Quantitative evaluation of forest favourability using GIS database in a hill area in the Transylvania Depression, Romania

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ABSTRACT
Many studies highlight the beneficial influence of forests on the quality of environment. There is an interest for identifying the pretability of a certain territory for representative forest tree species according to their pedological, hydro-climatic and geomorphological characteristics. The main purpose of this endeavour is the enhancement of a territory’s economic quality as well as the highlighting of the forest’s stabilizing role which is determined by new forest plantations with well-defined purposes. This study aims at proposing a quantitative model based on correlation equations between forest favourability classes and ecological factors/determiners for the main forest species from the hill bioclimatic zone. By using geographic information system (GIS) spatial analysis and integrating a specific digital database, forest favourability classes were identified for eight of the most common forest species from Someșul Mare Hills: pedunculate oak, Turkey oak, Hungarian oak, hornbeam, linden, sycamore tree, cherry tree and beech. The main focus was laid on developing and obtaining the necessary digital database for the GIS spatial analysis model and on the work stages of creating a GIS model which could be implemented in areas with similar characteristics.

1. Introduction
The classification methodology created for the territory of Romania by the Pedological Research Institute from Bucharest (Florea et al. 1987) states favourable and restrictive environmental factors for 24 of the most common plant cultures from Romania. This methodology was created in order to identify favourability classes for agricultural use and differentiates between ecologically homogenous territories in six classes of favourability (I-VI). Thus, the territories included in classes V and VI are highly restrictive to agriculture and are recommended to be used as pastures, hayfields and forests. The purpose of this study is to develop a quantitative model to identify the forest favourability classes for the hill area from the Transylvania Depression. This model is developed with the help of a digital spatial database which includes both favourable and restrictive environmental factors influencing forest productivity and the efficacy of forest plantations.

In this study case, the favourability classes of environmental factors need to be identified depending on correlation equations which describe the dependency between environmental factors and the...
requirements of each species. This type of classification, based on ecological favourability, qualitatively expresses the most and least favourable class for the main species under study.

Using the classical methodology, one needs to study the soil types and their characteristics in order to identify their support capacity as well as their vulnerability to slope erosion. This would help identify critical surfaces which hinder forest plantations (Negrușier et al. 2015). This first step is recommended both in the stage prior to forest improvement actions and in the process of establishing forest management measures. The focus is laid on soil favourability for this type of land use as well as on soil restrictivity, an important role being played by the units of forest pretability (according to the Methodology of writing pedological studies, Part III (Florea et al. 1987)).

The erosion potential of soils also represents an important element to be considered when studying the development of economic programmes based on afforestation and forest plantations (Bilașco et al. 2009; Irimuș et al. 2015). As areas with various soil erosion susceptibility are included in the category of degraded lands (Vâtcă et al. 2014; Moldovan et al. 2015), the identification of the latter is highly important as their economical value increases through the stabilizing effect of forest tree species (Wickenkamp et al. 2000). The identification of unforested areas with high vulnerability to surface erosion represents the first stage in identifying areas with degraded lands, the main purpose being their rehabilitation through pilot forest stations which can allow their inclusion in economic circuits through sustainable use of the resulting timber.

In this study, the main objective is to propose a quantitative model based on correlation equations between forest favourability classes and ecological factors/determiners for the main forest species from the hill bioclimatic zone using geographic information system (GIS) spatial analysis and integrating a specific digital database which we will present in the section Methodology and Database. Other objectives are to present and to analyse the results and to validate the model in the field based on a series of topographical survey performed as sample in the territory.

The soil erosion classes of the study area have been previously identified using the U.S.L.E. model (Colniță et al. 2016). This resulted in an estimation of 10.66 km² with more than 3 t/ha/year of soil loss, mostly in areas from the middle hill sector, characterized by high and medium slope angles and a low degree of vegetation cover. There is a need for integrating these territories in the productive area from the economic circuit, taking into consideration the protective role of forests on steep slopes (Ionescu 1972), as well as their positive influence on recovering degraded lands (Țărău and Dicu 2014).

2. The ecological babes of studied forestry species

The identification of land pretability to different types of forest stations relies on the spatial identification of land units with different pretability or restrictivity values, determined by soil, climate and drainage, using intensity degrees ranging between I and VI. The species that we analysed in this paper were: Quercus robur, Quercus Cerris L., Quercus Frainetto Ten., Carpinus Betulus L., Tilia Cordata Mill., Acer Pseudoplatanus L., Prunus Avium L. and Fagus Sylvatica L., these being the most widespread species in Romania.

