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AHP ANALYSIS FOR MICROZONING OF VINEYARDS BY GIS

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Abstract

The Analytic Hierarchy Process (AHP) is a widespread mathematical technique for multi-criteria decision-making analyses, deals with the structured hierarchical database models, gathered from interdisciplinary criteria for future perspective analyses in the specific sector. Viticulture microzoning and terrain selection for potential vineyards are becoming important knowledge for vine farming systems. In this study the AHP method is used to gather, structure and resolve the data of variety sorts of vine, evaluate the physical natural resources (climate, soil and relief), socio-economic and infrastructures conditions to dissolve different environmental problems of vineyards management. GIS (Geographical Information Systems) tools allow making multi-criteria analysis and combined various data of vineyards for digital complex environmental assessment. The site selecting for a new vineyard for wine-grape or wine production is a fundamental and crucial decision as several factors have influenced on it.

***Key words**: AHP, vineyards, microzoning, GIS, multi-criteria analysis.*

INTRODUCTION

Cultivation is the act of making use of land resources to get production for livelihood of mankind. Therefore, cultivation involves both land characteristics including qualities and human attitudes. Social parameter of human being determines the need moreover need make decision parameter for the type of crop to be cultivated in given plot of available land. Production from the land is based on the land capability and investment input in terms of materials and services. Land capability gives rough sketch of the land. Separating land area for specific use by knowing its capacity to support type of crop is land suitability classification. So the process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for a defined use (Giri et al., 2016).

Viticulture is an important agricultural sector with high economical and societal values for country like Bulgaria, with a cultivation area about 65,000 hectares. Bulgaria has a great potential and ability to provide diversity in viticulture due to the favourable geographic and climatic conditions and soil properties. Selection of the vineyard site in consideration with the delicate nature of grapes becomes the most crucial step for the precision viticulture. Determination of suitable lands for the viticulture and utilization of them for grape cultivation purposes have a direct effect on the yield and the quality of the products (Ugur et al., 2019). Most of the European Union (EU) member countries employed their own national viticulture information systems in order to gather the information related to grapevine production potential since the EU request production estimations from the member countries (Rodriguez-Perez et al., 2008).

Developments in satellite technology in conjunction with the new image analysis techniques enabled faster and easier information extraction related to Earth surface and also unlocked the ability to demonstrate the current land use/cover (LULC) status with use of up-to-date satellite images (Ugur et al., 2019). Precision viticulture uses the remote sensing technology for mapping several characteristics of the vineyard areas. Analysis of high-resolution satellite images gives highly precise maps of land use/cover (Giri et al., 2016).

Different studies reported the efficient use of satellite images in agricultural applications such as determining vineyards and other permanent or annual crops (Alganci et al., 2013; Sertel and Yay, 2014). Apart from distinguishing vineyards from other land use/cover classes, remote sensing technologies also serves precision viticulture as a data source to map many characteristics of the vineyard areas. Productivity of a vineyard depends on different biophysical/chemical characteristics of both the environment and the vineyards, therefore monitoring of these parameters is essential in vineyard management. The spectral and geospatial information derived from remotely sensed images are used to identify the grape varieties, to determine their spatial distribution and to monitor the crop condition (Hall et al., 2002; Bramley et al., 2011). Additionally, remote sensing technology has been successfully applied for assessing vineyard conditions with vegetation indices, estimating harvest and yield and early detection of distress (Gill-Perez et al., 2010; Meggio et al., 2010; Font et al., 2015).

The proposed spatial information system for site selection and vineyard management, its structure and functions, need to recognise and support the complex parallel processes and needs of grape growth, management, information flow, analyses and decisions (Smit, 2002). It will enable compilation of important information to spatially, and temporally, analyse and present information for decision purposes (Star et al., 1997). Analysis enables selection of sites, and decisions on how to use the sites, using optimum combinations of factors to achieve best desired results and minimising costs and risks - such as analyses of suitable combinations of vine performance, wine qualities and the vineyard environment, as managed by the strategic viticulture practices (Smit, 2002).

