISTRIBUTION OF CLIMATIC SUITABILITY FOR GRAPE GROWING IN HUŞI WINE-GROWING CENTRE (ROMANIA)

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ABSTRACT. This paper is part of a GIS-based approach aiming to develop the map of ecological suitability for grape growing in Huşi wine-growing centre, Huşi vineyard (Romania). The database underlying this study includes ten climatic factors and indicators that are considered to be defining for the climatic suitability of a geographic area. They are: solar radiation (kcal/cm^2/1.04-30.09), solar insolation (hours/1.04-30.09), annual average temperature (°C), the hottest month average temperature (°C), the sum of fractions of average daily temperatures above 10°C for the period from 1st April to 30 September (Σt_u°C), average rainfall for the period from 1st April to 30 September (mm), the length of bioactive period (mm), the heliothermal index (IHr), the bioclimatic index (Ibcv) and the index of oenoclimatic aptitude **(IAOe).** The values of climatic factors were grouped in three suitability classes, according to their influence on the grapes quality for wine grapes varieties, and included in a GIS database that has been used to generate the climatic suitability map of the wine-growing centre. The GIS-based analysis shows that 76.29% of Huşi wine-growing centre area has climatic potential for white qualitative wines production, 16.95% for red table wines production and 2.03% for white table wines, sparkling wines and distillates. No part of Huşi wine-growing centre has the climatic potential to produce red quality wines.

Key words: Grapevine; Vineyard; GIS; Climatic suitability; Spatial distribution.

REZUMAT. **Aplicaţiile GIS în viticultură. Distribuţia spaţială a favorabilităţii climatice pentru cultura viţei de vie în centrul viticol Huşi.** Lucrarea de faţă este parte a unui studiu GIS, care are ca scop realizarea hărţii distribuţiei spaţiale a favorabilităţii ecologice pentru cultura viţei de vie în centrul viticol Huşi, în funcţie de

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caracteristicile factorilor climatici, edafici şi orografici. Fundamentul analizei climatice a arealului, ca şi componentă a studiului GIS, îl reprezintă o bază de date care include zece factori şi indicatori climatici cu caracter sintetic, consideraţi definitorii pentru potenţialul viticol al unei regiuni geografice, respectiv: radiaţia solară (kcal/cm^2/1.04-30.09), insolaţia reală (ore/1.04-30.09), temperatura medie anuală (°C), temperatura medie a lunii iulie (°C), bilanţul termic util (Σt_u°C), precipitaţiile din timpul perioadei de vegetaţie (mm/1.04-30.09), lungimea perioadei bioactive a aerului (zile), indicele heliotermic real (IHr), indicele bioclimatic viticol (Ibcv), indicele aptitudinii oenoclimatice (IAOe). Valorile factorilor şi indicatorilor menţionaţi au fost grupate în trei clase de favorabilitate şi incluse într-o bază de date GIS, cu ajutorul căreia s-a realizat harta distribuţiei spaţiale a favorabilităţii climatice pentru cultura soiurilor de vin. Din analiza GIS a arealului rezultă că 76.29% din suprafaţa centrului viticol Huşi deţine condiţii favorabile pentru producerea vinurilor albe de calitate, 16.95% pentru producerea vinurilor roşii de masă, iar 2.03% pentru producerea vinurilor albe de masă, a vinurilor pentru distilate şi a vinurilor spumante. Conform rezultatelor acestui studiu, nici unul dintre plaiurile centrului viticol Huşi nu întruneşte condiţiile climatice necesare producerii vinurilor roşii de calitate.

Cuvinte cheie: viţă de vie; podgorie; GIS; favorabilitate climatică; distribuţie spaţială.

INTRODUCTION

This paper is part of a wider research aiming to develop the map of ecological suitability for grape growing in Huşi wine-growing centre, one of the oldest and most famous of Romania. The analyzed area is located in the eastern part of the country, at the southern limit of Central Moldavian Plateau (*fig. 1*). The study is based on *Geographic Information Systems* (GIS), tools of informational technologies currently widespread in the viticulture research. The GIS-based approaches of vineyard suitability use inputs including a large variety of physical, cultural, and economic factors which determine the suitability of environment for grape-growing (Vaudour and Shaw, 2005). The number and representativeness of the ecological factors used for such evaluations are highly variable, depending on the main climate characteristics of the region were the assessed area is situated and the researchers' approach (Scienza and Falcetti, 1991; Watkins, 1997; Boyer, 1998; Jones, 2004; Pythoud , 2006; Fulton *et al.,* 2010).