In Romania, oak forests occupy approximately 19% of the total forest surfaces (Clinovschi 2015). The pedunculate oak species is vastly spread on the European continent, especially in Central and Western Europe (Eaton et al. 2016) reaching its eastern limit at the Ural Mountains (Jones 1959; Ducousso and Bordacs 2003) and an elevation of up to 1300 m in the Alps (Roloff et al. 2010). It prefers a slightly acid soil (Aas 2012) and can play the role of a pioneer tree (Praciak et al. 2013; Savil 2013). In Romania, the average annual temperature below 7 °C determines a very low favourability for this species.

The Turkey oak (Quercus Cerris L.) is an indigenous species which entered Europe on small areas from the north of the Danube (Yurukov and Zhelev 2001; Bozzano and Turok 2003; Praciak et al. 2013). In Romania, it grows at the elevation of 500-600 m and can live up to 120–150 years (Praciak et al. 2013). Its ideal ecological requirements can be found in the southern part of the
continent and on the Atlantic seaside where it can grow up to 35 m high with a strong taproot adapted to dense soils (Clinovschi 2015). For an optimum growth, it requires a long vegetation period and a mild climate as it is very sensitive to frost. However, it is very adaptable to dry areas (Praciak et al. 2013; Majer 1984), as well as to relatively polluted ones (Tzvetkova and Kolarov 1996) and areas with slightly acid and pseudogleic soils (Majer 1984; Popović et al. 1997).

Quercus Frainetto Ten., known as Hungarian oak, is a species which can grow up to 40 m, it has a life span of approximately 200 years (Kostadinov 1984) and has a strong root fixation in the case of clay soils. It has a similar spatial distribution to the Turkey oak in Romania, up to an elevation of 550 m. On the continent, it can be found in the Balkan Peninsula (Bartha 1998) and the south of Italy (Corcuera et al. 2002). However, once the average annual temperature increases, one can expect an extension of this species to northern territories (Mauri et al. 2016).

The hornbeam (Carpinus Betulus L.) is found in broad-leaved forests with a wide spread in Europe up to 55°—57° latitude North (Paul 1974). It is resilient in drier areas (Taheri et al. 2013), therefore it can also be found in Romania where its westward limit is represented by the forest steppe limit between Moldavia and Wallachia (Clinovschi 2015). It is a sensitive species to soil characteristics (it tolerates a soil with a maximum Ph of 7) (Gilman and Watson 1993) and climate, hence one can notice that most of the ecological factors used in favourability classification are very restrictive.

The hill linden, as Tilia Cordata Mill. is usually known, is spread up to 60° latitude North in Europe, while in Romania it grows up to an elevation of 900 m and when it is used as a pioneer species it has a more advanced development compared to the beech (Clinovschi 2015). This tree species is well-known for its properties, its flower being used in medicine (EMA 2012), but also as a good source of pollen (Crane et al. 1984; Győr 2001; Pogorzelec 2006) and a decorative tree in urban areas.

Linden’s requirements to thermal characteristics include a high sensitivity to frost, therefore in areas with temperatures lower than 6.5 °C, the pretability class is very low–V, while the rest of the territory offers acceptable conditions.

Having a taproot system, the mountain sycamore or Acer Pseudoplatanus L. has the characteristics of a pioneer plant which can grow on alluvial fans, therefore being widely spread in flood plains and in the forests from low hills. It has important soil requirements, but can easily adapt to wet soils or to soils formed on limestone or volcanic rocks and it has a good resistance to temperature conditions (Clinovschi 2015).

The hill sycamore (Acer Platanoides L.) is well adapted to the conditions of excessive continental climate and is better adapted to limitative soil conditions than the mountain sycamore (Clinovschi 2015), being often associated to culturally anthropic landscapes (Fremstad and Elven 1996). The growth area of this species is represented by the central-eastern and southern part of Europe (Meusel et al. 1978; Weidema and Buchwald 2010).

The wild cherry tree, as Prunus Avium L. is usually known, is a tree species which prefers an elevation of up to 1000 m in Romania, with slopes acquiring a high amount of sunlight as it needs a long vegetation period, fertile soils without excessive humidity and good drainage (Clinovschi 2015). This species is mostly known for its fruits with highly anti-oxidating properties (Prvulović et al. 2011) and is generally spread up to 35° latitude North (Chadha 2003), in southern Europe, Asia Minor and the north of Africa. It requires very good soil and climatic conditions for proper growth (Ferretti et al. 2010; Wani et al. 2014).