The objective of this paper is to present, discuss, and apply the principles and techniques of the analytic hierarchy process (AHP) in the prioritization and selection of suitable vineyard locations. AHP is one of the main mathematical models currently available to support the decision theory. AHP was developed in the 1970s by Thomas L. Saaty and has since been extensively studied, and is currently used in decision making for complex scenarios, where people work together to make decisions when human perceptions, judgments, and consequences have long-term repercussions (Bhushan and Rai, 2004). This method has been attracting the interest of many researchers, mainly due to the mathematical features of the method and the fact that data entry is fairly simple to be produced (Triantaphyllou and Mann, 1995). Its simplicity is characterized by the pair-wise comparison of the alternatives according to specific criteria (Vargas, 1990).

Another important aspect is the quality of the evaluations made by the decision makers (Coyle, 2004). For a decision to be the most adequate possible, it must be consistent and coherent with organizational results. When looking into how organizations decide over which action to execute, we notice a constant desire to have clear, objective, and mathematical criteria (Haas et al., 2005). However, decision making is, in its totality, a cognitive and mental process derived from the most possible adequate selection based on tangible and intangible criteria (Saaty, 2009), which are arbitrarily chosen by those who make the decisions.

Determination of the suitable vineyard areas can be performed with the integrated spatial analysis of satellite images, meteorological, soil and topographic data in a Geographical Information System (GIS) environment. Topography (slope, aspect and elevation), meteorological conditions and soil type have considerable impacts on grapevine production. So these parameters should be taken into account when deciding the most appropriate areas for viticulture practice in various Bulgarian regions. Therefore, applying a GIS based decision rule, which integrates different spatial data into decision-making procedure, is a common approach for viticulture site selections (Rikalovic et al., 2014; Star et al., 1997).

However, GIS is limited to certain analysis with simple spatial content and can be more successful in managing variety of spatial and semantic data in combination with spatial multi-criteria analysis (SMCA) (Voogd, 1983). The SMCA enables a more complex investigation by considering multiple conflicting criteria and their effects on the desired results (Carver, 1991). This method has been used successfully for various environmental decision-making applications and many review works conducted to evaluate these studies (Malczewski, 2006; Huang et al., 2011; Seker and Yucel, 2017).

Previous researches used the SMCA to address the several environmental issues which can be categorized under waste, water, air, energy, and natural resources management/quality applications (Huang et al., 2011). Aliyu and Ludin (2015) asserted in their review work that SCMA is one of the best structures for analysis of environmental problems and sustainability evaluations. However, there are few researches related to analysis of sustainability and suitability for vineyards using the SMCA. Irimia et al. assessed the climatic suitability of three wine-growing regions in Romania using the GIS based multi-criteria analysis and their results provided that only one of the regions is suitable for high quality red wines (Irimia et al. 2013). Kumara and Sendanayake proposed a GIS based multicriteria analysis for exploring the potential vineyard sites in tropics (Kumara and Sendanayake, 2016). Dragincic et al. used a reverse approach to determine the most suitable grape variety for organic viticulture using group multicriteria decision making (Dragincic et al., 2015). The multi-criteria programming made through the use of the analytic hierarchy process is a technique for decision making in complex environments in which many variables or criteria are considered in the prioritization and selection of alternatives or projects. This paper also discusses the importance and some possible criteria for prioritizing the vineyards cultivation factors, it demonstrates AHP in a step-by-step manner accordingly to the viticulture in Bulgaria, where the resulting priorities are shown and the possible inconsistencies are determined.

MATERIALS AND METHODS

Many criteria will be involved in the vineyards site selection analyses and decisions. Spatial information systems are appropriate for this research because the used criteria's can be represented spatially as layers of geographic data, aggregating and assessing combinations of criteria's by different weightings to the various factors and applying priorities to them. The result will be able to produce a set of potential vineyards sites using Multi-Criteria Evaluation (MCE) (Malczewski, 1999), ranked according to their best fit conditions to the multiple criteria's and theat tribute ranges required. The Analytic Hierarchy Process (AHP) is a well-known multi-criteria decision-making method, proposed by Saaty in 1980 (Saaty, 1980; 1996; 2001). According to the author, the method provides a theory of relative measurement of intangible criteria for decision analysis.