Our GIS evaluation is designed to assess the vineyard suitability in temperate continental climate areas. Applied strictly to vineyard areas it allows to find and delimit the most favourable micro-zones for wine varieties, generically known as *terroir*. The database underlying this study includes fifteen climatic, pedological and topographic factors that in traditional European viticulture are considered to be defining for the ecological suitability of a geographic area. The values of these ecological factors were assessed according to their influence on grapes quality for wine varieties, the least suitable showing the possibility to produce white table wines and the most suitable red qualitative wines (Irimia and Rotaru, 2009).
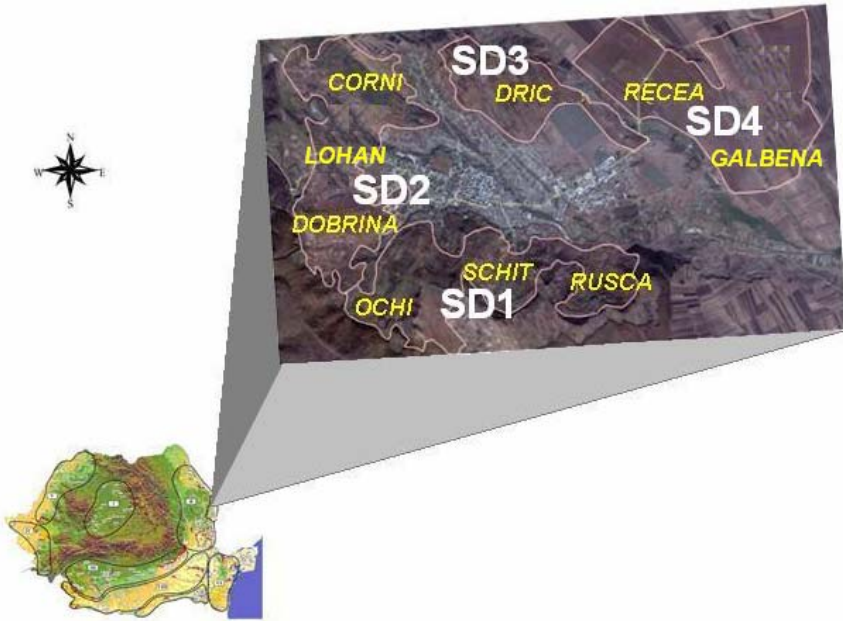
Figure 1 - Geographical location of Huşi wine-growing centre, with its fourth distinct terrain units (SD1, SD2, SD3, SD4) and the included lands

The first approach of this GIS-based research aimed to assess the ecological suitability for grape growing of topographic factors in Huşi wine-growing center (Irimia, Patriche, 2011). The current one deals with the suitability of the climatic factors for the same area, while the next study will focus on the suitability of the pedological factors.

MATERIALS AND METHODS

The identification and delimitation of Husi wine-growing center was based on satellite images integrated in Google Earth. In a previous analysis (Irimia, Patriche, 2011) in Husi wine-growing centre area were identified four terrain units with very distinctive ecological characteristics: **SD1** area, which includes *Rusca*, *Schit* and *Ochi* lands; **SD2** area with *Dobrina*, *Lohan* and *Corni* lands; **SD3** area with *Dric* land; **SD4** area that includes *Recea* and *Galbena* lands **(*Fig. 1*).**

The *digital elevation model* (DEM), underlying the modeling of climate variables, was developed at a 30 m resolution based on contour and altitude rates extracted from topographic maps at scale 1:25.000 (Condorachi, 2006).

The real global radiation was computed in two stages (Patriche, 2007): first, the potential (clear-skies) global radiation was derived on the basis of DEM using the Incoming Solar Radiation module from SAGA-GIS 2.0.4 software (Olaya, 2004), then the potential radiation was multiplied the potential radiation with the factor $(1 - 0.65 x N^2)$, where N is the cloud cover fraction (Entekhabi, 1997).

The potential (astronomical) solar insolation was derived by using the same SAGA-GIS module. This DEM-based computation has the advantage of taking into account the terrain configuration. Consequently, we shall encounter higher sunshine values on hilltops, because of the larger horizon, and lower values along valley bottoms, because of the narrower view of the sky. By multiplying the potential sunshine duration values with the insolation fraction, we obtained the spatial distribution of the real solar insolation.