The beech (Fagus Sylvatica L.) is an indigenous tree species which is largely spread both in Europe and in the study area, while in Romania it occupies 32% of the forest area between 300 and 1400 m elevation in the low-mountain area. It grows in mixed forests together with hornbeam and sessile oak or different coniferous tree species (Clinovschi 2015). Thermal and precipitation limitations (Dittmar et al. 2003; Fotelli et al. 2009; Weber et al. 2013) manifest themselves through a high variation of favourability classes due to heterogenous natural factors which directly and indirectly influence the development of beech (Breda et al. 2006; Nahm et al. 2006; Kramer et al. 2010). Previous analyses have
demonstrated that beech has a high sensitivity to drought (Ciais et al. 2015; Popa & Cais 2015). In high temperatures, it needs a larger quantity of rainfall or atmospheric humidity to replace the lack of water. Beech also needs fertile soils with a large quantity of humus and good permeability, but it can also adapt on soils which are poor in nutrients and in this case it grows as arboretum.

3. Study area

The development of the model was achieved based on a complex territory regarding the exploitation and introduction in the forestry circuit of degraded land. Submountain units from the western border of Transylvanian Depression represented by the Someș Mare Hills shows the greatest problems in terms of the manifestation of erosion processes (Figure 1), as well in the surface, as in the ground, due to the exacerbated deforestation from last period (Păcurar et al. 2013a; Petrea et al. 2014; Roșca 2014; Roșca et al. 2015a; Furtună 2017).

The solution for these problems is to try to implement strategies for developing forestry plantations with double role, first of stabilization of ground and second to economically develop the area and to introduce unproductive territories in the forestry circuit. The high variety of soil typology (Păcurar et al. 2013b) and thus, of their characteristics and the differentiated influence of the amount of rainfall and the caloric intake from temperatures on hilly unit of Someș Mare Hills driven mainly by the direct contact with the nearest mountain unit (Roșca et al. 2015b), as well as the morphological complexity of hill–valley–terrace variation (Mac 1972) has lead for choosing this territory as case study for the implementation of the quantitative model proposed with the aim of identifying the best species for forestry plantations establishment.

Someș Mare Hills represents a territory with a surface of 1074 km², situated in Transylvania Depression where for 180 km² prevails the agricultural areas as a way to use land, sector of very high hills (751–1000 m) is predominantly used as secondary pastures for 215 km² and the sector of mountains with low altitude (1001–1250 m) stands out for deciduous forests on 453 km² (Colnită et al. 2016).

4. Methodology

The GIS spatial analysis model used to classify the territory in forest favourability classes is structured in three main stages: the first stage of utmost importance for the model validity is represented by the database construction which includes the ecological factors influencing forest tree species. A database with high accuracy and precision will lead to a better validation rate of the final result and increase the accuracy of the modelled databases which rely on it.

4.1. Database construction

In the study of forest ecosystem favourability, one targets the capacity of the forest station in satisfying the ecological and functional requirements of the main forest tree species, according to the type of topography, rocks determining the soil underlying material, climate, water resources, physical and chemical soil characteristics (Chiriță 1977). The classification typology of the forest station can be determined directly, through the analysis of the influencing factors and ecological determiners known on the whole Romanian territory and established through the Florea et al. 1987, while the indirect approach uses present vegetation data at the time when the study is being written.

In the model proposed by the present study, the authors apply the direct method for identifying forest favourability, based on a GIS spatial database which includes the most representative determinant factors.

The digital database used in the model is created starting from a primary database (Table 1) including vector points which locate the representative weather stations from the analysed territory and the sites of soil sample collection, vector polygons representing soil types and classes and their
corresponding attributes (Map of Romanian Soils, 1:200000 scale, 1960). Primary raster data used in developing and finalizing the spatial analysis model include the digital elevation model as a primary source for modelled, intermediate data which result after the implementation of regression curves as spatial analysis equations in geoinformatic softwares.

Figure 1. Geographical position of the study area and the rate of the soil erosion (based on USLE model) and landslide probability (based on H.G. model).
The modelled databases (Table 1) used in the spatial analysis model include ecological determiners resulted from the spatial analysis equations implemented through intermediary models based on the analysis of multiple correlations between measured values (precipitation, temperature etc.) (Figure 2–6). The modelled databases format corresponds to the input databases of the intermediary models, namely GRID, a format derived from the digital elevation model.

Among the ecological factors and determiners being studied for the identification of forest favourability in the Someșul Mare Hills, two of the factors were represented by average annual temperature and precipitation. Their variation was identified using the GIS technology which allowed the implementation of equations for regression functions as a result of correlating elevation and the spatially distributed punctual values of the analysed parameters.