The Analytic Hierarchy Process consists of the decomposition of the decision problem into simpler components or levels and the definition of a hierarchy framework by pair wise comparison between the levels. The key element, of the method, is the pair wise comparison of the components at each level of the hierarchical structure, namely the criteria and sub-criteria of the alternative scenarios, which affect the problem. For this purpose comparison matrices are structured for the comparison of the elements of a level of the hierarchy with the elements of the next higher level and so. The top level of the hierarchy is the goal of the decision problem. The next level consists of the tangible and intangible criteria and sub-criteria used to assess the alternatives, which in turn, form the bottom level of the hierarchy.

AHP uses pairwise comparisons to assign weights to the individual elements of each level, by measuring their relative importance using Saaty´s 1-9 scale (Table 1), and then calculates the overall priority for the alternatives of the decision process (Saaty, 2005; 2008). The method also calculates a consistency ratio associated with each matrix of pairwise comparisons to verify the consistency of the calculated values. The mathematical foundations of the method can be found in Saaty (1994; 1996).

The decision-making process can be presented by the following steps:

➢ Structuring the problem into ahierarchy.

❖ Defining the overall goal of the decision problem.

❖ Defining the decision criteria in the form of a hierarchy by identifying the main criteria and the sub-criteria under each main criterion. In this way each main criterion can be analyzed in detail considering the respective contribution of each sub-criterion.

❖ Defining the decision alternatives. The process for the identification of the alternatives varies depending on the type of decision problem.

- Criteria prioritization. At this stage the local weights of the criteria are calculated by pairwise comparison among the criteria of each level and then the global weights are obtained.
- Prioritization of alternatives. The priorities of the alternatives are obtained for each criterion.
- Setting overall priorities associated with each alternative. At this stage, the global priorities of each alternative are aggregated to yield the overall priority of an alternative for a certain criterion.

The comparison between two elements using AHP can be done in different ways (Triantaphyllou and Mann, 1995). However, the relative importance scale between two alternatives as suggested by Saaty (Saaty, 2005) is the most widely used. Attributing values that vary from 1 to 9, the scale determines the relative importance of an alternative when compared with another alternative (Table 1).

Table 1. Saaty's Scale of Relative Importance (Saaty, 2005)

Scale of importance	Definition	Reciprocal
1	Equal importance	1
2	Equal to moderate importance	1/2
3	Moderate importance	1/3
4	Moderate to strong importance	1/4
5	Strong importance	1/5
6	Strong to very strong importance	1/6
7	Very strong importance	1/7
8	Very to extremely strong importance	1/8
9	Extreme importance	1/9

A criteria weight, is defined through several means and indeed based on the researchers experiences in the field, through deep literature view and field survey conducted among farmers, vineyard managers and decision makers of the supply chain. Analytical hierarchy process (AHP) that compares the criteria as a pair and assigns scores from 1/9 (as extremely less important factor) to 9 (as extremely more important factor) considering how strong or weak the relationship between the pair of factors (Table 1) (Saaty, 1977). It is common to always use odd numbers from the table above to make sure there is a reasonable distinction among the measurement points. The use of even numbers should only be adopted if there is a need for negotiation between the evaluators. When a natural consensus cannot be reached, it raises the need to determine a middle point as the negotiated solution (compromise) (Saaty, 1980). The data input in comparison matrices, which represent the expression of preferences of the decision makers, resulting from the fundamental scale of Saaty, which is a qualitative scale that includes values from 1 to 9. These values are used by the decision makers for the purpose of benchmarking as equal (1), moderately strong (3), strong (5), very strong (7) and very strong (9) importance. Based on the scale preferences Saaty, all possible gradations of preference is P = {1, 2, 3, 4, 5, 6, 7, 8, 9, 1/2.1 / 3.1 / 4.1 / 5.1 / 6.1 / 7.1 / 8.1 / 9}. Consequently, the scale proposed by Saaty, is a mathematical approximation of preferences and the importance of the criteria and alternative scenarios, attributed the decision makers. Nevertheless, in case that there is a precise measurement with respect to the preference of a criterion or alternative scenario over another, it is possible to use the exact measurement (Saaty, 1987; 1990; Karimi et al., 2011; Bottero et al., 2011). To ensure consistency in the pair wise comparisons, during AHP analysis, the calculation of the consistency ratio (CR) is essential to take place in order to evaluate any discrepancies in matrices of pair wise comparisons that should lead the decision makers to revise their initial estimates. AHP method is to set priorities among the criteria, and then for each criterion, among the different alternatives responding to paired comparisons as defined in the method. For each pairwise comparison matrix we verified that the consistency index was acceptable, i.e. less than 0.1 (Saaty, 1994). According to the literature, any pair wise comparison matrix is considered to be consistent and hence acceptable when CR is less than 10% (Ozdemir, 2005). In addition to that, a sensitivity analysis on the AHP weights is unfolded to show the impact of varying weights to the final outcome (Georgiou et al., 2012).