For temperature variables, we used the average annual and monthly altitudinal temperature gradients, computed from the available meteorological station data from eastern Romania, implemented in NewLocClim software (FAO/SDRN).

The climatic suitability was assessed by using the average annual values of 10 climatic factors and ecological indicators considered as defining for the ecological suitability for grape growing of a geographic area (Irimia and Rotaru, 2009): solar radiation, solar insolation, annual average temperature, the hottest month average temperature, the sum of fractions of average daily temperatures above 10°C for the period from 1st April to 30 September (Σt_u°C), average rainfall for the period from 1st April to 30 September, the length of bioactive period, the heliothermal index (IHr), the bioclimatic index (Ibcv) and the index of oenoclimatic aptitude (IAOe) (Oşlobeanu *et al.*, 1991). Spatial distribution maps were produced for each climatic factor. The suitability of climatic factors and ecological indicators were assessed by evaluation points (5, 8 and 10 points), depending on the influence the factor exerts on the quality and quantity of wine varieties production. The areas where the climatic factors values are below the minimum threshold for grape-growing were noted with 0 points and are considered to have low economic efficiency for grape growing. The evaluation points also represent three suitability classes that indicate the suitability of each ecological factor for grape growing: 5 points = third class; 8 points = second class; 10 points = first class. By using these data, a second series of maps was developed, as GIS raster layers, with classes of suitability. Within each layer, the points are distributed across the range of possibilities, with 0 points for unsuitable values, 5 points for low suitable values, 8 points for middle suitable values and 10 points for high suitable values. All ten layers were added together and then divided by 10 to produce an average composite image which, by its construction, ranks sites numerically based on the combined attributes of the individual variables. Consequently, each pixel in the final climatic suitability map represents the average of the corresponding pixels in the climate factors maps. These average climatic suitability values were further grouped into three classes of suitability: 9-10 points = high suitability (I class); 7-8 points = moderate suitability (II class); 5-6 points = low suitability (III class). The third class (III) reveals the potential for distillates, sparkling wines and white table wines; the second class (II) the climatic potential for white qualitative wines and red table wines; the first class (I) the potential for white and red qualitative wines.

RESULTS AND DISCUSSION

The spatial distribution of climatic factors and ecological indicators was achieved using the *digital elevation model* (DEM). The

climate features of the area were analyzed separately for each of the four terrain units (SD1, SD2, SD3, SD4) previously identified in the topographic factors assessment (Irimia, and Patriche, 2011). The spatial distribution of climatic factors is shown in *Fig. 2* and their values in *Table 1*.