Table 1. Database.

| Nr. | Database                                      | Database type | Format          | Generating process                                      |
|-----|-----------------------------------------------|---------------|-----------------|---------------------------------------------------------|
| 1   | Weather stations                              | Primary       | Vector (point)  | Vectorization                                           |
|     |                                               | Primary       | Vector (polygon)| Vectorization (based on Map of Romanian Soils, 1:200 000 scale) |
| 2   | Soil                                          | Primary       | Vector (GRID)   | Implementation in GIS environment of the equation for the regression function $Y = 0.435X + 533.51$, where: $Y$ – average annual precipitation (mm) $X$ – relative elevation (m) |
| 3   | Average annual precipitation (mm)             | Modelled      | Raster (GRID)   | Implementation in GIS environment of the equation for the regression function $Y = 205.29 - 0.075X$ where: $Y$ – average temperature $> 10^\circ$C (days) $X$ – elevation (m) (I.C.P.A., 1987) |
| 4   | Average annual temperature (degrees Celsius)  | Modelled      | Raster (GRID)   | Implementation in GIS environment of the equation for the regression function $Y = \frac{14.607.97 - (40.311 - x)^{0.754}}{1216.12 + x^{0.754}}$ Correlation coefficient = 0.995 $Y$ – average annual temperature ($^\circ$C) $X$ – altitude (m) |
| 5   | Number of days with average temperature $> 10^\circ$C | Modelled      | Raster (GRID)   | Implementation in GIS environment of the equation for the regression function $Y = 373.03 - 2.2744X$, where: $Y$ – sum of temperatures for days with average value $> 10^\circ$C ($^\circ$C) $X$ – elevation (m) (I.C.P.A., 1987) |
| 6   | Sum of temperatures from days with temperature $> 10^\circ$C | Modelled      | Raster (GRID)   | Implementation in GIS environment of the equation for the regression function $Y = 205.29 - 0.075X$ where: $Y$ – average temperature $> 10^\circ$C (days) $X$ – elevation (m) (I.C.P.A., 1987) |
| 7   | Precipitation excess/deficit (mm)             | Modelled      | Raster (GRID)   | Implemented from the grid of average annual precipitation |
| 8   | Useful edaphic volume (unit fractions)        | Derived       | Raster (GRID)   | Interpolation of point values determined on the field |
| 9   | Digital Elevation Model (DEM)                 | Primary       | Raster (GRID)   | Direct acquisition |

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In the statistical analysis used for determining the correlation using regression functions, the weather stations from the near vicinity of the analysed territory were considered (Dej, Bistrița, Târgu Lăpuș and Iezer), as they are in approximately the same topoclimatic conditions as the territory under analysis. The results highlight the variation of precipitation between 639–1050 mm/year (Figure 5), with different values depending on the influence of elevation and slope orientation. The average annual temperature was modelled (Figure 6) starting from the punctual values from the weather stations, which vary between 4.01–8.92 $^\circ$C. These average temperature values limit the growth of the Quercus pedunculiflora K. Koch which needs average temperatures above 9.8 $^\circ$C, of the Hungarian oak which requires temperatures above 9.95 $^\circ$C and of the hornbeam which has a very low thermic favourability (Table 2). The latter conditions are also valid for the Turkey oak and the sycamore.

The temperature variation and its influence on the vegetation stage of the studied forest tree species manifests itself due to absolute values, average annual values and the number of days with
Figure 2. Map of average annual precipitation in Someșul Mare Hills.

Figure 3. Map of average annual temperature in Someșul Mare Hills.
Figure 4. Map illustrating the number of days with temperature above 10 °C.

Figure 5. Thermal sum with values above 10 °C.
temperatures above 10 °C (Figure 7). There is an increase in the number of days with temperature above 10 °C from 186 days favourable to vegetation growth in the low hill sector and a decrease to 116 days in the higher sector.

The negative influence of temperature on the pedunculate oak is illustrated by the inclusion of most of the territory in the low favourability class, while linden and sycamore are also included in the low and medium favourability, respectively (Table 2). The sum of the temperatures from the days with temperatures above 10 °C ranges between 181 and 2326° for the territory of the Someșul Mare Hills. The most sensitive species to this factor are the pedunculate oak, the Turkey oak, the hornbeam and the cherry tree (Table 2).

In what concerns the sum of temperatures from the days with temperature >10 °C, the Someșul Mare Hills are included in the low and very low favourability classes only for the pedunculate oak, the hornbeam and the cherry tree (Table 2).

The precipitation amount being analysed through the precipitation excess/deficit indicator (Florea et al. 1987), which varies between 50 and 596 mm, offers good conditions for most of the analysed species, except for sycamore and cherry tree which have a lower water necessity (Table 2).