The production of wine grapes is a complex process of analyses, expert understandings, decisions and management determined by natural and managed factors, and dependent on the characteristics of the vineyard site. The suitability of the site depends on how well it has been assessed, selected and developed. These processes scan be supported by an information system that integrates appropriate factors and data, particularly using spatial relationships as the key - a system with data management, analytical, decision support, and interfaces functions. The modular system proposed above combines these functions, with the intention of providing a comprehensive practical system for its users (Smit, 2002).

RESULTS AND DISCUSSIONS

The production of high-quality wine is a complex process that depends on many factors, such as type of soil, climate, the characteristics of the vineyard, socio-economic and infrastructure components. When an investor wants to invest money in the production of high-quality wine actions have to be focused on a complex decision-making systems (Arnaudova et al., 2010). The present work addresses the problem of vineyard selection to produce high-quality wine using the Analytic Hierarchy Process (AHP) in the Bulgarian regions.

Viticulture is a particularly intense form of agriculture, producing high value grape crops from specific areas of land. Results are dependent on the location of the vineyard and associated factors, and the management inputs and controls. This is site specific knowledge of the spatial and variable contributes to the success of the profitable resulting product. Seasonal variations and events also affect the results so temporal factors must also be understood and managed. And, economic and other operational successes depend on the scale and degree of detail of the vineyard management processes (Smit, 2002).

Although the grapevine can grow in many places, its successful cultivation for quality wine production is limited to sites where specific characteristics and conditions occur and the necessary management practices can be achieved. The main factors affecting vines, their development and annual cycle of growth, and the coproduced each year include: Physical Environment- landform, altitude, slope, aspect, soils, nutrients, water and drainage, erosion and urbanization risk, climate, heat summations, season al variations, longer term cycles and fluctuations, weather and hazards, and Viticulture and Vineyard Management- selection of sites, design and layout of vineyards, varieties and rootstocks, infrastructures and services such as irrigation, road network, capital investment, mechanization, transportation of the product and another parameters (Smit, 2002; Arnaudova, 2008; Wolf et al., 2003; Baniya, 2008). Multifunctional structure can be used for analyses of viticulture factors, for decision support, and for identification of suitable sites for vineyard establishment. It will provide the main visual interfaces for the proposed system. The purpose of this module is to enable an evaluation process, of the potential sites that meet particular suitability criteria, leading to a site selection (Kirkby et al., 1996). It will include multi-criteria evaluation to support a complex decision process, and multi-objective evaluation to meet several defined business objectives, that may be complementary or conflicting (Malczewski, 1999; Voogd,1983). Using a series of spatially referenced layers of information, analysing, merging and joining, areas of suitability can be derived, based on selected criteria, in order of significance. Unsuitable area scan be eliminated, and sites with potential can be classified, prioritised or ranked. First choices can be analysed in more detail, from more specific detailed information, in stages of an iterative process of analysis and decision (Kirkby et al., 1996). Determination of the suitable lands for vineyard plantation basically consists of two important steps. The first step is to determine the crucial parameters that should be involved in analysis and the second step is to apply a suitable weighting method for these parameters. These two steps can be performed simultaneously with a multi-criteria decision-making strategy (Sertel et al., 2011). Weightings can be applied to criteria/factors, some more important than others, or ‘tradeable’ factors, with comparative weightings between them, to set their empirical, ordinal or relative importance. This will help establish suitability thresholds for site selection, sites that are included or rejected, or to prioritise/rank the suitability of sites (Hossain et al., 2007).