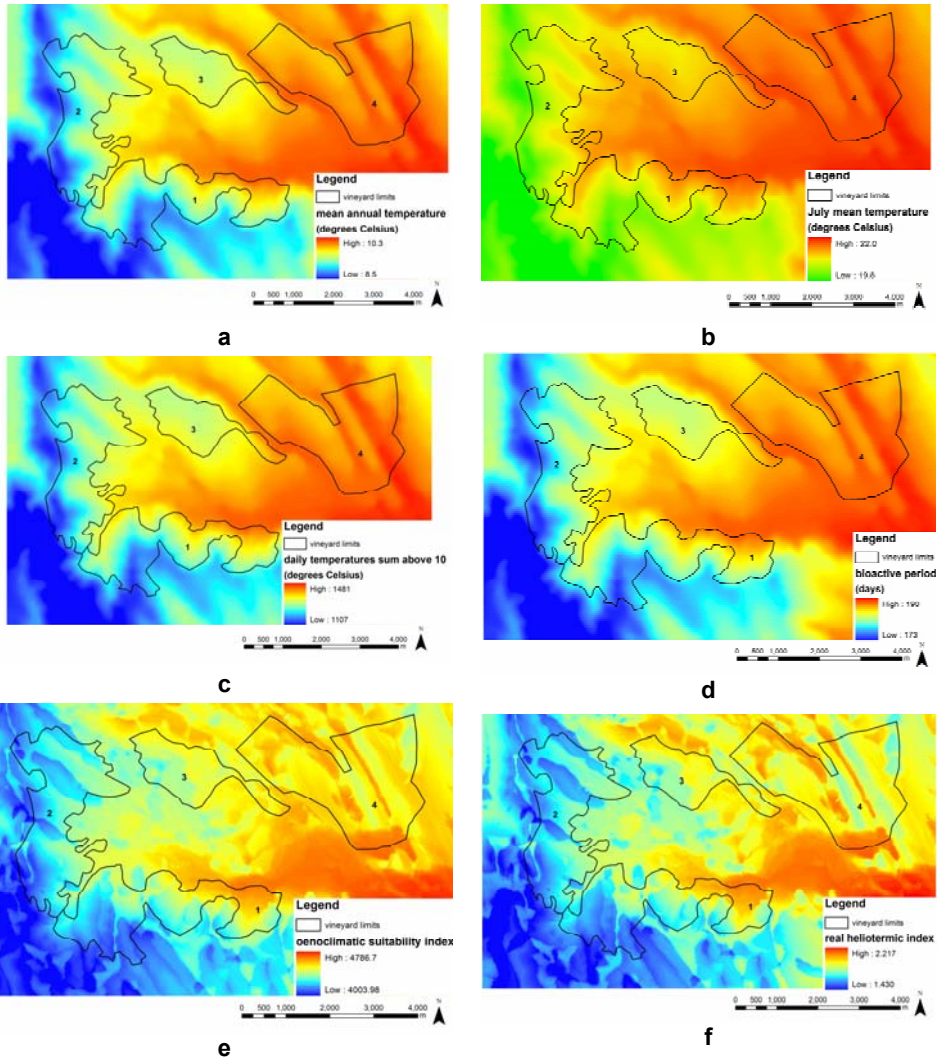**a**

b

c

d

e

f

Figure 2 – The spatial distribution of some climatic factors and indicators in Huşi wine-growing centre: a. annual average temperature; b. the hottest month temperature; c. sum of fractions > 10ºC (1.IV-30.IX); d. the length of bioactive period; e. oenoclimatic suitability index (IAOe); f. real heliothermal index (IHr).

The GIS-based analysis of spatial distribution of heliothermal factors shows that they vary widely, not only from a terrain unit to another but also within each unit.

The thermal regime characterized by the *annual average temperature, the hottest month temperature* and *the sum of daily fractions >10ºC* is the least favourable in SD1 and SD2, where these factors show the lowest values (8.75ºC; 20.05ºC; 1147.96ºC). The same two terrain units are also characterized by the widest temperature variations due to the high altitudes differences (*Table 1*). On the contrary, the highest temperature values are registered in SD3 and SD4 (10.29ºC; 22.0ºC; 1475.59ºC), where there are also the lowest thermal variations. The radiative characteristics of the climate, expressed by solar radiation and solar insolation values fall partly in the same frame, recording the lowest levels in SD1 and SD2 units (74.93 kcal/cm2; 1244.10 hours). Unlike the thermal factors, the highest values of radiative factors are also recorded in the same two units due to the wide altitude variation within them. However, the average values of radiative factors in SD3 and SD4 and their constancy assure the highest average values within them.

The significant local variation of thermal and radiative resources is synthesized by the spatial distribution of *heliothermal index (IHr),* whose values are minimum (1.55 and 1.49) in SD1 and SD2, and maximum (2.13) in SD4. The *precipitation regime* of the wine-growing centre is moderate (cu valori mijlocii), with a very uniform spatial distribution (339.55 - 373.19 mm). In this case, the maximum is registered in SD2, which is the coolest unit, and minimum in SD4, which is the warmest one. The values of bioclimatic index (Ibcv) vary between 5.5 and 7.83 and characterize the area as one with moderate heliothermal and hydric resources, which is fairly favourable for grape-growing. The maximum values of Ibcv are also registered in SD3 and SD4, which are the warmest in the entire wine-growing centre.

The average values of *oenoclimatic aptitude index* (*IAOe)* classify the SD3 and SD4 units with the highest values (4521.06 and 4599.51) in the class of moderate suitability for red wines production, while the SD1 and SD2 units with the lowest values (4430.88 and 4362.22) in the class of suitability for white wines.

The length of bioactive period varies between 175 and 189 days, the highest values being also found in SD3 and SD4, which have the climatic potential for grapes surmaturation, compared to SD1 and SD2 where the values are at the lowest limit for grapes maturation.

