Elaboration of climatic maps using GIS.
Case study: Olãnesti drainage basin, Romania

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Abstract

Creating precise climatic maps (temperature and precipitation map especially) on small areas such as drainage basins or landform units is always very useful for ecology of plants, distribution of vegetation and also different types of agricultural land. The geographic information system (GIS) analysis of several key-factors (aspect and slope of terrain, insolation degree, thermal gradient, geology and structure of landforms) offers the necessary tools to operate with in order to create an accurate climatic map. This method was applied in order to create a map showing the distribution of temperatures in the Olanesti drainages basin, a 235 km^2 area located at middle latitude, in Romania. After creating the DEM, aspect and slope of the terrain, reclassifying categories and calculating the thermal gradient, a map showing the distribution of the annual mean temperature is obtained. Other climatic parameters could be calculated for small areas too, with precise results. These demonstrate that not only elevation and mathematical location of an area are important factors in the distribution of temperature, but also the aspect, the gradient, the insolation, the type of rock and the structure .

Introduction

The importance of geographic information system (GIS) analysis in construction of maps showing distribution of climatic elements has strongly increased during the last decade, as many papers and projects reveal (Dyras and Serafin-Rek, 2005; Dyras *et al*, 2005; Ustrnul and Czekierda, 2005; Wel van der, 2005; Bac-Bronowicz and Nobuyuki, 2007; Irimia and Patriche, 2009). The Cambridge Journals edited in 2005 a special issue volume dedicated to implementation of GIS analyses in meteorological studies and applications (Cambridge Journal – Meteorological Applications, 2005). Some projects also sustain elaboration of climatic maps for Europe, such as PRUDENCE Project, PESETA Project etc. But these maps show only at a global scale the climate changes, making it difficult to appreciate and analyze them on limited areas, like small and medium drainage basins.

Why drainage basins? Slope and aspect of the terrain are two key-factors analyzed in this study, influenced mainly by the stream network, lithology and structure. For example, every basin has a dominant aspect depending on the drainage direction of the main river. Smaller catchments of its tributaries also have their own dominant aspect. Geological structure highly controls the aspect of

the terrain, especially monocline structure. For example, if the rock layers incline towards north-east, then the dominant aspect is north-east also. The slope depends on lithology (some hillslopes have higher gradient due to harder rocks – sandstone, conglomerate or limestone), rate of erosion and structure. The gradient of a flat area (a plain or a plateau) does not change the angle of incidence of the sunlight that strikes the surface.

The present GIS analysis is focused on the average distribution of the annual mean temperature over a half mountainous - half hilly drainage basin in the northern hemisphere at middle latitude (45°N). Mathematical location is of high importance, because of the angle at which sunlight strikes the Earth surface. This angle varies during the year at different latitude. So, it means that not only latitude matters, but also the gradient. As larger the slope angle is, the more perpendicularly the sunlight strikes the surface. In Romania, both angle and insolation were calculated for the vegetation season (21st of March – 23rd of September) at 45°N by Nicolae Stanciu in 1981. We have integrated the values of the geomorphological and climatic parameters into a GIS database in order to elaborate a more accurate and detailed map showing the distribution of the annual mean temperature over a small area.

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Materials and Methods

The Olănesti drainage basin is a medium geomorphological unit (235 km²) located approximately in the central part of Romania. The upper sector belongs to the South Carpathians (Cāpātānii Range) while the lower sector is part of the Vâlcea Subcarpathians (Fig. 1).

The general drainage direction is from north-west towards south-east. The basin has an elongated feathered shape and the main stream network (orders 6 and 7 in Horton – Strahler's system) is mainly parallel and the secondary (orders 3 and 4) is trellis.

The basin's main features are controlled by some important factors: elevation, geological structure and base level (Olt river). Elevation decreases from 1,979 m (Ionascu peak) to 226 m at the junction with Olt. Considering the basin's length of 37.5 km, it results that the average gradient is 4.22%. The geological structure is generally homoclinal, both in the mountainous (Jurassic – Cretaceous) and Subcarpathian area (Eocene to middle Miocene). Rock strata are tilted in the same direction, from north-west towards south-east, and the gently-dipping sequence covers the largest area. If corroborated with the drainage direction, it results that the general aspect of the terrain is south-east.