The methodologies developed and use two objectives: evaluation of viticulture potential and the proposal of suitable sites based on dominant observations of results (Baniya, 2008). The whole physical/natural analysis can be presented by some steps or modules. The first module is development of indicators. Indicators represent mainly the climate and extend to soil, topography and land cover. The information presents key indicators and their meaning to the vineyard natural establishment, management and zoning. Data collection and databases development about natural main characteristics (climatic, soil, topography, land cover) have been built based on available data sets informants that can be directly used for the analysis. Second module consist the AHP analyses for each mention indicator and obtain appropriate weights based on the data using software and represented by a thematic maps. All individual suitability maps of climate, soil, topography and land cover aggregated in to one map showing potential values for vineyard establishment leading to selection of prospective sites (Beltrán et al., 2010). Accuracy assessment results can be assessed and compared with the existing vineyard locations to check the reliability of the method and then develop new indicators. Finally module includes zoning and exploration of potential sites. Potential site selection is a process of selecting best sites or better alternatives where a decision has to be taken considering several constraints and factors depending on their relative importance to the final objective integrated with GIS tools and procedures (Malczewski, 1999).

The first step in building the AHP model lies in the determination of the criteria that will be used. Each structure develops and organizes its own set of criteria, which in turn must be aligned to the strategic purpose of the organization (Baniya, 2008). The application of AHP begins with a problem being decomposed into a hierarchy of criteria so as to be more easily analysed and compared in an independent manner (Teknomo, 2006). After this logical hierarchy is constructed, the decision makers can systematically assess the alternatives by making pair-wise comparisons for each of the chosen criteria. This comparison may use concrete data from the alternatives or human judgments as a way to input subjacent information (Saaty, 2008). AHP transforms the comparisons, which are most often empirical, into numerical values that are further processed and compared. The weight of each factor allows the assessment of each one of the elements inside the defined hierarchy. This capability of converting empirical data into mathematical models is the main distinctive contribution of the AHP technique when contrasted with other comparing techniques (Vaidya et al., 2006).

The methodology relies on weighting the parameters derived from geo-spatial data in multi-criteria analysis. Weight is defined as the value that represents the importance of a particular assessment criterion relative to the other criteria in the equation; in which the more influential criteria possess greater weight. Therefore, derivation of weight is an essential step, which directly influences the production of final map. The ranking, rating, pairwise comparison, binary and trade-off analysis methods were the mostly used methods for weighting (Sertel et al., 2011b; Zardari et al., 2015). Pairwise comparison method was selected due to its accuracy, theoretical strength and the wayit is implemented in GIS-based multicriteria analysis (Malczewski, 1999; Makropoulos and Butler, 2006). Pairwise method is an objective and simple method that allows ranking similar parameters by comparing and choosing between two parameters in each step. Then, parameters selected the most ranked accordingly (Saaty, 1980). It is widely used to assign weights in numerous studies (Malczewski, 2004). The pairwise comparison method trusts two-way comparisons to create the ratio matrix. The method uses two-way comparisons of the input data and produces the relative weights. The method consists of three steps, which are namely, constructing the two-way comparison matrix, calculation of the criteria weights and inferring the coherence ratio. Land suitability assessment for vineyard development in Bulgaria is influenced by many fundamental parameters namely, soil and land parameters, climatic attributes, terrain and physiographic, social characteristics, cultural aspects, cultivation customs, infrastructure development, services available, market situations and many more. All of them can logically be discussed under three categories:

Physical and environmental parameters (PHYENV); Socio-economic parameters (SOCECO) and Infrastructure parameters (INFSTR). Cultivation trend in society and land use practices is social and cultural traits, which makes impacts on yield of vineyard. From field to home (from soil to consumer) or to market is affected by the socio-economic and infrastructure attributes (Baniya, 2008).