The spatial distribution of climatic factors and indicators show significant differences between the four units of wine-growing area: the SD3 and SD4 areas are warmer and poorer in water resources while SD1 and SD2 are cooler and wetter.

Table 1 - The main climatic features of Huşi wine-growing centre

Terrain units	Surface (ha)	Minimum	Maximum	Range	Average
Annual average temperature (°C)					
SD 1	554.31	8.89	10.18	1.29	9.55
SD 2	570.69	8.75	9.90	1.15	9.43
SD 3	264.42	9.59	10.13	0.53	9.72
SD 4	749.70	9.88	10.29	0.41	10.09
The hottest month (July) average temperature (°C)					
SD 1	554.31	20.22	21.85	1.63	21.06
SD 2	570.69	20.05	21.50	1.46	20.90
SD 3	264.42	21.11	21.79	0.68	21.28
SD 4	749.70	21.48	22.00	0.52	21.74
Average rainfall (mm / 01.IV – 30.IX)					
SD 1	554.31	342.06	370.15	28.09	355.68
SD 2	570.69	348.08	373.19	25.10	358.38
SD 3	264.42	343.12	354.77	11.66	351.96
SD 4	749.70	339.55	348.50	8.95	344.06
The sum of fractions of daily temperatures > 10°C (°C / 01.IV – 30.IX)					
SD 1	554.31	1176.60	1450.36	273.76	1316.09
SD 2	570.69	1147.96	1390.37	242.41	1289.67
SD 3	264.42	1324.58	1439.81	115.23	1352.17
SD 4	749.70	1386.24	1475.59	89.35	1430.41
Solar insolation (hours / 01.IV – 30.IX)					
SD 1	554.31	1244.10	1513.80	269.70	1393.39
SD 2	570.69	1252.80	1513.80	261.00	1365.46
SD 3	264.42	1287.60	1513.80	226.20	1427.61
SD 4	749.70	1261.50	1505.10	243.60	1386.48
Solar radiation (kcal/cm^2/01.IV – 30.IX)					
SD 1	554.31	74.93	95.39	20.46	84.69
SD 2	570.69	75.72	96.78	21.07	88.85
SD 3	264.42	80.10	92.78	12.68	89.98
SD 4	749.70	82.02	94.48	12.47	90.10
The heliothermal index (IHr)					
SD 1	554.31	1.55	2.12	0.57	1.83
SD 2	570.69	1.49	1.92	0.43	1.76
SD 3	264.42	1.73	2.06	0.32	1.93
SD 4	749.70	1.80	2.13	0.33	1.98
The bioclimatic index (Ibcv)					
SD 1	554.31	5.71	7.79	2.08	6.74
SD 2	570.69	5.50	7.05	1.56	6.47
SD 3	264.42	6.36	7.55	1.19	7.08
SD 4	749.70	6.62	7.83	1.21	7.28

Terrain units	Surface (ha)	Minimum	Maximum	Range	Average
The index of oenoclimatic aptitude (IAOe)					
SD 1	554.31	4177.33	4704.96	527.64	4430.88
SD 2	570.69	4093.95	4534.30	440.35	4362.22
SD 3	264.42	4371.51	4647.74	276.23	4521.06
SD 4	749.70	4455.35	4713.40	258.05	4599.51
The length of bioactive period (daily temperature > 10ºC) (days)					
SD 1	554.31	176	188	12	182
SD 2	570.69	175	185	10	181
SD 3	264.42	183	188	4	184
SD 4	749.70	185	189	3	187

The spatial distribution of the suitability classes of climatic factors and indicators in Huşi wine-growing centre. The ranking the climatic factors and indicators reveals the significant local variation of the suitability classes for grape-growing in the analyzed area. The spatial distribution of climatic parameters follows closely the local topographic factors variation *(Fig. 3)*. From data analysis it is found that in the entire surface of wine growing centre, the climatic factors fall predominantly in the first and second class of suitability *(Table 2)*.

The most abundant heliothermal resources are in SD4 unit where most of the factors fall in the first suitability class. Significant heliothermal resources are also registered in the SD3 unit, where most of the climatic factors fall in the second suitability class. As opposed to these two units, in SD1 and SD2 areas the second and third suitability classes predominate for all climatic factors.