The base level is very low for a Subcarpathian area – only 226 m at the junction with the Olt river and the reason is considered by many authors to be the continuous downcutting by the Olt into the bedrock since the middle Pliocene till present (Popescu, 1972). The presence of a fault (Munteanu-Murgoci, 1910) has not been confirmed by the geophysical and geological research. The large valley corridor allows warm air masses from south and south-west to move far towards north, so the annual mean temperature is consequently higher than normal in the Subcarpathians (over 10ºC). For this reason, even if the colder air masses from the north occur frequently during autumn and spring (wind frequency 9%), sometimes in the winter, they are counterbalanced by the warm air coming from south (wind frequency 11.8%). That is why we did not insist on taking the wind parameter into account for the whole area. It might though influence the mean annual temperature on smaller areas.

Database was built by using topographic map 1:25,000 (1970 edition) and climatic data from three weather stations located in and around Olănesti basin: Râmnicu Vâlcea, Cozia and Parâng. Temperature data covers a 20 years period (1983-2002). The Râmnicu Vâlcea weather station lies at the lowest elevation in the basin (239 m). As for the Carpathian area, the most representative climatic data were given by Parâng (1,585 m) and Cozia (1,640 m) weather stations, located on the same west – east alignment. Another useful instrument in building the database and temperature map was the insolation diagram (Stanciu, 1981) (Fig. 6). The classification of slope and insolation was made in respect with the cited author's calculations and conception, based on the fact that on slopes having a gradient higher than 45º.

The two key-factors which must be primarily analyzed are the aspect and gradient of hillslopes. After creating the digital elevation model (DEM) of Olanesti basin, the necessary maps can be automatically generated. Only the area inside the rectangle will be exemplified, in order to notice details more easily (Fig. 2).

In parallel, we calculated the thermal gradient for the study area. Generally, the thermal gradient is established at 0.65ºC 100 m^{-1} in aeronautics. But considering the high implications it has upon the distribution of mean temperature over an area, it was separately calculated for the Olănesti drainage basin. The value obtained (0.52ºC 100 m^{-1}) was low compared to the standard value and even to the regional values in Romania, at the same latitude (Sāvulescu. has obtained for the Íezer Range 0.56ºC 100 m^{-1}), demonstrates the high incidence of warm air masses from south and south-west over the southern hillslopes. Based on the value of thermal gradient and elevation data (contour lines), we obtained the annual mean isotherms, which helped us to create a primary, unweighted map showing the distribution of the annual mean temperature in the Olănesti drainage basin (Fig. 3).

The next step was reclassifying the categories of values for both maps showing the aspect and slope of terrain. The reclassification was made according to the insolation intervals established by Stanciu in 1981 (Sāvulescu, 2010). This operation consisted in attributing the appropriate values to the slope and aspect break values (Table 3), so that, after multiplication, a new map resulted: Insolation map or incident solar radiation map. The values in the table were grouped in six categories, each of them corresponding to an insolation degree (Stanciu, 1981).

The final operation consisted of combining map of insolation degree with the unweighted map of annual mean temperature calculated at the beginning. The resulted map was correct one, showing the most possible distribution of the annual mean temperature over the studied area.

Results and Discussion

The correlation between the aspect and the slope of the terrain, respectively the insolation degree, and the distribution of the annual mean temperature, is illustrated by the general and detailed maps in fig 5, 6 and 7. The dominant southern and south-eastern drainage direction is proven by the high percentage (59%) of slopes facing east (15%), south-east (14%), south (15%) and south-west (15%) inside the entire basin. In the middle sector with a homoclinal structure, they represent the dip-slopes, which obviously occupy a larger area than steep slopes facing north-west and north.