The useful edaphic volume available in the study area was spatialized using GIS technology. It is included in the category of soil characteristics which influence the land pretability for different types of uses together with the reaction and saturation in bases, the humus content, the degree of gleification, stagnation-gleification etc. (Teaci 1980). After interpolating the punctual data at national level (Dumitru 2011), using the Spline interpolation method (which has the best field validation), method which was also used in previous studies (Malone et al. 2009), the value of the useful edaphic volume was modelled for the study area and it ranges between 0.175 and 1.102 unit fractions (Figure 7). The Edaphic useful volume of the soil represents the soil volume that could be used by the tree (Toti et al. 2015). The edaphic volume (measured in fractions of unity) was determined for all the Romanian country for all the plots as an index of the overall profile that is showing the fine material content, without skeleton witch is useful to the plants. The edaphic volume can be expressed in
| Ecological factor | FS | S       | M       | R       | FR       | Excess I | Excess II | Species                                      |
|-------------------|----|---------|---------|---------|----------|----------|-----------|----------------------------------------------|
| Average annual precipitation (mm) |    |         |         |         |          |          |           |                                              |
| <755              | –  | –       | –       | 755-820 | >820     | –        | –         | Pedunculate oak (Quercus robur)              |
| 765-815           | 765 | 816-850 | 851-875 | >875    | –        | –        | Turkey oak (Quercus cerris L.)               |
| >820              | –  | –       | –       | 820-875 | >875     | –        | –         | Hungarian oak (Quercus Frainetto Ten.)      |
| –                 | <750| 760-860 | >860    | –       | –        | –        | Hornbeam (Carpinus betulus L.)               |
| –                 | <790| 790-875 | >875    | –       | –        | –        | Linden (Tilia cordata Mill.), sycamore (Acer Pseudoplatanus L.) |
| –                 | <750| 760-860 | 861-915 | >915    | –        | –        | Cherry tree (Prunus avium L.)                |
| Average annual temperature (°C) | >7.9| 8-9.9   | 9-11   | >11     | –        | –        | Pedunculate oak                             |
| <7.9              | 7.1-7.9| 9-11   | >11     | –       | –        | –        | Turkey oak                                  |
| <9.4              | 9-11   | >11.8   | –       | –        | –        | –        | Hungarian oak (Quercus Frainetto Ten.)      |
| <0.5>11.3        | 7.1-7.9| 9.4    | 11.8   | >11.8   | –        | –        | Hornbeam (Carpinus betulus L.)               |
| Number of days with average temperature >10 °C | <176 | 176-189 | 190-197 | >197    | –        | –        | Pedunculate oak                             |
| <176             | 162 | 162-170 | 171-179 | 180-183 | 180-183  | >193     | Sycamore                                     |
| <162             | 162 | 162-170 | 171-179 | 180-183 | 180-183  | >193     | Turkey oak                                  |
| <162             | 162 | 162-170 | 171-179 | 180-183 | 180-183  | >193     | Hungarian oak                               |
| Sum of temperature of days with temperature >10 °C | <2850 | 2850-3185 | 3186-3400 | >3400  | –        | –        | Pedunculate oak                             |
| <2850            | 2350 | 2561-2920 | 2921-3200 | >3200  | –        | –        | Turkey oak                                  |
| <2850            | 2350 | 2561-2920 | 2921-3200 | >3200  | –        | –        | Hungarian oak                               |
| <2850            | 1600 | 2601-2800 | 2800    | >2800  | –        | –        | Hornbeam (Carpinus betulus L.)               |
| <2800            | 2500 | 2571-2700 | 2701-2900 | 2901-2970 | 2901-2970 | 2901-2970 | Sycamore                                     |
| <2800            | 2500 | 2571-2700 | 2701-2900 | 2901-2970 | 2901-2970 | 2901-2970 | Cherry tree                                  |
| <2800            | 1600 | 2601-2800 | >2800   | –       | –        | –        | Beech                                        |
| <2800            | 1600 | 2601-2800 | >2800   | –       | –        | –        |                                               |