The multifactorial analysis, expressed by the values of the synthetic ecological indicators (IHr,

Ibcv, IAOe), highlight more clearly the ecological potential of the area. The **IHr** indicator, which expresses the thermal and radiative interaction, shows that 87.95% of the area is part of the second suitability class, revealing the ecological potential for white qualitative wines production. The **Ibcv** index, which comprises the interaction of temperature, insolation, rainfall and the length of vegetative period, places 97.92% of the entire area into the second suitability class. In fact, the spatial distribution of the two suitability indicators is almost the same, placing the SD1 and SD2 in the second and third suitability classes, and the entire SD3-SD4 surface in the second suitability class *(Table 2)*.

On the other hand, the **IAOe** index, which reveals the ecological potential of the vineyards for red wines production, places 21.41% of the entire area in the first suitability class, 68.01% in the second suitability class and 10.56% in the third suitability class. One can also notice a prevalence (51.1-95.54%) of second suitability class in all four units, a significant proportion (48.8%) of first

suitability class in SD4 unit and an important proportion (19.06-21.06%) of the third suitability class in SD1 and SD2 units (*Table 2).*
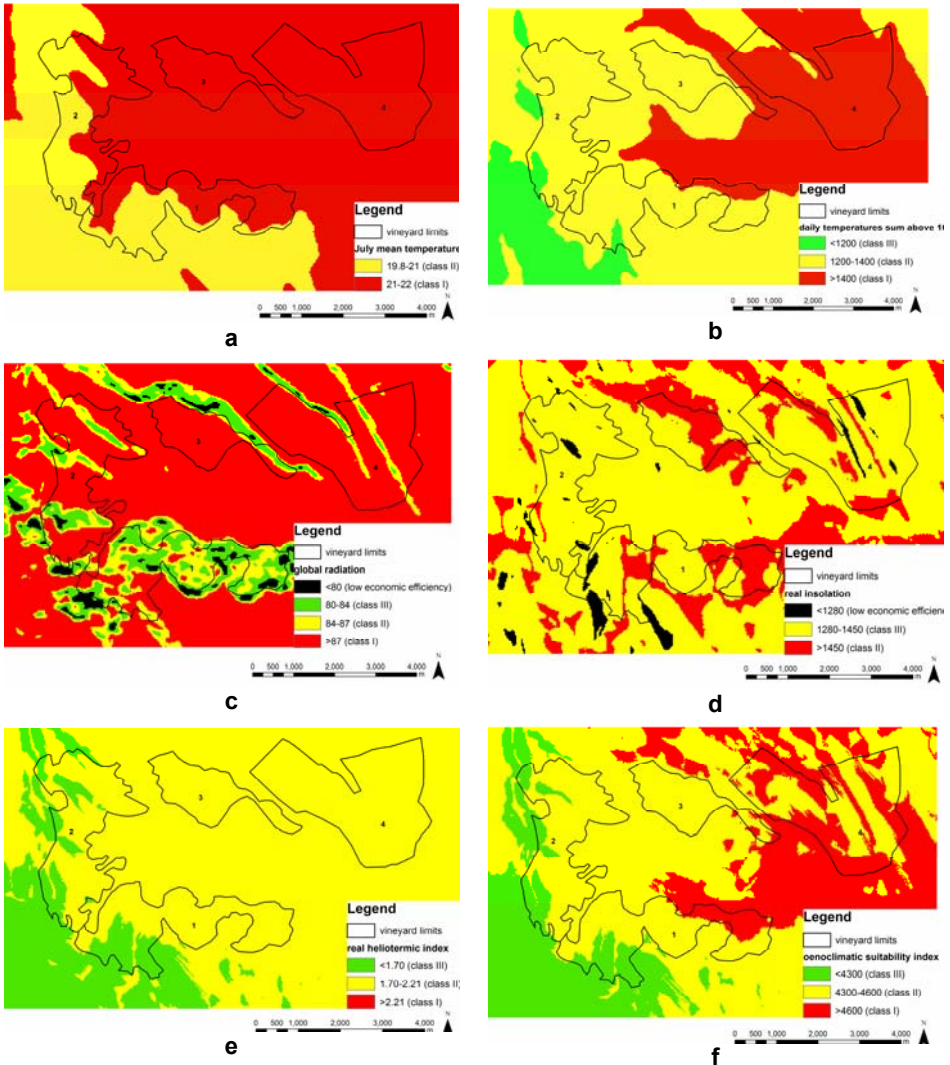

Figure 3 – The spatial distribution of suitability classes for some of climatic factors and indicators: a. the hottest month (July) temperature; b. the sum of fractions > 10ºC (1.IV-30.IX); c. solar radiation; d. solar insolation; e. real heliothermal index (IHr); f. oenoclimatic suitability index (IAOe).