The highest gradient of hillslopes was in the mountainous area, where rivers and streams have cut deeply into during the Quaternary uplift movements. The crystalline area has uplifted the most, along with the Jurassic limestone deposits lying upon it (Vânturarita-Buila Massif), where rock strata were uplifted almost vertically. Cretaceous area has been brought to daylight like
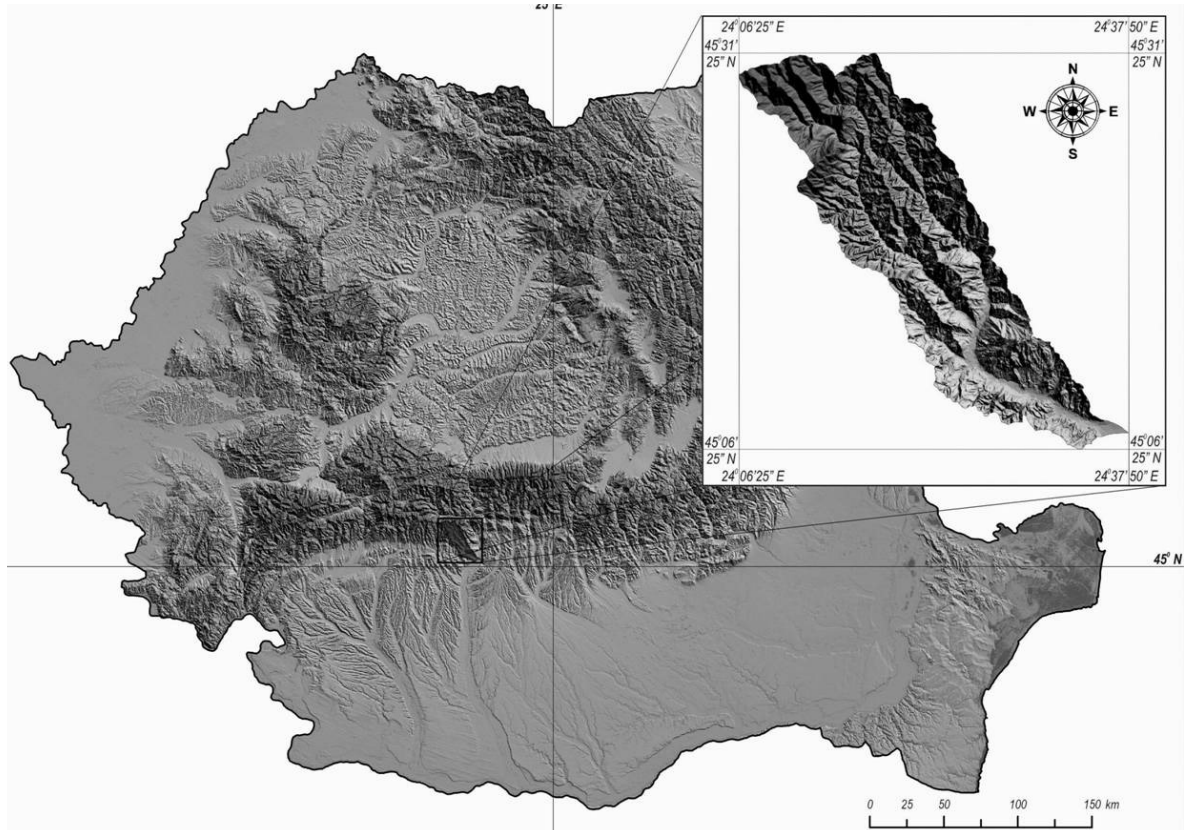
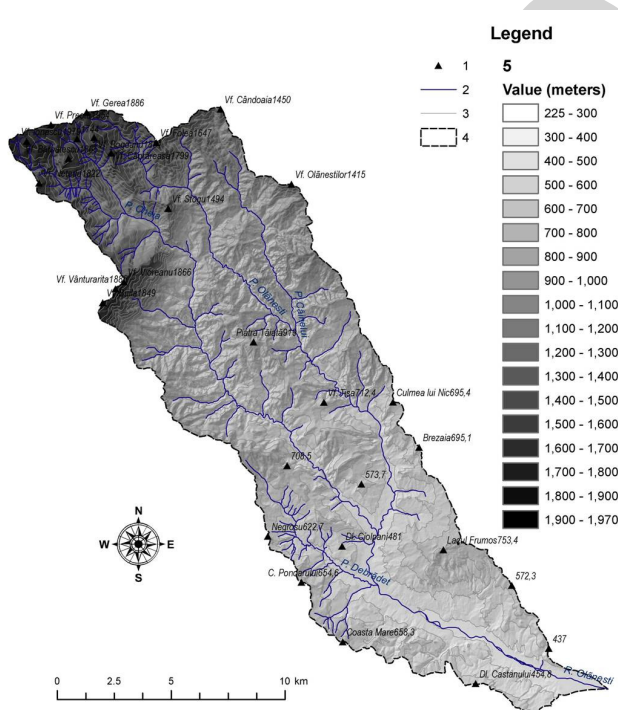**Fig. 1:** Location of the Olãnesti drainage basin in Romania (DEMs: USGS, 2004, modified)