(continued)
| Ecological factor                  | Forest favourability class | Species                    |
|-----------------------------------|---------------------------|--------------------------|
|                                   | FS | S      | M     | R     | FR   | Excess I | Excess II |
| Precipitation excess/deficit (mm) |    |        |       |       |      |          |            |
| –                                 |    | <36    | 36–110| 111–150| >150 | –        | –          |
| –                                 |    | <224   | 225–292| 293–336| >336 | –        | –          |
| <8                               |    | 8–12   | 13–40 | 41–70 | >70  | –        | –          |
| –                                 |    | <174   | 174–364| >364   | –    | –        | –          |
| –                                 |    | –      | <106  | 106–148| >148 | –        | –          |
| –                                 |    | –      | <174  | 174–364| 365–456| >456    | –          |
| –                                 |    | –      | <174  | 174–364| 365–550| >550    | –          |
| –                                 |    | <0.94  | 0.94–1.10| 1.11–1.21| >1.21 | –        | –          |
| Useful edaphic volume             |    | <0.42  | 0.43–0.72| 0.73–1.20| 1.21–1.81| >1.81   | –          |
| (unit fractions)                  |    | <0.49  | 0.50–0.63| 0.64–0.87| 0.88  | 1.20     | >1.20     |
| –                                 |    | <0.36  | 0.37–0.90| >0.90   | –     | –        | –          |
| –                                 |    | <0.29  | 0.30–0.49| 0.50–0.90| >0.90 | –        | –          |
| –                                 |    | <0.37  | 0.38–0.90| >0.90   | –     | –        | –          |
| Soil capacity for usable          |    | <0.24  | 0.24–0.80| >0.80   | –     | –        | –          |
| water (mm)                        |    | <95    | 96–200 | >200   | –    | –        | –          |
| –                                 |    | <96    | 97–200 | >200   | –    | –        | –          |
| –                                 |    | <90    | 90–135 | 136–250| >250 | –        | –          |

Note: (the boldated data represents the classes of the studied coefficients which was identified in the studied territory, the italic data represents the scientific name, where: Class I – values without limitations, corresponding to very high favourability (FR); Class II – values with low limitations, corresponding to high favourability (R); Class III – values with moderate limitations, corresponding to medium favourability (M); Class IV – values with high limitations, corresponding to low favourability (S); Class V – values with very high limitations, corresponding to very low favourability (FS); Class VI – factor values which exclude the forest use of the land as they are practically unproductive.)
percentages or in fraction of unit and the values that are higher than 1 described the soils with thickness greater than 1 meter (Dumitru et al. 2011).

The influence of this parameter on the analysed species is illustrated in Table 2, a slight limitation of the pedunculate oak, sessile oak and Turkey oak being visible. These species do not have the necessary conditions to include the territory in the high and very high favourability class.

The soil capacity for usable water represents a specific soil factor which influences the forest pret-ability class for hornbeam, cherry tree and beech. In this case study, this parameter varies between 28.73 and 62.79 mm, with low values in the south-western sector and high values in the high hills from the north-east of the region where there is a higher amount of precipitation due to higher elevation on the ground.

4.2. G.I.S. methodology

The functions included in the GIS spatial analysis models allow the user to directly create databases or model primary and previously modelled databases (Figure 8). This model used vectorization modules for punctually identifying the data collection points and spatially distributing soil types and their characteristics. In order to generate modelled databases necessary for finalizing the model, the Raster Calculator function was used to implement equations for regression functions in order to model the spatial distribution of average annual temperature, average annual precipitation, the number of days with temperatures above 10 degrees, the sum of temperatures above 10°C (number of days) the thermal sum higher than 10°C (in degrees Celsius), etc.

The second stage relies on the method of qualitative classification (values ranging between 0 and 1 are attributed according to the favourability or restrictivity to each forest tree species) performed with the help of GIS techniques of reclassification on modelled databases (presented in the Table 2).
The results of reclassification are included in a derived, qualitative, grid database which will act as input in the final spatial analysis equation used to identify forest pretability.

The third and last stage of the spatial analysis model is represented by the application of spatial analysis equations relying on derived grid databases and mathematical identifiers for spatial analysis (identifier +) used to identify spatially distributed favourability classes for the eight forest tree species included in the model.

The results of the model are represented as a raster database which highlights, relying on the data obtained for each cell, the very high (I), high (II) and medium (III) forest favourability classes for the hilly sector of the Transylvania Depression. The raster database was obtained using the Spatial Analysis equation based on average overlay between all the factors used in the model.

In 1974, Chiriță C.D. studied and recommended the classes for the ecological factors which allow the use of five favourability classes: V being the maximum favourability value and I the class with the highest limitation for this use. These classes were connected to forest pretability classes, in this case a territory from class I had maximum pretability, whereas a territory from class V had severe limitations determined by topography, climate or soil.