Table 2 - The proportion of suitability classes for climatic factors and indicators in Huşi wine-growing centre

Suitability classes	% in the total wine growing area				Total surface	
	SD 1	SD 2	SD 3	SD 4	ha	%
Annual average temperature (°C)						
< 9.4 (class III)	29.4	38.3	0	0	382.2	17.86
9.4 -10 (class II)	63.5	61.61	93.66	20.9	1108	51.80
> 10 (class I)	7.01	0	6.33	79.09	648.0	30.32
The hottest month (July) average temperature (°C)						
(class III)	0	0	0	0	0	0
19.8-21 (class II)	43.1	56.26	0	0	560.1	26.18
21-22 (class I)	56.8	43.73	100	100	1578	73.81
The sum of fractions of daily temperatures > 10°C (°C / 01.IV – 30.IX)						
<1200 (class III)	3.01	6.10	0	0	51.5	2.41
1200-1400 (class II)	86.7	93.8	90.7	6.1	1303	60.91
>1400 (class I)	10.2	0	9.25	93.8	784	36.67
Solar radiation (kcal/cm^2/01.IV – 30.IX)						
<80 (low economic efficiency)	6.10	1.35	0	0	41.58	1.94
80-84 (class III)	35.7	11.9	4.6	1.16	287.7	13.45
84-87 (class II)	36.9	18.3	5.4	7.1	377.8	17.66
>87 (class I)	21.1	68.2	89.8	91.6	1143	66.94
Solar insolation (hours / 01.IV – 30.IX)						
<1280(low economic efficiency)	4.80	2.52	0	2.6	60.6	2.83
1280-1450 (class III)	66.0	96.1	57.69	78.05	1652	77.2
>1450 (class II)	29.1	1.32	42.30	19.32	426	19.92
(class I)	0	0	0	0	0	0
The heliothermal index (IHr)						
<1.70 (class III)	22.0	23.7	0	0	257	12.04
1.70-2.21 (class II)	77.9	76.2	100	100	1881	87.95
>2.21 (class I)	0	0	0	0	0	0
The bioclimatic index (Ibcv)						
<6 (class III)	3.99	3.89	0	0	443	2.07
>6 (class II)	96.0	96.10	100	100	2094	97.92
(class I)	0	0	0	0	0	0
The index of oenoclimatic aptitude (IAOe)						
<4300 (class III)	19.06	21.0	0	0	225	10.56
4300-4600 (class II)	66.53	78.9	95.54	51.10	1454	68.01
>4600 (class I)	14.40	0	4.458	48.8	458	21.41

The map of climatic suitability for wine varieties in Huşi wine-growing centre. The multifactorial analysis of the Huşi wine-growing centre climate, based on its water, heat, radiation and length of vegetation period parameters (10 parametres) reveals that the largest

part (76.29%, i.e. 1632.0 ha) of the Huşi wine-growing centre area falls in the second suitability class, revealing the climatic potential for white qualitative wines *(Table 3)*. This second suitability class includes the

lower and middle thirds of SD1 and SD2 slopes (*Rusca, Schit, Ochi, Dobrina, Lohan* lands), the entire surface of SD3 unit (*Dric*) and more than a half (51.76%) of SD4 unit (*Recea* and *Galbena* lands) *(Fig. 4).*

Table 3 - The distribution of climatic suitability classes for wine varieties in Huşi wine-growing centre