Fig. 2: Hypsometry of the Olãnesti drainage basin. (1) Peaks (meters), (2) Contour lines of 100 meters equidistance, (3) Rivers, (4) Drainage divide, (5) Terrain elevation (meters)
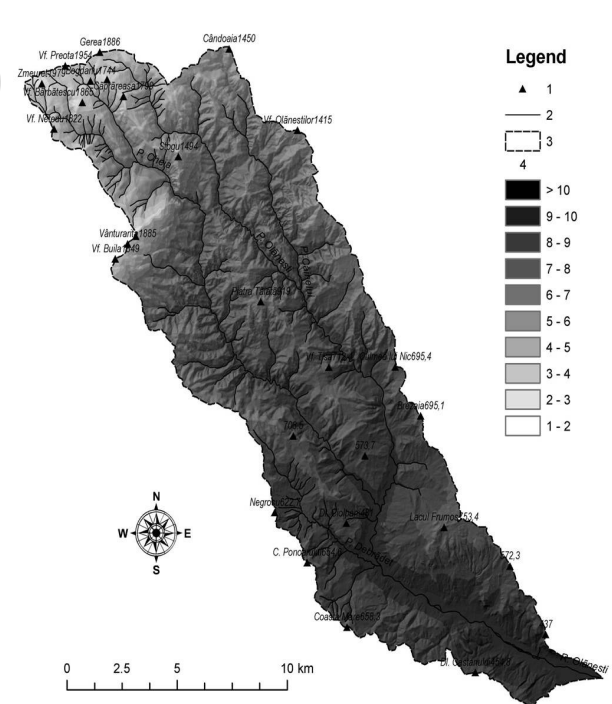

Fig. 3: Hypsometry of the Olãnesti drainage basin. (1) Peaks (meters), (2) Rivers, (4) Drainage divide, (4) Annual mean temperature (°C)
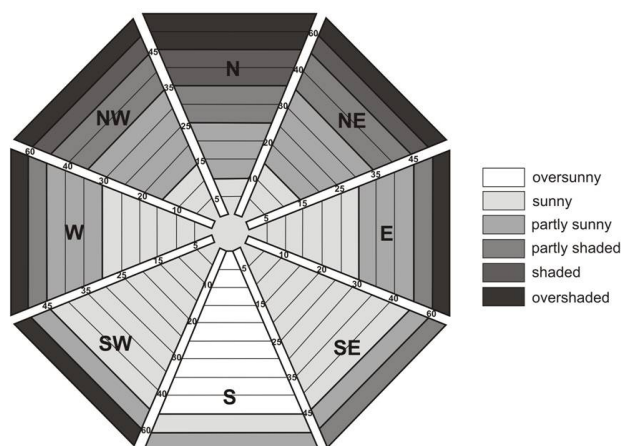
Fig. 4: Insolation diagram (Stanciu, 1981, modified). For specific gradient and aspect of hillslopes combined, a type of insolation is characteristic at 45°N during the vegetation season. The slope categories are numerous, and the sun angle was calculated for each of them. All southern hillslopes dipper than 45°C are oversunny, south-eastern hillslopes are never shaded or overshaded, and south-western hillslopes are only sunny, partly sunny or overshaded. The other aspects resemble almost each of the given categories except oversunny.

nowhere else in the Southern Carpathian Range. Towers, cliffs and other landforms were shaped into the sandstone and conglomerate. In consequence, these landforms had the highest gradients (over 45 degrees), which determined changes of the insolation degree during the year, which was the lowest (Fig. 6). Annual mean temperature was also lower. Instead, in the marl and claystone area, the gradient was lower, and the insolation degree

Table - 1: Elevation of the annual mean isotherms

Elevation (m)	Temperature (annual mean, °C)
395	10
590	9
780	8
970	7
1170	6
1360	5
1550	4
1740	3
1920	2