In order to validate the results of the model we performed a series of arbitrary topographical survey in the field using the GEOMAX Zenith35 GPS and the Nikon NPL352 total station for the most common tree species (beech and garneau) in order to compare with the favourability classes that we will obtain. The contour points acquisition for the surfaces considered valid for validation was done using the GPS in the RTK mode taking as reference station for measuring the Bistrita station, this station is near to the study area. Where vegetation coverage did not allow GPS measurements to be used, the total station was used for the acquisition of contour points staring from a known GPS point and with orientation to another known GPS point from the immediate vicinity of the measurement area. As the main measurement methods, traverse and polishing were used to highlight the contour points with great precision.

Figure 8. Conceptual scheme (where: DEM – digital terrain model, Temp – average annual temperature; \( T > 10^\circ \text{C} \) (no of day) – the number of days with temperature above \( 10^\circ \text{C} \); sum \( T > 10^\circ \text{C} \) (Celsius degree) – thermal sum with values above \( 10^\circ \text{C} \); PP – average annual precipitation; \( Q_I \) – quality index for average annual temperature; \( Q_{I_T} \) – quality index for the number of days with temperature above \( 10^\circ \text{C} \); \( Q_{I_S} \) – quality index for sum with values above \( 10^\circ \text{C} \); \( Q_{I_{pp}} \) – quality index for average annual precipitation; \( Q_{I_{vou}} \) – quality index for useful edaphic volume; \( Q_{I_{water}} \) – quality index for water excess/deficit (mm).
5. Results of the model

Specialized studies for Europe highlight the negative influence of temperatures below $-3\,^\circ C$ and $-6\,^\circ C$ (Praciak et al. 2013; Savil 2013) as well as the adaptation of this species to less favourable conditions in mixed forests (Bohn and Neuhäusl 2000; E.E.A. 2007; Ellenberg 2009). The bioactive period represents a limitative factor for the pedunculate oak, therefore 824 km$^2$ are included in the low pretability class (IV). The pedunculate oak needs minimum 180 days with daily temperature $\geq 10\,^\circ C$ for an optimum growth (Pâcurar 2006). The precipitation amount which is characteristic to the Someșul Mare Hills indicates a favourable situation in the high-hill sector and a very high favourability in the middle-hill sector. Any limitations related to precipitation, precipitation excess and deficit as well as useful edaphic volume are kept to a minimum, the territory being included in the first two pretability classes (Figure 9).

Considering the fact that Turkey oak is a tree species which prefers a mild climate, one notices that the territory of the Someșul Mare Hills is included in the low and very low favourability classes in what concerns the average annual temperature and the sum of the days with temperature above 10 $^\circ C$. By applying the forest classification methodology which was previously presented, the adding and mediation of the rasters which represent the six ecological factors determining the favourability to the Turkey oak species lead to an inclusion of the Someșul Mare Hills in the medium (III) pretability class (Figure 10).

As the Hungarian oak, *Quercus Frainetto Ten.*., is a species which does not have special climatic requirements, being sensitive only to frost, the analysed thermal indicators offer average conditions (Florea et al. 1987), hence the presence of the favourability class III. Precipitation and especially

![Figure 9. Favourability classes to pedunculate oak (*Quercus robur*) and the percentage distribution of the determinant factors of territory pretability.](image)

![Figure 10. Favourability classes to Turkey oak (*Quercus Cerris L.*) and the percentage distribution of the determinant factors of territory pretability.](image)
precipitation excess offer very good conditions for the Hungarian oak in 100% and 72% of the territory. In what concerns the useful edaphic volume, the most favourable areas for this species are found in the western part of the study area, but also the middle hill sector is characterized by favourable conditions.

Considering the fact that the Hungarian oak is a very adaptable species on clay, with a high water absorption capacity from excessively wet soils, it is a valuable species on soils affected by landslides or in areas with high landslide susceptibility due to the presence of clays, high slope angles and other landslide causing factors. Most of the Someșul Mare Hills (96%) is favourable to the growth of the Hungarian oak, thus being classified in the good favourability category (IIth classes of favourability), while only 4% of the territory is included in the medium favourability class (IIIth classes of favourability) (Figure 11).

Previous studies on *Carpinus Betulus* L. have shown that this tree species has a great resistance to late freeze, but a low resistance to drought (Hamerlynch et al. 2002; Pallardy 2008; Clinovschi 2015), which explains its inclusion in low favourability classes for the first three factors (Figure 12).