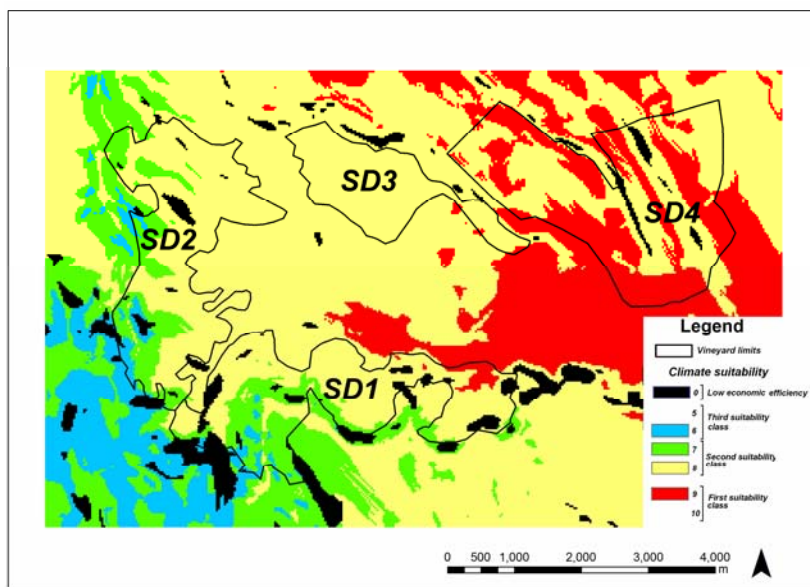| Suitability class	Evaluation points	Surface (ha)				Total surface	
		SD 1	SD 2	SD 3	SD 4	ha	%
I Class	10	0	0	0	0	0	0
	9	17.7	0	3.06	342.0	362.7	16.95
II Class	8	329.7	390.6	261.3	388.0	1369.8	64.03
	7	129.4	132.8	0	0	262.2	12.26
III Class	6	18.3	25.1	0	0	43.47	2.03
	5	0	0	0	0	0	0
Low economic efficiency	0	59.0	22.1	0	19.6	100.8	4.71
Total	-	554.3	570.6	264.4	749.7	2139.1	100

Figure 4 - The map of climatic suitability for wine varieties in Huşi wine-growing centre.

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The first suitability class, which reveals the climatic potential for red wines production, occupy 362.7 ha (16.95%). The biggest part of it (342 ha) is located in SD4 unit (*Recea* and *Galbena* lands), lesser (17.7 ha) in SD1 unit (*Rusca* land) and very little (3.06 ha) in SD3 unit (*Dric* land).

All these first suitability areas have been assessed with 9 evaluation points, reflecting the climatic potential for red table wines, no part of Huşi wine-growing centre being assessed with maximum ranking of 10 evaluation points, corresponding to the climatic potential for red quality wines.

The third suitability class, showing the lowest climatic potential, which could be valorized by white table wines, distillates and sparkling wines production, covers a surface of 43.47 ha (2.03%), corresponding to the upper third of SD1 and SD2 slopes (*Rusca, Schit, Ochi, Dobrina, Lohan* lands).

The low economic efficiency areas, less suitable for grape-growing, totals 100.8 ha (4.71%). The largest part of them (59.0 ha) are located in SD1 unit, and much lesser in SD2 (22.1 ha) and SD4 (19.6 ha) units.

CONCLUSIONS

The multifactorial GIS-based analysis of Huşi wine-growing centre climate shows that 1632.0 ha (76.29%) of the assessed area falls in the second suitability class, which reveals the climatic potential for white qualitative wines production. The second suitability class areas are found along the lower and middle thirds of SD1 and SD2 slopes (*Rusca, Schit, Ochi, Dobrina, Lohan* lands), on the entire surface of SD3 unit (*Dric* land) and on more than a half (51.76%) of SD4 unit (*Recea* and *Galbena* lands).

The first suitability class totalize 362.7 ha, being represented by areas with an average of 9 evaluation points, a value which reflects the climatic potential for red table wines. These areas occupy 342.0 ha in the SD4 unit (*Recea* and *Galbena* lands), 17.17 ha in SD1 unit (*Rusca* land) and only 3.06 ha in SD3 unit (*Dric* land). No part of Huşi wine-growing centre has been assessed with maximum 10 evaluation points, which would show the climatic potential for red quality wines production.

The third suitability class, which corresponds to the lowest climatic potential and which could be valorized by white table wines, distillates and sparkling wines production, covers a surface of 43.47 ha (2.03%), throughout the upper third of SD1 and SD2 slopes (*Rusca, Schit, Ochi, Dobrina* and *Lohan* lands).

In the wine-growing area there are also areas with unsuitable climatic conditions for grape-growing. These totals 100.8 ha (4.71% from the total surface) and they are located in the largest part in SD1 unit (59.0 ha), and much lesser in SD2 (22.1 ha) and SD4 (19.6 ha) units.

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