Table - 2: Reclassifying the aspect and slope of terrain

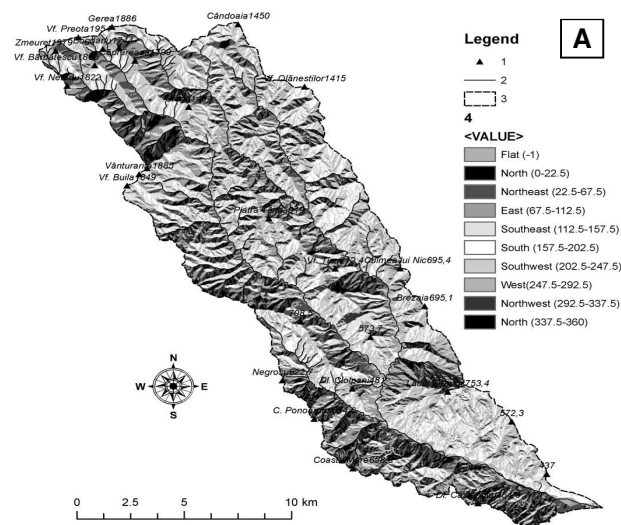| Slope	Reclass	Aspect	Reclass
< 5°	50	S	120
5° - 10°	45	SE	34
10° – 15°	40	E	20
15° – 20°	35	NE	12
20° – 25°	30	N	10
25° – 30°	23	NW	12
30° – 35°	20	W	20
35° – 45°	15	SW	29
45° – 60°	10		
> 60°	3		

Fig. 5: Aspect (A) and slope (B) of terrain in the Olăneşti drainage basin. (1) Peaks (meters), (2) Rivers, (3) Drainage divide, (4) Aspect of terrain, (5) Slope of terrain
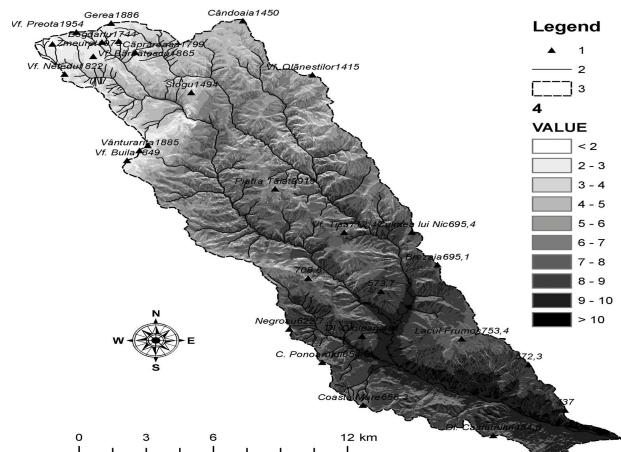

Fig. 6: Map of insolation degree. Overshaded and shaded hillsides are only steep slopes facing generally north, cut into hard sandstone and conglomerate

Table - 3: Values obtained after multiplying aspect and slope data. Conventional colours are the same as in the insolation diagram for a more clear illustration of corresponding data

Aspect/Slope (sexagesimal degrees)	< 5⁰ 50	5⁰ - 10⁰ 45	10⁰ – 15⁰ 40	15⁰–20⁰ 35	20⁰–25⁰ 30	25⁰-30⁰ 23	30⁰-35⁰ 20	35⁰–45⁰ 15	45⁰–60⁰ 10	>60⁰ 3
S=120	6000	5400	4800	4200	3600	2760	2400	1800	1200	360
SE=34	1700	1530	1360	1190	1020	782	680	510	340	102
E=20	1000	900	800	700	600	460	400	300	200	60
NE=12	600	540	480	420	360	276	240	180	120	36
N=10	500	450	400	350	300	230	200	150	100	30
NW=12	600	540	480	420	360	276	240	180	120	36
W=20	1000	900	800	700	600	460	400	300	200	60
SW=29	1450	1305	1160	1015	870	667	580	435	290	87

Table - 4: Type of insolation, break values and percentage of normal insolation calculated for the vegetation season at 45°N (Stanciu, 1981)

Insolation	Break values	Percent of normal insolation
Oversunny	> 1701	90 – 100
Sunny	430 – 1701	70 – 90
Partly sunny	239 – 430	50 – 70
Partly shaded	179 – 239	30 – 50
Shaded	101 – 179	10 - 30
Overshaded	< 101	0 - 10

and the temperature were higher; they offered better conditions for settlements (the town of Bãile Olãnesti the villages Tisa and Cheia) and anthropogenic activities. The map of the insolation degree illustrated a dominant oversunny and sunny terrain over the entire basin.