The useful edaphic volume is characterized by higher values than 0.9 and includes the western sector of the study area in the medium favourability class (III). Considering the fact that the territory of the Someșul Mare Hills has a usable soil water capacity ranging between 28.73 and 62.79 mm, the whole territory is included in the very low favourability class. The high number of climatic and pedologic limitations explain the limited favourability to hornbeam in the analysed territory, thus most of it is characterized by low and very low favourability. The medium favourability (III) is characteristic to the upper hill sector which is located in the north of Salva settlement, the rest of the territory

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**Figure 11.** Favourability classes to Hungarian oak (*Quercus Frainetto Ten.*) and the percentage distribution of the determinant factors of territory pretability.

**Figure 12.** Favourability classes to hornbeam (*Carpinus Betulus* L.) and the percentage distribution of the determinant factors of territory pretability.
being favourable to the development of forest stations with less sensitive species to the environmental conditions of this region.

The precipitation amount of 639–1050 mm/year from the Someșul Mare Hills includes 17% of the territory in the very high favourability class and 31% in the high favourability class for *Tilia Cordata Mill*. By analysing the number of days with temperatures above 10°C, one can notice for 7.6% of the territory a very high favourability in low-elevation areas, characteristic to the Someș flood area and the valleys of its first rank tributaries, followed by 26% of the territory with high favourability (Figure 13).

The soil requirements for linden refer to soils with good fertility, good aeration and constant humidity. A restrictive factor is represented by fluctuating humidity and excessive humidity as well as highly compacted soils. Considering the characteristics and the environmental conditions of the study area, linden is included, for most of the territory (81.9%), in the medium favourability class. However, in 18.1% of the area, linden has the most appropriate conditions for growth. The most favourable areas are found in the flood plain of the Someș, in the low-hill area of Dej and locally, along the low valleys of Someș tributaries.

The average annual temperature and the thermal sum do not meet the sycamore’s requirements. However, the precipitation amount, the precipitation excess, its bioactive period and the useful edaphic volume are indicators which allow the existence and growth of this species on large surfaces. Thus, most of the territory is included in the medium favourability class (76.3%), while the rest of 23.7% match the specific conditions for the high favourability class, especially in the Dej Hills and in the low valley sectors of the main tributaries from the right side of the Someș (Figure 14).

![Figure 13](image1.png)

**Figure 13.** Favourability classes to linden (*Tilia Cordata Mill*) and the percentage distribution of the determinant factors of territory pretability.

![Figure 14](image2.png)

**Figure 14.** Favourability classes to sycamore (*Acer Pseudoplatanus L.*) and the percentage distribution of the determinant factors of territory pretability.
These requirements for thermal conditions for *Prunus Avium L.* that make the study are to be included in the low favourability class (V) as the average annual temperature is too low for the cherry tree, or even very low (V) for 96% of the territory in the case of the thermal sum. The bioactive period is too short and the usable soil water capacity are two limitative factors to cherry tree plantations, therefore only 35.5% of the territory can be included in the medium favourability class while the remaining 64.5% have low favourability (Figure 15).

A pedological limitation for *Fagus Sylvatica L.* is represented by clay soils, pseudogleic soils and peat or dry soils. By analysing the spatial distribution of the favourability to beech classes on Someșul Mare Hills, 2.2% of the area has the proper conditions for starting a forest station (IIth classes of favourability), especially in the upper sector of the hills from the south and center of the study area, while the rest of the territory is included in the medium favourability class (IIth classes of favourability) (Figure 16).

### 6. Model validation

The validation of the results was performed by directly comparing them with the reality from the field. This method included a series of topographical surveys performed as samples from the analysed territory, for different forest areas with beech and Hungarian oak (Figure 17). The overlaid results compared with the field data confirm the validity of the model and highlight the fact that it can be applied to similar conditions, as the spatial overlay of the modelled/measured ratio is above 76.8% for all the forest tree species included in the study.
7. Conclusions

The identification of suitable lands for starting forest stations represents one of the main objectives when introducing degraded lands in the economic circuit and for increasing the economic efficiency of lands used exclusively as forests. The implementation of spatial analysis GIS models considerably reduces the necessary time for the analysis of the territory and increases the precision and accuracy of the results. The multitude of spatial databases can be unitary integrated and analysed using the same GIS software when analysing a heterogeneous surface with territorial limitations of the forest areas.

The development of spatial analysis models using databases, culture technologies and the existent methodologies move the classification methods to a superior level, together with the integrated research of the environment and of the land favourability to forests.

The results of this study could be useful not only for new plantations in the hills of Transylvanian Depression but also for the use of highly assured tree species in the degraded area (by landslide and soil erosion) in order to reduce the negative effects on the territory.

The present study has highlighted the utility of managing and integrating GIS spatial databases in a complex model for identifying forest pretability, a model which can lead to the development of other more proficient models and can also represent an intermediary stage in a larger scale model.

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