Plant growth is influenced by components of the physical environment. Almost all agronomical need of a crop is fulfilled by components of physical environment. Whereas latter parameter is more likely to effects on final yield and handling of the product and postharvest handling is also depends upon same parameters (Baniya, 2008). For the development of the viticulture farming in the areas like Bulgaria needs tounderst and fully the land capability, which is the first and far most important aspect. Land set up and soil characteristics are of unique type. Physiographic setting allows specific plant species attains full growth in such an environment. Planning of vineyard begins with the selection of the suitable species based on the ecological condition of the region. Very often local species are selected for the cultivation because of the genetic acclimatisation for specific environment (Jones et al., 2000). It was observed in several instances that under production and economic loss are caused by introduction of the new species. Traditional way of cultivar improvements and selection is cultural practice in many parts of regions on which farmers area customer (Tonietto et al., 2004).

Accordingly to the Physical/natural parameters, the main criteria and factors are presented on Table 2.

Table 2. Physical/natural (PHY) assessment parameters for suitability vineyard sites

Criteria	Factors
Soil	Soil depth
	Soil reaction (pH, H_2O)
	Soil texture
	Organic matter content
Relief	Elevation
	Slope
	Aspect
Climate	Total vegetation temperature
	Annual precipitation
	Minimum temperature in the coldest month
	Maximum temperature in the warmest month
	Mountain/river influence

As a first step of data preparation, the precipitation map of the researched region is produced from meteorological stations by interpolation method and agro statistical information about Bulgarian regions. Secondly, aspect, slope and elevation maps were produced from the DEM elevation data. Thirdly, vector based soil map was converted to raster format in order to make it compatible with remaining data set and raster based calculations in GIS environment.

Land use capability classes are defined according to several parameters of soil such as soil depth, soil salinity, erosion factor, etc., and consists of 4 levels that describes their potentialities and limitations for sustained production. The first level (0) corresponds to lands that their structure is even not suitable and can only be used for recreational purposes and the last level (3) corresponds to suitable and feasible lands for agricultural activity. Land use capability classes were assigned as attribute information in the soil map. Land use capability map was converted to raster format according to this attribute and ranked according to the land use capability classification as (0-1-2-3) where 0 represents the inconvenient lands and 3 represents the most convenient lands. The reason for re-ranking the data is to give higher weights to more suitable land classes.

Soil and climate are the most two important criteria for viticulture (Unal et al., 2014). These two criteria were considered more important than the others when constructing the comparison matrix.

Viticulture can be performed without the necessity of irrigation in some regions of the Bulgaria, where annual precipitation amount is around 500-600 mm/year. It is found out that regions with elevation around 500 m are less compatible for viticulture due to temperature condition changes (Unal et al., 2014; Orman et al., 2016).

Aspect information is also an important parameter because of its effects on moisture holding capacity of soil and sun illumination efficiency. The south, south-east and south-west directions were asserted to be convenient for viticulture (Pitz and McKillip, 1984). According to Wolf and Boyer (2003), aspect has the least importance for viticulture suitability when compared with the other physical characteristics such as elevation and slope. They also asserted that south and east directions has possible advantage by early morning exposure triggering the photosynthesis progress and also early drying after rain that prevents possible disease. According to Sertel et al. (2012), vineyards should receive direct sunlight even for the hot climatic regions. East direction is optimal for illumination and photosynthesis activity will start faster as sunlight will reach to the crops in early hours of the day. Moreover, grape crop starts the germination process earlier in south direction when compared with other directions.

The elevation map was created using digital elevation data for the studied region. Elevation data was ranked with respect to different elevation levels using the reclassification technique and vineyard plant requirements. Elevation ranking was performed with respect Arnaudova (2008), which is also compatible with the local researches on the study region. In their study, they ranked the absolute elevation intervals according to ranking coefficients, which are 0-1-2-3. Absolute elevations of the study area and their respective ranks are given in thematic map according to their suitability for viticulture activity.

Aspect map produced from DEM data, was used as one of the parameters to determinate suitable areas for viticulture. Distribution was established based on south, north, east and west directions. Then, all directions were ranked with reclassification; giving higher value to south and south east facing directions.