The distribution of the annual mean temperature in the Olãnesti drainage basin was clearly illustrated by the map in Fig. 7. The highest values (over 10°C) were registered along the floodplains of the main rivers (Olãnesti , Cheia and Debrãdet), but only in the Subcarpathian area and by the southern hillside of Lacul
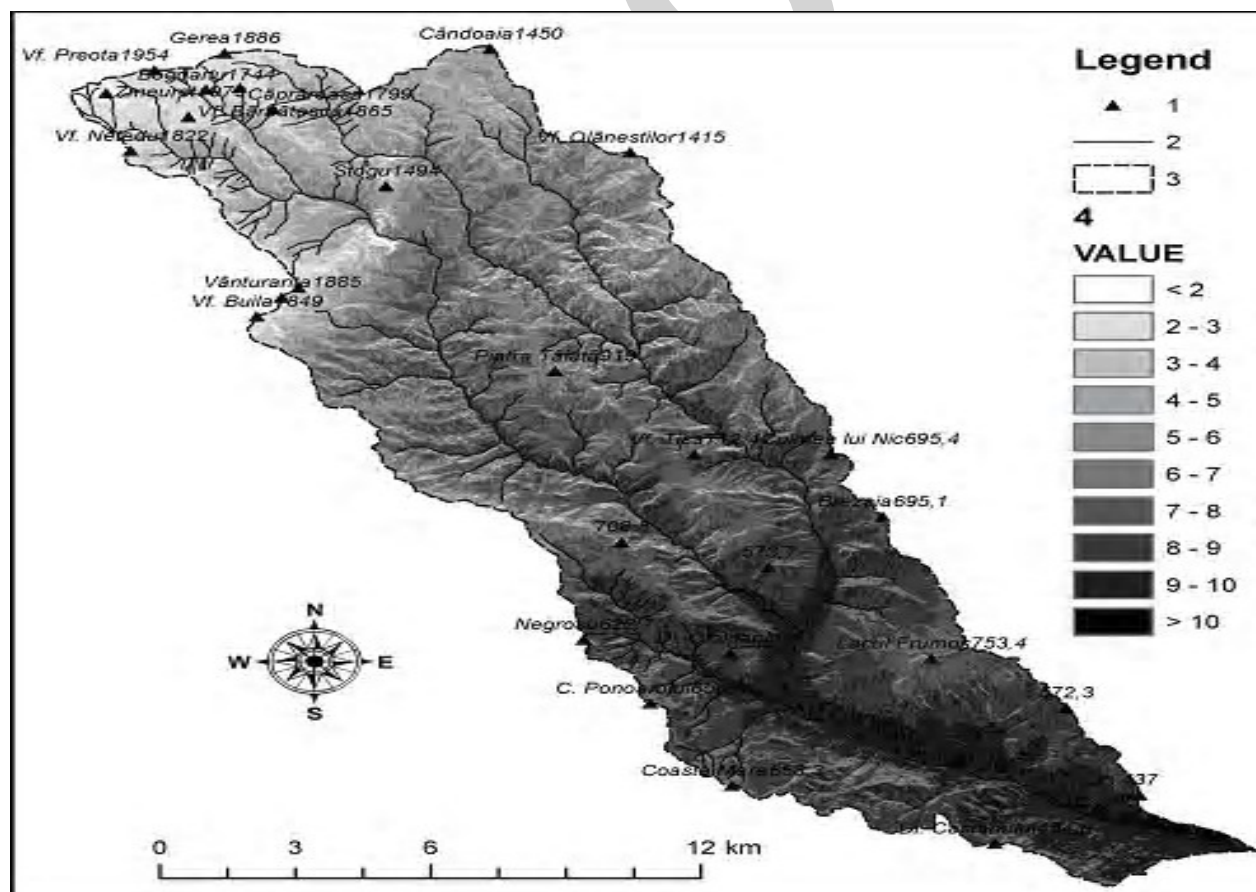
Fig. 7: The annual mean temperature map of the Olãnesti drainage basin (based on the climatic data 1983 – 2002). Legend: (1) peaks (elevation in m); (2) rivers; (3) drainage divide; (4) annual mean temperature (°C)

Frumos hill at reduced altitudes (350 – 450 m). The values between 7 and 10°C were registered on the Subcarpathian hillslopes except those facing north-west and north. These slopes had temperatures of 6 to 7°C and even 5 to 6°C (altitudes of 700 m).