Slope map produced from DEM data was also analysed for the same purpose of spatial analysis. The slope data is classified into groups defined in the guideline published by Food and Agriculture Organization of the United Nations (FAO) in (FAO, 2006) slope for grading eligibility in viticulture. Gently sloping land is preferred in viticulture for its ability to reduce the risk of frost injury and cold winter temperatures by allowing the cold air to drain low areas. Slopes greater than 15% are asserted to be inconvenient due to roll-over risks and management difficulties (Wolf and Boyer, 2003). Within the light of above mentioned researches, the main parameters were selected as precipitation, soil type, elevation, aspect and slope in the physical/natural criteria.

Infrastructure development and investment of state and central government on the viticulture sector also plays role. Road access network, setting up market place and controlling price, agricultural subsidy, would make impact on the yield and economic benefit from the farming. In several instances, lack of proper storage arrangement caused heavy economic loss to the farmers (Baniya, 2008). Distance to nearest road head and to the market is also a problem. From these facts, it can simply be concluded that vineyard cultivation is act which need to be considered with set of conditions from all possible sector like physical environment, climatic, social, economic, infrastructure and agricultural input availability. Relationship among different influencing factors should be judged properly for selection of the land area according to agronomical need of plants, capability possess by land area, farming attitude of the society and economic potentiality with infrastructure investment inland. Similar consideration has been shown by Hossain et al. (2007). All these criteria are considered in the order of importance i.e. ratings. Evaluation of rated component of the factors will generate land area which is suitable for the specific type of grape with degree of difficulty and limitations. The classification result will yield suitability evaluation of land area. Suitability evaluation is carried out considering each component separately. Physical land suitability, socio-economic suitability and environmental suitability are established ones. Each basic category is consisted by a number of environmental, economic and technical sub-criteria (Table 3).

In this research, all mention criteria can be presented by vineyard plantation suitability map of some Bulgarian regions or about the whole country, with variable viticulture activity and determined using multi-criteria decision analysis approach. This process was applied by the integration of socio-economic and infrastructure information derived from statistical data, in addition with the soil parameters derived from soil type maps, the meteorological information about the climate and topography accordingly to the studied region.

Table 3. Assessment parameters for suitability vineyard sites

Criteria	Factors	Description
Infrastructure (INFSTR)	Irrigation (IRIGN)	The influence of rainfall pattern on grape quality, the impact of humidity on plant water balance, the availability of potable water sources and/or the distance to a water supply network
	Road (ROAD)	The conditions of the access roads from the wine cellar to distribution centres, Production transporting
	Mechanization (VALUE)	Mechanization of the working
	Marketing (MARKET)	The impact of the distribution and marketing channels on the final product cost
	Field size (FSIZE)	Size of the land fields
	Distance to the collecting centre or winery (DCEN)	The distance from the vineyards to the winery or a collecting centre
Social and Economic (SOCECO)	Qualification (QUALIF)	Qualification of the farmers
	Motivation (MOTIV)	Motivation of the farmers
	Labour force (LABFR)	The difficulty and cost of grape harvest
	Land price (LPRICE)	The price range of land, in leva (BG)/ha
	Capital investment (CAPINV)	Investment capacity
Environmental and physical/natural (PHYENV)	Physical/natural (PHY)	The suitability of the land, soil and climate
	Erosion (ERO)	Erosion potential of land
	Urbanization (URB)	Urbanization risk of site

Weighting methods were investigated to assign the order importance between these parameters. The pairwise comparison method was selected as the most appropriate method of weighting according to review of previous researches (Arnaudova, 2008). The weights calculated by the comparison matrix was checked with consistency rate estimation and 'acceptable consistency' is obtained by performing the pairwise comparison. Lastly, the suitability map and the current vineyard spatial distribution map of researched parameters are compatible with cadastre map in order to investigate the suitability of existing vineyard locations and parcels.

Calculating the weights of geographic, meteorological and soil data was one of the most important parts of the study. Weights were calculated by pairwise comparison method which compares all pairs of criteria and composing optimal weighted (Saaty, 1980). Consistency ratio values demonstrated the efficiency of weighting process for the parameters included in the AHP process (Beltrán et al., 2010). In the next step, ranked parameter maps are multiplied by the calculated relative weights and summed to produce 'weighted sum overlay analysis map' on the GIS environment. For this purpose, site statistics was applied to determine the statistical distribution of current parcels in terms of suitability classes. Comparison results are presented as overlay map. When this result evaluated together with the transportation networks of the area, intense vineyard plantation suitable lands can be explained by their closeness to the transportation infrastructures, water resources, highly modern mechanization and another infrastructure factors. Moreover, constructed AHP method is suitable for adding more parameters if available due to weighted sum capability which is an important advantage over direct assignment strategy (Kurtural et al., 2007).