In the low Carpathian area (Cretaceous hilly area), southern hillsides registered only 7- 8°C, the northern hillsides only 5- 6°C and the hillsides having other exposure registered 6– 7°C. The high mountainous area (the Vânturarita – Buila Massif and the Cãpãtânii Range) registered the lowest temperatures (between 1 and 4°C, depending on the aspect of terrain).

The elaboration of a climatic map for a limited area involves the analysis of some main control parameters (altitude, thermal gradient, aspect, slope, and insolation). Local variations occur frequently due to the aspect and slope of the terrain. Temperature is lower on the highly inclined (over 45 degrees) and north-facing slopes, comparing to south-facing slopes having low gradient (15- 20 degrees and below). The variation in temperature is about 1- 2°C for the same landform unit on different hillsides.

Other secondary variations depend on the presence of different types of rocks such as limestone and conglomerates, which determine an increase of the temperature. Wind frequency and speed do not have a significant role in the distribution of the mean annual temperature in this case, because the frequency of the cold and warm air masses is quite well balanced (this situation is indirectly revealed by the values of air temperature at the specified weather stations); nevertheless, they are important control factors in the distribution of precipitation.

The methods applied in this study are useful in geography for other purposes too. It is necessary to elaborate maps showing the distribution of the factors involved in different climatic, geomorphic or other kind of processes, before a map of the distribution of the process itself is created. For the precipitation map, a DEM analysis is also required, then of pluviometric gradient, frequency and speed of prevailing winds, orographic barriers (if case) with a supplementary analysis of aspect, slope and elevation. Each type of climatic map requires a previous analysis of several control factors. The research of the geomorphic risk (susceptibility to landslides especially) of a given area is also based on GIS analysis, by studying the combined effect of climatic parameters, geological support – structure and lithology, type of land use, soil erosion and others (already approached in previous studies by Clerici *et al.*, 2002; Lee *et al.*, 2002).

References

Bac-Bronowicz, J. and M. Nobuyuki: GIS as a useful tool for spatial distribution of climate parameters observed in point over relatively long period of time. The Geospatial Resource Portal: Climate Change (2007).

Clerici, A., S. Perego, C. Tellini and P. Vescovi: A procedure for landslide susceptibility zonation by the conditional analysis method. *Geomorphology,* **48**, 349-364 (2002).

Dyras, I. and D. Serafin-Rek: The application of GIS technology for precipitation mapping. In *Meteorological Applications,* London: Cambridge University Press. ISSN: 1350-4827, EISSN: 1469-8080. **12**, 69-75 (2005).

Dyras, I., H. Dobesch, E. Grueter, A. Perdigao, O. E. Tveito, J. E. Thornes, F. J. M. van der Wel and L. Bottai: The use of geographic information systems in climatology and meteorology: *Meteorolog. Appli.,* **12**, 1-5 (2005).

Irimia, L., and C.V. Patriche: Spatial distribution analysis of the ecological factors in the Averesti wine growing centre – Husi vineyard. *Cercetãri Agronomice în Moldova, **42**, pp. 139* (2009).

Lee, S., U. Chwae, and K. Min: Landslide susceptibility mapping by correlation between topography and geological structure: The Janghung area, Korea. *Geomorphology, **46**,* 149-162 (2002).

Munteanu- Murgoci, Gh.: The geological synthesis of the South Carpathians. C.R. XI-e Congrès Géol. International (1910).

Popescu, N.: The valley of the Olt river between Turnu Rosu and Cozia - A geomorphic analysis. *Bull. Romanian Geograp. Soc., **2**,* 90-98 (1972).

Stanciu, N.: Applied forest ecology. Bucharest: Ceres. (1981).

Ustrnul, Z. and D. Czekierda: Application of GIS for the development of climatological air temperature maps: An example from Poland. *Meteorolog. Appli., **12**,* 43-50 (2005).

Wel van der, F. J. M.: Spatial data infrastructure for meteorological and climatic data. *Meteorolog. Appli., **12**,* 7-8 (2005).