The proposed GIS multi-criteria evaluation approach with the set of indicators presented here underlines the great potential in extending the performance of previous research on zoning and vineyard site selection in Bulgarian region. AHP method is based on weights to evaluate a set of different indicators and range the dominant influence on vineyard site selection. Each basic category is consisted by a number of environmental, economic and technical sub-criteria (Table 2 and Table 3).

The multi-criteria method is applied on geo-spatial data and including various and different forms of information in order to produce the vineyard plantation suitability map of the Bulgarian regions, where considerable amount of grape production take place. Specifically, the main objectives and purpose can be grouped in the next two levels:

- ✓ Develop a spatial multi-criteria decision analysis with pairwise comparison weighting method and determine the vineyard suitability by use of various geospatial and meteorological data

- ✓ Perform a comparative evaluation of the current vineyard plantations and produced suitability map to uncover if the current vineyards are located in the suitable regions and if not, what could be the main factors influencing the current distribution patterns.

In this paper the AHP method is used to help an investor to select the location of a vineyard for the production of high-quality wine. The method has the advantage of being able to systematically and reliably analyse multiple criteria (Kurtural et al., 2007). The problem relating to the case study is of great conceptual complexity due to the large number of criteria which had to be taken into account by the decision making system, aided by an expert winemaker and vineyard farmers (Beltrán et al., 2010). The method is very useful because it allows sorting out a large amount of information. Additionally, the process forced analysis maker to deeply reflect on the problem in a simple and easy manner, as the questions in the questionnaire were easy to answer (Voogd, 1983). So the AHP method will be applied to the case study analysed and account the influences among the different elements of the problem.

CONCLUSIONS

In this paper the multi-criteria decision making technique AHP (Analytic Hierarchy Process) is used to select a sustainable vineyard location in Bulgarian regions for the production of high-quality wine. The analysis was conducted with the knowledge of an expert winemaker, proficient farmers, who acted as the decision maker, and AHP decision-making tools. The whole process includes: vineyard selection, criteria selection and analysis and criteria weighting process, ranking of the alternatives and final aggregated priorities.

In this study are introduced the most important socio-economy, infrastructure and environmental indicators for the Bulgarian regions. Representing climate, soil, terrain, land cover and land-use is investigated with the purpose of employing these indicators for evaluation of existing viticulture, potential site selection and zoning in the country of Bulgaria. Data can be collected from various information studies, expert knowledge and specific databases created for the analysis based on GIS approach. Reported works define different weights depending on the major characteristics of the region, authors experience based on the arguments supported by the literatures and the scale of analysis. GIS multi-criteria evaluation approaches are dominant in the above studies due to significant improvements of digital cartography and software platforms.

Different parameters are compared for suitable and sustainable vineyard practice in Bulgaria by weighting method. Pairwise comparison method is the most appropriate one due to its suitable structure for GIS integration and its more objective strategy with taking into account all data pairs in comparison. Determination of suitable lands for viticulture could be assessed using multi-criteria analysis by the integration of different parameters such as aspect, elevation, slope, soil, land use capability and precipitation in GIS environment and assigning different weights to each parameter based on their importance. Weighting is one of the important steps of AHP analysis to produce more accurate results.

Comparison of different factors as environmental, socio-economic and infrastructure criteria made for current vineyard parcels can be presented by suitability map in GIS platform. The results present the important factors that demonstrate the behaviour and perspective of farmers and/or companies in the site selection. A suitability map can assist the decision makers and farmers in evaluating the feasibility of current vineyards and deciding new vineyard plantation locations.

This methodology enables full and intensely staged development of clearly defined components, rate their influence and modifications without restructuring the whole mechanism. The overall system of site selection becomes a tool of precision viticulture along with multi-criteria analysis combined with the spatial information systems. It is proposed as a module for the purposes described as the information backbone of a Precision Viticulture system.

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